CERGY PARIS UNIVERSITÉ

« Habilitation à Diriger des Recherches »
Specialty/Spécialité: Electronic/Electronique

How to optimise detection/recognition with radar sensing and fusion?
Comment optimiser la détection/reconnaissance avec la détection radar et la fusion?

Dr Julien Le Kernec,
Senior Lecturer at University of Glasgow,
James Watt School of Engineering,
Communication, Sensing, and Imaging group.

Defended on/soutenue le 07/12/2022
At/A CY Cergy Paris Université
In front of a jury composed of/devant un jury composé de:

Dr Virginie Fresse	Associate Professor (HDR)	Chair	Université Jean Monnet Saint-Etienne
Prof Dr Mihai Datcu	Research Director (HDR)	Rapporteur/Examiner	DLR – the German Aerospace Center
Dr Jean-Philippe Ovarlez	Research Director (HDR)	Rapporteur/Examiner	CentraleSupélec Gif sur Yvette, France
Prof Maria Sabrina Greco	Full Professor (eq. HDR)	Rapporteur/Examiner	University of Pisa, Italy
Prof Hedi Tabia	Full Professor (HDR)	Examiner	Université d'Evry
Dr David Guyard	Chief Technology Officer (PhD)	Guest examiner	Bluelinea
Dr Bruno Philippe	Head of the Programmed Medicine and Chronic Diseases Unit (MD, PhD, HDR)	Guest examiner	Groupement Hospitalier de Territoire (GHT) Nord-Ouest Vexin Val-d'Oise (NOVO)
Prof Olivier Romain	Full Professor (HDR)	Scientific Guarantor/Examiner	Université Cergy-Pontoise

Acknowledgements

I want to thank my dear friends: Anthony Kolar, Cédric Vignaud, Renaud Bellais, Thomas Noël, Olivier Romain, Francesco Fioranelli, Duncan Bremner, Derek Gray, and Gilbert McInnes, who made this adventure so much more pleasant even in the thick of it.

I want to express my most sincere thanks to my kids, Lou-Ann and Ulysses, for bearing with my aspirations and the cost it has had on family life. I want to express my thanks for the unconditional support I got from my partner. I would also like to thank my parents, Louis and Catherine, without whom none of this would be possible, for bringing me up to be the person I am and believing in me through and through. And I would like to thank my brothers Franck and Sebastien, who have always been there for me in the sound and challenging times.

I want to thank Prof Dr Mihai Datcu, Dr Jean-Philippe Ovarlez, Dr Virginie Fresse, Prof Maria Sabrina Greco, Prof Hedi Tabia, Dr David Guyard, Dr Bruno Philippe, Prof Olivier Romain for their participation in this panel for my HDR viva.

I am also very grateful to my colleagues at the University of Glasgow, the University of Electronic Science and Technology of China, and the ETIS lab for their support and the good times over the past six and half years.

I would like to particularly thank my PhD students, Master's students and B.Eng students who have contributed in one way or another to the research effort.

Special thanks to my colleagues (Prof. Teng Long, Prof. Xiaopeng Yang, Prof. Cheng Hu, Prof. Tao Zeng, Dr Quanhua Liu and their team) in Beijing Institute of Technology for their support over the years and their trust. They allowed me to complete my early experiments in human activity recognition and provided me with a springboard for growth.

Special thanks as well to Prof. Zhiqin Zhao from UESTC, who believed in my potential and enabled me to supervise students in China.

Special thanks as well to Prof. Muhammad Imran and Professor John Marsh for enabling my development as a researcher at the University of Glasgow through support and advice.

Finally, I would like to thank the person who supported my work and my research effort, who was there from the very beginning and still is: Prof. Olivier Romain.

Résumé

Je, Dr Julien Le Kernec, suis actuellement « Senior Lecturer » (équivalent à MCF en France) à l'Université de Glasgow ou je mène des activités d'enseignement, de recherche et de valorisation. Depuis 2016, mon activité de recherche s'est considérablement développée autour de la thématique des radars intelligents appliqués à des défis dans le domaine de la santé, vétérinaire et de la sécurité. Mes axes de recherche s'inscrivent dans traitement du signal (définition de chaines de traitement basées sur des formes d'onde non-conventionnelles ou standardisées), la conception de front-end radar analogique, l'adéquation algorithme architecture (définition d'accélérateurs de traitement sur cibles CPU, GPU et multicœurs) et le prototypage de preuves de concept (démonstrateur à large échelle). Les domaines d'application s'inscrivent dans l'estimation précoce de pathologies médicales/vétérinaires (défaillance de la marche, pathologies cardiaques, …) et le suivi de drones. Au cours des 10 dernières années, je me suis intéressé aux problématiques de recherche sur les systèmes radars intelligents, le radar pour l'assistance de vie et pour le bien-être animal. J'ai ainsi démontré avec mes collègues et étudiants :

- L'application du radar pour la détection des défauts de la marche des chevaux et des vaches laitières au travers d'algorithmes de classification adaptés aux applications vétérinaires au travers d'expérimentations menées à différentes fermes et étables.
- L'application du radar dans l'assistance de vie pour la détection d'activités avec la publication en ligne de notre base de signatures radar (la première de ce genre - 2019) pour démocratiser cet axe de recherche et des contributions au travers de simulation pour le développement de nouveaux radars, de développement de systèmes et composants radars, et d'algorithmie de traitement du signal et de classification consolide par des résultats expérimentaux et une approche embarquée.
- Le développement de systèmes radars intelligents pour la déformation de structures civiles (ponts, éoliennes), détection de drones avec des radars MIMO, de plateformes reconfigurables et leur algorithmie.

Ces résultats originaux ont été valorisés dans le cadre de 29 journaux, 5 chapitres de livres, 5 articles de conférences sans actes, et 62 articles de conférences avec actes, et 2 brevets. J'encadre/ai encadré 15 doctorants (taux d'encadrement moyen de 30%) dont 5 ayant déjà soutenus leurs thèses. J'ai enseigné dans le domaine de l'électronique analogique et numérique, de l'informatique, l'entrepreneuriat, du traitement du signal et l'encadrement de projets de fin d'année à hauteur de plus 3000h de cours/encadrements. Je suis responsable du management pastoral des 2000 élèves au Glasgow College UESTC. J'ai été pendant mon détachement en Chine responsable des liaisons entre les 2 universités et des séminaires sur l'enseignement pour homogénéiser les pratiques entre les 2 campus. Je commence maintenant un mandat de directeur de programme de la filière électronique et développe mes responsabilités en recherche avec la coordination d'équipement capital et d'activités de rayonnement.

Abstract

I, Dr Julien Le Kernec, am currently a "Senior Lecturer" (equivalent to MCF in France) at the University of Glasgow where I carry out teaching, research, and development activities. Since 2016, my research activity has developed considerably around the theme of smart radar systems applied to challenges in the field of health, animal welfare and security. My research is focused on signal processing (definition of processing chains based on unconventional or standardized waveforms), the design of analogue radar frontend, the adequacy of algorithm architecture (definition of accelerators processing on CPU, GPU, and multi-core targets) and proof-of-concept prototyping (large-scale demonstrator). The fields of application fall within the early estimation of medical/veterinary pathologies (gait analysis, cardiac pathologies, etc.) and drone monitoring. During the last 10 years, I focused my research on smart radar systems, radar for assisted living and animal welfare. I have thus demonstrated with my colleagues and students:

- The application of radar for the detection of lameness in horses and dairy cows through classification algorithms adapted to veterinary applications through experiments carried out on different farms and barns.
- The application of radar in life support for the detection of activities with the online publication of our radar signatures database (the first of its kind - 2019) to democratise this line of research and contributions through simulation for the development of new radars, development of radar systems and components, and signal processing and classification algorithms consolidated by experimental results and an embedded approach.
- The development of smart radar systems for the deformation of civil structures (bridges, wind turbines), detection of drones with MIMO radars, reconfigurable platforms, and their algorithms.

These original results have led to 29 journals, 5 book chapters, 5 conference papers without proceedings, and 62 conference papers with proceedings, and 2 patents. I supervise/have supervised 15 doctoral students (average supervision rate of 30%), including 5 who have already defended their theses. I have taught in the field of analogue and digital electronics, computer science, entrepreneurship, signal processing and the supervision of end-of-year projects for more than 3000 hours of lessons / supervision. I am responsible for the pastoral management of the 2000 students at Glasgow College UESTC. During my secondment in China, I was responsible for liaison between the 2 universities and seminars on teaching to standardise practices between the 2 campuses. I am now starting a mandate as program director of the electronics programme and developing my responsibilities in research with the coordination of capital equipment and outreach activities.

Contents

Table of Figures

Table of Tables

1 Personal details

1.1 Civil status.

Dr. Julien LE KERNEC
DOB: 22/05/1981
French citizen

Professional addresses:

- University of Glasgow (Senior Lecturer since 08/2020, Lecturer since 01/2016)
  James Watt School of Engineering
  James Watt South Building
  University Avenue
  G128QQ Glasgow, UK
  Email: julien.lekernec@glasgow.ac.uk
  Tel: 0044 141 330 4801
  Mob: 00447871754839

- University Cergy-Pontoise (Adjunct Associate Professor since 02/2018)
  Laboratoire ETIS
  site de l'ENSEA
  6 avenue du ponceau
  95000 Cergy-Pontoise

1.2 Current position

- Since 02/2018 Adjunct Senior Lecturer in Electronic Engineering, University Cergy-Pontoise (95), France
  - Conducting research in assisted living with radar and event camera
  - Supervising Ph.D. students and post-docs.
- Since 08/2020 Senior Lecturer in Electronic Engineering, University of Glasgow, Glasgow, UK.
  - Lecturing: module convenor of "Engineering and the law", "Signal Processing for Wireless Sensor Networks", and co-teaching on "Digital Circuit Design", "Circuit Analysis and Design", "Summer projects", "Final year projects", "Introductory programming" at Glasgow College UESTC.
  - Research: Radar for assisted living and animal welfare, Smart radar systems
  - Admin: Senior adviser, University liaison officer UoG side for UESTC-Glasgow research collaborations through university wide lectures, coordinator of monthly presentations for autonomous vehicle and connectivity group, programme director (EEE) for Glasgow College Hainan.

1.3 Research area

- Radar for assisted living and animal welfare
- Smart radar systems

1.4 Degrees and training

Table 1 shows my education progression from technician to my qualification in academic practice for teaching in higher education.

Table 1: Degrees and training

2019	***Postgraduate Certificate*** in Academic Practice University of Glasgow, Glasgow, UK
2011	***PhD degree*** in Electronic Engineering – industry scholarship LIP6, University Pierre and Marie Curie, Paris (75), France ONERA, the French Aerospace Lab, Palaiseau (91), France
2004/2006	***Master of Engineering Degree*** in Electronic Engineering – research scholarship Cork Institute of Technology, Cork, Ireland
2002-2004	***Bachelor of Engineering Degree*** in Electronic Engineering – 1st class honours – 3rd/40 Cork Institute of Technology, Cork, Ireland
2002-2003	***University Diploma*** for Post UDT Training in a Foreign Language – 3rd class honours Cork Institute of Technology, Cork, Ireland University Institute of Technology, Lannion (22), France
2000-2002	***University Diploma of Technology*** in Electronic Engineering and Industrial Computer Science, University Institute of Technology, Lannion (22), France – 3rd/122
1999-2000	***Preparatory course for "grandes écoles,"*** Physics, Technology, and Engineering Science – Lycée Alain René Lesage – Vannes (56) - France
1999	***Baccalauréat*** – Scientific - elective Technology – specialty: Physics – mention: assez bien

1.5 Professional registration

This section reports on my professional affiliations and the status I hold in them (Table 2).

Table 2: Professional registration

Institute of Electrical and Electronics Engineers (IEEE)	Senior Member'17, Member'12, Student'04
The Institute of Engineering and Technology (IET)	Member'12, Chartered Engineer'16
Higher Education Academy (HEA)	Associate Fellow'14
Conseil National des Universités	CNU63 Maitre de Conference'18 CNU61 Maitre de Conference'19
Recognising Excellence in Teaching	Fellow'19

1.6 Work experience

I was recruited in 2016 at the University of Glasgow as a Lecturer in Electronic Engineering. This post was associated with a secondment to the University of Electronic Science and Technology of China 80% of the time in Glasgow College - UESTC. In 2018, I have become an adjunct associate professor at Université Cergy-Pontoise where I also continue my research in collaboration with Prof. Olivier Romain on assisted living and smart radar systems. Table 3 summarises my professional experience.

Table 3: Work Experience

<table>
<tr><td>Since 08/2020</td><td>Senior Lecturer in Electronic Engineering, University of Glasgow, Glasgow, UK
Senior Lecturer in University of Electronic Science and Technology of China, Chengdu. (Secondment ended 11/2021)</td></tr>
<tr><td colspan="2">• Lecturing: module convenor of “Engineering and the law”, “Signal Processing for Wireless Sensor Networks”, and co-teaching on “Digital Circuit Design”, “Circuit Analysis and Design”, “Summer projects”, “Final year projects”, “Introductory programming” at Glasgow College UESTC.
• Research: software-defined radar/radio, RF sensing for assisted living, drone detection, 5G/6G
• Admin: Senior adviser, University liaison officer UoG side for UESTC-Glasgow research collaborations through university wide lectures, coordinator of monthly presentations for autonomous vehicle and connectivity group, programme director (EEE) Glasgow College Hainan.</td></tr>
<tr><td>Since 02/2018</td><td>Adjunct Senior Lecturer in Electronic Engineering, University Cergy-Pontoise (95), France</td></tr>
<tr><td colspan="2">• Conducting research in assisted living with radar and event camera
• Supervising Ph.D. students and post-docs</td></tr>
<tr><td>01/2016-07/2020</td><td>Lecturer in Electronic Engineering, University of Glasgow, Glasgow, UK
Lecturer in University of Electronic Science and Technology of China, Chengdu.</td></tr>
<tr><td colspan="2">• Lecturing: module convenor of dynamics and control, electronic system design at Glasgow College UESTC
• Research: software-defined radar/radio, RF sensing for assisted living, deformation monitoring
• Admin: Senior adviser, exchange officer for the Glasgow College UESTC EEE program for 2+2 and 3+1 students.</td></tr>
<tr><td>Aug 2012-Jan 2016</td><td>Lecturer in Electronic Engineering, University of Nottingham Ningbo, China</td></tr>
<tr><td colspan="2">• Lecturing: module convenor of electronic construction project, introduction to real-time systems, laboratory skills, business planning for engineers, Business Awareness in Technical Education, Career Skills for Electrical and Electronic Engineers
• Research: software defined radar/radio, SAR, radar system development, deformation monitoring
• Admin: Learning Community Forum, Senior Tutor, Ethics committee, Professional Advisory Board, H&S rep, Lab strand leader</td></tr>
<tr><td>Aug 2011-June 2012</td><td>Project Manager, Kuang-Chi Institute of advanced technology, Shenzhen, China</td></tr>
<tr><td colspan="2">• Sub-lead projects and conducted research in wireless telecommunications</td></tr>
<tr><td>Sept 2010-Aug 2011</td><td>Assistant Professor, CNAM, Paris, France</td></tr>
<tr><td colspan="2">• Taught Analogue and Digital Electronics, Component physics, RF transmissions, and design</td></tr>
<tr><td>Sept 2009-Aug 2010</td><td>Assistant Professor, Polytech, University Paris VI, France</td></tr>
<tr><td colspan="2">• Taught Digital and Analogue Electronics, Digital Telecommunications & Signal Processing, System architecture, Codesign (SW/HW - NIOS), System C for UG students</td></tr>
<tr><td>Sept 2007-Aug 2009</td><td>Part-time lecturer, University Paris VI, France</td></tr>
<tr><td colspan="2">• Taught Digital electronics for PG and UG students</td></tr>
<tr><td>Sept 2005- June 2006</td><td>Part-time Lecturer, Cork Institute Of Technology, Cork, Ireland</td></tr>
<tr><td colspan="2">• Taught Computer Science and IT skills for UG students</td></tr>
<tr><td>July - August 2004</td><td>Electronic engineer, Cork Institute Of Technology, Cork, Ireland</td></tr>
<tr><td colspan="2">• Programmed an interface for the master sensor node to read, store & display data received from slaves.
• Soldered and maintained sensor nodes.</td></tr>
<tr><td>April - June 2002</td><td>Trainee in electronic engineering, SERPE-IESM, Guidel (56), France</td></tr>
<tr><td colspan="2">• simulated and designed RF circuits for an RF intrusion barrier</td></tr>
</table>

1.7 Research grants

Figure 1 and Table 4 give an account of the funding I received for research from public funding, internal funding, mobility and externally funded PhDs. The details can be found in section 7.3.

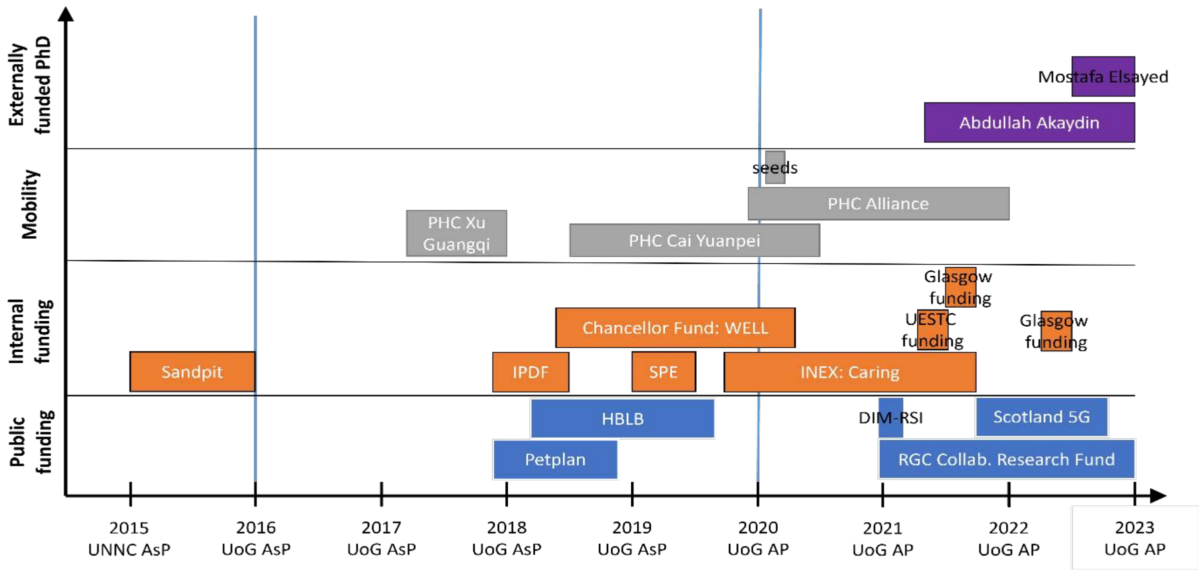


Figure 1: Chronology of grants – UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, AsP: Assistant Professor, AP: Associate Professor

Table 4: research grants

Jul 2022-Jun 2025	**Egyptian government – £90k externally funded PhD – Mostafa Elsayed**
Jun 2022	**Glasgow funding – mobility lab £6.2k – Mocap + accessories**
Oct 2021-Sep 2024	**Turkish Government – £90k externally funded PhD – Abdullah Akaydin**
2021-2022	Scotland 5G centre – phase 2 - £250k (Co-I)
Jun 2021	**Glasgow funding – mobility lab £6.5k – Mocap**
May 2021	**UESTC funding – mobility lab £36k – Gaitrite connected mat**
2021-2023	collaborative research fund one-off crf covid-19 and novel infectious disease exercise – hk$6,849,390 – c7174-20g – super reality for hands-on online education (Co-I)
Jan 2021	42k€ - dim-rfsi – smart_gait : mobility lab for the study of frailty (co-i)
Mar 2020	**£10k – PI(UK) – Seeds meeting – with CYU (France) and University of Glasgow (UK) – funded by the French Embassy in London, UK –PI(Fr) Prof. Olivier Romain – UK-France**
Jan 2020–Dec 2021	**£7.5k – INSHAPE: Intelligent multimodal Sensing for falls and HeAlth PrEdictions – PHC Alliance – with CYU (France) Prof. Romain and UoG (UK) – funded by Campus France – PI(UK) Dr Le Kernec – UK-France**
Jul 2019-Jun 2021	106k€ - co-I – RF sensing for assisted living – INEX – CYU, France – PI(Fr) Prof Romain – France
Feb 2019-Jul 2019	**£3k – PI – Industry engagement from SPE division, school of Engineering, UoG – UK**
Jul 2018-Dec 2021	42k€ - co-I(Fr) – PHC Cai Yuanpei – 41457UK – INSHAPE: Intelligent radio-frequency Sensing for falls and HeAlth PrEdictions with CYU (France) Prof. Romain (PI) and UESTC with Prof. HE (PI) and Miss LIN (Ph.D. student) – funded by Campus France and China Scholarship Council.
May 2018	**£5,125 – PI – Chancellor fund – WELL: Wireless Equine Lameness Locator with RF sensing – UK**
Jun 2018-May 2019	**£9,960 – PI – Horse Betting Levy Board Small Research Grant – ATLAS: Automated Thoroughbred Lameness Assessment System at the racetrack or yard – PI with Dr Fioranelli, Dr Marshall and Dr Voute as Co-Is – UK**
Oct 2017-Oct 2018	£9,8k - co-I - Petplan Trust Pump Priming Grant - Detection of horses' lameness with contactless radar sensors – with Dr Fioranelli (PI), Dr Voute, and Dr Marshall (Co-I). UK
Dec 2017	**£3k - PI - Support from the IDPF to develop the collaboration between the School of Engineering at UoG, ETIS lab at CYU, France, and UESTC, China.**
Apr-Dec 2017	6,540€ - co-I – PHC Xu Guangqi 2017 – Campus France – "Radar remote sensing to prevent falls in older and vulnerable adults." With Prof Romain (PI) – France

* **PI: Principal Investigator**, Co-I: co-investigator, UESTC: University of Electronic Science and Technology of China, CYU: University Cergy-Pontoise, UoG: University of Glasgow, SPE: Signal, Power and Energy, IDPF: International Partnership Development Funding.

1.8 Supervision, PhD annual progression and Viva.

Table 5 summarises my completed/ongoing supervision loading for PhD students, postdoctoral researchers, postgraduate and undergraduate taught students.

Table 5: supervision loading and role

Percentage	Supervision role
630%	15 PhD: 8x UoG (2x graduated), 1x UNNC (graduated), 1 UESTC (graduated), 1x UoG-UESTC, 1x NJUST (graduated); 2x CYU, 1xBIT - details in section 7.4.3
	5 Ph.D. theses defended (180%) 1. Research Fellow in Energy at Institute of Energy & Environmental Technology – Jomo Kenyatta University of Agriculture and Technology – Juja, Kenya (UNNC) (20%) 2. Postdoc Scholar CRRC Corporation Ltd, Beijing, China (UESTC) (50%) 3. Postdoc University of Glasgow (UoG) (50%) 4. Assistant Professor NJUST (NJUST) (10%) 5. Assistant researcher Hitachi, Japan (UoG) (50%)
80%	2 post-doc – details in section 7.4.4.
820%	12 Master students (11 completed) – details in section 7.4.2.
5100%	51 Final Year Projects (51 completed) – details in section 7.4.1.

Figure 2 shows the progression of my supervision loading before I was employed at University of Glasgow combined in one and after. I only supervised one visting PhD student for the 3 months he spent at University of Nottingham China. I started to supervise PhD students in 2016. Note that because I was seconded in China until November 2021, the postgraduate school at the University of Glasgow limited my supervision load on postgraduate students to 50% at most. The details of these numbers can be found in the appendices in section 7.4, and the supervision loading is shown in Figure 2.

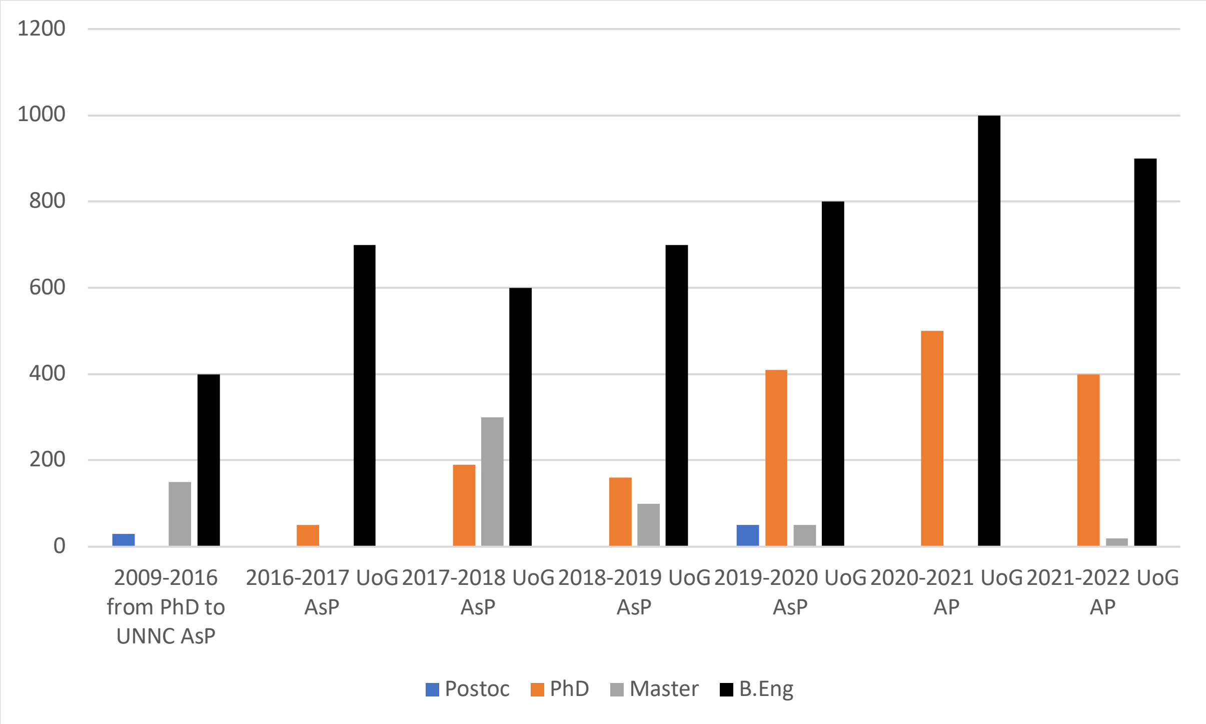


Figure 2: Supervision loading progression from 2009 to 2022 – UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, AsP: Assistant Professor, AP: Associate Professor

1.9 PhD annual progression, thesis review, and viva

I also participate in the review, convening and examination for PhD annual review, thesis review and viva, as shown in Table 6. In the UK, there is a requirement to examine student progress annually during their PhD. This results in internal examination and convening for the annual progress review (details on the process are available in Appendix 7.5). Students present their work for 15-30mn after which the examiner asks questions about the written report and the presentation as well as questions regarding the research plan, supervision, and challenges encountered by the student. The convenor is here to report on the examination and ensure the good conduct of the process as well as recommending a progression status depending on the examination result. I have participated in such internal examinations as examiner or convener in university of Nottingham Ningbo China and University of Glasgow where the examiner and/or convener are from engineering but are not necessarily specialists in the area (10 students) since 2013. In the Netherlands, the PhD students also have annual progress reviews that they call go/no-go points where an external examiner is an expert in the domain (1 student) since 2021. Finally, I have examined 3 theses since 2020 as an external examiner – one in University of Strathclyde and 2 for Visvesvaraya Technological University since 2020. The details are shown in Table 6.

Table 6: PhD annual progression and viva

Student	Function	University*	Title	Supervisor	Year+
Mr Yushi Liu	Convenor	UoG	Surrogate model-assisted global optimization techniques for 5G base station antenna synthesis	Dr Bo Liu	2022 – to date
Mr K M Prakash	External Examiner	VTU	Polar Codes for Low Complexity Encoding and Decoding and Their Performance analysis	Prof. Sunitha	04/2022 I
Ms H R Vani	External Examiner	VTU	Study and Development of a Novel Miniaturised Microstrip Metamaterial Antennas with Suppressed Mutual Coupling	Prof. Paramesha	03/2022 I
Mr Liyuan Xue	Convenor	UoG	Machine Learning-assisted Global Optimization Techniques for Communication Engineering	Dr Bo Liu	2021-to date (P)
Mr Nicolas Kruse	External Examiner	TUD	Radar Aware Activity Recognition	Prof. Alexander Yarovoy	2021-to date (P)
Mr Shibo Li	Internal Examiner	UoG UESTC	Wireless Signal Sensing Technology for Health Care System	Dr Qammer Abbasi	2021-to date (P)
Ms Amirah Algethami	Convenor	UoG	Engineering N-body Orbital Dynamics Problems used in Near Earth Asteroids	Prof Colin McInnes	2021-to date (P)
Mr Rainer Kuusvek	Convenor	UoG	Structures for CubeSat Platforms	Prof Colin	2021-to date (P)

				McInnes	
Dr Pasquale Striano	External Examiner	UoS	Dual operative Radar for Vehicle To Vehicle and Vehicle To Infrastructure Communication	Dr Carmine Clemente	12/2020 (V)
Mr Yushen Miao	Internal Examiner	UoG	Big Data Associated with Control Strategies for Microgrids	Dr Yang Jin	2019-to date (P)
Mr Simeon Skopalik	Internal Examiner	UoG	Fractional flow reserve derived through computational fluid dynamics: a non-invasive diagnostic measure to assess the importance of various arterial stenotic diseases	Prof Douglas Paul	2018-2020 (P)
Mr Skriptyan N.H. Syuhri	Internal examiner	UoG	Travelling wave in finite structures	Dr Hossein Zare-Behtash	2019-2020 (P)
Ms Hannah Rose (part-time)	Internal Examiner	UoG	d36 mode transducers for underwater SONAR (Thales)	Prof Alexander Cochran	2018-to date (P)
Mr Oluleke Bamodu	Internal Examiner	UNNC	Optimal indoor environment quality control using virtual sensing and intelligent management system	Dr Tong Yang	2014 (P)

*UESTC: University of Electronic Science and Technology of China, UoS: University of Strathclyde, UoG: University of Glasgow, TUD: Technical University Delft, UNNC: University of Nottingham Ningbo China; VTU: Visvesvaraya Technological University, (P) annual progression, (V) Viva, thesis review

1.10 Publications and esteem

As an example of the dynamic change in my academic career, I did not have a single journal article before 2017. I had a book chapter, but this is not considered with the same weight for academic consideration. I have since 2016 published 29 journal articles (14x Q1, 9x Q2), 50 conference papers, 4 book chapters, and filed 2 patents. This is also correlated with my increased research activities with the supervision of both undergraduate and postgraduate students.

1.10.1 Research Profile

Here are the addresses to my profiles on:

- ORCID: orcid.org/0000-0003-2124-6803
- SCOPUS: https://www.scopus.com/authid/detail.uri?authorId=36104247400
- GOOGLE SCHOLAR: https://scholar.google.com/citations?user=ca9gpo8AAAAJ&hl=en

Figure 3 provides my citation dynamic from my google scholar profile showing the progression in citations since 2015 up to 26/09/2022 against my different roles in employment. You can observe an increased citation dynamic since 2016. The details of my publication list can be found in 7.1.

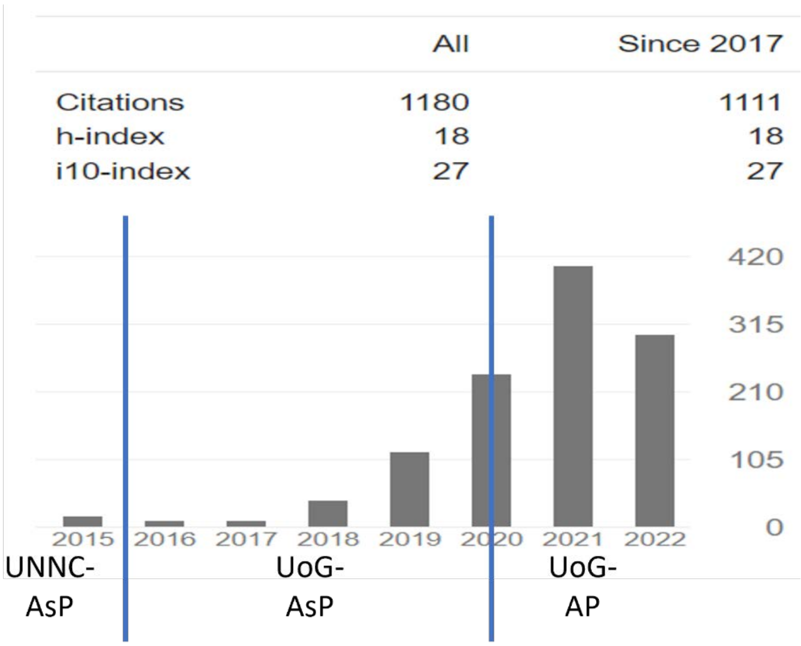


Figure 3: Citation dynamic from 2015 to 26/09/2022 and associated posts (see google scholar profile for updates) – UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, AsP: Assistant Professor, AP: Associate Professor

Figure 4 shows my publication since 2005 when I published my first workshop paper until the 26/09/2022. You can observe a sustained publication dynamic since 2012 that increased significantly since 2017.

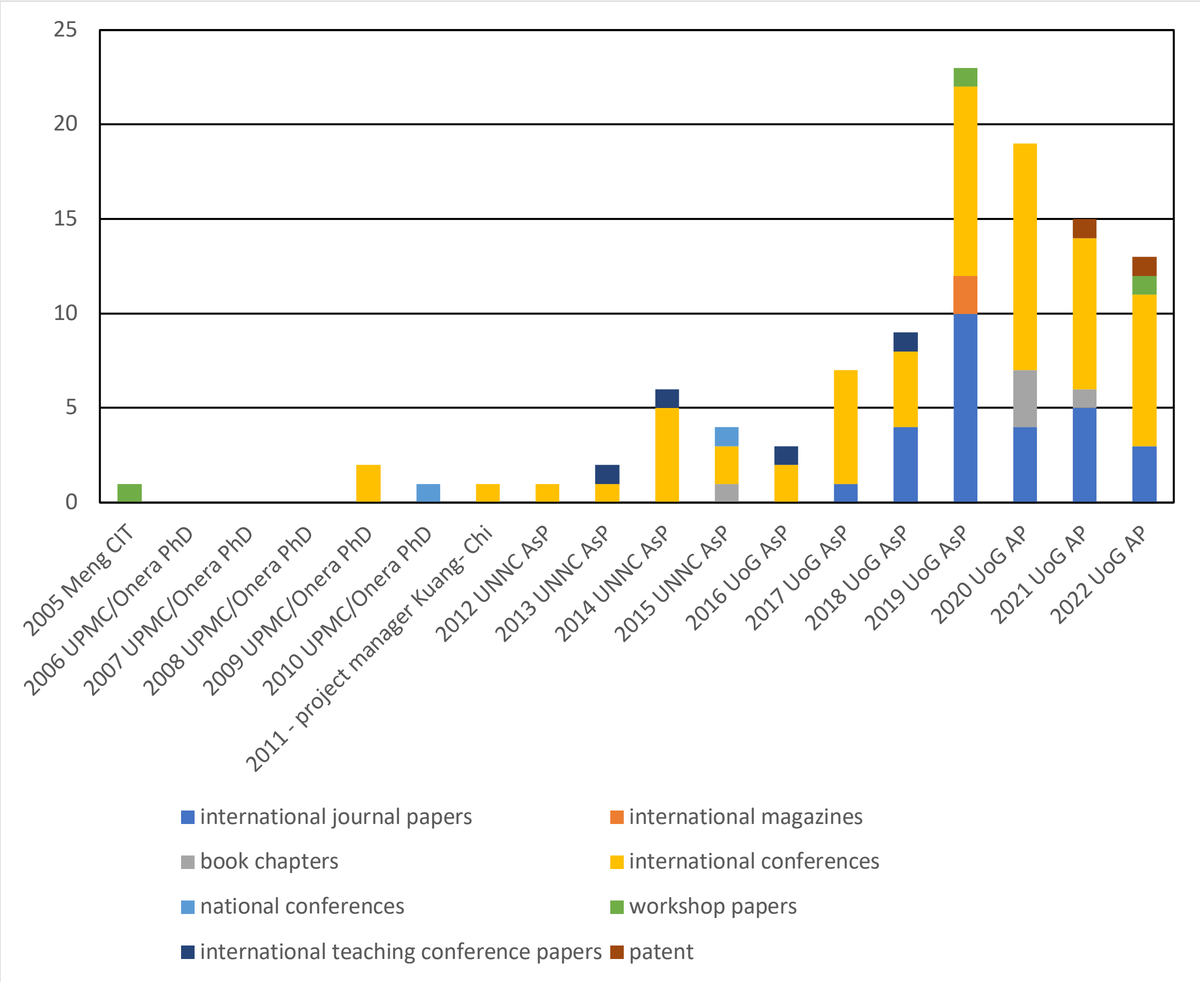


Figure 4: Publication dynamic from 2005 to 26/09/2022 – CIT: Cork Institute of Technology, UPMC: University Pierre and Marie Curie, Onera: The French Aerospace Lab, Kuang-Chi: Kuang-Chi Institute of Advanced Technologies, UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, AsP: Assistant Professor, AP: Associate Professor.

1.10.2 Special sessions / Research community work

Before 2016, I was invited sparingly as a reviewer / technical programme committee member for conferences. Since 2016, I have become an associate editor for IEEE Access, and am a reviewer for a number of international journals and magazines. I contribute to the IET international radar conference series since 2013 as technical program committee member and organiser of special sessions. This year for the 2022 IET radar conference, I am part of the organisation committee. I have organised 7 special sessions in conferences of which 6 since 2016. It is noteworthy to mention that 4 of them revolved around the applications of radar in signal processing, feature extraction and classification. The radar challenge organised for IET radar international conference was based around a public dataset that we released in 2019. A total of 23 organisations worldwide from 20 different countries registered, 12 teams from academia, and industry, participated in the inaugural Radar Challenge by submitting their results and papers to the conference. The detailed list is shown in Table 7.

Table 7: Special sessions / Research community work

24-27 Oct 2022	Organising committee member – IET radar 2022 – Edinburgh, UK.
16-17 Oct 2022	International Advisory Committee for Second Edition of IEEE Mysore Subsection Flagship International Conference "MysuruCon-2022", JSS Science and Technology University, Mysuru, India.
27-20 Sep 2022	Technical Program Committee, IEEE BHI-BSN 2022 – IEEE Biomedical and Health Informatics joined with Body Sensor Networks, Ionnina, Greece
12-15 Sep 2022	Technical Program Committee, 7th IEEE Cyber Science and Technology Congress (CyberSciTech 2022), Calabria, Italy.
12-14 Aug 2022	Publication chair, 3rd International Conference on Intelligent Computing and Human-Computer Interaction (ICHCI 2022), Guangzhou, China August.
8-10 July 2022	International Advisory Committee Member, International Conference on Electronics, Computing and Communication Technologies, CONECCT 2022, Bangalor, India.
9-10 Jun 2022	Reviewer – 33rd Irish Signals and Systems Conference ISSC2022, Cork, Ireland
2-7 Apr 2022	European Microwave week 2021 (postponed 2022 – covid19) – workshop/short course on "Advanced Radar Processing for Indoor Sensing", London, UK.
15-20 Dec 2021	Session chair and organizer of special session on "MicroDoppler based Feature Extraction for Target Classification and Beyond", 2021 CIE international conference on radar, Haikou, China
July-Oct 2021	EMSIG Hackathon – "Radar-based Human Activity Recognition Challenge 2021" – UK wide competition for the UK radar community – https://emsig.grand-challenge.org/Home/
04-06 Nov 2020	Radar Challenge "Human Activity Classification with Radar" hosted by IET International Radar Conference Chongqing, China – www.ietradar.org/NOTES: Based on our open dataset available at http://researchdata.gla.ac.uk/848/ doi:10.5525/gla.researchdata.848 leader board with 124 registered users, 24 test result submissions (https://humanactivitiyclassificationwithradar.grand-challenge.org/) and 12 papers submitted to the conference for the special session
20-21 Aug 2020	Local organizer, 5th International conference on UK-China Emerging Technologies (UCET2020), Glasgow, UK
21-22 Aug 2019	Publicity Chair, 4th International conference on UK-China Emerging Technologies (UCET2019), Glasgow, UK
06-08 May 2019	Special Session on "smart flats for assisted living" and "UAV detection, signatures and classification with radar" in IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China
17-19 Oct 2018	Technical Program Committee Member, IET international Radar Conference, Nanjing, China. Special Sessions on "radar medical applications for assisted living" and "UAV detection, signatures and classification with radar"
14-18 May 2018	Special Session chair on "Radio Frequency Remote Sensing", 2018 Joint IEEE International Symposium on EMC & APEMC, 14-18 May 2018, Singapore.
Since Oct 2018	Associate editor IEEE Access
29 Jun 2017	Publication chair, 1st International conference on UK-China Emerging Technologies (UCET2017), Chengdu, China
Since Apr 2017	Executive board member of IET Electromagnetic technical and professional network
14-16 Oct 2015	Technical Program Committee Member, IET international Radar Conference, Hangzhou, China.
Since Nov 2014	Reviewer, IEEE Transactions on Aerospace and Electronic Systems, IEEE Journal of Sensors, IEEE Access.
08-06 Oct 2013	Special Session Software Defined Radio – Systems and Applications Co-Chair, DASIP Conference on Design and Architectures for Signal and Image Processing, Cagliari, Italy
14-16 Apr 2013	Technical Program Committee Member & session chair, IET international Radar Conference, Xi'an, China.
28-30 Jan 2013	Reviewer, SPIE International Conference on Communication and Electronics System Design, Jaipur, Rajasthan

1.10.3 Seminars/Keynotes/distinguished lectures

I have between 2013 and summer 2022 delivered 28 Seminars/Keynotes/distinguished lectures on radar in assisted living and software defined radio at conferences, workshops, seminars at universities (Table 8). 27 of which have been since I started my research on radar-based human and animal activity recognition. Three of those are noteworthy:

- I was invited to give a talk at the "Advanced Processing and Deep Learning Approaches for Indoor Sensing using Short-Range Radars" at EuRad 2021, the largest Radar conference in Europe within the European Microwave week. I was invited by Avik Santra from Infineon for a special session composed only of invited speakers on radar-based human activity recognition in 2022.
- I was invited as a speaker at the CIE international radar conference which is the largest radar conference in Asia-Pacific in 2021 also about radar in assisted living in 2021.
- I was invited for a distinguished Lecture for the International Forum on Advanced Radar and Signal Processing at Beijing Institute of technology, China as part of an IEEE lecture series in 2019.

Table 8: seminars/keynotes/distinguished lectures

29 Sep 2022	Invited Talk - Radar sensing in assisted living: latest developments, IEEE Biomedical & Health Informatics joined with Body Sensor Networks (BHI-BSN 2022), Ionnina, Greece
29 Jul 2022	Keynote speaker, "radar sensing in assisted living : latest developments", International Conference on Data Science and Information System (ICDSIS – 2022), Hassan, India
8 Jul 2022	Invited Speaker - Radar sensing in assisted living: latest developments, International Conference on Electronics, Computing and Communication Technologies (CONECCT 2022), Bangalor, India.
7 April 2022	**Invited seminar - radar sensing in assisted living, 2021 European Microwave Week, London, UK (delayed covid)**
1 April 2022	Invited talk - Radar sensing in assisted living: latest developments, UK-China Biological Imaging and Sensing Workshop, NJUST, Nanjing, China
25 Feb 2022	Keynote Speaker - Radar sensing in assisted living, AEIC 2nd International conference on Artificial Intelligence, Automation and High Performance Computing (AIAHPC) 2022, Zhuhai, China
16 Dec 2021	**Invited Speaker - Radar sensing in assisted living", 2021 CIE international conference on radar, Haikou, China.**
06 Aug 2021	Keynote - Radar sensing in assisted living, 3rd international conference on integrated intelligent computing, communication, and security ICIIC-2021, Bengaluru, India
02 Jul 2021	Seminar - Radar sensing in assisted living, University College London, UK.
01 Jun 2021	Keynote speaker in the International Webinar on Radar Sensing in Assisted Living organized by Department of Electronics and Communication Engineering, GSSSIETW Mysuru in association with IETE Mysuru Centre, Karnataka, India.
19 Mar 2021	Keynote Speech – Radar for assisted living – ICEDME2021, Qingdao, China
11 Dec 2020	EMSIG MODEST Workshop - Radar sensing for assisted living - 3rd annual workshop
29 Oct 2020	Advances in Radar IEEE LUMS chapter seminar series - Radar in Assisted Living - Islamabad, Pakistan.
16 Oct 2020	IEEE Webinar series - Radar sensing in assisted living - IEEE joint Microwave Theory & Techniques, Antenna & Propagation and Electromagnetic Compatibility/Interference (MTT-AP-EMC) chapter Pakistan
5-6 Sept 2020	Distinguished speaker - Radar sensing in assisted living, IEEE International Conference for Convergence in Engineering (ICCE 2020), Kolkata, India
30-31 Aug 2020	Seminar - Radar sensing in assisted living - workshop on advances in radar, Xidian University, Xi'an, China.
12-14 Jun 2020	Keynote Speech - Radar for assisted living - IWECAI2020, Qingdao, China
20-22 Mar 2020	Keynote Speech - Radar for assisted living - ICEDME2020, Qingdao, China
20-21 Dec 2019	Invited talk - Radar sensing in assisted living - 7th Chengdian Forum Information and Communication Engineering 2019, Chengdu, China
16-17 Dec 2019	**Distinguished Lecture - Radar in assisted living - the International Forum on Advanced Radar and Signal Processing - Beijing Institute of technology - Beijing, China**
11-13 Dec 2019	Invited Talk - Radar sensing in assisted living - IEEE ICSIDP2019, Chongqing, China

15 Oct 2019	Seminar - Radar sensing in assisted living - Supelec, Gif s/ Yvette, France
27 Aug 2019	Seminar - Radar sensing in assisted living - Cardiff University, Cardiff, UK
16 Jun 2019	Keynote Speech - RF sensing for assisted living - ICET 2019, Chengdu, China
15-17 Jan 2019	Seminar - Radar sensing in assisted living - Kings College London, London, UK
9-11 Jan 2019	Keynote Speech - RF sensing for assisted living - Smart Industry 2019, Nottingham, UK,
04 Oct 2018	Seminar - Performances of Multitones for Ultra-Wideband Software-Defined Radar and future interference mitigation - Supelec, Rennes France
23-27 Jul 2018	Seminar - Radar applications: assisted living, animal lameness, and agriculture - Queen's University Belfast, UK
10-11 Aug 2013	Keynote Speech - Contribution of Multitones to UWB software-defined radar - International Conference on Mechatronics and Automatic Control Systems ICMS2013, Hangzhou, China

1.10.4 Awards

- **<u>Excellent paper award</u>**

Julien Le Kernec, Olivier Romain, "Empirical Performance Analysis of Linear Frequency Modulated pulse and Multitones on UWB Software Defined Radar prototype," IET international radar conference 2013, Xi'an, China, 14-16 April 2013

See the scan of the award in section 7.2.

2 Executive Summary

2.1 Management Roles

Figure 5 summarises the management roles I have held over the years in my employment at University of Nottingham Ningbo China (UNNC), and University of Glasgow (UoG) in research, teaching and administration.

Details in section 4.

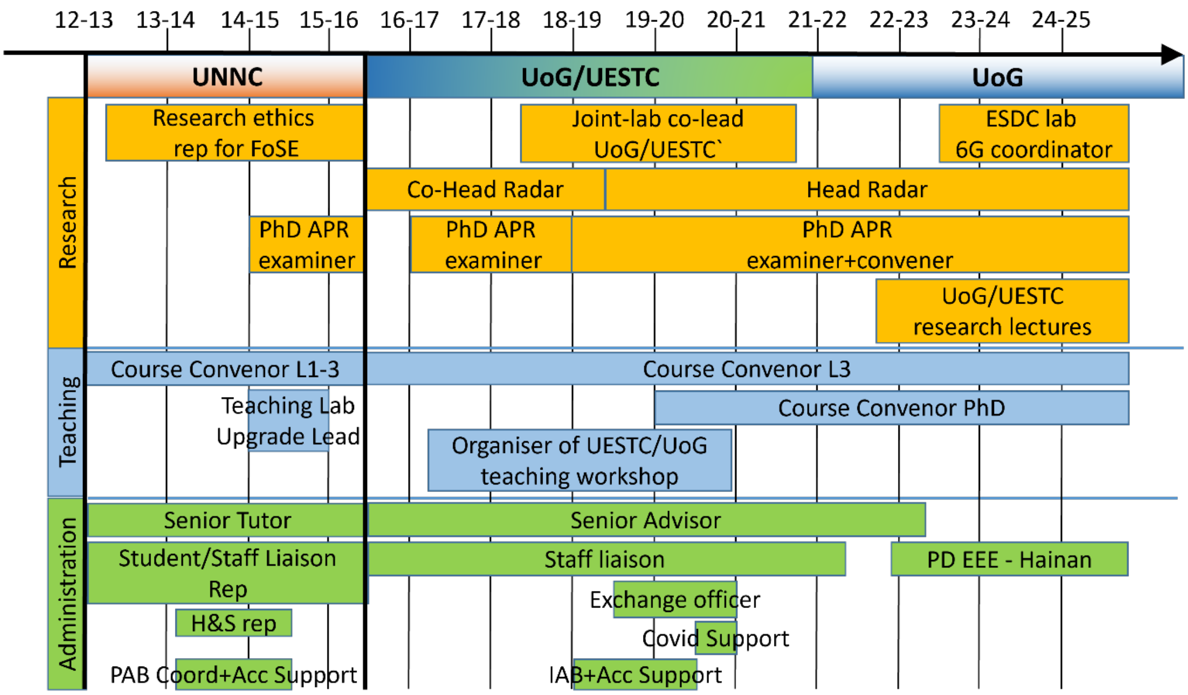


Figure 5: Management roles overview from 2012 – to date – UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, UESTC: University of Electronic Science and Technology of China -FoSE: Faculty of Science and engineering, APR: Annual Progress Review, L1-3: Level year 1- year 3, Rep: Representative, PAB: Professional Advisory Board, IAB: Industrial Advisory Board, Coord: Coordinator, H&S: Health&Safety, PD: Programme Director, Acc: Accreditation, EEE: Electrical and Electronic Engineering, ESDC: Electronic Systems Design Centre.

2.1.1 Research

At UNNC, my role as the research ethics for the faculty of Science and Engineering was to review the research proposal involving human subjects and/or animals to determine whether the proposals were compliant with the ethical policies from University of Nottingham (UoN). This was to ensure that the research proposal complied with the ethical standards from UoN before they were submitted for external funding or used for research studies by our staff and/or postgraduate students.

At UNNC, I was a PhD annual progression review (APR) examiner in which students undergo a miniviva. They submit a review document and pass a mini-defense for which the examiner has to emit an advisory recommendation for the progression of the student to the next year of study. If the review was unsatisfactory, the PhD student had to pass another one at a later date or in worst cases be dismissed from university. At UoG, I have continued to be a PhD APR examiner but I also convene the APR meetings where I oversee the process ensuring the process is conducted appropriately and write the report and recommendations for the graduate school.

At UoG, I have co-led the development of the joint lab between UoG and UESTC which included working with my UESTC counterpart to compile a list of equipment suitable for joint research projects to pump prime research applications. The 2 themes that were selected first were quantum and radio frequencies. I oversaw the tender application for the RF equipment and the refurbishment of facilities worth £550k sourced from UoG. UESTC match funded the UoG contribution for quantum devices and high-performance computing equipment.

I have been the co-lead of the radar team in UoG since I started in 2016 with my colleague Francesco Fioranelli until he left in 2019 after which I was the lead on the team. This role consists of coordinating the research direction for the radar related research and finding funding for the research work, staff, and PhD recruitment. Currently, I am focusing on capability building for the radar lab around mobility for human and animal research as well as applications for drone detection. This lab will also allow further research collaboration within the university and outwith.

This year I have started a new role as coordinator of the UoG/UESTC research lectures to promote research collaborations between UoG and UESTC. I have to coordinate with UESTC to find academics on both sides to have research areas that closely match each other and then have them deliver an online talk that is advertised in UESTC and UoG.

I will be next year in charge of the ESDC lab 6G equipment for the time-domain equipment waveform generation and oscilloscope. My role will consist in managing the equipment and training staff/students in their usage as well as the organisation of users through the booking system.

2.1.2 Teaching

At UNNC, I was the course convenor for all the courses I was teaching from level 1 to level 3 courses over my time there. This included the coordination of the staff involved in teaching, the teaching delivery, maintaining the virtual learning environment for the course and adapting the labs to the local provision as the teaching material was dictated by the UK campus but not all the laboratory equipment was compatible.

I was the coordinator for the laboratory upgrade for the EEE department for which I provided a report that granted our department an extra laboratory space in a heavily resource constrained space. I also oversaw the refurbishment and renewal of the lab equipment with a budget of £600k. This included work benches, stools, electrical installation upgrade, new computers, full set of instruments (oscilloscope, multimetres, power supplies, and signal generators).

At UoG, I am a course convenor for level 3 courses and a PhD course as well. I am coordinating the staff and graduate teaching assistants to deliver the course, the laboratory experiments, and coordinate the marking duties throughout the semester, and maintain the virtual learning environment.

I have been responsible for the organisation of the UESTC/UoG teaching workshops that were held to promote a better alignment between UESTC and UoG academics on various aspect of teaching practice. The first 2 years were focused on "assessment and feedback" for which we reviewed the theoretical framework aspects in the first year and took a practical approach to review our practice in year 2. The event was very well received by UESTC as the second year they sent senior staff from the UESTC university level teaching office to attend the event. The 3rd edition was supposed to be on blended learning but this was cancelled due to Covid.

2.1.3 Administration

From 2012 to date both at UNNC and UoG, I have held the Senior Tutor/Advisor role. A tutor/advisor is in charge of a group of students for pastoral care and academic advice. The senior tutor/advisor is responsible for overseeing all the tutors/advisors on staff. My role included staff training for members of staff to understand how the referral system worked and their responsibilities. I am the port of call for complex cases, academic misconduct, and good cause review for the exam board. My role in UNNC as a senior tutor included the supervision of 12 members of staff and 140 students for that role and te development of the tutoring structure for academic support and professional skills development. At university of Glasgow, I am now managing about 30 advisors and 1800 students. I have amended the guide to correspond to the regulations of the Glasgow College UESTC and video tutorials so that the students can watch the guide for tutees as their own pace.

At UNNC, I was the student-staff representative for the EEE department. This role consisted in attending the student-staff meeting happening once a semester and liaising with staff about the student comments about teaching and compiling the staff answers for students within 2 weeks of the meeting as well as forming an action plan if necessary to fix urgent issues with teaching.

I was the Health and Safety representative for the EEE department for 18 months in which I had to make sure all the risk assessments for the laboratory were produced for us to comply with the legal requirements and prepare for the accreditation. I wrote the risk and assessment policies for the EEE labs and managed the staff to produce the risk assessments for the experimental work in their respective modules.

The accreditation of the EEE degree by the IET (UK professional engineering body) required that the department had a professional advisory board. I coordinated the recruitment of the advisory board with 15 members from industry and the academic sector and managed the topical discussions for the board to work on and compiled the reports on the board advice to be archived. I was also actively involved in the support for the accreditation visit in which the accreditors come and visit the facilities, study our records, and question staff and students on the practices for 2 days before providing their recommendations.

At UoG, I was the staff liaison officer for UoG at UESTC as part of my secondment. This role was very diverse in responsibilities. I was representing university of Glasgow locally in China. This role covered attending events, logistical issues, dealing with administration/teaching issues, maintaining effective communication between both sides, being a port of call at UESTC for any questions related to UoG regulations and advising senior staff on practices at UESTC.

I was the exchange officer for which I was making sure that the students from UESTC going after year 2 to Glasgow had the required level and looking for programmes abroad that could qualify for an exchange compatible with the degree programme they were following. This activity was abruptly stopped by Covid.

I was part of the Covid response team when Covid hit China in January 2020. All the courses delivered by UoG in China had to move to online provision. I contributed to finding and testing IT solutions that would work in China as there were technical difficulties and provision issues of certain software in the country and blockages from regional firewalls. I also wrote a guid for video editing for other staff that was used throughout the school of engineering also to have videos with subtitles for accessibility.

I was also involved in UoG in the industrial advisory board and accreditation to find industrial partners to sit at the board, supported the activities during the board meetings, and actively contributed to the accreditation preparation and visit.

I have just started my role as programme director for the EEE degree for the new Hainan campus that is officially opening I September 2022. I will be responsible for the coordination of teaching in Hainan for the UoG teaching provision and the specificities of the laboratory provision.

2.2 Teaching activities

I started teaching in 2005 as a part-time lecturer at Cork Institute of Technology in 2005. Figure 6 shows the total number of hours taught per subject area vs the number of hours for which I was a convenor. The denominations Digital Electronics 1/2 (DE1/2), Analogue Electronics 1/2 (AE 1/2), Signal Processing 3 (SP3) refer to the level of the course. Level 1 indicates introductory level course whereas level 2 and 3 refer to more advanced notions. It can be observed that I have been responsible for a lot of the delivery as a convenor since I have been teaching. It can be seen as well that I covered both analogue and digital electronics as well as signal processing and various topics. My project supervision of undergraduate and postgraduate students accounts for a large proportion of my time and is research driven. Note that in the institutions I have worked in, the teaching material was dictated by my supervisors when I was a postgraduate student until 2012 so prior to my lecturer positions or dictated by the headquarter institution because the programmes were based on the UK provision for accreditation purposes and there was little leeway to propose new courses or changes to existing courses in my postings at UNNC and UoG. I will offer a breakdown per period pre-academic, UNNC, and UoG.

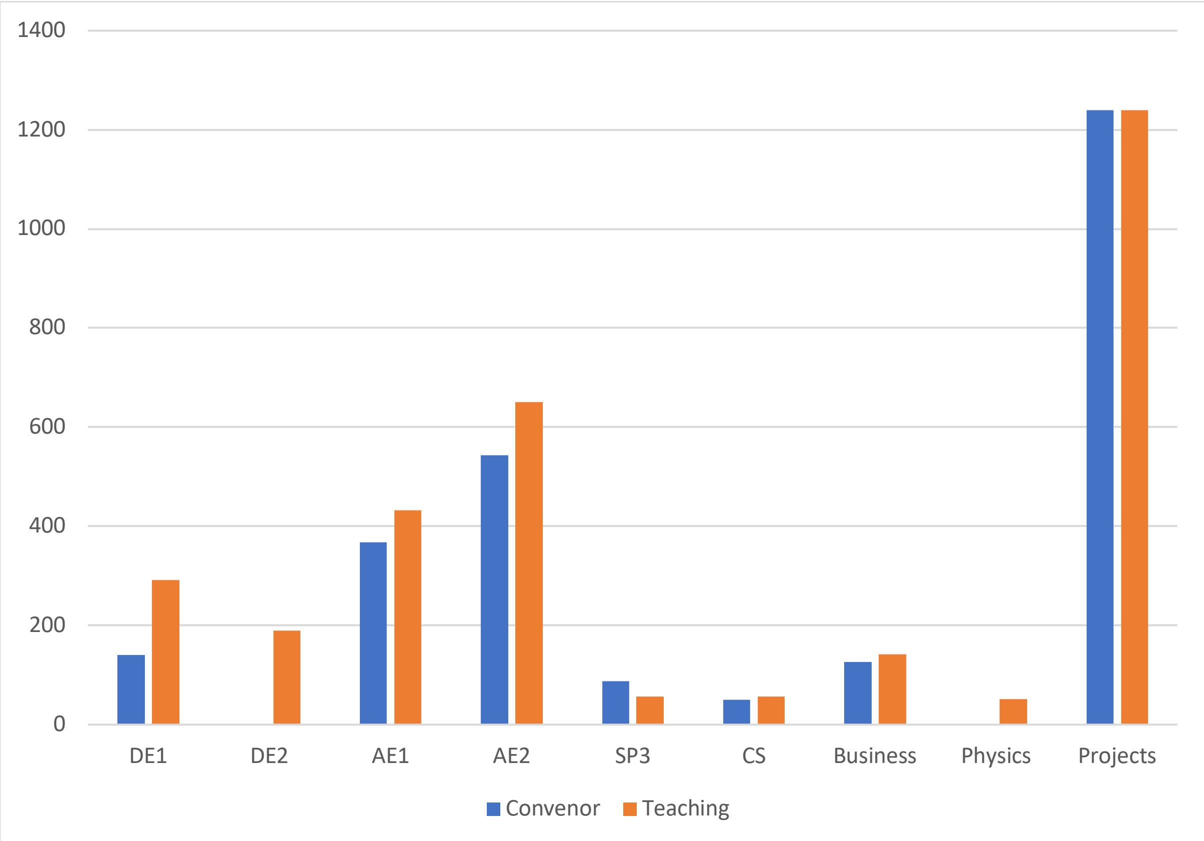


Figure 6: Total of teaching hours since 2005-2022 per subject – DE1/2: Digital Electronics 1/2, AE1/2: Analogue Electronics 1/2, SP3: Signal Processing 3, CS: Computer Science.

2.2.1 Pre-academic posts teaching and convening load

In terms of course leadership, I started in 2005-2006 at Cork Institute of Technology where I was given 2 courses (level 1) students to create from scratch for the computer science department on the "history of computing and office automation" and "operational system architectures" (50h – CS). My teaching experience from 2007-2009 was as a PhD student providing labs and tutorials as required by the teaching team. In 2009-2010, during my ATER post in UPMC, I took the lead in the development of the lab materials (44h – DEII) for "Systems Architecture" (level 3) and the other components were delivered from level 3 to level 5 as required by the teaching team. At CNAM for my second ATER post, I had to adapt the teaching plan for the mature students as the labs were covering notions the students did not cover previously. The labs (21.5h AE1) were adapted to be 1/3rd lecture and 2/3rd lab/tutorials for the students to be able to complete the course adequately. In 2011-2012, I was in industry and therefore did not do any teaching. I also supervised a master student in 2010-2011 on a subject related to my PhD. As can be observed from Figure 7, I was given most of the materials to teach from my supervisors.

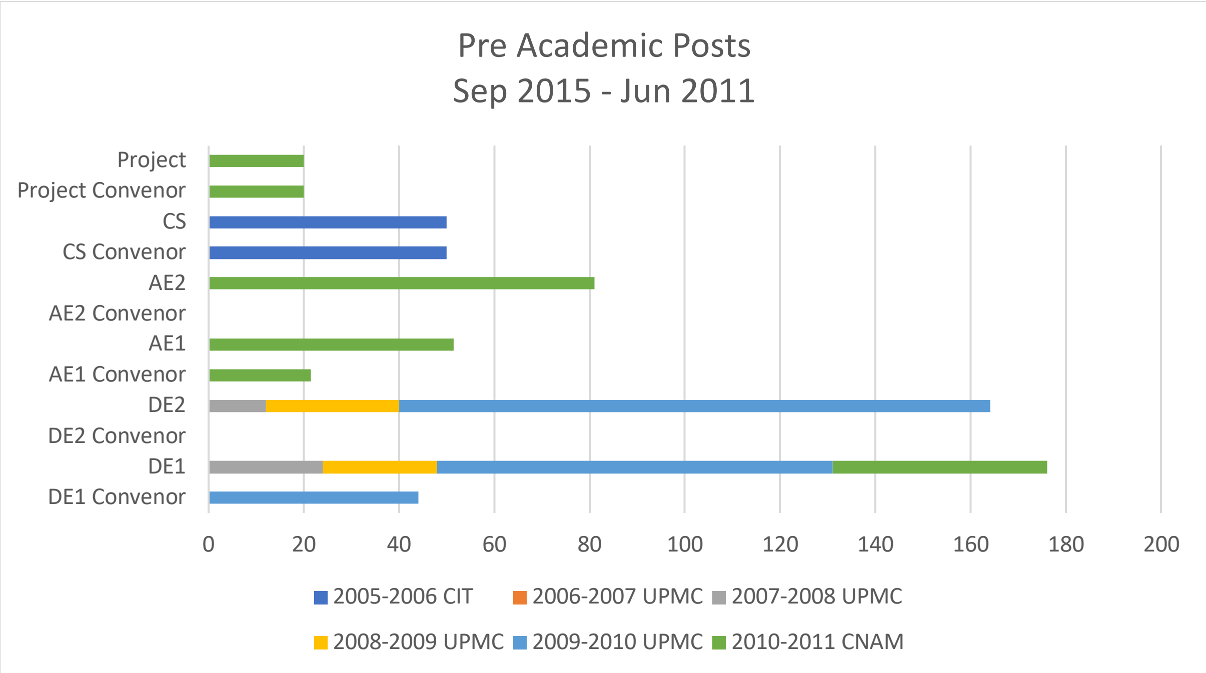


Figure 7: Teaching load vs Convenor load for my pre-academic posts from 2005 to 2011.

2.2.2 Assistant Professor at UNNC teaching and convening load

In 2012, I began my post in Nottingham as an assistant professor. I was in charge of "Electronic Construction Project" (level 2 – AEII) for which I rewrote all the session objectives to provide some guidelines for the students on the important notions to focus on session by session and Introduction to Real-Time Systems (Level 1 – DEI) for which I rewrote all the labs to fit the new platform that we were going to use in my first year until the end of my post. In the second year (2013), I got "Introduction to laboratory techniques and presentation" (Level 1) (2013-2015) and Microwave communications (level 3) in 2013 only. For MCM, I updated the notes to be more current and incorporated some of my research in the radar section of the course. I was also the course lead for "Business Planning for Engineers" in which I coordinated with the business school the content and the assessments based on the final year projects. I also created during that time two extra-curricular courses "Professional Skills for EEE Engineering" (Level 1) and "Business Awareness in Technical Education" (all levels welcome). Professional Skills for EEE Engineers was created to support the pastoral care and academic support for EEE students so it would be credit bearing and incorporated professional skills such as CV writing looking for internships, … to help the students find summer jobs in industry and benefit them by allowing them to collect credits for further studies showing extracurricular activities since the academic support was mandatory in year 1. "Business Awareness in Technical Education" was created to be a 101 course to being a well-rounded engineer/scientist for which I organised seminar series from various academics to deliver each topic on their research specialty. As can be observed from Figure 12, I have been responsible for the delivery and convening of most my courses while at UNNC. The drop in responsibility in 2015 was because I was leaving for UoG so a lot of my teaching was passed on to other colleagues. Also, I started to supervise project students for their final year project and I also got 1 MSc student from Nottingham UK to supervise.

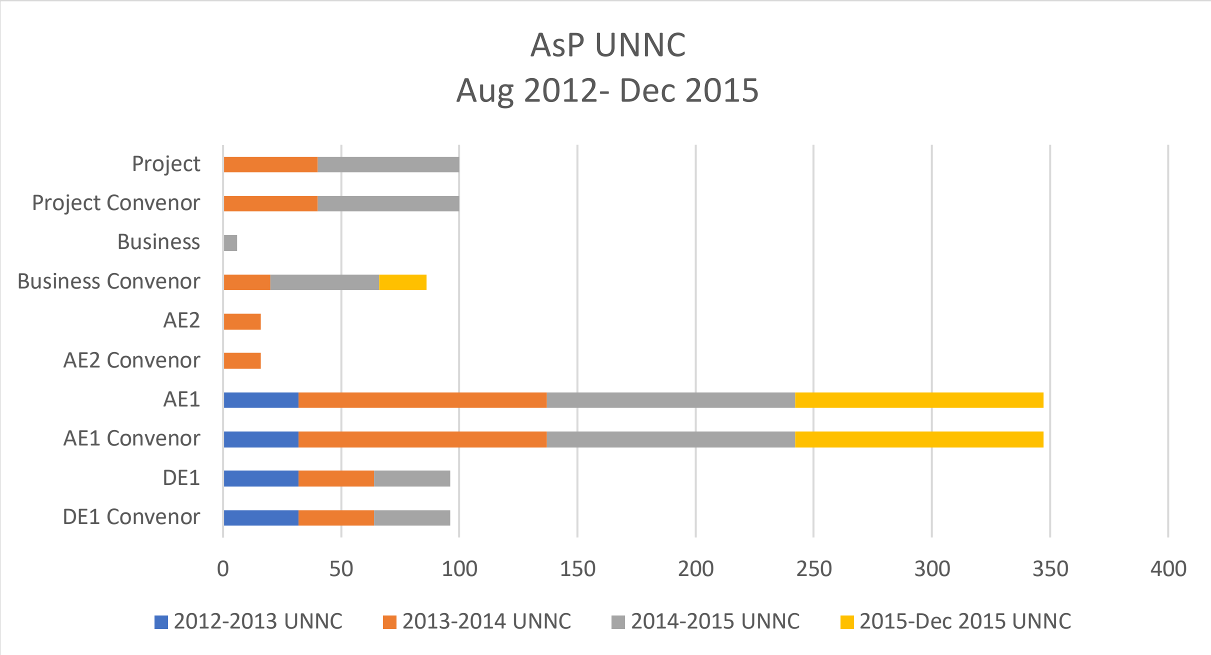


Figure 8: Teaching load vs Convenor load from 2012 to 2015 as an assistant professor at UNNC.

2.2.3 Assistant/Associate Professor at UoG teaching and convening load

Since 2016 at University of Glasgow, I have been course lead for "Dynamics and Control" (level 3) until 2019 and then co-teacher between 2019-2020. In this course, I reworked the labs so that they were more in line with the concepts taught in the course for students to improve their mastery using MATLAB programming rather than analogue implementations of control circuitry on breadboards. The labs were made interactive by giving them reflective assignments on the tasks to test their comprehension of the course material in the lab and correct any misunderstandings through the discussions before signing off their work. I am the course convenor for "Engineering and the Law" (Level 3) that I created by splitting "Professional Practice" (Level 3) into 2 parts as it was a yearlong course by joining ethics, product development, standards and marketing and adding professional skills to it. With the course team, we have expanded the parts to be a quarter each on marketing, product development, ethics, and law, and the professional skills were moved to year 2 after a course review of the business strand of courses. The latest development consists of fully removing the exam and assessing the students on 4 authentic tasks built around an umbrella project dealing with each aspect of the course. The authentic assignments are based around my research topics to bring expert knowledge to the assignments and disseminate research to a wider audience. In 2020, I delivered 8h derived from research on wireless sensor nodes going over building blocks, energy consumption, and scheduling. Since 2020, I put together a course for 1st year PhD students who are enrolled on our dual degree program based on channel modelling, estimation, communication signal processing and beamforming. The students have 20h of lectures and 20h of labs in which they apply their skills learnt during the lectures. At the end of the course, they prepare a research paper revolving around their research and the course content. As can be seen from Figure 9, the student cohorts being much larger we teach in teams, and I have been responsible for a large portion of the modules I am involved in. My project supervision loading between undergraduate and postgraduate students has also increased significantly since 2016 and is sustained year after year.

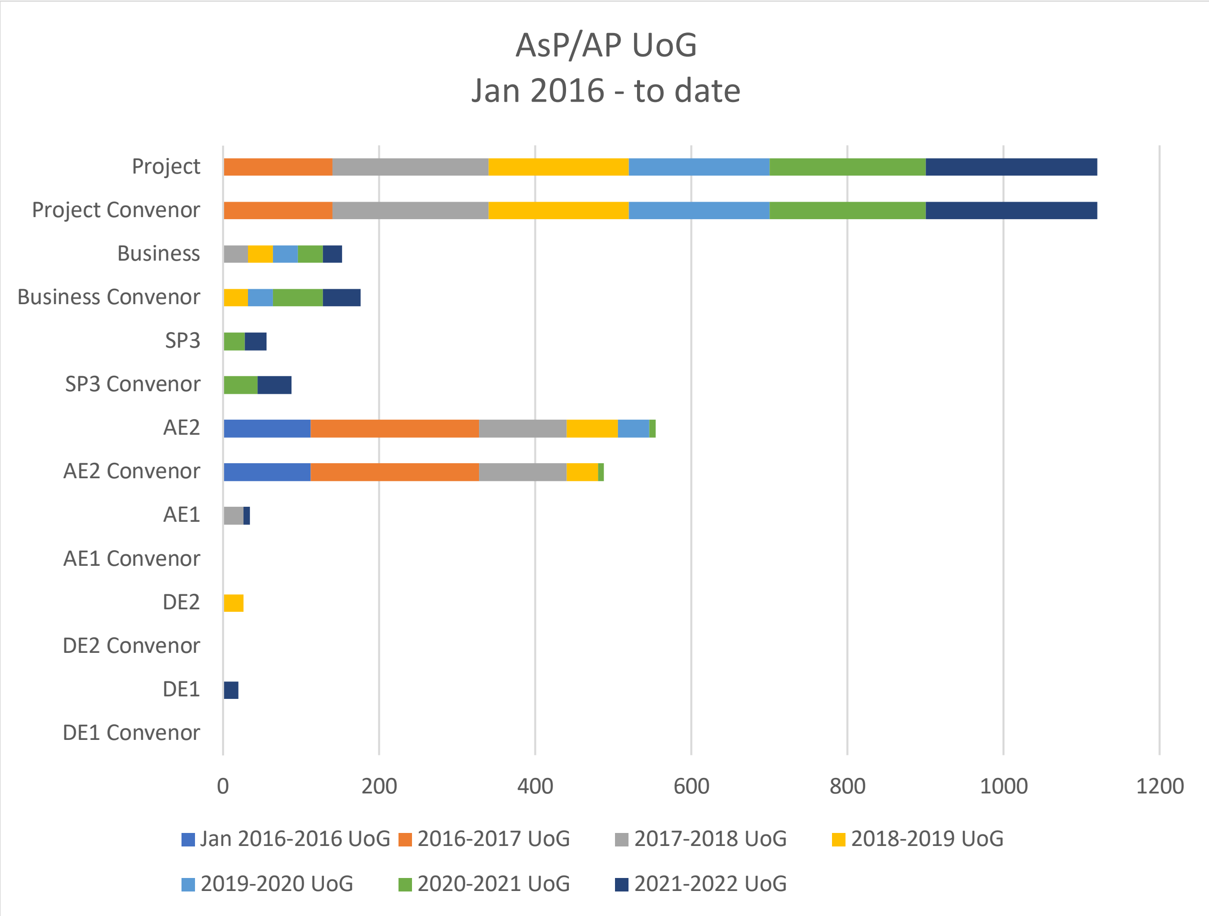


Figure 9: Teaching load vs Convenor load from 2016 to 2022 as an assistant/associate professor at UoG.

2.2.4 Research-enhanced teaching

Further to the seminar activities in other universities for research dissemination, I delivered Science, Technology, Engineering, and Mathematics (STEM) presentations and research seminars for dissemination to the wider public (Table 9).

Table 9: Research seminars for UG/PG students and high school students

4 feb 2022	University of Glasgow - engineering open day – radar in assisted living demonstration – high school students
26 Nov 2021	**Seminar, M2 BIOSAN, University Cergy-Pontoise, “radar sensing: principles and applications in healthcare and animal welfare.”**
3 Feb 2021	Seminar – Continuous activity monitoring – lessons learned and future challenges – University of Glasgow – MliS RNN colloquium
6 Oct 2020	Seminar –Radar sensing for the automatic assessment of animal mobility scoring, Veterinary school – University of Glasgow – Glasgow, UK
11 Sept 2019	Seminar – Radar sensing in assisted living – Hainan University, China
22 Jan 2019	Seminar – Animal lameness detection with radar – Moreton College, Royal Lemington Spa, UK
19 Apr 2019	STEM* presentation – James Watt Class year 2 – University of Electronic Science and Technology of China.
15 Jun 2018	STEM* presentation – Introduction to radar – Chengdu Foreign Language School

*STEM: Science, Technology, Engineering, and Mathematics.

I also supervised 12 Master students and 51 Final Year Projects which are based on my research topics. Some of those have given rise to publications in 4 international journals, 18 international conferences and 2 research challenges completed. I also work on extracurricular projects where students are trained in non-credit bearing activities for research, currently I work on cyclostationarity for radar-based human activity recognition. This approach is to de-risk credit bearing final year projects and be more adventurous/prospective with non-credit bearing research projects. The PhD course on "signal processing for wireless sensor nodes" is also used to put radar research in action through labs and the assessment is a research paper linked to their PhD topic and the course content for them to get used to academic writing and practice the identification of research gaps and a methodology to address the identified issue.

Notably, my undergraduate students have published in international journals and conferences.

- Two international publications in IET Radar Sonar and Navigation and MDPI Sensors:
    - Zhou, B., Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Simulation framework for activity recognition and benchmarking in different radar geometries. IET Radar, Sonar and Navigation, 15(4), pp. 390-401. (doi: 10.1049/rsn2.12049)
    - Li, X., Li, Z., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2020) Hierarchical radar data analysis for activity and personnel recognition. Remote Sensing, 12(14), 2237. (doi: 10.3390/rs12142237)
- Seven articles in prestigious international radar conferences:
    - Du, Y., Li, J., Li, Z., Yu, R., Napolitano, A., Fioranelli, F. and Le Kernec, J. (2021) Radar-based Human Activity Classification with Cyclostationarity. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 – 19 December 2021, (Accepted for Publication)
    - Guo, J., Shu, C., Zhou, Y., Wang, K., Fioranelli, F., Romain, O. and Le Kernec, J. (2021) Complex Field-based Fusion Network for Human Activities Classification With Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 68-73. ISBN 9781839535406 (doi: 10.1049/icp.2021.0572)
    - Jiang, H., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Human Activity Classification Using Radar Signal and RNN Networks. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1595-1599. ISBN 9781839535406 (doi: 10.1049/icp.2021.0556)
    - Li, X., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Radar-Based Hierarchical Human Activity Classification. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1373-1379. ISBN 9781839535406 (doi: 10.1049/icp.2021.0566)
    - Zhou, B., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Interferometric Radar for Activity Recognition and Benchmarking in Different Radar Geometries. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1515-1520. ISBN 9781839535406 (doi: 10.1049/icp.2021.0571)
    - Bennett, C., Jahangir, M., Fioranelli, F., Ahmad, B. I. and Le Kernec, J. (2020) Use of Symmetrical Peak Extraction in Drone Micro-Doppler Classification for Staring Radar. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266702)
    - Zhou, X., Le Kernec, J. and Gray, D. (2017) Vivaldi Antenna for Railway Cutting Monitoring. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059180)
- Three radar challenge competitions entered by my students:

- IEEE radar challenge 2022 where my undergraduate students Jipeng Li and Yaxin Du finished 4th out of 10 entries from leading research institutions.
  - https://www.radarconf2022.org/radar-challenge
- EMSIG 2021 hackathon where my undergraduate students Jipeng Li and Yaxin Du finished first.
  - https://emsig.grand-challenge.org/
- The IET radar challenge 2020 where my undergraduate students Chang Shu and Jiaqi Guo finished tied with leading research teams worldwide
  - https://humanactivitiyclassificationwithradar.grand-challenge.org/

2.3 Research activities

2.3.1 PhD research overview

Since I conducted a Master of Engineering in Cork Institute of Technology on impulse Ultrawideband (UWB) technology for people location and tracking, I wanted to pursue in this field to further my scientific knowledge in radar and also test different technologies linked to Ultrawideband technologies with Orthogonal Frequency Division Multiplexing (OFDM) which was another waveform considered to be used in the UWB spectrum with multiband OFDM. My research activities started in 2006 with my Ph.D. study at the University Pierre and Marie Curie and conducted in the French Aerospace Lab Onera. This work "Contribution of Multitones for Ultra-WideBand Software-Defined Radar" was supervised by Prof. Patrick Garda. The thesis (specialty: electronics) was defended on the 08/07/2011 in front of a jury composed of Prof. Jacques David (Plasma and energy conversion lab - INP Toulouse), Prof. Alain Merigot (IEF-University Paris-Sud), Prof. Pascal Chevalier (CEDRIC- CNAM), Prof. Victor Fouad Hanna, Dr Martin Klepal (Cork Institute of Technology – Adaptive Wireless Systems Group), Dr Julien Denoulet (LIP6-UPMC), Mr Philippe Dreuillet (Dpt Electromagnetism and Radar-Onera), Mr Gerard Bobillot (Dpt Electromagnetism and Radar-Onera), Dr Olivier Romain (LIP6-UPMC)

The research aim was to learn from exponential evolution in telecommunication that occurred in the 90s and early 2000 to devise innovative solutions for radar. From the literature review, it was apparent that there was a gap in quantifying the performances of multitone waveforms specifically for radar applications, and experimental results were not commonly found. This research focused on the radar performance analysis of multitones (OFDM) with P3 phase-codes in simulation and experimentally to determine the effect of hardware on radar performances. For this purpose, a software-defined radar (SDR) approach has been designed, implemented, and used, including a digital core with hardware-in-the-loop controlled by MATLAB and an analogue front end that uses bandpass sampling and a reference channel. This approach is flexible, and entirely arbitrary waveforms can be generated with an instantaneous bandwidth up to 800 MHz in X-band. The performances were analysed with respect to quantization and saturation. This work has been used directly on an operational radar in Onera - Salon de Provence for airborne synthetic aperture radar, where the digital core and the waveform design software were integrated to upgrade existing capabilities.

After my PhD in 2011, I worked as a project manager in industry where my focus was on the application of metamaterial in the communication and RFID (Radio Frequency Identification) fields. I then returned to university and resumed my research on software-defined radar in 2012.

2.3.2 Post-doctoral research overview

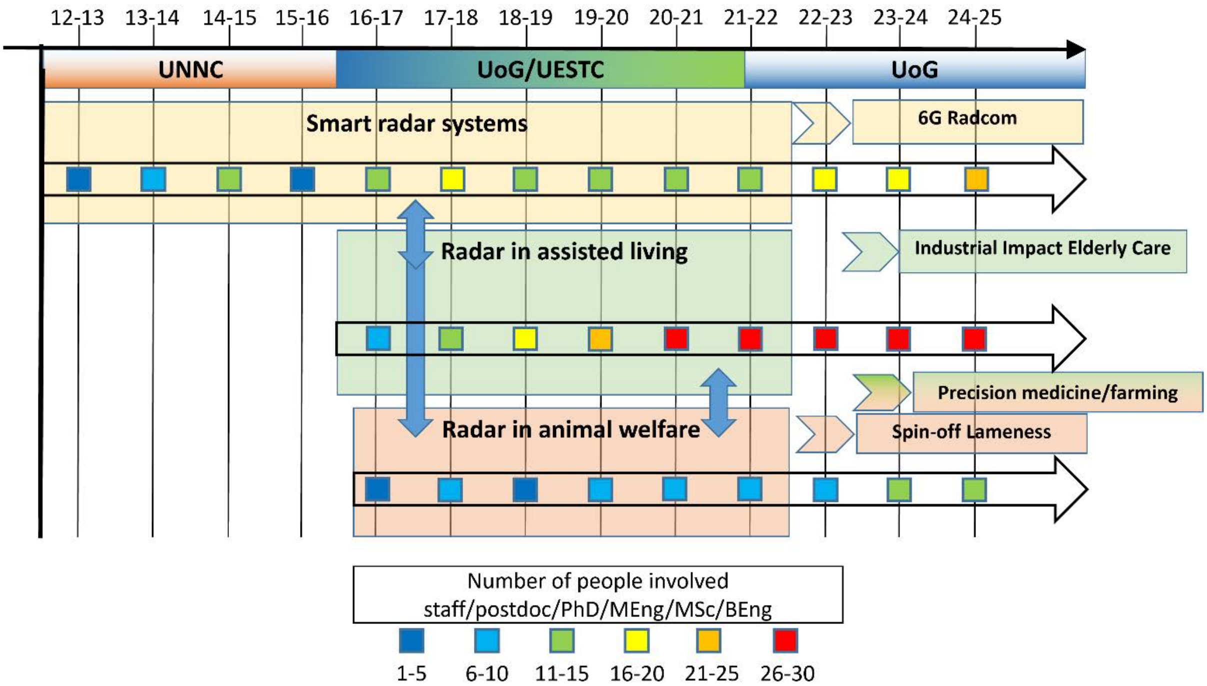


Figure 10: Research overview from 2012 – to date – UNNC: University of Nottingham Ningbo China, UoG: University of Glasgow, UESTC: University of Electronic Science and technology of China.

Figure 10 illustrates the progression of my research portfolio over the years. I restarted my research when I joined University of Nottingham Ningbo China (UNNC) in 2012 to date at University of Glasgow (UoG).

While in post at UNNC, I resumed my work around Software defined radar in the research theme “smart radar systems” that has continued to date.

When I joined UoG in 2016, I started working on “Radar in assisted living” which span off in 2017 into “Radar in animal welfare” that are ongoing research strands in my portfolio.

The central research question in these 3 strands is how to optimise detection/recognition with radar sensing and fusion?

2.3.2.1 Smart Radar Systems

With the growing overcrowding of the spectrum, new threats (e.g., UAVs near airports), the need for spectrum reuse, and the emergence in 6G of radio and sensing capabilities, there is a need to develop novel radar systems that can evolve in that environment and communicate amongst themselves. This starts with developing the radar spectrum sensing and actively communicating with neighbouring radars or communication nodes to collaborate and fuse information. These functions have to be executed alongside radar functions and switch from one mode to another or combine several modes together in its operation via resource management. Having a software-defined radar platform to do this would mean that the radar could dynamically change its operating mode to fit the task at hand by acting via software on both hardware and processing configurations. This topic explores target detection, software-defined radar, antenna development, deformation monitoring.

2.3.2.2 Radar in assisted Living

With a growing elderly population worldwide, new paradigms of care are necessary to keep people living at home longer. In assisted living, radar systems are increasingly being employed in healthcare applications for human activity recognition and vital signs due to their advantages in terms of privacy, contactless sensing, and insensitivity to lighting conditions. Proposed classification algorithms are often complex, which necessitate significant computational resources. A multitude of radar data representations, radar systems (geometry, MIMO, …), and machine learning can be used to achieve these tasks. It is important to bring domain knowledge from radar, kinematics, and medical point of view to maximise the performances and the relevance of the system to meet the needs of the end user. This topic explores simulations in human activity recognition, phenomenology exploration for adaptation to radar, algorithm development, and platform development.

2.3.2.3 Radar in Animal Welfare

Lameness is among horses and farm animals in the top three welfare issues. Lameness problems are usually located on the animals' hooves, and they cause various issues, from gait change to impaired fertility, sub-optimum carcass and milk reduction which impacts revenue for the farmer and the welfare of the animal. Several methods have been proposed but all present drawbacks regarding accuracy, reliability, equipment cost and rapidity. Radar systems can be used to detect gait abnormalities in horses and farm animals as well as their vital signs. The importance of domain knowledge for the application from veterinary surgeon is paramount for those applications. This topic explores horse and cow lameness.

2.3.2.4 Common thread

As shown in Figure 11, this is articulated around simulations, algorithms, and applications/experiments.

- Simulations are used to save resources and explore novel ideas at a lesser cost. It also allows reproducibility when testing different approaches. The research question around the simulation revolves around how to develop an environment with fidelity that allows testing new sensing platform and algorithmic design ideas in a reproducible way with reliable ground truth?
- Algorithms are developed to fit the platform and application being. This can take the form of exploring the effect of pre-processing on the data domains for classification, or estimating parameters for analysis, to improving the detection. The research question revolves around how to design adaptive methods both in signal processing and machine learning to adapt to a changing environment?
- Finally, results need to be validated through experiments and meet the application requirements. These in turn help to refine our knowledge and feeds in new simulations and algorithm developments before being validated experimentally again. The research question in this section, revolves around the development of bespoke smart platforms that address the deployment challenges of the application.

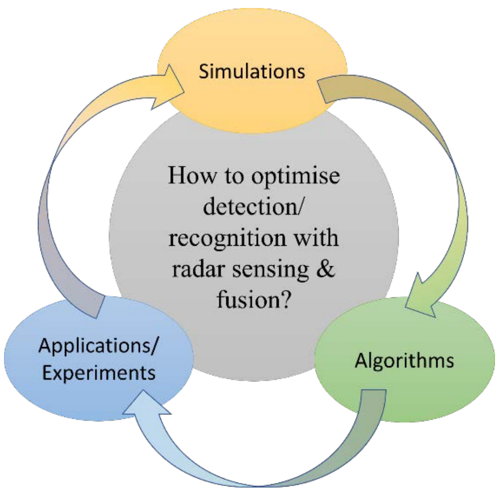


Figure 11: Research question and cycle of research

2.3.3 Research vision

For future developments in research, I intend to continue on the topics of smart radar systems, radar in assisted living and radar for animal welfare.

6G Radcom: The development of platforms supporting both communication and radar function on a single frontend is going to become a key enabler for automotive, healthcare, and unmanned aerial vehicle applications, among others, in the context of the internet of things (IoT). This technology will be of importance for 6G telecommunications which will employ radar techniques in future standards.

Precision medicine / farming will shift the paradigm of medicine/ farming to cater for individuals. The work conducted in assisted living and animal welfare is the foundation towards predicting health/welfare outcomes based on current sensing. Digital twins will be developed based on the daily readings that the sensors will collect from patients/animals to predict the “future health/welfare state” of the patient/animal

This will be supported by industrial impact in elderly care with our industrial partners with whom I will work on technology transfer, and I am also working on a spin-off from university on automatic ruminants.

Furthermore, I will be working on diversifying my portfolio starting with propagation effects in regolith for spacecraft landing, sport science and rehabilitation.

3 Teaching

3.1 Context

The UK higher-education system is not the same in England and Scotland. In England, a bachelor's degree is 3 years (1 introductory year and 2 honour years) whereas, in Scotland, it is 4 years long (2 years introductory material and 2 honour years). The pass mark is 40%, 40-50% is third class honours, 50-60% is second class second division honours, 60-70% is second class first division honours, and from 70% first-class honours. The particularity is that the introductory years are not degree awarding years, the students have to validate their credits following progression rules which is no more than 20 credits as a soft fail (between 30-40%), a hard fail counts double (if you fail 10 credits then it is counted as 20 credits). The degree weighting is 50:50 for year 3 and 4 courses. Only the mark obtained on the first attempt is retained for the degree classification. The students are allowed only one resit opportunity to make up for their grades and progress. The final year project spans two semesters and cannot be compensated or resat. Therefore, it is a make-or-break course for the engineering degree. Years 1 and 2 are usually heavier in contact hours but lighter in terms of the Honus on the student for self-study. Years 3 and 4, however, see a reduction in contact hours but an increased demand for self-directed study. Failure to progress will usually result in the termination of the degree unless there are extenuating circumstances. If the conditions are met, an exit degree of lower standing (BSc honours, BSc ordinary, Higher diploma or higher certificate). Lecturers at University are required to pass the 30 credits of English Postgraduate Certificate of Higher Education (PGCHE) or Scottish Postgraduate Certificate in Academic Practice (PGCAP – 60 credits) to meet the UK Professional Standards Framework for Teaching and Supporting Learning. It is noteworthy that there is no obligation of service (as opposed to the 192h of service in France) meaning that we can have a small teaching load or a large one depending on requirements and operational needs.

In China, the B.Sc. degree (eq. of B.Eng. in the UK) is a 4-year course. The pass mark is 60%, and all credits without exception must be validated. The students have unlimited resit chances to improve their score, and only the best score is retained. This also applies to the final year project. The courses include political courses (e.g., Marxism, Mao), military training, physical education, English qualifications (Chinese English Test level 4 (CET4) or above for undergraduate students), as well as content courses. The 1st and 2nd year are heavily loaded, and the student life is heavily regulated by the student councillors with study periods and dorm inspections. Year 3 and especially year 4 are lighter to allow the students to prepare for their postgraduate studies or state job entrance exams. Students have a maximum of 6 years to complete their degree studies. There is no exit degree either they get the B.Sc., or they leave with nothing.

Working in a Sino-British transnational education university, we must account for both systems. So, the students have to pass every single module, so they are given 2 resit opportunities per year per course (except for the final year project), but only the mark obtained on the first attempt is retained for the degree classification. This is to meet the Chinese standard that all credits must be validated without exception. There is a strong demand for the English language requirements. In Nottingham, this was passing the foundation year, which was heavily loaded with English for Academic Practice courses and would theoretically bring the student to an equivalent of 6.0 in every subtest (reading, listening, speaking, writing) of IELTS. In Glasgow, the requirement is IELTS 6.0 in every subtest, which would meet the UK Visa and Immigration requirements for studying in the UK. Since 2021, the requirements are now to pass all English courses in years 1 and 2 to reach an equivalent of IELTS 6.0 in all categories. Year 3 and year 4 are following the UK system in loading, which the students still get caught with as they must deal with heavier loading and passing their entrance exams which usually results for some in a severe reduction in grades because they focused on entrance exams and not on their study (usually in semester 1 of year 4). Because the degree in China is 4 years, the Sino-British curriculum is also 4 years. The curriculum still includes military service, physical education and political education that count towards their Chinese degree but are not counted for the British degree. The students have the possibility to study 4 years in China (4+0) or 2 years in China and 2 years in the UK (2+2). The students, when they graduate, receive a dual degree from the British institution and the Chinese institution unless they fail English requirements, in which case, they can only obtain the Chinese degree. The students have a maximum of 6 years to complete their degree from the time they start, whatever the circumstances.

3.2 Academic Practice Statement

After running a course, I critically reflect on what went well, what needs improving and where students had difficulties in my course. I use the student evaluations, my own reflection and existing literature to improve my course and its evolution with accreditation and legal requirements (accessibility, equality, diversity and inclusion). In my current job post, I teach Chinese students who have gone through different education systems and cultures. It is important to set a clear context for the learning to be effective and how the material being taught is linked to their previous knowledge. A diverse student audience requires an alignment of exercises and experiments with the course linked with in-class/lab feedback to ensure that everybody can improve and that allows to identify difficulties and resolve them quickly. Learning happens both ways, students learn from me the relevant knowledge and I learn from them what methods work more effectively and where improvements are needed in the course material to improve the course material. Furthermore, the course material has to evolve with state-of-the -art to follow the newest technological trends.

I have taught for 17 years, primarily in Electrical and Electronic Engineering, and Business acumen. The difficulty is on how to change the students' perception of education from a mere increase of knowledge to an engineering mentality of making sense of what they have learnt and putting it in practice. I prepare interactive sessions/labs to ensure that in-class feedback happens so that misconceptions or clarifications are dealt with early to avoid difficulties to pile up for students who may have misunderstood a concept. This is why aligning the lab material or assessments with the course material so that the intended learning outcomes are met by design. Teaching non-technical subjects to engineering students is trying as the students do not understand its value. Soft skills and business acumen are now integral to engineering and represent a significant percentage of their future day-to-day as qualified engineers. The lecturer must strive to make the material relevant to make sure students engage with the subject in a meaningful way.

I believe that the course material for technical/non-technical topics should be applied through tutorials, labs, and projects to put the course content into action. This is so that they can "experience the material" and not just rote learn it. For assessment, I design labs, projects, homework, presentations and/or exams that evaluate the intended learning outcomes. These assessments are done in pairs/small groups to encourage collaborative work and are designed to put the student in real-life conditions for homework and contextualisation for exams. And assessed fairly against marking descriptors for objectivity.

As an educator and researcher, I pursue knowledge, and address issues to further understand and develop future technology. Personally, I believe in excellence, rigour, honesty, respect, and tolerance. So, I will strive to pass on those values to the students in all aspects, personal and professional, as they are traits of good engineers.

The Covid-19 outbreak disrupted our way of teaching dramatically, and we had to teach everything remotely and run exams online. It brought us from using technology sparingly to it being pervasive. This has helped tremendously to support learning and accessibility as well as allowing students to revisit the course material at their own pace. Technology in the classroom also allows the more reflective students to participate in the activities so this promotes inclusion.

Details in Appendix 7.6.2.

3.3 Formal training in academic practice

3.3.1 Postgraduate Certificate in Academic Practice (PGCAP) – University of Glasgow (started 2018- finished 2019)

The PGCert in Academic Practice (PGCAP) is designed to support the professional development of staff involved in teaching and supporting learning in Higher Education at various points in their career but with a focus towards staff on the Early Career Development Programme (ECDP). The Programme strives to provide a variety of practical advice and support to enhance the competence, confidence, and professional development of teachers in higher education as well as provide an opportunity to engage in scholarly practice, theory and research and scholarship related to higher education. I obtained my Postgraduate Certificate in Academic Practice in 2019 and became a Fellow in Recognizing Excellence in Teaching. RET is the University of Glasgow's continuous professional development framework, which aims to provide development opportunities as well as professional recognition of expertise in teaching and supporting learning.

I have only accounted for the part on supervising students which I really engaged with in the course and keep working on this topic to date.

Details in Appendix 7.6.3.

3.3.1.1 Supervising students (10 credits)

This course aims to provide you with an opportunity to evaluate and reflect on supervision practices and develop an evidence-based understanding of approaches to supervision of students. The course will cover supervision at undergraduate, postgraduate taught, PhD, and professional doctoral levels. You will have the opportunity to compare practice against both institutional requirements and recent literature on effective supervision. The goal was to analyse approaches to supervision relevant to your context; and critically evaluate research and scholarship focused on supervision and relate this to proposed enhancements to practice.

This work consisted in the review of my PhD supervision role and look through self-evaluation and student feedback on my supervision style and which model I should strive to achieve as shown in the following paragraph.

For the future, I will strive to stay in the contractual scheme for supervision which is from the literature and the PGR code of practice the way forward while implementing flexibility based on the different stages of a PhD. My supervision practice evolves with experience, and I am glad to see that I'm heading in the right direction with the take away messages below:

1) Contractual supervision model with flexibility,2) More interaction to bring a sense of community in the research group
2) Keep working on better ways to provide remote supervision and see how technology could enhance the experience for sharing knowledge between students
3) Participating in supervisory development training to keep up to date with education theories and ways to improve practice
4) Work on feedback on written work to enable discussions and improve timeliness

Details in Appendix 7.6.3.4.

3.3.2 Postgraduate Certificate in Higher Education (PGCHE) – 30 credits – University of Nottingham Ningbo (started 2013- finished 2014)

It is designed to support staff with teaching responsibilities to be effective teachers. The course provides a practical and theoretical grounding in learning and teaching in higher education and emphasises the links between conceptual frameworks and teaching practice. The PGCHE aims to encourage you to develop a scholarly, reflective inquiry base to inform your teaching and its development. At University of Nottingham Ningbo, we could only take 30 credits out of the 60 credits required to complete the PGCHE. These 30 credits were mandatory for staff in lecturing positions to complete within 3 years after employment. On completion in 2014, I obtained an associate fellowship of the Higher education academy.

Details in Appendix 7.6.4.

3.4 Scholarship

I am engaged in scholarship in teaching to enhance my practice through the PGCHE and the completed PGCAP with formal training but also by engaging in research with currently 4 publications:

- Bremner, D. J., Le Kernec, J., Fioranelli, F. and Dale, V. H. M. (2019) The Use of Multiple Choice Questions in 3rd year Electronic Engineering Assessment: a Case Study. In: IEEE TALE 2018, Wollongong, Australia, 4-7 Dec 2018, pp. 887-892. ISBN 9781538665220 (doi:10.1109/TALE.2018.8615153)
- Le Kernec, J. , Levrai, P. and Bolster, A. (2016) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical and Electronic Engineering Students. In: IEEE TALE2016, Bangkok, Thailand., 7-9 Dec 2016, ISBN 9781509055982 (doi:10.1109/TALE.2016.7851761)
- Levrai, P., Bolster, A. and Le Kernec, J. (2014) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical Engineering Students. ICED 2014: International Consortium for Educational Development, Stockholm, Sweden, 16-18 June 2014.
- Levrai, P., Bolster, A. and Le Kernec, J. (2013) Mixed Panel Oral Presentation Assessment: Preparing Electrical & Electronic Engineering Students for Work. In: 11th Biennial Conference of the Association for Academic Language and Learning, Melbourne, Austr.alia, 13-15 Nov 2013

I also organise annually a teaching workshop between UESTC and UoG on assessment and feedback (framework 2018, practice 2019), and I had planned Blended Learning in 2020 for staff development in collaboration with the Learning Enhancement and Academic Development Service (LEADS) in Glasgow however those are on hold since the pandemic started. I organise with the head of LEADS for 2 of their staff to come to China for them to deliver the workshop around the areas of development required after consultation with staff in China and the UK. This has led to changes in practice in Glasgow College regarding assessment and feedback through LEADS training at UESTC by reviewing the alignment of assessment with the intended learning outcomes for both curricula currently running and improved practices/guidelines for exam setting. Following these events' success, the human resources department in UESTC has decided to widen the participation to more UESTC staff.

I also use the educational frameworks I learned in PGCAP that I started in dynamics and control:

- Active learning: Providing lab answer sheets that require students to report on their understanding of the experiments rather than just the experiment results. The completion of the work and the understanding was checked in the lab session to address any misunderstanding. This increased engagement in the lab and every student submitted their work timely. Furthermore, this tackles plagiarism as students must discuss their understanding to validate the work.
- Blended learning: Provision of video recordings of all the threshold concepts and a platform to collaboratively build resources for revisions through "peerwise" which enhanced engagement and empowered students in/out of the classroom.

3.5 Contributions to teaching

I was an Assistant Professor (01/2016 – 07/2020) and am now an Associate Professor (since 08/2020) at the University of Glasgow in the UK in the James Watt school of engineering. For this academic year

(2021-2022), I was responsible for the Level 3 modules: "Engineering and the law" (2018-2020), 1st year PhD "Signal Processing in Wireless Sensor Network" and co-teach in different courses (Level 3) Digital Circuit Design, (Level 2) Circuit Analysis and Design, (Level 1): Introductory Programming. I supervised 9 final-year project students (Level 4) and 1 M.Sc. Project level 5 and 1 M.Eng. project level 4. Prior to this position, I was an Assistant Professor at the University of Nottingham Ningbo, China (2012-2016), a project manager in the private sector at Kuang-Chi Institute of Advanced Technologies (2011-2012 so no teaching activities), A.T.E.R. (Attaché Temporaire d'Enseignement et de Recherche – Temporary post as assistant professor prior to graduating with a PhD) at Polytech Paris (Pierre and Marie Curie University), and the National Conservatory of Arts and Crafts (CNAM) from 2009 to 2011. I also worked as a part-time teacher during my master's and doctoral degrees from 2005 to 2009 at UPMC from 2007-2009 and CIT from 2005-2006. I did not teach in 2005-2006 in the 1st year of my PhD. As shown in Table 10, this corresponds to more than 1500 hours of teaching in analogue and digital electronics. I also taught courses in computer science (56h), business (142 hours), and physics (51 hours). The project supervision for undergraduate and postgraduate taught students amounts to over 1200 hours. My teaching and convening load are shown per year and per post Figure 12. By convening load, is meant how many hours are in the course that needs to be overseen as a convenor.

Table 10: Teaching hours per discipline and per activity

Subject level	Type of teaching activity	Teaching (hrs)	Convening (hrs)
Digital Electronics 1 (DE1)	Lectures	33	6
	Tutorial	34	0
	Labs	91	44
	Projects	134	90
Digital Electronics 2 (DE2)	Tutorials	22	0
	Labs	88	0
	Projects	80	0
Analog Electronics 1 (AE1)	Lectures	82	38
	Labs	138.5	138.5
	Projects	212	192
Analog Electronics 2 (AE2)	Lectures	195	160
	Tutorials	28	0
	Labs	428	344
Computer Science (CS)	Lecture/Labs	56	56
Business (B)	Lectures	142	110
Signal Processing III (SP3)	Lectures/Labs	56	88
Physics (Ph)	Lecture/Labs	51	0
Project supervision (B.Eng, M.Sc, M.Eng)	Supervision	1240	1240
	Total	3110.5	2506.5

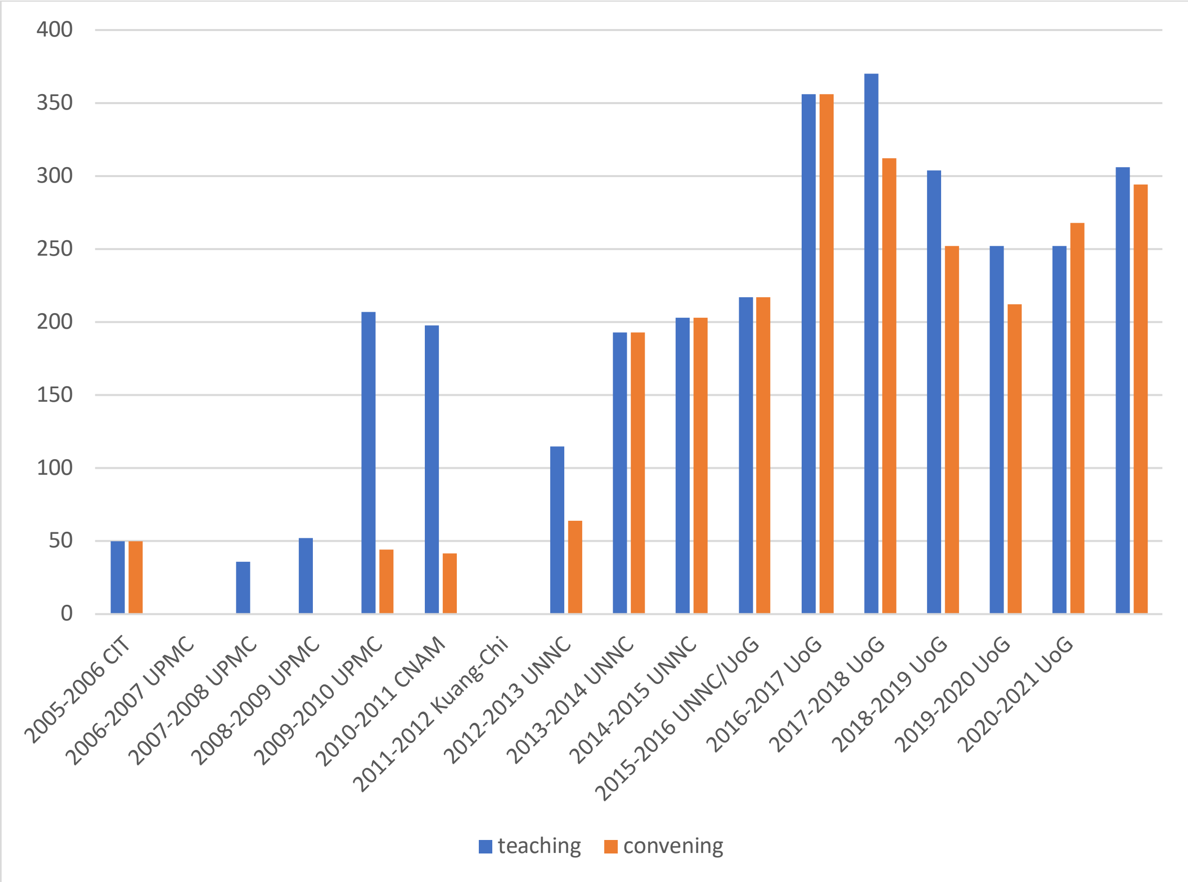


Figure 12: Teaching load and convening load in hours per academic year and affiliations – CIT: Cork Institute of Technology, UPMC: University Pierre et Marie Curie and Polytech Paris, CNAM: Conservatoire National des Arts et Metiers, Kuang-Chi: Kuang Chi Institute of Advanced Technologies, UNNC: University of Nottingham Ningbo, UoG: University of Glasgow

The details of the modules and my activities covering this period can be found in Appendix 7.6.1. The nature of the positions I have held was limiting regarding research-led teaching. I have managed to incorporate my research with project supervision, extracurricular activities, and summer projects.

3.5.1 Pre-academic posts teaching and convening load

I started teaching in 2005 when I was a master's student at Cork Institute of Technology as a part-time lecturer. I was hired by the computer science department to teach 2 courses to year 1 students. I was the module convenor for both courses "History of computer science and office automation" and "Operational Systems Architecture". I created the material from scratch for both courses and the assessments. I was reporting directly to the head of the computer science department.

In 2006, I started my PhD, so I did not teach in the first year. I resumed teaching in 2007 at University Pierre and Marie Curie and Polytech' Paris for master's students and Engineering students. I primarily covered lab activities in Digital Electronics as instructed by my supervisors mainly on VHDL for FPGA programming. In 2008, I taught the same modules and covered the labs for digital communications with FPGA for the baseband and analogue circuitry for the RF part over several sessions.

In 2009, I was hired as a temporary lecturer at University Pierre and Marie Curie where I taught a full teaching load 192h.The teaching was mainly on digital electronics covering VHDL for FPGAs as in the previous years, C for embedded platforms, and system-C for modelling. In the "System Architecture" course, I wrote the labs for the semester by adapting lecture material from Altera to work up to creating a microprocessor on FPGA.

In 2010, I was hired as a temporary lecturer at the Conservatoire National des Arts et Métiers where I taught a mixture of courses between digital electronics and analogue electronics. I taught all levels from technicians, to engineering students, mature students, and master students both face-to-face and for distance learning. Notably, I had to adapt the course for Analogue Electronics to turn the lab sessions to 1/3 lecture/tutorial and 2/3 labs as the students did not cover the theoretical knowledge prior to the lab sessions.

During this period, I was mostly given material to teach aside from a couple of exceptions and covered mainly labs and tutorials. The details can be found in section 7.6.1.1.

3.5.2 Assistant Professor at UNNC teaching and convening load

In 2012, I started as an assistant professor at the University of Nottingham Ningbo China. The program was being rolled out in China to deliver the same programme as the main campus in the UK. I arrived at the start when year 3 out of 4 was starting. I covered a variety of subjects ranging from digital electronics to analogue electronics, to physics and business. I taught engineering students from year 1 to 4. I was the convenor of all my courses. The teaching team being small there were no teaching assistants, and we were generally teaching modules alone as the student cohort was quite small ~140 in the 3 years of the engineering programme year 2,3, and 4 as year 1 is the foundation year.

For the electronic construction project (Level 3), the students had to build an audio amplifier and its power supply. They had to go from the theory to simulations to implementing the circuit and determining its performance. I created a session-by-session plan to guide the students through the process. I also prepared a bid for tender to procure the soldering stations, fume extractors and all the consumables and get the material ready for the course to design an audio amplifier and its power supply.

For Introduction to Real-Time Systems (level 2), this project was based on the implementation of a digital audio processor on a microprocessor of an input signal in C to learn the basics of real-time systems. In this course, I had to procure the cards from Microsim and develop the courses from scratch as well as the project at the end of the semester. This included procuring equipment for a second lab as our student numbers had increased. This meant putting together a proposal to the faculty for a budget to increase the capacity by incorporating the occupancy rates of the labs and the student numbers to justify the expenditure.

The module Laboratory techniques and presentation (Level 2) covered laboratory techniques for electronics that complemented the other more theoretical electronics modules taught simultaneously. This included labs and a project to learn about operating the lab equipment (oscilloscope, multimetre, power supply, signal source), MATLAB (basic commands and communications), Motors, and modelling with OrCAD. The project combined all these into the construction of a signal generator, signal selector and active rectifier filter. The students then had to present their findings in a report and give a presentation. This new course further stretched our capabilities to get students in labs in concurrently with physics. I had to write another proposal to turn another room in the building in a new lab space for electronics by putting in a proposal with the faculty reviewing the entire curriculum and other curricula in the faculty making use of our lab facilities. This course was imported from the UK and only required adjustment for lab procedures in relation to the differences in equipment between the UK campus and the Chinese campus.

I was the course convenor for Business planning for engineers (Level 4) but I did not teach it. However, I wrote the exam based on the course material as it was just a Multiple-Choice Question exam as the main part of the course was writing a business plan based on their final year project. This was interesting as the students had to combine the different projects into a product, write a business plan and present their ideas. I was marking presentations with a panel of academics from the business school, the English department, and engineering to provide feedback on all 3 aspects business, technical and language skills. I had to liaise with the Business School to find a lecturer to deliver the module and come up with that person with a syllabus suited to engineers because I was involved in the development of the syllabus and stayed in close collaboration with the lecturer for the design of the assessment the module was a success as opposed to other business modules ran in my Faculty that were not very welcome by students and had very low attendance rates because the lecturers from the business school were given the modules without a staff liaison in Engineering.

The module Microwave communications (Level 3) provided an overview of microwave telecommunications systems and radar. The course material was given by headquarters, but I updated the material especially the radar part as most of the content was outdated.

As part of my postgraduate certificate in higher education projects, I have integrated in core modules (Figure 13 a)) business awareness for my modules and other modules with the collaborations of the convenors constituting business awareness in technical education (Figure 13 b). Since this British university operates in China, this system aimed at monitoring and giving feedback on the student's English skills and presentation skills. They were asked to report on the technical aspects of their projects as well as on a business aspect that surrounds the project to a mixed audience e.g., audio amplifier and power supply and cost of components and manufacturing looking at China, the US, and the UK for sourcing, labour costs, and other running costs. By practicing their presentation skills throughout the engineering curriculum through the Kolb's cycle of learning (Figure 14): experience, get feedback, reflect on it, plan for development, and repeat. This framework was run with the collaboration of the EEE department, the Business School (NUBS), the English for Academic Purpose Unit (CELE), and the Academic Support unit. This was to provide professional feedback on all aspects of the presentations: language proficiency, technical proficiency, business awareness, and have workshops supporting the growth of students through the 3 years in Nottingham.

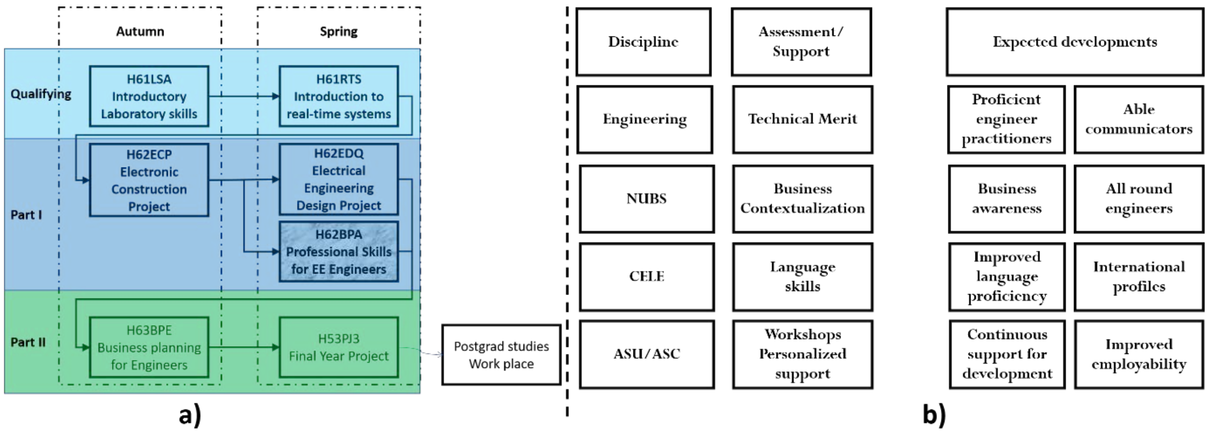


Figure 13: BATE framework a) embedding in the curriculum of EEE b) Expected skillset, support, and assessment by activity

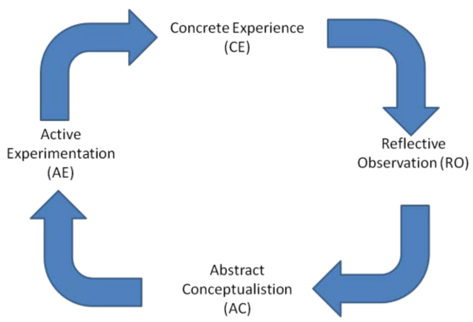


Figure 14: Kolb cycle of learning [1]

In 2014, I created 2 modules from scratch for Nottingham Advantage Awards which are extra-curricular modules from the main EEE modules: "Career Skills for Electrical and Electronic Engineers" and "Business Awareness in Technical Education".

"Professional Skills for Electrical and Electronic Engineers" aimed to enhance the career education and personal development of electrical and electronic engineering students in preparation for work experience, postgraduate study, and future career paths. It included support on technical report writing, presenting technical data using the Microsoft Office suite, careers, and employability, skills in seeking employment and postgraduate opportunities, and academic skills pertaining to level 1 modules undertaken in EEE department.

"Business Awareness in Technical Education" aimed to enhance the career education and personal development of engineering and science students in preparation for work experience, postgraduate study, and future career paths. It included business acumen, presentation skills, entrepreneurship, and innovation from 13 different guest lecturers including lecturers from Business and Engineering, EAP tutors, the innovation director of TCL Alcatel One-touch, an IP lawyer, and a technical venture capitalist. For this, I had to liaise with the Business School, Engineering departments in my Faculty, Professional services, and speakers from the industry. This module's assessment put students in a one-day competition to put a business plan together and a presentation to be presented the same day in the evening about the product/service business plan they came up with in multi-disciplinary teams.

In University of Nottingham, I acquired a lot of experience in teaching/managing various subjects from digital electronics to analogue electronics, physics, and business. I developed several courses. You will find the details on all the courses in section 7.6.1.2.

3.5.3 Assistant/Associate Professor at UoG teaching and convening load

In 2016, I was hired at University of Glasgow for a secondment where I spent 80% of my time at the University of Electronic Science and Technology of China and 20% in the UK. I taught in year 1 to 4 and at PhD level. We have 1800 students in the 4 years in Chengdu and the Hainan campus is opening this September with 120 students for starters. The PhD cohort has 5-10 students a year on the dual-degree programme. Because the cohorts are much bigger, we often teach in teams with the help of graduate teaching assistants. I joined the programme when year 3 of the first programme EEE was rolled out. Since then, two more programmes were opened introducing a communication specialty and a microelectronics specialty 2016 and 2019 respectively.

I took over Dynamics and Control (level 3). As the course convenor, I imported the lectures from UK. However, as in the UK they used very specific lab benches for that module. All the lab procedures had to be rewritten to reduce the cost of the labs as imposed by procurement rules in UESTC. In this course, I have experimented a few times on the lab and have found that active learning in the labs work very effectively. For labs, I prepare an answer sheet that requires students to present their work and findings during the lab time to check that they have understood the work. The questions are aimed to see if they have understood what they are doing as opposed to just reporting the measurements they obtained from following the instructions. This makes for hectic lab sessions, but the reward is that I can eliminate misconceptions for most students by linking the teaching material and the labs constructively.

I was the convenor for 1 year on electronic system design (level 3). This course presents an introduction to specification driven design of analogue systems. In this course, the lectures were imported from UK. However, the lab sessions had to be written from scratch as there were no labs for this course in the UK. This also included the preparation of a theoretical design assignment.

I was a teacher on professional practice (Level 3). This course was designed to introduce the concepts of Professional Practice to Engineers in line with the accreditation requirements for either ABET or Engineering Council (UK). The course also covered additional material for engineers on effectively contributing to new organisations after graduation. I was given half the course to teach by the module convenor that he developed the previous year. I incorporated new materials relative to ethics and in -class debates about case-studies as well as updating some of the material.

Professional practice was split in two halves "Engineering and the law" (Level 3) and "Engineering Finance and Management" (Level3). I proposed a split of the material by reviewing the module content and linking material together. I prepared the course proposal to Senate for approval and modified the course material of "Engineering and the law" to incorporate Health and Safety, the differentiation of engineering ethics and business ethics as well as research methods to prepare the students for the expectations of the written assignment. The product requirement document required the students to come up with a project and provide a document at stage 2 of the stage-gate process for review by their manager (me in this context) with sales projections for three years around a technical product or service. This course evolved after a course review where the research methods were transferred to the new English course. I expanded the material on marketing and my colleague expanded on the law section to compensate. The assignments have been more authentic by using my research projects as the technical base for the assignments with product development, marketing-based coursework. The course has now been modified to provide better support for the students and have them engage further in the material. There is now an umbrella project based on my research and 4 assignments (no exam) on ethics, law, marketing, and product development that will be interconnected.

In Team Design Project and Skills (Level 3), students divide into teams of 8-10 members to design and construct electronic and electrical systems (typically autonomous vehicles) which perform assigned tasks on time and within budget. Students make oral and written presentations of their work and give a demonstration of their final design. In this course, I was in charge of guiding 7-8 teams per year for their projects. This included project meetings where we discussed their ideas and ways forward as a facilitator.

In Wireless Sensor Network (level 4), I introduced the basic principles of a wireless sensor node, simple scheduling on a processor or multiple processors with the concepts of adaptive voltage and frequency scaling as well as some concepts of control engineering with respect to the dynamic changes within the chip to avoid damages derived from research material from leading researchers in the area.

The course Signal Processing for Wireless Sensor Networks was designed from scratch for the new PhD cohort starting in academic year 2020-2021. I had to develop the module for the doctoral training programme as there is a taught element for the first year and 3-4 years of research after that, have it approved by the school of Engineering in Glasgow, the School of information and communication engineering in UESTC, and the programme including all courses and the proposal validated by the Ministry of education in China. This course is research-led based on my specialty in radar and my colleague's specialty in communication.

At the University of Glasgow, I have been teaching mainly analogue electronics and business courses and I am starting to teach digital electronics again. The PhD course is very interesting as it allows to interact with the students as it is a small cohort and is directly linked to my research with signal processing. I have developed courses, created new ones from scratch and managed a number of teachers and graduate teaching assistants to deliver the courses. I am now a programme director in which I look forward to making changes in the programme to enhance the teaching experience of students and introduce more research-led material in courses. The details of the teaching activities can be found in section 7.6.1.3.

3.5.4 Research-enhanced teaching

Further to the seminar activities in other universities for research dissemination, I delivered Science, Technology, Engineering, and Mathematics (STEM) presentations and research seminars for dissemination to the wider public ranging from software-defined radar, radar in assisted living, introduction to radar and radar in animal welfare from high school students to master's students. I adapt the content based on who I am delivering the talk to.

My research is also disseminated through project supervision to my undergraduate and postgraduate students either under formal supervision or through extra-curricular activities. I also supervise students on summer research projects. I have supervised 12 Master students, 51 Final Year Projects, and several summer project students. I find the supervision quite enriching as I can improve my research discussions and disseminations by translating complex concepts to match their training. The culmination of supervision is when we obtain publishable results. This started in Nottingham on low-cost radar development for deformation monitoring that led to 3 conference publications on porting SAR processing from MATLAB on an FPGA platform and antenna development for the train-mounted radar platform with a collaboration with Xi'an Jiaotong Liverpool University.

- Melnikov, A., Le Kernec, J. and Gray, D. (2015) Porting Spotlight Range Migration Algorithm Processor from Matlab to Virtex 6. In: 2015 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Turin, 7-11 Sept. 2015, pp. 1429-1432. ISBN 9781479978090 (doi: 10.1109/APWC.2015.7300214)
- Melnikov, A., Le Kernec, J. and Gray, D. (2014) A Case Implementation of a Spotlight Range Migration Algorithm on FPGA Platform. In: 2014 International Symposium on Antennas and Propagation (ISAP), Kaohsiung, 2-5 Dec. 2014, pp. 177-178. (doi: 10.1109/isanp.2014.7026588)
- Melnikov, A., Le Kernec, J. and Gray, D. (2014) FMCW rail-mounted SAR: Porting spotlight SAR imaging from MATLAB to FPGA. In: 2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Guilin, 5-8 Aug. 2014, pp. 780-785. ISBN 9781479952724 (doi: 10.1109/ICSPCC.2014.6986303)
- Zhou, X., Le Kernec, J. and Gray, D. (2017) Vivaldi Antenna for Railway Cutting Monitoring. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059180)

At that time I had 1 or 2 students a year to supervise and some students for extra-curricular activities. I then joined Glasgow where my supervision load increased where I have 10-20 students at any given time to supervise. The dissemination of an open radar dataset (Radar signatures of human activities - Enlighten: Research Data (gla.ac.uk)) containing over 2000 signatures and 10 different activities in 2019 and the use of motion capture databases (Carnegie Mellon University - CMU Graphics Lab - motion capture library, https://www.v7labs.com/open-datasets/hdm05) to emulate radar signatures and test new radar geometries and classification algorithms for repeatable results allowed to boost collaborations and also facilitate student projects for radar in assisted living.

This generated 3 international journal papers 2 on simulation work with data augmentation and radar geometry for aspect angle robustness in human activity recognition and 1 on the classification of radar signatures and extraction of gait parameters using a lightweight hierarchical classification:

- Zhou, B., Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Simulation framework for activity recognition and benchmarking in different radar geometries. IET Radar, Sonar and Navigation, 15(4), pp. 390-401. (doi: 10.1049/rsn2.12049)
- Li, X., Li, Z., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2020) Hierarchical radar data analysis for activity and personnel recognition. Remote Sensing, 12(14), 2237. (doi: 10.3390/rs12142237)
- Li, J., Shrestha, A., Le Kernec, J. and Fioranelli, F. (2019) From Kinect skeleton data to hand gesture recognition with radar. Journal of Engineering, 2019(20), pp. 6914-6919. (doi: 10.1049/joe.2019.0557)

It also allowed for 6 prestigious conference publications out of 11 on simulation results and classification on the open dataset in radar for assisted living on a range of techniques for human activity recognition using fusion, feature selection and deep learning from multiple radar data domains

- Yang, K., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Bespoke Simulator for Human Activity Classification with Bistatic Radar. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 71-85. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_7)
- Zhang, X., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Elderly Care - Human Activity Recognition Using Radar with an Open Dataset and Hybrid Maps. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 39-51. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_4)
- Du, Y., Li, J., Li, Z., Yu, R., Napolitano, A., Fioranelli, F. and Le Kernec, J. (2021) Radar-based Human Activity Classification with Cyclostationarity. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 - 19 December 2021.
- Guo, J., Shu, C., Zhou, Y., Wang, K., Fioranelli, F., Romain, O. and Le Kernec, J. (2021) Complex Field-based Fusion Network for Human Activities Classification With Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 68-73. ISBN 9781839535406 (doi: 10.1049/icp.2021.0572)
- Jiang, H., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Human Activity Classification Using Radar Signal and RNN Networks. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1595-1599. ISBN 9781839535406 (doi: 10.1049/icp.2021.0556)
- Li, X., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Radar-Based Hierarchical Human Activity Classification. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1373-1379. ISBN 9781839535406 (doi: 10.1049/icp.2021.0566)
- Zhou, B., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Interferometric Radar for Activity Recognition and Benchmarking in Different Radar Geometries. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1515-1520. ISBN 9781839535406 (doi: 10.1049/icp.2021.0571)
- Jia, M., Li, S., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Human Activity Classification With Radar Signal Processing and Machine Learning. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205461)
- Jiang, H., Song, Q. and Le Kernec, J. (2020) Searching the Adversarial Example in the Decision Boundary. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205320)
- Li, S., Jia, M., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Elderly Care: Using Deep Learning for Multi-Domain Activity Classification. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205464)
- Li, Z., Li, B. and Le Kernec, J. (2020) Activity Recognition System Optimisation Using Triaxial Accelerometers. In: International Conference on 3D Imaging Technology (IC3DIT2019), Kunming, Yunnan, China, 15-18 Aug 2019, ISBN 9789811538667 (doi: 10.1007/978-981-15-3867-4_15)

Our collaboration with companies allowed to work on smart radar systems with a master's student that had an internship with Aveillant on the development of techniques for a staring radar to detect drones with explainable AI.

- Bennett, C., Jahangir, M., Fioranelli, F., Ahmad, B. I. and Le Kernec, J. (2020) Use of Symmetrical Peak Extraction in Drone Micro-Doppler Classification for Staring Radar. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266702)

I continue to work with undergraduate and postgraduate students on leading edge research topics as it allows to enrich the relevance of the projects and I can advise based on my research expertise.

4 Management roles

This section covers the details of my management roles in my academic jobs at University of Glasgow, University of Nottingham Ningbo China and briefly as project manager at Kuang-Chi Institute of Advanced Technologies.

4.1 Senior Lecturer in Glasgow-College UESTC (GC-UESTC) – 08/2020 – to date (Lecturer 2016-07/2020)

The undergraduate Joint Educational Programme in Electronic Information Engineering (Grant No: MOE51UK2A20121313N), offered jointly by the University of Glasgow and the University of Electronic Science and Technology of China (UESTC), was approved by the Ministry of Education of China in October 2012. UoG-UESTC Joint School was established on 5th January 2013, which is the first school of UESTC with a focus on Sino-Foreign Joint Education. The first cohort of Electronic Information Engineering was enrolled in September 2013. This agreement covers 240 students.

The Joint Educational Institute partnership between the University of Glasgow and UESTC was authorized by the Ministry of Education (Grant No: MOE51GBA02DNR20161735N) in February 2016. With the birth of 'Joint Educational Institute,' UoG-UESTC Joint School was renamed Glasgow College, UESTC, and a new degree programme 'Communications Engineering' was included in the undergraduate activity plan in September 2016 and "Microelectronic Engineering" in September 2019. This agreement covers 280 supplemental students to be split between the 2 programmes.

The mission of the Glasgow College, UESTC is to deliver undergraduate degree programmes in China at a standard commensurate with the highest quality education available internationally, providing students with the scholarship and skills that will equip them for lifetime careers as leaders in industry and academia. These three programmes are taught 50% by University of Glasgow (UoG) staff and 50% by University of Electronic Science and Technology China (UESTC) staff. In 2020, it also started a dual-PhD programme for 10 years starting with cohorts of 5-10 students a year that are co-supervised by UoG and UESTC professors with a member of the fly-in fly out team as a co-supervisor.

Both universities have separate administrative structures and 2 deans of the Glasgow College – UESTC one from UoG and one from UESTC. There is therefore much interaction between the two at the teaching, administrative levels and now growing at the research level.

Figure 15 shows the reporting structure for the GC-UESTC comprising the University of Glasgow (UoG) in blue and University of Electronic Science and Technology of China (UESTC) in green.

I was a member of the Covid-19 task group in charge of mitigating measures for the disruption to our operations in Glasgow College – UESTC due to the outbreak. The range of activities included policies under exceptional circumstances: exam provision, online provision, student communication, mitigation for projects and lab-based deliveries, progression (technical, English proficiency). I participate in the meetings and have worked actively on online provision to find and test solutions liaising with IT services to support the delivery of the program in China by UoG members of staff in China, the mitigation of lab-based, and projects to minimise the impact of the closure of facilities on the progression of students by adopting a policy shifting the labs to simulation only or providing datasets of measurements for analysis.

I am a member of the Joint Academic Committee which deals with all the issues related to administration, teaching and more recently research for the GC-UESTC. The Joint-Academic Committee handles Equipment and Infrastructure, Pastoral Care, Administration, Research issues as well as joint events. My main contributions at that meeting are as

- a Senior Tutor with the modification of advising forms for a better joint coordination of the actions to follow student cases between UoG and UESTC that has led to a more streamlined and faster response for students.
- a Facilities upgrade coordinator (UoG) of the Glasgow-College UESTC office space with central air-conditioning and fire-safety (£100k), the joint-research-lab of RF and Communication refurbishment (£50k), acquisition of RF+comms equipment (£200k). I followed the specification of the upgrade for the offices and laboratory with the head of logistics in GC-UESTC to address issues in relation to specifications, the estate and facilities department, security department, and procurement department. I was liaising with UESTC to find a lab space for the new joint-lab and refurbish it to house the equipment. I also liaised with the lab coordinator in UESTC and the staff in Glasgow to constitute a list of lab equipment for purchase and managed the bid to tender with the procurement office for £200k of equipment for Glasgow to purchase equipment in China. I serve as the joint RF+comms lab coordinator for UoG as access to the labs need to be organised as well as the future evolution of the lab as we are getting a yearly budget to run the lab and maintain it. The second round so an investment of £300k in the UK and £300k in China to boost collaboration in 5G research and healthcare between China and the UK in 2021.
- a Teaching workshop coordinator (UoG) of UoG/UESTC where academics from UoG and UESTC come together to discuss a topic related to the delivery of the programme to improve the standards of delivery and share good practices in line with the Quality Assurance Agency and UESTC central teaching office. I had to come up with a theme by consulting staff on both sides and finding the resources from the learning enhancement and academic development by negotiating with the head of their services to spare them for a week to go to China. The first edition in 2017-2018 was on the theoretical framework for assessment and feedback for the students based on constructive alignment. The second edition in 2018-2019 focused on the practical implementation of the assessment and feedback in the modules we were teaching. The events have been very successful and now the central teaching office and HR department of UESTC want to participate and expand participation. The 2020 edition was supposed to be on blended learning to enhance provision, but it was cancelled and instead we have had a live practice with the outbreak. The week the workshop happens is also used for the provision of student training workshops on academic writing, revision strategies, and Graduate Teaching Assistants GTA training for year 1, 2, 3, and 4 as well as organising the teaching observations for staff who are following the Postgraduate Certificate in Academic Practice (PGCAP).

.

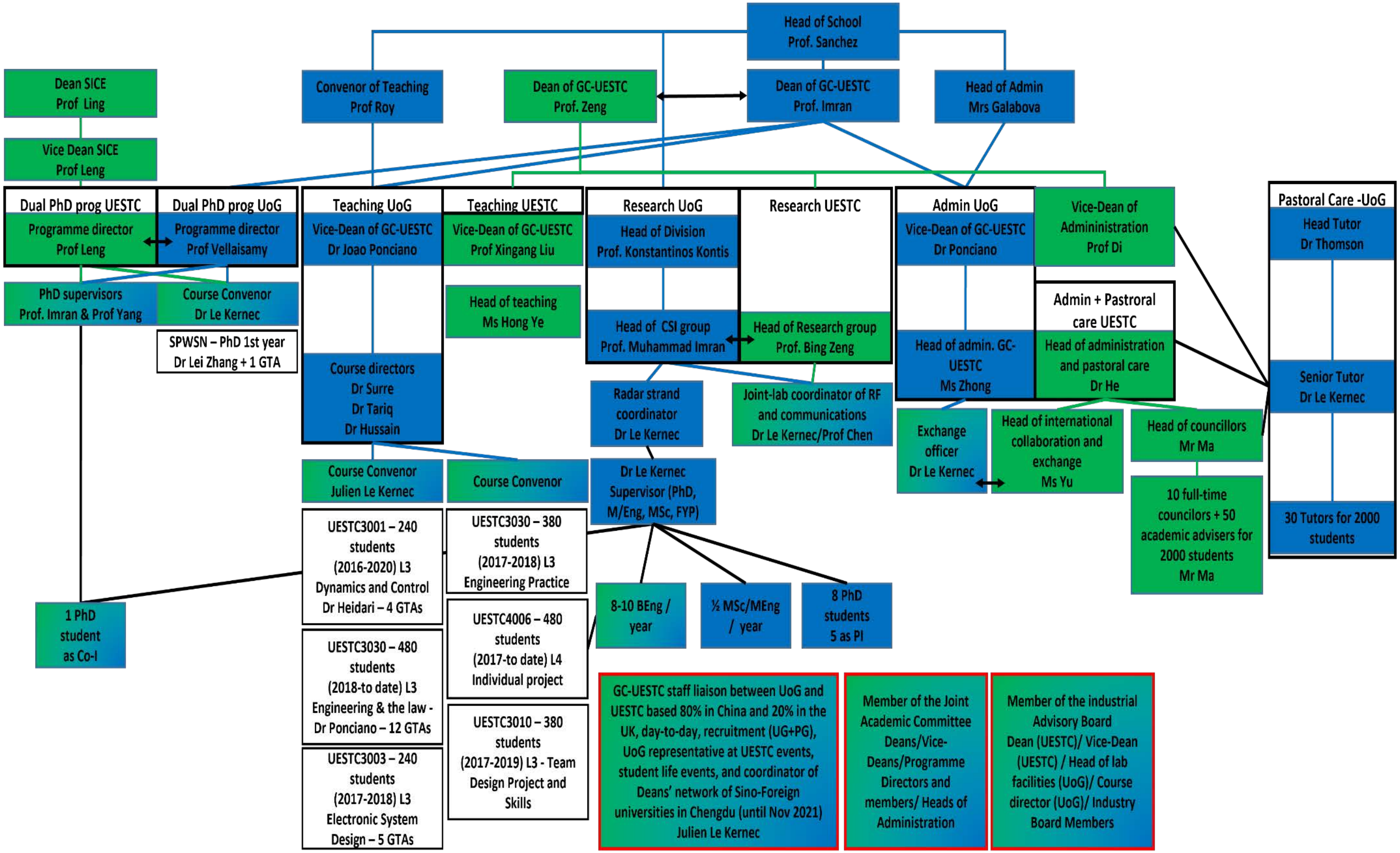


Figure 15: Reporting structure at Glasgow College – UESTC

I was also involved in the professional accreditation (2019) of our program as a member of staff reporting on my courses for the provision of data, GTA training, teaching workshop, tutoring arrangements to the organisation but also in liaising between UESTC and UoG to ensure smooth communication on both sides to ensure timely completion. I was actively involved in the rehearsal visit and the accreditation visit where accreditors came for an inspection of the documentation, inspection of facilities, advisory board, interview staff and students after which they make recommendation for the school. This led to a 5-year accreditation (maximum awarded) and we obtained a commendation on student support for the work on pastoral care jointly organised by UoG and UESTC. We are now preparing for the 2022 accreditation for the 2nd programme as we graduated the 1st cohort of the electronic with communication cohort in 2021. The accreditors come 1 year after the 1st graduation.

I am also a member of the Industrial advisory board in which I help recruit board members from industry with visits in China and help with the organisation of the meeting once per semester. This has been on hold since the pandemic started.

Every year before the pandemic, I participated in the recruitment events of students for Glasgow/College-UESTC ranging from talks and recruitment events in the top high schools in Chengdu, China, to recruitment events in the city especially after the University entrance exam (3-day event) in Chengdu as well as the annual recruitment event for postgraduate students for the University of Glasgow organised in UESTC. I also promote postgraduate studies within GC-UESTC for MSc student recruitment.

As the exchange officer, I liaise directly with the head of international cooperation and exchange to work on the exchange of students between GC-UESTC and Glasgow where students can spend 2 years in UESTC and then 2 years in Glasgow or alternatively 3 years in UESTC and 1 in Glasgow. We are also working on the development of exchanges with US universities, but this was put on hold because of the Covid-19 outbreak.

As Senior Tutor for GC-UESTC, I liaise directly with the Vice-Dean/Head of Administration and pastoral care, the head of councillors to provide student support. The role of a tutor is to handle pastoral care meaning that we are a gateway to the University support services when students approach us with issues, we refer them to the appropriate service in relation to their issue or help them with the University procedures in relation to sick leave, absence, progression, academic misconduct, and various issues. I oversee the training of the tutors in GC-UESTC, organising the meetings with the advisees in small groups every semester, and I am a point of contact when the tutors are not available or if they do not know how to handle a case. The head of councillors and I often discuss cases that come up to our attention so that we have a coordinated action to best support the student as we have 2000 students to care for. Senior tutors in Glasgow report directly to the Head Tutor in charge of the entire School of Engineering.

As course convenor, I am responsible for the content delivery and the academics co-teaching the course as well as the GTAs who help us with the lab delivery and marking of lab reports. Because we are so many dealing with students, there is a need to standardise marks and therefore 20% of lab reports and assignments are double marked to ensure consistency. For exams, questions are only assigned to academics who mark the entire cohort to maintain consistency in marking. As module convenor, I report directly to the course directors and the head of the teaching office in GC-UESTC. As a co-teacher, I am responsible for the GTAs, lab and the content delivery for my part of the course and I report directly to the course convenor. With my colleagues we have developed material collaboratively and delivered with high standards maintaining 4-5 out of 5 in UESTC teaching evaluations pre-pandemic and post pandemic where a lot of courses fell to 3 out of 5. I am currently leading a new PhD-level course development in Signal processing for Sensor networks for GC-UESTC which started in semester 2 of the academic year 2020-2021.

As a supervisor of PhD, Master, or undergraduate level, I manage 30 students officially on a yearly basis. Even though my level of involvement changes depending on whether I am a PI or Co-I. Managing such a large cohort demands a clear view and understanding of what the research/development directions are to empower students to perform well in their projects. This is done through regular meetings and reporting adapted to the students. Furthermore, I manage most of my students remotely this demands flexibility and organisation to juggle with time zones and teaching schedules. The most important in this is to maintain contractual scheme for supervision which means from the beginning the student and I agree on the duties and expectations on both sides before we start the project. By managing expectations, it becomes easier to remind them when they stray and shows the student that we are committed to their study which often works well.

As a staff liaison officer between UoG and UESTC, I represent UoG at events, for day-to-day operations, I facilitate communication at all levels VP/Dean/Academics/Administration/Teaching/Research. I also take part in the Education Network of the China British Business Council, and I organise the Deans Network meeting annually for Deans of Transnational Education Universities (Leeds-SWJTLU, Pittsburgh-Sichuan University, Sino-British Collaboration, SWUFE) in Chengdu to come together and discuss issues regarding operation (pre-Covid, the last one was in 2019). For this, I was seconded 80% of the time in UESTC and 20% in the UK until November 2021 to facilitate communications and represent Glasgow on the day-to-day to be a point of contact they can discuss issues, find out whom to contact, or for me to assist in resolving an issue. I am there to represent Glasgow and facilitate communication and manage expectations on both sides. This led to UESTC hiring more staff to be based locally 100% which has made my role redundant. I have now re-joined the fly-in fly-out cohort to focus on my research development within the UK. I also became, in June 2022, the programme director (EEE) for the Glasgow College Hainan that is launching this year officially mirroring the EEE and Communications degree already in place in Glasgow College UESTC.

4.2 Lecturer in Electronic Engineering, University of Nottingham Ningbo, China (Aug 2012-Jan 2016)

The University of Nottingham Ningbo China (UNNC) was the first Sino-foreign university to open its doors in China. Established in 2004, with the full approval of the Chinese Ministry of Education, we are run by the University of Nottingham in partnership with Zhejiang Wanli Education Group, a key player in the education sector in China. The entire education programme is mapped on the Bachelor of Engineering degree in Electrical and Electronic Engineering from the University of Nottingham). The bachelor’s degree is a 3-year degree in England. However, in China, a bachelor’s degree is 4 years. So, the first year in China consisted of pre-sessional year w where the science and engineering students were all in the same cohort. This year, the students acquired English for Academic Purposes to bring their English to the requirements for studies in Engineering in the UK. At the end of year 1, they made a choice of major. Year 2 is mostly introductory courses in Electrical and Electronic Engineering. Year 2 and Year 3 are called honour years; this means that the marks obtained on the first attempt count towards the degree award they receive if they qualify. Resits count for progression but will not be considered for the degree classification. The UK system does not allow much for error in honour years as the Bachelor of degree (Honours) can only tolerate up to 20 failed credits on the first attempt before the students are retrograded to Bachelor of Engineering (Ordinary). The students in China however must validate all credits in resits to fulfil the degree requirements for China to get their Bachelor of Engineering qualifications from the Ministry of Education in China.

The Bachelor of Engineering degree is accredited by the Institution of Engineering and Technology on behalf of the UK Engineering Council in partial completion of the Chartered Engineer recognition.

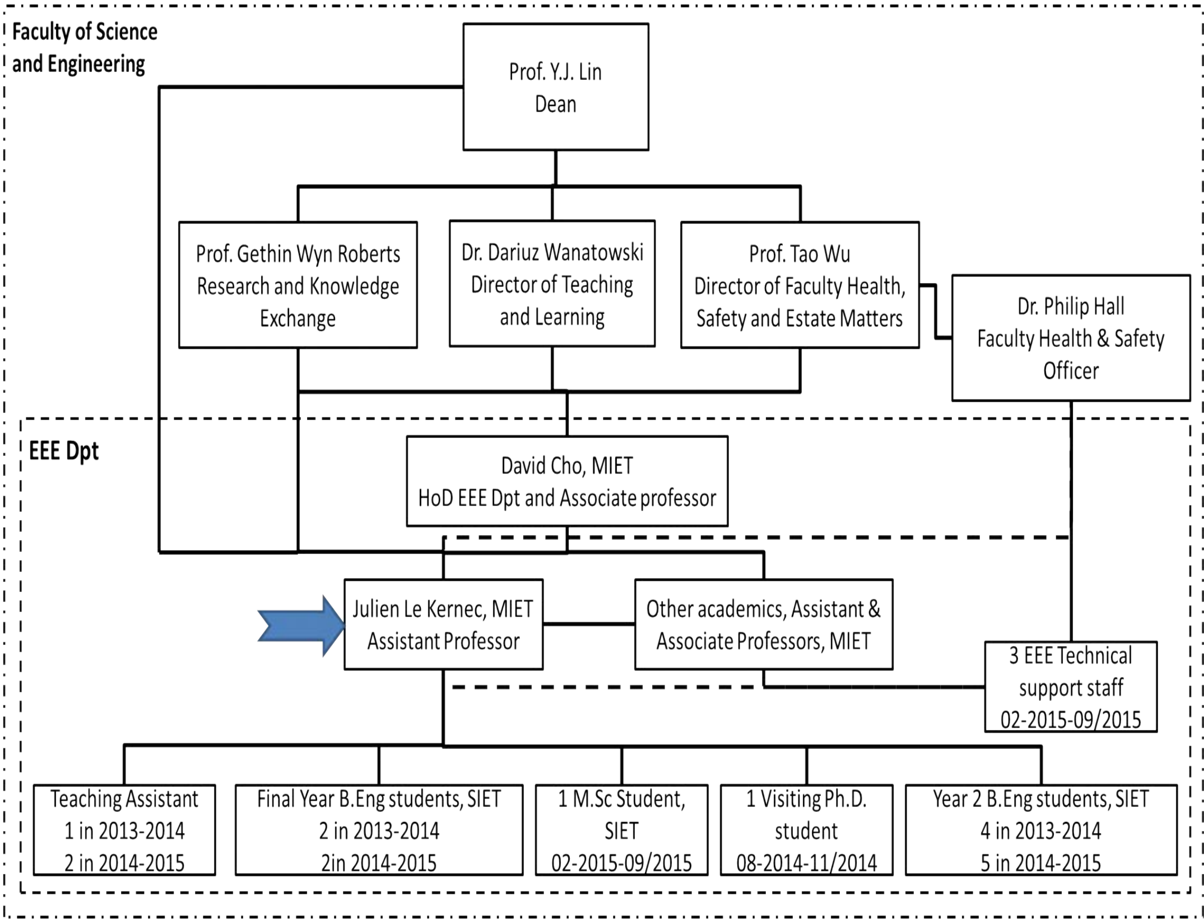


Figure 16: accountability diagram for my role in University of Nottingham Ningbo as assistant professor

I was lecturing undergraduate modules at the University of Nottingham Ningbo China. I have been the convenor of the "electronic construction project," "introduction to real-time systems," "laboratory and presentation skills," "business planning for engineers," "Business Awareness in Technical Education, Career Skills for Electrical and Electronic Engineers" in the EEE department that has been accredited by the IET from 2015 for 5 years and retroactively to 2010 following our first batch of graduates in 2014 up until 2019. The quality is monitored using student evaluation of teaching, student evaluation of modules, tri-campus review forms, and recommendations from the IET.

In my role as module convenor of these modules, I oversaw the administration of the modules, the coordination of the staff involved in the modules, and the delivery content.

To be more specific, I had to ensure that the material I was sent from the UK was fit for the operation in China based on the equipment that was available on the ground. I had to modify several laboratory procedures to reflect the differences in models. I was also ensuring the proper sourcing of components for projects and testing them beforehand as counterfeits or unsafe equipment for students were sometimes sourced. For this, I also liaised with technical support staff to ensure that the lab equipment was operational and ready for the planned lab sessions and that there was a sufficient supply of components for all labs and projects under my supervision.

I was also responsible for the upgrade of the laboratory suites for the EEE department. These comprised 3 lab rooms for a total budget of £600k. I designed the requirements for all the test benches in terms of equipment (oscilloscopes, signal generators, multi-meters, computers, …), furniture, electrical installation requirements based on equipment ratings and emergency buttons to cut the power for safety during experiments.

I wrote a business case for the addition of one lab room to our facilities by using student number projections and occupancy rate of rooms based on the programs from our department and other departments that could use those facilities to maximize occupancy for a maximum return on investment. This room was assigned to our department based on that report.

I was the decision maker on the sourcing decisions of measuring equipment, stools, shelving, and entire work benches. I liaised with estates and IT for the electrical installation requirements and the computer features for the labs.

I produced the risk assessment sheets for all the lab procedures under my modules by looking at UK safety standards on electrical safety, soldering, …. The safety in the labs during the upgrade was kept in mind by adding emergency stop switches at both ends of a line of benches and purchasing residual current devices to protect the staff/students involved in experiments with currents greater than 5 mA. The soldering equipment has smoke extractors to ensure that the students do not have long-term effects from soldering operations as well as lead-free solder and rosin-free flux for the same reasons. The risk assessment sheets provided alongside the laboratory instructions inform the students of the risk and describe the procedure to operate the equipment or perform the operation safely. I also delivered at the start of each of my lab-based or project-based modules a safety talk to inform students about the risks in EEE labs and that they need to take care of themselves and others while in the lab and act responsibly to ensure everyone's safety. This talk also reminded them about emergency procedures in case of a fire, or an accident and contact information of relevant services at the university and outside.

I have also been an internal reviewer for 2 PhD projects at my university on "Pervasive and Mobile Sensing Network" and "Optimal indoor environment quality control using virtual sensing and intelligent management system".

Administration Learning Community Forum representative, Senior Tutor, Ethics committee representative, Professional Advisory Board coordinator and H&S representative, task group lead on the development of a joint master between Engineering and the Business School.

Learning and Community Forum representative is a complicated task that requires liaising with the student body, academic staff in the department, and professional services to respond to the queries and solve issues students may have. This requires a lot of finesse to liaise with people without brushing people the wrong way, it is also critical to phrase things appropriately because the minutes of those meetings are public records on all 3 campuses of the University of Nottingham. I managed to do this for 3 years (2012-2015) with very few dissatisfactions in my completion of the task.

Senior Tutor is about looking after the pastoral care of students at the university level within the Senior Tutor Network and managing the personal tutors (15 academics) within the department to ensure that they know about the procedures, the support services, and be a point of contact in case they cannot solve issues they met with students. I was also in charge of dealing with academic misconduct, extenuating circumstances, and complaints from students. I also had to ensure that an academic support system was put in place and coordinated the student groups with the academic tutors as well as liaising with the UK to understand their expectations and deliver the content in China. I also put together the guide for tutoring to help existing staff and new staff to get familiar with the operation of the university support services and on how the EEE Department tutoring system works and general operational information for lectures, labs, and assessments based on the Quality Assurance Agency manual and the university procedures. I was also delivering information sessions for students to make sure they were aware of all relevant information about tutoring. I fulfilled this role from 2013 to 2015.

The ethics representative ensures that the researchers submitting projects for an ethics review follow the research ethics code from the university which was based on the Framework for Research Ethics (FRE) 2010 for research projects involving animals or human subjects before they can be conducted. This is to ensure best practice. During my service (2013-2015), I was reviewing applications from the faculty of science and engineering and advising on procedures and how to address ethical concerns about research proposals if any.

In 2014, I organized the department's first professional advisory board meeting one-day annual event on the theme of business awareness in technical education (BATE), thus complying with the IET accreditation requirements for the EEE department. I coordinated the efforts with 3 academics and an external chair from the industry to gather 12 people from various backgrounds and positions to discuss the theme. I presented the BATE approach in our department and how the supplemental module and the BATE spirit were embedded in core modules to form rounder engineers. Taking into consideration their feedback, I refined my approach to modules and the content of the BATE module. This was to get feedback from the professional advisory board members to improve the core modules and the Nottingham awards modules to prepare students better to enhance their employability. Running the industrial advisory board is also integral to the requirements of the accreditation process.

From 2014 to 2015, I was also the Health and Safety (H&S) representative for my department. I was in charge as module convenor to produce my own risk assessment (RA) sheets for the labs and projects under my supervision inclusive of Control Of Substances Hazardous to Health (COSHH), Material Safety Datasheet (MSDS) but also reviewing/approving and advising academic staff and final year project students in my department on Health and Safety procedures at the university and at the faculty level. I also reviewed H&S questionnaires to make sure students were aware of H&S points of contact, emergency procedures, and how to identify their nearest extinguisher, fire alarm but mostly to identify if their projects required an RA sheet.

4.3 Project manager, Kuang-Chi Institute of advanced technology, Shenzhen, China (Aug 2011-June 2012)

During the 10 months, I worked for Kuang-Chi Institute, I was sub-lead on projects and conducted research in wireless telecommunications.

This position was in a start-up company/research institute that was developing meta-material. I was in the antenna design department working on the development of a MIMO Wi-Fi Router product and looking at prospective projects for electronic toll collection, automatic car surveillance and car cloning monitoring for the government.

During my 10 months in KCIAT, I was the project lead on the development of the Wi-Fi MIMO router. I was specifying the project requirements based on the management board requirements for this product development and supervised the work of the electronic engineers, mechanical engineers, industrial designers and software engineers, antenna designers, and test engineers. Based on the Chinese market requirements for connectivity, consumers, the vision of the management board for this product for internationalisation and image. I first surveyed the existing chips from Wi-Fi manufacturers Qualcomm, Marvell, Broadcom, Quantenna to find suitable candidates for the product with the highest performance. After the review and the selection of 4 suitable candidates, I provided my report with my recommendation on the optimum time to market option based on the resources in terms of staff and money. My recommendation of using Broadcom for 3x3 MIMO was taken onboard as well as the novel Quantenna chipset for 4x4 MIMO. I then pursued to deliver a document specifying the features of the product based on authorized Wi-Fi bands in China, Wi-Fi alliance certification requirements, CCC requirements, RoHS, … This document was then used by all the development teams to develop the product. I then proceeded to negotiate the NDA, obtaining the technical documentation and the reference designs. I was solely responsible for checking the electronic designs, BOM list sourcing (RoHs), and integrating the work from all the departments in the product as well as designing test scenarios and certification tests to evaluate the performance in a Chinese market setting with thick walls to evaluate throughput and range. I also specified the emission limits for the test engineers to verify that the product's emission fits in the masks prior to sending the product for certification to save costs. A working prototype was produced within 3 months and the refined software functionalities were completed after I left because of the limited resources of software programmers available within the company.

I also worked on the feasibility of a metamaterial vehicle number plate antenna embedded with RFID chips for electronic toll collection, automatic car surveillance and car cloning monitoring for the government. I reviewed existing technologies and listed the advantages and disadvantages of the available technologies against our proposed solution. The RFID tag thus needed to withstand the manufacturing process of the metamaterial antenna and the metamaterial needed to be sufficiently robust to endure the harsh environment in China. I produced a report with the research and the findings of this feasibility study, the way information could be encoded in the tag for law enforcement monitoring and car cloning avoidance. This report also looked at IT infrastructure requirements to implement such a system.

I was also in charge of Wi-Fi MIMO performance demonstrations for the company show room for the visit of government officials and potential customers as well as for trade shows like the high-tech fair in Shenzhen. This included setting up video streaming demonstration of HD movies between several MIMO Wi-Fi routers and computers to demonstrate the performances in an attractive and visual way.

Project advancement was reviewed weekly with the section manager and part of the management board. I had to prepare weekly presentations of progress and development from the various departments concerning my MIMO Wi-Fi router project.

5 Research

My research portfolio comprises 3 main themes smart radar systems that started in 2012 when I was at UNNC and, radar in assisted living and radar in animal welfare which started in 2016 when I started at UoG.

5.1 Smart Radar Systems

5.1.1 Context

The context for smart radar systems spans quite a few activities from software-defined radar, target detection and antenna development. It covers quite a few activities ranging that are linked to the companies we collaborated with such as Leonardo, Aveillant, and NXP for drone detection and automotive. I will present the context of these studies in the subsections of this part. The underlying evolution is the advances in digital core technologies that allows working on waveform design for direct conversion with more ease than 15 years ago and the dramatic reduction in the cost of hardware to obtain radar off-the-shelf with relatively large bandwidth and MIMO capabilities. In this section on smart radar system development, we will discuss the work on deformation monitoring conducted at UNNC in section 5.1.2. The antenna development activity started about the same time as the deformation monitoring activity but continued up to this date as will be discussed in section 5.1.3. The activity on target detection (5.1.4) and software-defined radar (5.1.5) stemmed from my PhD work and continue on to this date. I recently started to work on 5G/6G technology in preparation for the fusion of sensing and communication capabilities in the mm-wave and THz bands for 5G/6G networks.

5.1.2 Deformation monitoring

5.1.2.1 Publications

Journal articles:

1. Ochieng, F. X., Jiang, H., Hancock, C. M., Roberts, G. W., Le Kernec, J., Tang, X. and de Ligt, H. (2019) Deflection characterisation of rotary systems using a ground-based radar. Journal of Engineering, 2019(20), pp. 7215-7219. (doi: 10.1049/joe.2019.0503)
2. Ochieng, F.X., Hancock, C.M., Roberts, G.W. and Le Kernec, J. (2018) A review of ground-based radar as a non-contact sensor for structural health monitoring of in-field wind turbines blades. Wind Energy, 21(12), pp. 1435-1449. (doi: 10.1002/we.2252)

Book Section:

1. Ochieng, F. X., Hancock, C. M., Roberts, G. W. and Le Kernec, J. (2020) Optimal design and operational monitoring of wind turbine blades. In: Maalawi, K. Y. (ed.) Optimization of Wind Energy Conversion Systems. IntechOpen. ISBN 9781789844085 (doi: 10.5772/intechopen.90258)

Conference proceedings:

1. Ochieng, F. X., Hancock, C. M., Roberts, G. W., Le Kernec, J. and Tang, X. (2018) Novel Non-contact Deformation Health Monitoring of Towers and Rotating Composite Based Wind Turbine Blades Using Interferometric Ground Based Radar. In: FIG Congress 2018, Istanbul, Turkey, 06-11 May 2018, ISBN 9788792853783
2. Zhou, X., Le Kernec, J. and Gray, D. (2017) Vivaldi Antenna for Railway Cutting Monitoring. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059180)
3. Melnikov, A., Le Kernec, J. and Gray, D. (2015) Porting Spotlight Range Migration Algorithm Processor from Matlab to Virtex 6. In: 2015 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Turin, 7-11 Sept. 2015, pp. 1429-1432. ISBN 9781479978090 (doi: 10.1109/APWC.2015.7300214)

4. Melnikov, A., Le Kernec, J. and Gray, D. (2014) A Case Implementation of a Spotlight Range Migration Algorithm on FPGA Platform. In: 2014 International Symposium on Antennas and Propagation (ISAP), Kaohsiung, 2-5 Dec. 2014, pp. 177-178. (doi: 10.1109/isanp.2014.7026588)
5. Melnikov, A., Le Kernec, J. and Gray, D. (2014) FMCW rail-mounted SAR: Porting spotlight SAR imaging from MATLAB to FPGA. In: 2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Guilin, 5-8 Aug. 2014, pp. 780-785. ISBN 9781479952724 (doi: 10.1109/ICSPCC.2014.6986303)

5.1.2.2 Contributors

Staff:

- Dr Derek Gray – University of Nottingham Ningbo China (UNNC)/Xian Jiaotong Liverpool University (XJTLU) (2013-2019)
- Dr Andrew Sowter – University of Nottingham (UoN) (2013-2015)
- Prof Gethin Roberts – UNNC (2015-2019)
- Dr Craig N. Hancock – UNNC (2016 - 2019)
- Dr Xu Tang – UNNC (2015)

PhD student(s):

- Dr Francis X. Ochieng – UNNC (2016-2019)

Undergraduate and Postgraduate Students

- Alexandr Melnikov – UNNC (2012-2015) – B.Eng EEE
- Yash Shikarwar – UNNC (2013-2015) – B.Eng EEE

5.1.2.3 Contributions

Train-mounted railway cutting deformation monitoring

At the university of Nottingham Ningbo China, I started working with the civil engineering department on deformation monitoring. It started from a technical document "Microrail – monitoring vegetated road and railway cuttings using radar interferometry" [2]. Although infrequent, railway cutting collapses and landslides cause disruption to both passenger and cargo transport, as well as endangering trains and crew. Historically, cutting collapses were a result of use of inappropriate materials, poor foundations, insufficient compaction and overly steep gradients. With climate change, extreme weather is expected to worsen, so earthworks are expected to dry and crack during heat waves, then saturate and potentially liquefy during heavy rainfall. Small movements and deformation of a slope often *occur a reasonable period prior to a catastrophic collapse; detection of that deformation would enable mitigation action. Prior to the 1950s, cuttings were fastidiously cleared of vegetation to minimize the risk of fires caused by cinders from steam engines. Since the change to electric trains, the growth of shrubs and grass has been unchecked. Clearing vegetation off short sections of cuttings and performing laser-based surveys to monitor possible movement is possible but is considered impractical for the full lengths of all cuttings throughout a rail network due to high labour costs. One potential means of slope monitoring is high range resolution P/L-band vegetation penetrating radar to be carried by service trains which already make periodic passes of all lines within rail networks to monitor track health.

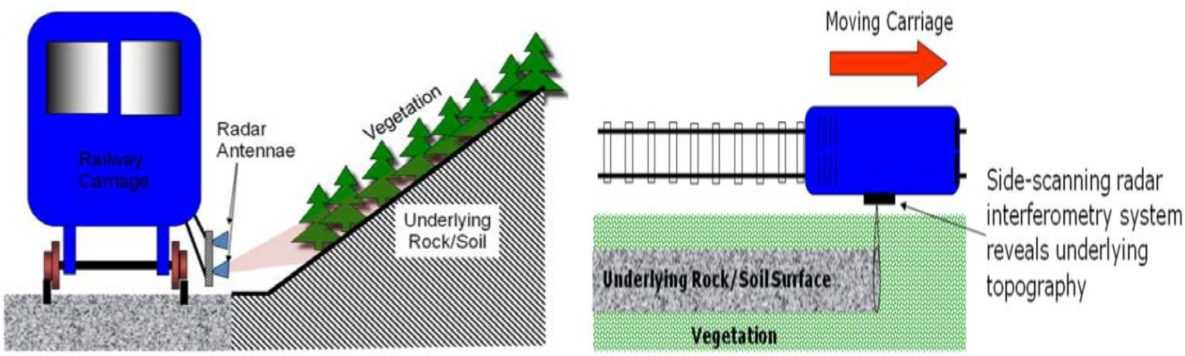


Fig. 1. left) End view, right) top view of radar system measuring cutting surface as the service train carriage passes [2]

As the object of the proposed system is to accurately measure the position of railway cuttings which are covered in grass and shrubbery, radio frequencies that penetrate such foliage must be used; this precludes the use of high frequencies such as X band [3]. P and L-bands are typically used for foliage penetrating radar, being frequencies from 500 MHz to 2 GHz.

Also, the ground backscatter from the woody parts of the ground cover can be minimized by use of horizontal linearly polarized transmit and horizontal linearly polarized receive (H-H).

Dr Derek Gray (2013-2019) worked on the development of the antennas for the application and Dr Andrew Sowter provided the technical document to look at the experiments and the results they obtained. I worked on devising a SAR system for the train-mounted deformation monitoring application.

Alexandr Melnikov (2012-2015) worked on adapting the MIT courseware build a small radar [4] and porting the algorithms from MATLAB to FPGA which resulted in publications o the results [5-7]. A real-time implementation of a spotlight range migration algorithm processor on FPGA platform for the MIT open courseware radar [4]. Dr Derek Gray adapted the design of the cantennas to use beer cans that did not present the ridges on the side to avoid losses in the end fire antennas. The electronics was also modified to replace obsolete parts and improve the video amplifier. We described the use of FPGA resources on a Virtex-6 DSP kit board, and compared the results obtained with the hardware implementation and the MATLAB equivalent. The implementation and optimization of the Synthetic Aperture Radar process Spotlight Range Migration Algorithm processor on the FPGA fitted on the chip. The mean/max error compared to a software implementation was -54/-28.74dB for 55 elements and 882 samples as shown in Figure 17. I continued working on the implementation of the SAR platform with Yash Shikarwar that designed a raspberry Pi based inertial motion unit sensor to register the acceleration in 6-degree of freedom to work on the phase compensation of SAR images (2013-2015). The unit was completed but I left the university of Nottingham shortly after leaving the hardware and FPGA boards behind. This project last contribution was in the design of a planar Vivaldi antenna was reconstructed and assessed as a candidate for a short range, high range resolution railway cutting monitoring radar. The initial flare section of the Vivaldi antenna was found to control the return loss of this type of antenna at lower frequencies, and a compact antenna for 120% fractional bandwidth was demonstrated experimentally. The group delay was used as a UWB antenna assessment method, and the prototype antenna gave reasonable performance across the lower half of the band considered. This activity was discontinued due to the lack of funding available and critical mass to work on such a complex project. However, it lead to my involvement in structural health monitoring as Andrew Sowter was the advisor for that subject and left the university recommending that I got involved in this to the supervision team.

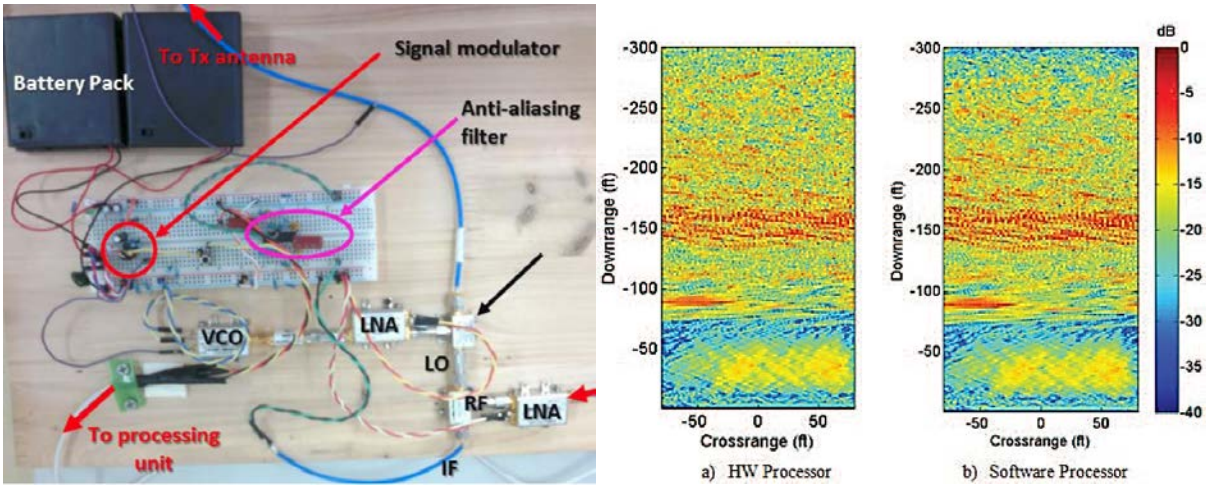


Figure 17: left) SAR imaging system, right) hardware processor and software processor SAR images

<u>Structural health monitoring</u>

Using GNSS to monitor deflections of bridges, has been an ongoing area of research in civil engineering for almost 30 years. Both the magnitudes and frequencies, using simple FFT and Power Spectral Density approaches, can be measured. This project brought together expertise in GNSS and structural engineering from Prof Gethin Roberts (2015-2019) and Dr Xu Tang (2015) and signal processing, electronic engineering to research into other methods of signal analysis and using these to create a Structural Health Monitoring system.

We worked on the analysis of the data set gathered from the Severn Bridge in the UK in 2010, whereby 9 GNSS receivers were attached at various locations, gathering data at 20 Hz for 3 days, as well as temperature, wind and traffic information. The idea was to use alternative joint time frequency transforms, Gabor transforms, continuous wavelet transform, Winger-Ville distribution or Cohen's time frequency distribution series to enhance the frequency resolution and to analyse the changes over time. Some results were obtained from this analysis but the efforts were focused on the structural engineering that was closer to the expertise of Dr Xu Tang so no publications arose from this work on bridges.

Just after I started at University of Glasgow, I was called upon to supervise a PhD student from University of Nottingham Ningbo China to work on a similar project involving wind turbines with Francis Xavier Ochieng (2016-2017) with Prof Gethin Roberts as main supervisor (2015-2019) and Dr Craig Hancock (2061-2019). I have been advising on electronic engineering, signal processing and experimental protocols for the use of a ground-based radar for deformation monitoring. The context of this study stems from metrological features like vertical gradients in wind speeds, wind direction and turbulence intensity that influence the design of wind turbines (WT).

Using the GBR for WT during real time operations provides data to enable validation and improvement of current aeroelastic models for flutter analysis and improving future models. The work validated the use of radar as a non-contact sensor for damage detection for infield WT composite blades. This work gave rise to 2 journal articles, 1 book chapter, and 1 conference paper [8-11].

A simplified model of a wind turbine was developed to analyse the modulations for the radar as the GBR was only providing the processed data as an output. This has helped make sense of the interferometric measurements used in this study for deformation monitoring as shown in Figure 18. It was observed that the Spectrogram generated using this approach had richer information especially when sharp changes were observed in the spectrogram [11].

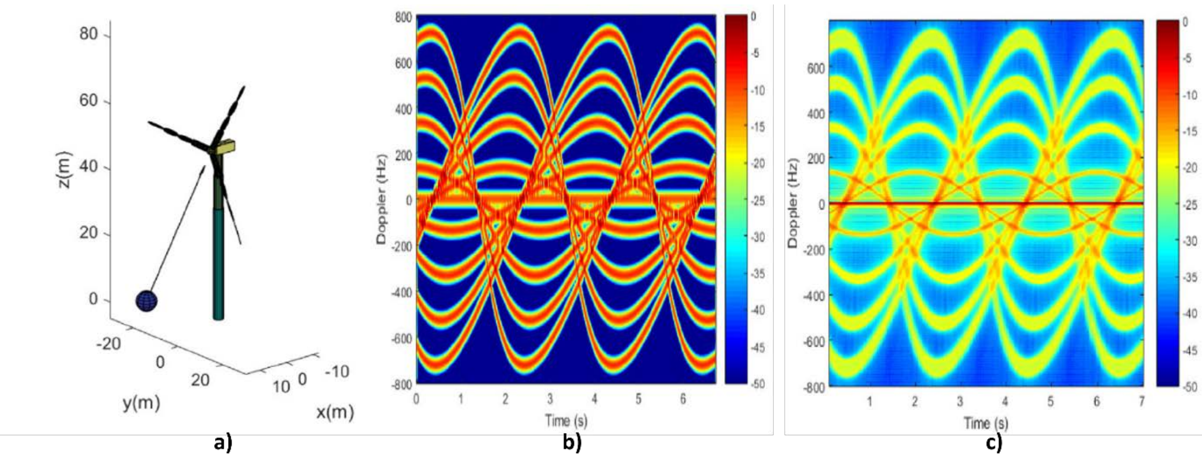


Figure 18: advanced simulator results from a wind turbine, a) model of wind turbine and radar position and line of sight direction, emulated radar signature of a rotating wind turbine: b) using the classic model, c) using our advanced model.

The GBR resonant natural frequencies were identified at ± 5% of the resonant frequencies simulated in the Bladed® design software validating the use of the radar for structural health monitoring through the careful validation of the radar through simulation, a static I-beam, a controlled rotating arm and in-field measurement of wind turbines. This activity was discontinued as the members of staff all moved on to different universities and the PhD student had finished his thesis.

5.1.3 Antenna development

5.1.3.1 Publications

<u>Conference Proceedings:</u>

1. Gray, D., Thornton, J. and Le Kernec, J. (2022) Homogeneous Spherical Lens for Marine Retro-reflector Application, Part 3. In: IEICE Technical Committee on Antennas and Propagation (AP), Kobe, Japan, 19-20 May 2022.
2. Gray, D. and Le Kernec, J. (2020) Scan Performance of Small Spherical Retro-Reflectors. In: 2019 International Radar Conference, Toulon, France, 23-27 Sept 2019, ISBN 9781728126609 (doi: 10.1109/RADAR41533.2019.171391)
3. Gray, D. and Le Kernec, J. (2018) Aluminium Feeds for Reflector for NadirSAR. In: 2018 IEEE EMC and APEMC Symposium, Singapore, 14-17 May 2018, ISBN 9781509039555 (doi: 10.1109/ISEMC.2018.8393966)
4. Gray, D. and Le Kernec, J. (2018) Structural Antennas for 3cm Radar Onboard Multi-Rotor UAV. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0394)
5. Zhou, X., Le Kernec, J. and Gray, D. (2017) Vivaldi Antenna for Railway Cutting Monitoring. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059180)
6. Gray, D., Xin, X., Zhu, Y. and Le Kernec, J. (2014) Structural Slotted Waveguide Antennas for Multirotor UAV Radio Altimeter. In: 2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Guilin, 5-8 Aug. 2014, pp. 819-824. ISBN 9781479952724 (doi: 10.1109/ICSPCC.2014.6986311)
7. Gray, D., Le Kernec, J. and Thornton, J. (2014) Assessment of Sochacki Lenses for Autonomous Maritime Patrol FLAR. In: 2014 International Radar Conference (Radar), Lille, 13-17 Oct. 2014, pp. 1-6. ISBN 9781479941957 (doi: 10.1109/RADAR.2014.7060439)

5.1.3.2 Contributors

<u>Staff:</u>

- Dr Derek Gray UNNC/XJTLU/Nagoya Institute of Technology (2012 – to date)

5.1.3.3 Contributions

My contribution is this research on conformal antennas is on the development of use cases followed by the theoretical estimation of system performance and the analysis of the radar returns. Dr Derek Gray designs, simulates, builds, and characterises the antennas and reflectors.

We worked on applications ranging from historical radar performance estimation for conformal antennas for unmanned aerial vehicles [12-15], and shipborne maritime reflectors to meet the ISO8729 for Radar Cross Section governing reflectors at sea.

The initial numerical and experimental results for the FLAR [12] as shown in Figure 19 , given for minimal layer lens antennas as the primary sensor onboard small Unmanned Aerial Vehicles adapted for fully autonomous long distance maritime patrol. 27dBi was achieved by a half lens and reflector plate material lens that is dimensionally compatible with the fuselage of a 6-meter class Unmanned Aerial Vehicle. This simplifies the construction of the lens as there is only one material to worry about. The simplified lens was shown to have comparable results to the reflector antennas presently used in P-3C and P-8A manned maritime patrol aircraft while reducing the weight for UAV applications.

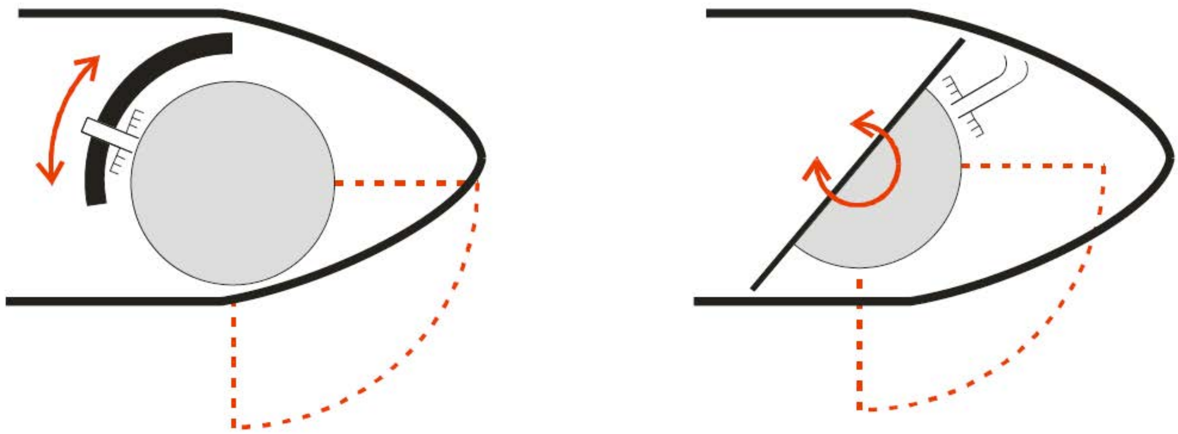


Figure 19: Sketch of nose mounted lens antenna configurations; spherical lens with feed antenna and TRM on gimbal, stationary feed antenna with gimballed hemispherical lens reflector. [12]

In [13, 14], I started the work on a stepped frequency modulated continuous wave radar as a light weight implement for an altimeter and side-looking antennas for collision avoidance on a drone. Dr Derek Gray designed the antennas to be mounted on the drone and we considered how this could be done to ensure a lightweight implementation. Using the drone booms was a good alternative to using additional patch antennas that did not offer significant gain and still added weight to the structure for different functions. We demonstrated a wideband open waveguide mouth antenna was developed that can be made from the existing arms of a multirotor UAV without any increase in weight for side-looking wall detection ranging radar Figure 20and a downward looking radio altimeter, cutting slots in the arms to form slotted waveguide antennas was shown in simulation to cover 500 MHz in X-band and be structurally sound despite the slots in the boom .A similar approach was used to demonstrate a Nadir SAR application using a conceptual dish antenna for a custom UAV as shown in [15] for which I calculated the theoretical performances for the nadir SAR and radar system design parameters for operation.

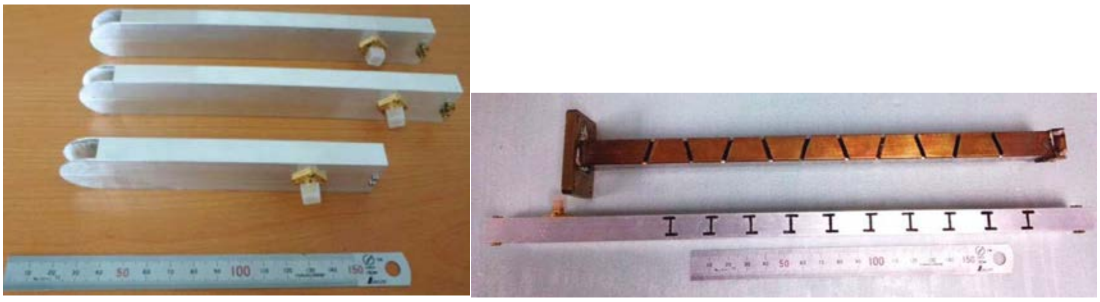


Figure 20: left) Photographs of prototype end fire antennas; half ellipse length was 18.5mm long on all 3 antennas, right) a conventional copper WR-90 inclined edge slot antenna and a Z-slot aluminium tubing antenna.[14, 15]

For the last two papers [12, 16], this is an extension from the half lens antenna in the FLAR work for maritime targets where boat reflectors should met the ISO8729 RCS requirements in X-band to be visible at 9.41 GHz X-band with an RCS > 8.75 dBsqm from 5 nautical miles if placed 4m above sea level. The work is still ongoing to work on a prototype before designing an experiment for the assessment of its performances. It was shown in simulation that a 3-lens array with reflector plate separated by an airgap weighing 4kg each was sufficient to meet the ISO8729 which is not met by a standard 8 corner reflector array. The work on antennas continues to this date as this is a vital part of the research for the frontends and the performance in detection. We are working on formalising the collaboration now that I am back in the UK through bilateral funding.

5.1.4 Target detection

5.1.4.1 Publications

Journal article

1. Yang, F., Xu, F., Fioranelli, F., Le Kernec, J., Chang, S. and Long, T. (2021) Practical investigation of a MIMO radar system capabilities for small drones detection. IET Radar, Sonar and Navigation, 15(7), pp. 760-774. (doi: 10.1049/rsn2.12082)

Book Section:

1. Fioranelli, F. and Le Kernec, J. (2021) Advanced classification techniques for drone payloads. In: Clemente, C., Fioranelli, F., Colone, F. and Li, G. (eds.) Radar Countermeasures for Unmanned Aerial Vehicles. The Institution of Engineering and Technology. ISBN 9781839531903 (In Press)

Conference proceedings:

1. Yang, F., Le Kernec, J., Fioranelli, F. and Liu, Q. (2021) Shape Feature Aided Target Detection Method for Micro-drone Surveillance Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 390-395. ISBN 9781839535406 (doi: 10.1049/icp.2021.0839)
2. Bennett, C., Jahangir, M., Fioranelli, F., Ahmad, B. I. and Le Kernec, J. (2020) Use of Symmetrical Peak Extraction in Drone Micro-Doppler Classification for Staring Radar. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266702)
3. Ren, C., Le Kernec, J., Galy, J., Chaumette, É., Larzabal, P. and Reneaux, A. (2015) Borné de Cramér-Rao sous contraintes pour l'estimation simultanée de paramètres aléatoires et non aléatoires. GRETSI, Lyon, France, Sept. 2015.
4. Ren, C., Le Kernec, J., Galy, J., Chaumette, E., Larzabal, P. and Renaux, A. (2015) A Constrained Hybrid Cramér-Rao Bound for Parameter Estimation. In: 2015 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), South

Brisbane, QLD, 19-24 Apr 2015, pp. 3472-3476. ISBN 9781467369978 (doi: 10.1109/ICASSP.2015.7178616)

5.1.4.2 Contributors

Staff:

- Prof. Eric Chaumette – Onera/ENS Cachan (2014 – 2015)
- Dr Francesco Fioranelli - University of Glasgow (UoG) / TU Delft (TUD) (2016 - to date)
- Prof Teng Long – Beijing Institute of Technology (BIT) (2016 – to date)
- Dr Quanhua Liu – BIT (2016 – to date)
- Dr David Anderson – UoG (2017 – to date)

PhD student(s):

- Dr Chengfang Ren – ENS Cachan (2014-2015)
- Jarez Patel - UoG (2017- to date)
- Fawei Yang – BIT (2019 – to date)

Undergraduate and Postgraduate Students

- Charlie Owens – UoG/Leonardo (2017-2018) – M.Eng EEE
- Vlad Coman – UoG/Onera (2017-2018) – M.Eng EEE
- Conor McHarg – UoG/NXP (2018-2019) – M.Eng EEE
- Cameron Bennett – UoG/Aveillant (2019-2020) – M.Eng EEE
- Juelo Asha – UoG (2022) – M.Sc. EEE

5.1.4.3 Contributions

The democratisation of radar has seen an explosion of its usage in military, civilian airspace surveillance and countermeasures, and in automotive applications which has driven the development of affordable radar units which enable the developments we have discussed in assisted living and animal welfare too.

In 2014, I received Chengfang Ren as a visiting student at UNNC (2014) who was working on “Lower bounds on the mean square error: theory and applications in signal processing field” under the supervision of Prof. Eric Chaumette. The purpose of Chengfang’ s visit was to apply his estimation techniques to a different application to test the versatility of the constrained hybrid Cramer Rao bound (CHCRB). I was charged with explaining the operation of a multifunction radar for Doppler estimation and guide him during the modelling stage before applying the CHCRB which have been shown to outperform the Maximum A Priori Maximum Likelihood Estimation (MAPMLE) for the Maximum Square Error at varying signal to noise ratio levels [17, 18].

I have been the university contact with Dr. Francesco Fioranelli as primary supervisor for 2 students Charlie Owens and Vlad Coman. I was not a primary supervisor because of my secondment. The detail of their work is confidential but here is a brief of the topics.

- Charlie Owens (2017-2018) did an internship at Leonardo in Edinburgh on a “Processor Architecture Analysis of Task-Based Scheduling for Airborne Radar”. This aim was to model the behaviour of a multifunction radar and identify the bottlenecks in the scheduling to determine whether they were limited in throughput or resource usage and timings for the transitions between nodes using a high-level programming language.
- Vlad Coman (2017-2018) worked on “Radar absorbing metamaterials: active vs passive” at Onera, Palaiseau. The aim was to determine the performance of an active stealth technique to mask a hull versus a passive one.
- Conor McHarg (2018-2019) worked on “ADAS radar – beamforming and detection performance evaluation” at NXP, Glasgow. He worked on the detection performance of the

new MIMO ADAS Radar from NXP and especially on the Angle of Arrival Estimation performance and associated techniques.

The rapid growth of the UAV market has granted the general public with unprecedented access to unmanned aviation. Therefore, the detection, tracking, and classification of drones with radar and other sensing modalities have become an area of great interest to counter misuses of drones be they accidental or voluntary.

In 2017, Dr Francesco Fioranelli, Dr David Greig (Leonardo) and Dr David Anderson recruited Jarez Patel (2017 – to date) to work on "Innovative radar detection & classification of small UAVs or drones" sponsored by Leonardo. They compiled a state-of-the-art review on radar classification and RCS characterisation techniques for small UAVs or drones [19]. The article looked at the different techniques to detect UAVs and RCS characterisation. The preliminary findings pointed at the design of a multiband radar to validate some of the findings in [20] regarding the RCS assessment of drones in different polarisation VV or HH from L-band to X-band. The idea was to have one channel used to track the body of the drone in VV and the other detect the blade modulations in HH. I was asked to join to advise on the hardware development of the platform and its testing. Jarez has been working on this platform and has developed the baseband of the hardware for both channels as a software-defined platform with a chirp that could reach up to 300MHz that could feed transmitter/receiver boards for bandwidth ranging from S-band to X-band, the design of the RF boards have started for S-Band and C-band transmitter/receiver boards, but the testing is till ongoing and took heavy delays because of Covid.

In 2019, Fawei Yang (2019- to date) came to University of Glasgow as a visiting student to work on MIMO radar and wideband arrays techniques for the detection, tracking and classification of low, slow, and small targets with Dr Francesco Fioranelli and me. We worked on the analysis of the range-Doppler signatures from a MIMO Doppler Division Multiple Access (DDMA) radar and the classification of observed targets. In [21], we started the analysis on microDoppler but the revisit time of the rotating MIMO radar was too slow to capture the phenomenon caused by bird flaps or propellers so we reverted to more classic feature extraction based on Hu moments from the range-Doppler domain. We have continued to advise on Fawei's thesis who is supervised by Prof. Long Teng and Dr Quanhua Liu. In [22], the radar design, implementation and test were reported showing all the theoretical and practical considerations for the MIMO DDMA from the array design to the signal processing to the analysis of performance against theoretical analysis. We have advised on the comparison of the measurements to the theoretical analysis and the key performance indicators to focus on.

Cameron Bennett (2019-2020) worked on "Classification of UAVs in holographic radar" at Aveillant. In this project, the focus was on the classification of drones near an airport for example with Explainable AI at the heart. In [23], Cameron reports his work undertook using the Aveillant staring radar GAMEKEEPER [24] with Dr Jahangir (Aveillant) and Dr Francesco Fioranelli as co-supervisors. A simple and effective method of extracting salient symmetry features from the microDoppler signatures of the UAVs generated by the propellers. This approach being rule-based is explainable as the symmetry feature is directly related to the kinematics of the UAVs. A large dataset collected from multiple locations with over 280 minutes of rotary and fixed wing drone flights has been collected and used to demonstrate the generalization capability of this approach. It was shown that this feature was decisive in the detection of drones vs other targets.

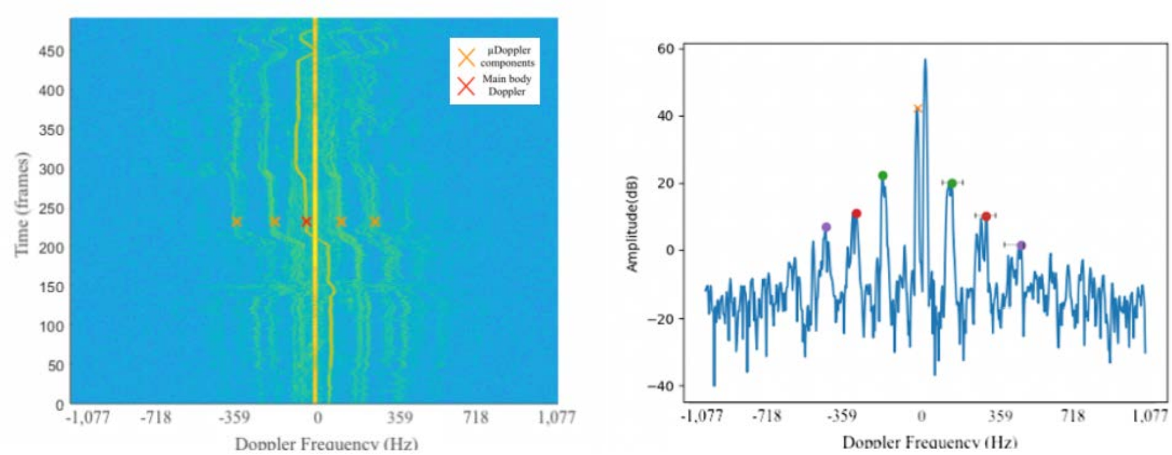


Figure 21: left) Spectrogram of DJI Inspire 1 rotary wing drone, right) Example of symmetry feature extraction applied to a single frame from the drone spectrum. The orange cross shows extracted main body and colored dots show extracted symmetric microDoppler pairs. Error bars indicate error window used. [23]

Jueluo Asha (2022) is working on the detection of HERM lines in drones using multistatic radar and interferometry in X-band based on results obtained by Nanzer [25] and the increase in robustness observed in our human activity recognition using the fusion of the receiver channels with the interferometric channel.

This activity continues as I have a student who just started on this as an M.Eng student for 2022-2023 following the work of Asha in collaboration with Leonardo. This work is central to generating impact with companies as the applications are driven by the algorithms for detection as well as waveform design and radar systems. However, companies are now looking at enhancing the detection capabilities using software-defined radar by leveraging the digital capabilities to store large quantities of data and the possibility of multiple shots at using various signal processing strategies with the increase in online computational capabilities but also for offline exploitation of the data.

5.1.5 Software-defined radar

5.1.5.1 Publications

Journal articles:

1. Tan, K., Bremner, D., Le Kernec, J., Sambo, Y., Zhang, L. and Imran, M. A. (2022) Intelligent handover algorithm for vehicle-to-network communications with double-deep Q-learning. IEEE Transactions on Vehicular Technology, (doi: 10.1109/TVT.2022.3169804) (Early Online Publication)
2. Tan, K., Bremner, D., Le Kernec, J., Zhang, L. and Imran, M. (2022) Machine learning in vehicular networking: an overview. Digital Communications and Networks, 8(1), pp. 18-24. (doi: 10.1016/j.dcan.2021.10.007)
3. Le Kernec, J. and Romain, O. (2017) Performances of multitones for ultra-wideband software-defined radar. IEEE Access, 5, pp. 6570-6588. (doi: 10.1109/ACCESS.2017.2693300)

Book Section:

1. Le Kernec, J. and Romain, O. (2015) Multitones' performance for ultra-wideband software defined radar. In: Radhakrishnan, S. (ed.) Applications of Digital Signal Processing through Practical Approach. Intech. ISBN 9789535121909 (doi: 10.5772/60804)

Conference Proceedings:

1. Tan, K., Bremner, D., Le Kernec, J. and Imran, M. (2020) Federated Machine Learning in Vehicular Networks: a Summary of Recent Applications. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205482)
2. Tan, K., Le Kernec, J., Imran, M. and Bremner, D. (2019) Clustering Algorithm in Vehicular Ad-hoc Networks: A Brief Summary. In: UK-China Emerging Technologies Conference, Glasgow, UK, 21-22 Aug 2019, ISBN 9781728127972 (doi: 10.1109/UCET.2019.8881833)
3. Le Kernec, J. (2017) Inter-Range-Cell Interference Free Compression Algorithm: Performance in Operational Conditions. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059232)
4. Le Kernec, J., Gray, D. and Romain, O. (2014) Empirical Analysis of Chirp and Multitones Performances with a UWB Software Defined Radar: Range, Distance and Doppler. In: 3rd Asia-Pacific Conference on Antennas and Propagation (APCAP), Harbin, China, 26-29 Jul 2014, pp. 1061-1064. ISBN 9781479943548 (doi: 10.1109/apcap.2014.6992691)
5. Le Kernec, J. and Romain, O. (2013) Empirical Performance Analysis of Linear Frequency Modulated Pulse and Multitones on UWB Software Defined Radar Prototype. In: IET International Radar Conference 2013, Xian, 14-16 April 2013, 0440-0440. ISBN 9781849196031 (doi: 10.1049/cp.2013.0228)
6. Le Kernec, J., Romain, O., Garda, P. and Denoulet, J. (2012) Empirical Comparison of Chirp and Multitones on Experimental UWB Software Defined Radar Prototype. In: 2012 Conference on Design and Architectures for Signal and Image Processing (DASIP), Karlsruhe, 23-25 Oct. 2012, pp. 1-8. ISBN 9781467320894
7. Le Kernec, J., Dreuillet, P., Bobillot, G., Garda, P., Romain, O. and Denoulet, J. (2009) Case Study Analysis of Linear Chirp and Multitones (OFDM) Radar Signals Through Simulations and Measurement with HYCAM-Research Test Bench. In: Radar 2009 Surveillance for a Safer World, Bourdeaux, France, 12-16 Oct 2009.

5.1.5.2 Contributors

Staff:

- Prof. Olivier Romain – University Cergy-Pontoise (CYU) (2012 – to date)
- Dr Francesco Fioranelli - University of Glasgow (UoG) / TU Delft (TUD) (2016 - to date)
- Prof Muhammad Imran – UoG (2019 – to date)
- Dr Duncan Bremner – UoG (2019 – to date)
- Dr Guodong Zhao – UoG (2019 – to date)
- Dr Yusuf Sambo – UoG (2020 – to date)

PhD student(s):

- Kang Tan – UoG (2019- to date)
- Shuojie Wang – UoG (2019 to date)
- Petros Hadjichristodopoulou – UoG (2017-2018)

Undergraduate and Postgraduate Students

- Chong Shen – UNNC (2013-2014) – B.Eng EEE
- Pin Zeng – UNNC (2014-2015) – B.Eng EEE
- Harmony Kerry – UoN (2015) – M.Sc. EEE
- Zhi Xuan Loh – SIT/UoG (2016-2017) B.Eng. Mechatronics
- Yinghao Li – UoG (2016-2017) B.Eng. EEE
- Yi Li – UoG (2016-2017) B.Eng. EEE
- Yucheng Xia – UoG (2016-2017) B.Eng. EEE
- Yixiao Huang – UoG (2017-2018) B.Eng. EEE

- Yiming Lyu – UoG (2017-2018) B.Eng. EEE
- Jian Li – UoG (2017) M.Sc. EEE
- Kit Wa Li – SIT/UoG (2018-2019) B.Eng. Mechatronics
- Jun Qi Ng – SIT/UoG (2018-2019) B.Eng. Mechatronics
- Muhammad Iqbal Bin Sapii – SIT/UoG (2019-2020 B.Eng. Mechatronics
- Chengfeng Yue – UoG (2022-2023) B.Eng. EEE

5.1.5.3 Contributions

The evolution of digital technologies driven by the telecommunication industry has opened new opportunities in waveform design notably for the future 5G standard [26-28] for multitones with OFDM and Generalized Frequency Division Multiplexing. Even though multitones are ubiquitous in telecommunications, its adoption in operational radar is slower. The radar industry relies on proven technology and continues to use linear frequency modulated (LFM) pulses for its reliability and cost effectiveness.

Lately, the use of OFDM for the concurrent implementation of radar and communication (e.g. Radcom [29, 30]) for Intelligent Transport Systems and radar networks [31] present a challenge for conventional radar and cannot be achieved with LFM pulses. This stemmed research efforts in applying multitones to radar applications.

Another aspect of the evolution in digital technologies are the advances in converter technologies analogue to digital and digital to analogue, now enabling ultra-wideband (UWB) platforms. UWB coupled with digital cores in radar translates into sub metric spatial resolution and greater flexibility in waveform design & agility. These technological advances enabled software-defined radar, which allows the simultaneous transmission of data and performing radar SAR imaging [32].

Multitones is used rather than OFDM to reflect that radar is not bound by telecommunication standards when designing waveforms and also are not necessarily orthogonal e.g., [26, 33-35]).

My contribution in this area started from my PhD that produced [36-42] where I looked with Prof. Olivier Romain at the influence of digitisation on a software-defined radar comparing chirp vs multitones (OFDM) with passband sampling as shown in Figure 22. I showed in 2017 from the literature review, there is a gap in quantifying the performances of multitone waveforms specifically for radar applications and experimental results not commonly found. The work focused on the radar performance analysis of multitones with P3 phase-codes in simulation and experimentally to determine the effect of hardware on radar performances. For this purpose, a software-defined radar (SDR) approach has been used, including a digital core with hardware in-the-loop controlled by MATLAB and an analogue front end that uses bandpass sampling and a reference channel. The proposed radar setup with processing algorithm has been evaluated in terms of processing time, showing that a real-time implementation on the field programmable gate array chipsets available in 2017. This approach was shown ot be flexible and entirely arbitrary waveforms can be generated with an instantaneous bandwidth up to 800 MHz. An empirical equation was defined to determine the number of effective bits needed to obtain the required spurious free dynamic range based on the Bandwidth time product of the chirp and multitones. However, different phase codes overlaid on multitones would yield different performances, a higher PMEPR like in communications from 10 dB typically up to 15 dB – would translate in a further reduction of maximum detection range from 50 to 100% - compared to chirp. The outcome of this study using a novel approach is that multitones are close in performances to chirp when the receiver bandwidth is equal to the signal bandwidth for phase codes that match P3PC performances in PMEPR. Multitones opens to more flexibility in terms of signal diversity and spectrum reuse. The path towards multifunction, spectrum insertion, sub band independence and signal diversity, is a complex question. Moreover, the fusion of communication and radar frontends are still an open problem and optimization problems for the optimization of radar and communications concurrently in different scenarios will emerge. The development of 5G technology and it's asynchronous and non-orthogonal waveforms could prove to be a valuable trend to follow to improve on radar waveform design and spectrum insertion.

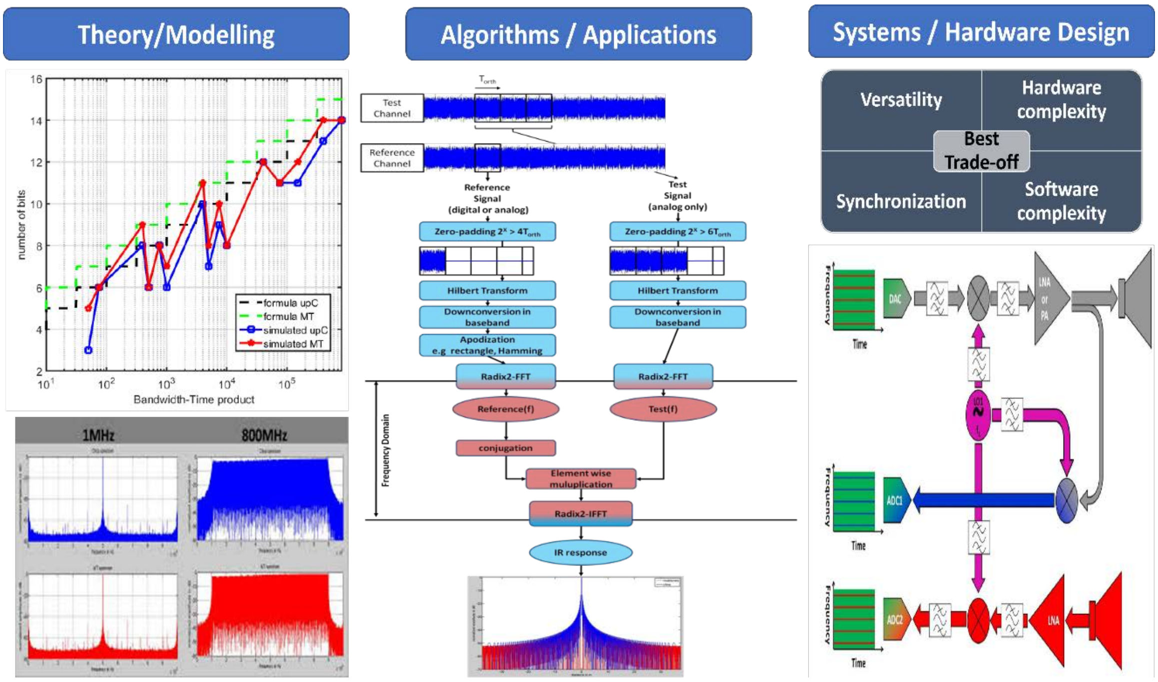


Figure 22: Overview of software-defined radar performances activity

Nowadays, the frequency spectrum has become a rare commodity, and therefore, prices have increased significantly for licensing. The number of mobile users is increasing rapidly with ever more adopters with the jumps between GSM, Edge, 3G, 4G, 5G and beyond [43].

This pushes the applications into higher frequencies to push data to reduce latency and increase capacity [44]. This has led to allotted bands moving much closer to radar dedicated bands [45], and the race for higher resolution is confronted with the problem of larger bandwidth which cannot be allotted because of spectrum regulations in sub 6GHz. Large bandwidth will only be available in the mm-Wave and THz region. With larger bandwidth comes finer resolution. This is in response to requirements for finer microDoppler information being required to sense smaller targets such as unmanned aerial vehicles or humans for indoor applications to obtain fine-grained information about the nature of the target [46] or posture [47]. Furthermore, the rise of autonomous vehicles with V2X and radar being equipped on almost every car calls for the integration of radar and communication functions on a single frontend. Furthermore, the fact that 6G will integrate sensing capabilities to the communication standard for improved channel modelling is another drive in that direction. The two functions have different key performance indicators (target visibility by controlling the sidelobes in range and Doppler heavily reliant on phase coherence, and maximum entropy for communication, for example) where the optimisation of one may be to the detriment of the other. So, a trade-off has to be found between the two functions based on a use case scenario [48] such as Vehicle-to-Vehicle (V2V) or indoor localisation and sensing [49] for 6G and beyond. The two systems use very similar hardware. However, a good communication system requires maximising the entropy embedded in the transmitted waveform, while a good radar system requires coherent waveforms to maximise detection performance. Consequently, a good radar-communication system results in compromising between the two [50].

Digital communication modulations offer a wide choice for use with radar such as Pulse Amplitude Modulation(PAM), M-ary Phase-Shift Keying (MPSK with M = [2, 4, 16, 32, 64, 128, 256]), M-ary Quadrature Amplitude Modulation (M-QAM with M = [4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768]), Continuous Phase Modulation (CPM), Minimum-Shift Keying (MinSK), Orthogonal Frequency Division Multiplexing (OFDM), Spread Spectrum signals, Direct Sequence

Spread Spectrum Signals (DSSS), Frequency-Hopped Spread Spectrum (FHSS), Multiple Input Multiple Output (MIMO) communications. At the same time, radar more classic waveforms include frequency-modulated signals (Linear and Non-linear Frequency Modulation (LFM&NLFM), Costas Frequency Coding), Phase-Coded Pulses (Barker odes, Chirplike phase codes, Golomb's codes, Ipatov code, Huffman code, …), Frequency Hopping, Multicarrier Phase-Coded Signals, and MIMO radar [51].

In terms of supervision, I started this strand by supervising Chen Shen (2013-2014) to work on software-defined radio using the Ettus Universal Software Radio Peripheral to reproduce the results I had in my thesis but on a different ADC and using direct sampling of the bandwidth. The equipment could sample 100MHz but the ethernet only supported the operation for 10MHz which provided limited results. Pin Zeng (2014-2015) worked on the implementation in FPGA of a signal generator and acquisition implementing a continuous wave, chirp, and non-linear chirp to replace the analogue parts of the SAR implementation mentioned earlier but also to experiment on waveform design. The project attained the objectives and digital core was available for the radar with a synchronisation of the ADC and DAC that were free running on the MIT design. I supervised in the summer of 2015 Harmony Kerry Ojehomon on the development of a simulator to test further modulations for the multitones and compare to the chirps but the results were limited given the short time available.

After I started at UoG, I supervised Zhi Xuan Loh (2016-2017) to reproduce the SAR equipment from UNNC alas in Singapore but this was successful as well as its adaptation to 5GHz ISM band in (2018-2019) by Jun Qi Ng who worked on the design and subsequently Muhammad Iqbal Bin Sapii (2019-2020) who worked on its implementation based on Singaproean emission limits.

Yinghao Li (2016-2017) worked on the implementation of an FPGA-based signal generator and digitizer to create a PC interface for the MIT radar to reproduce the result obtained by Pin Zeng (2014-2015) and this was successfully implemented but we did not have the hardware available for it, so it was tested on an oscilloscope for the signal generation and using a signal generator for the ADC as the signal generator was based on feeding a VCO for signal generation. The design was reconfigurable on the fly. Yi Li (2016-2017) worked on multi-target detection using Linear Frequency Shift Keying (MFSK) derived from automotive radar [52]. Jian Li (2017) continued on the MFSK project during the summer but aside from rudimentary performance evaluations against the regular chirp signal there were not much advances. Dr Francesco Fioranelli hired a PhD student Mr Petros Hadjichristodopoulou that we co-supervised to work on radcom waveforms in 2017 but he quit after 1 year. His contribution was on a review of the state of the art and no scientific advances were made in that area. Since 2019, I have started to work in 5G in prevision of the fusion of radar and communication capabilities in 6G. 2PhD students were recruited by my colleagues Kang Tan (2019-to date) on machine learning in vehicular networks supervised by Dr Duncan Bremner and Dr Yusuf Sambo primarily and Shuojie Wang (2019-to date) on Robotic arm wireless system control based on 5G supervised by Dr Guodong Zhao and Prof. Muhammad Imran primarily for me to better understand the key performance indicators and design constraints for 5G waveforms. Chengfeng Yue (2022-2023) will work on the co-design of radcom in the context of 6G reviving this work as well as benefiting from the purchase of a 70 GHz direct bandwidth signal generator and a 40 GHz oscilloscope to verify the simulation results.

Hardware development is a complex activity and requires a lot of funding for radcom. It is continuing and will benefit from the acquisition of time-domain equipment to test the developments in waveform design and conduct tests on real targets as well as testing frontends.

The development of algorithms, platforms and subsystems continues and is an essential activity for the development of research. The availability of radar units as components off the shelf has played a very important role in democratising radar in civilian applications. This has been driven by the integration of radar in automotive applications. However, they are often sub-optimal for the task at hand. For this reason, the development of bespoke platforms is required on a continued basis to stay at the forefront of research. In 2016 when I joined Glasgow, I restarted work on microDoppler I had done during my PhD to complement my colleague’s research on human activity recognition. This later evolved to the next theme on radar in assisted living.

5.2 Radar in assisted living

5.2.1 Context

The global burden and threat of noncommunicable diseases (NCD) constitute a major public health challenge that undermines social and economic development throughout the world. An estimated 9.2 million deaths, or 89% of the 10.4 million deaths that occurred in China in 2016, were due to noncommunicable diseases, comprising mainly cardiovascular diseases (43% of NCD), cancers (23%), chronic respiratory diseases (9%) and diabetes (2%) [53]. These major NCDs share four behavioural risk factors tobacco use, unhealthy diet, physical inactivity, and harmful use of alcohol and one environmental risk air pollution.

According to China's Office of National Working Commission on Aging, the population over the age of 60 has already reached 17.3% of the population in China (240 million people) in 2015 and is projected to double (486 million) representing 33.3% of the Chinese population by 2050 [54] (see Figure 23). Note that the share of seniors in the population will reach the same levels as in developed countries but lagging in terms of infrastructure as about 90% of Chinese seniors rely on family support, 7% on residential community-based care services, and 3% on nursing homes [55]. The transformation of Chinese society and the single child policy is putting a strain on the sustainability of healthcare with growing urbanization, lifestyle diseases, and increased demand for better health coverage. Fuelled by increasing consumer income, population aging, and government initiatives, China's health care market has grown rapidly, with annual expenditures expected to reach RMB6.5 trillion in 2020 or 7% of the country's GDP [56]. The improvement of healthcare in China is one of the five priority areas for improvement by 2020 is in medical-service provision [57] and will be ever more a priority for the 14th five-year plan in which the population's wellbeing and better infrastructure is at the heart of Chinese Premier Li Keqiang's design spearheaded by the healthy China 2030 plan [58] which looks into digital solutions and enhanced healthcare information systems to support this plan for interoperability across country to enable health innovations in all sectors hospital, supervision, insurance, community, and family for a patient-centric approach.

For the elderly population, scientific development should be aimed at the prevention or care for non-communicable diseases (NCDs) away from primary care units to first reduce the load on health institutions given the rise in the elderly population and also to provide greater access to care to facilitate the management of long-term diseases for families as 86.6% of premature death in China are caused by NCDs [56].

Worldwide the elderly population is growing, e.g. (Scotland 19% over 65 [59], China 12% over 65 [60]) as the life expectancy is growing. Bio-ageing and lifestyle changes bring an increase in noncommunicable diseases (NCD). France has more than 1.1 million dependent and at-risk people, with an estimated growth trend of 2% per year by 2040 [61].

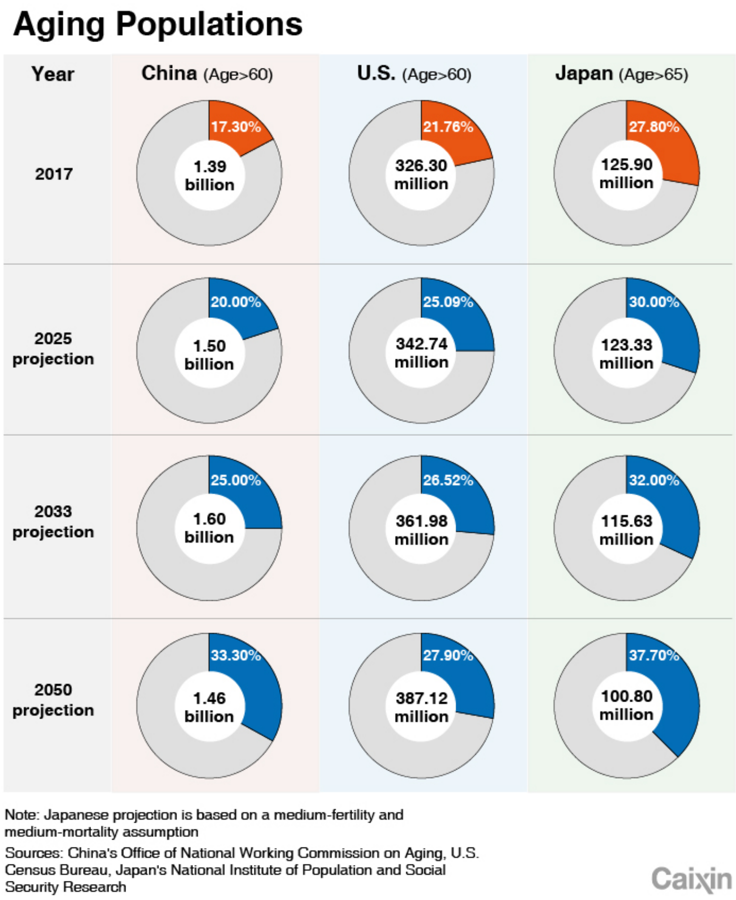


Figure 23: China's aging population compared to the US and Japan [54]

NCDs are not restricted to the elderly population but have a very high prevalence in this age group and usually not just one, this means managing more and more people suffering from multi-morbidity (multiple chronic diseases – e.g., arthritis, asthma, cancer, chronic obstructive pulmonary disease, diabetes) and a rise in the number of people recovering from strokes.

Focusing on just pulmonary NCDs, we look at lung cancer and chronic obstructive pulmonary disease COPD, which are respectively top 6 and 3 in the ten causes of death globally [62] (Figure 24).

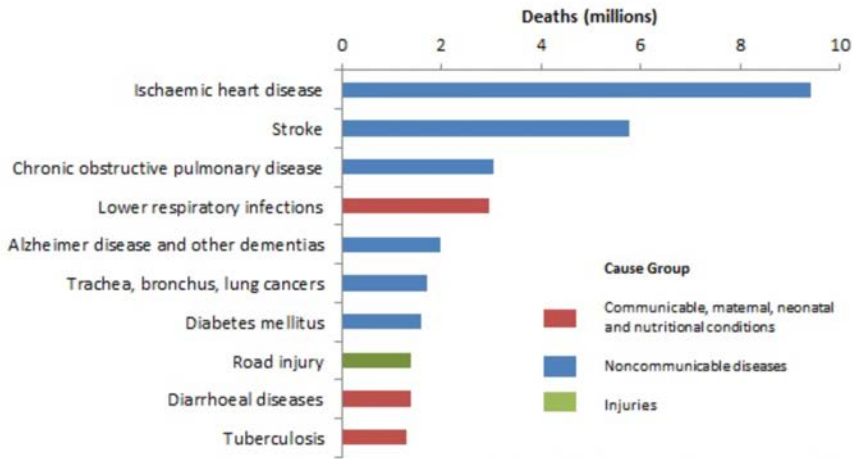


Figure 24: Top 10 causes of death – 2016 [62]

Medical practitioners are leveraging the advantages of mobile Health (mHealth) to keep in contact with the patients, educate them about cancer, monitor them, and provide high-quality follow-up care. This is to improve the Quality of Life (QoL) of patients.

- For lung cancer patients (Figure 25 left)), mHealth applications registries can provide important information concerning disease epidemiology, prevalence rates, treatment practices, and patient outcomes especially in China where such registries are in the maturation process at the provincial and national level, but **patient activity and vital signs are not monitored** [63]. A similar study in Italy further highlighted that such platforms were **missing** valuable information in terms of **patient activity and vital signs** [64]. A lack of physical activity in cancer patients is linked with a higher burden in cancer disease and higher chances of rehospitalization. [65]
- For COPD patients (Figure 25 right)), Physical inactivity in patients is associated with poor health status and increased disease burden [66]. A report from a leading pneumologist in France states that follow-up care for COPD patients **lacks information on patient activity and vital signs** after they are released from the hospital and could help explain exacerbation factors in disease relapses, which lead to hospitalization [67].

Given the trend of the aging population and the prevalence of these 2 NCDs with old age coupled with air quality issues, developing strategies to follow-up patients at home is going to be increasingly more important. Medical practitioners have started this trend but identified a gap in the monitoring of patients in-home, which comprises physical activity and vital sign monitoring.

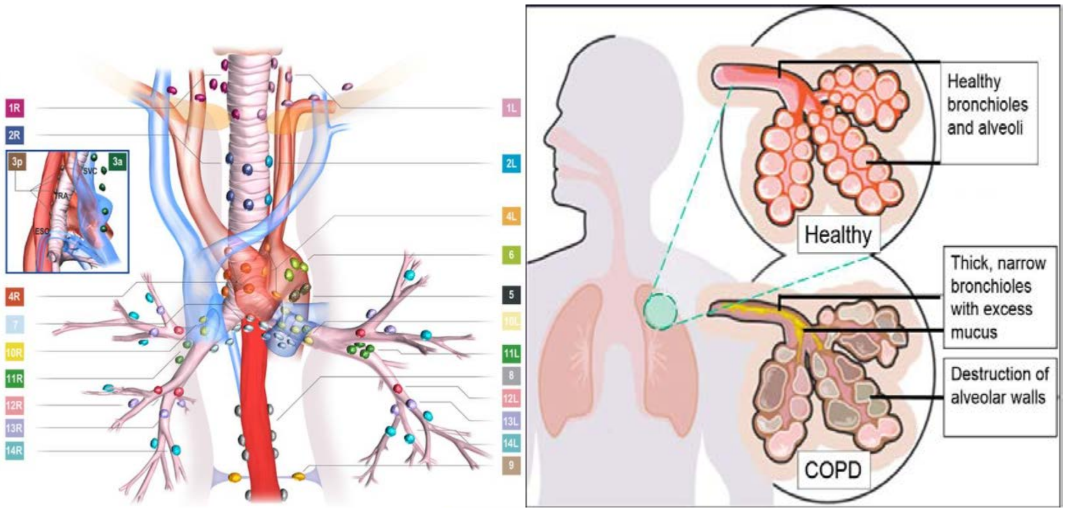


Figure 25: Lung Pathology left) Lung cancer nodules, right) Chronic Obstructive Pulmonary Disease [67]

Inequalities in healthcare provision in urban and rural areas are growing, and the healthcare infrastructures are not ready to handle the incoming wave of elderly by 2050. Furthermore, critical events (e.g., Falls, Strokes) are both serious and costly. These could also be caught if physical activity monitoring is put in place and checking the vital signs of the person after a fall are paramount for the timely intervention of emergency services. **Monitoring activity levels of the elderly, notably activities of daily living and their vital signs, aid medical practitioners in medical prognosis for decision support and assess whether a person can be maintained in-home longer** [68, 69]. This is a trend seen in France [70], the United Kingdom [71], the United States [72], and China [57, 58, 69], which promote in-home care for the elderly.

We observe that activity and vital signs monitoring in the elderly population, and patients with lung cancer or COPD will require in-home solutions and integration with mHealth services to support communities. The problem of monitoring people's activities in indoor scenarios has been addressed by several research works, to discriminate fall events against other actions and activities reliably, and more, in general, being able to analyse the daily activities patterns of the monitored subjects [73-98] and their vital signs [92, 93, 98-127].

5.2.2 Existing sensor solutions in assisted living and why radar

It should also be noted that reliable monitoring systems can be beneficial not only for fall detection, but also to evaluate the pattern of life of an individual. This includes, for instance, how active the person is, how often he/she moves in different parts of the house, and what activities are performed, in particular, fundamental activities (the so-called Activities of Daily Living – ADL) such as food intake and personal hygiene. Irregularities in the normal pattern of life of a person can be used for early detection of deteriorating health conditions (for instance, initial symptoms of dementia), providing the opportunity for timely and more effective treatment [128].

Many different technologies have been proposed in the literature for assisted living [87, 88, 129], and Figure 26 gives an overview of the information richness and perceived privacy per sensor. Radar stands out as it provides rich information and good perceived privacy because it does not take plain images. Furthermore, in case of a leakage of the data, some very sophisticated know-how would be required to make sense of the data obtained by hacking. This is important given the amount of personal information that can be obtained with ambient sensors in the home environment to ensure data security. Sensors for assisted living include wearable devices such as accelerometers, gyroscopes, and panic push buttons, inertial sensors such as those within smartphones, infrared, vibration, acoustic, magnetic sensors, video cameras, RGB-Depth (RGB-D) sensors, and radar sensors, or a combination of these systems, whereby their information is used jointly and fused to optimise the overall performance.

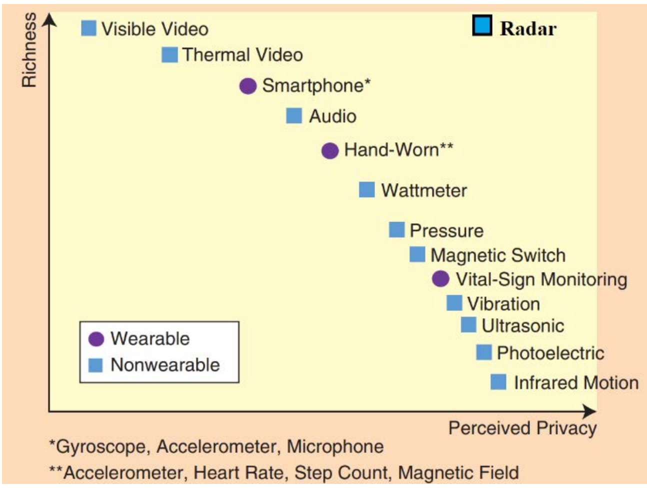


Figure 26: Perceived user privacy and richness in information for different types of sensors used for indoor monitoring and assisted living [87] with the added entry of radar

Looking at the most prevalent solutions for assisted living that offer a transformative potential to improve the quality of life for the elderly and chronic patients, we will look at the challenges going forward for indoor monitoring.

Wearable sensors, despite giving very good classification results [82] greater than 98%, they suffer from several major problems [68]:

- They need to be worn, which relies on user compliance or to think about it if you wake during the night to go to the washroom.
- They can break if dropped or sat on or during a fall.
- They need to be recharged, which can be a challenge in usability for cognitively impaired people.

In [130, 131], an entire apartment has been fitted with sensors PIR motion sensors, stove sensors, bed sensors, floor sensors… and give good patterns of activities of daily life. However, they are not able to give finer-grained information about vital signs and gait analysis for change detection and requires a lot of changes for fitting or retro-fitting sensors in a person's living environment.

In [132], an extensive review is proposed of video cameras and radar technologies for assisted living. For both radar and RGB-D systems, open challenges remain to be addressed to deploy and employ these systems in practical scenarios, as shown in Table 11.

Some feedback from MAIF Foundation (Health insurance company in France) stated that "even though there were more technological challenges with radar, the fact that there is no legal issue regarding image rights and that no plain images of people are taken therefore respecting privacy, this would help acceptance both of the end-users and investors." For the reasons mentioned above, the radar modality is the focus of this proposal as the preferred technology.

To conclude this section, radar has gained popularity as a sensing technology to support innovative/personalized healthcare services [73, 93, 118, 133, 134]. Why Radar? Many sensors have been investigated for assisted living (AL) [135], ranging from wearable sensors (e.g., accelerometers, gyroscopes, optical for heart rate (HR)/oximetry), sensors embedded in the built environment (e.g., pressure, acoustic, infrared sensors), to cameras based on visible/infrared light, or depth information. Amongst these, the attractiveness of radar in AL lies in its contactless nature, versatility, and privacy preservation. People under observation need not wear/interact with devices or comply with instructions that would change their routines. Radar would not be perceived as a stigma, as it can be beautified with a personalized radome fixed on a wall that could look like a painting of the person's choosing. Figure 27 presents a scenario that could be developed.

Table 11: current outstanding challenges for cameras and radar technologies for assisted living

Camera [132] – challenges	Radar [85] – challenges
• **Coverage area and depth-sensing range**. Differently from wearable devices, vision-based sensors have a limited coverage area, and many sensors may be required to monitor the whole apartment, leading to higher costs of installation. • **Occlusions**. Vision-based sensors suffer from occlusions, for example, from pieces of furniture. The coverage area may also be limited by the presence of some occluding objects, which are temporarily interposed between the subject to be monitored and the sensor. • **Skeleton data reliability**. Many algorithms based on Kinect sensors rely on skeleton data, which can be used to extract the position and posture of the human. However, for the skeleton information to be correctly estimated, the person should be facing the sensor. Moreover, the estimation algorithm can detect some spurious skeletons that are objects. • **Privacy:** The people surveyed fill a sense of privacy invasion with cameras. • **Law:** The data/image rights that apply to the cameras and ethics linked to its operation are not mature yet and could quickly become a legal minefield in the future.	• **Presence of strong scatterers and clutter** in indoor environments which may generate multipath and ghost targets, or obscure the person to be monitored from the sensor, which can also be a problem for RGB-D sensors. • **Multi-occupancy** – the possibility of having pets or other people (e.g., visitors, multiple elderly) moving inside the monitored area, thus complicating the signature and generating false alarms. Again, this could potentially be a problem for RGB-D sensors as well. • **Emission regulations** – the compliance of the selected radar waveforms with directives from the telecommunication regulatory bodies, with potential constraints in terms of the achievable bandwidth and transmitted power, hence limiting the range resolution and the Signal to Noise Ratio (SNR). • **Aspect angle dependence** – the dependence of the microDoppler signature on the cosine of the aspect angle between the velocity vector of the movement and the line-of-sight of the radar, which in some cases can significantly attenuate the signatures and make them unsuitable for feature extraction aimed at fall detection. • **Fine-grained activity classification in a continuum** – the possibility to reliably detect a fall, irrespective of the type of movement or activity performed before, and of the dynamics of the fall itself (falling forward or backward, tripping rather than losing balance or consciousness, falling while sitting or standing up from chairs or sofas). This would imply developing fall detection procedures that can take into account the actual dynamics of elderly people moving, for instance, the effects on the radar signatures of using walking assistive devices.

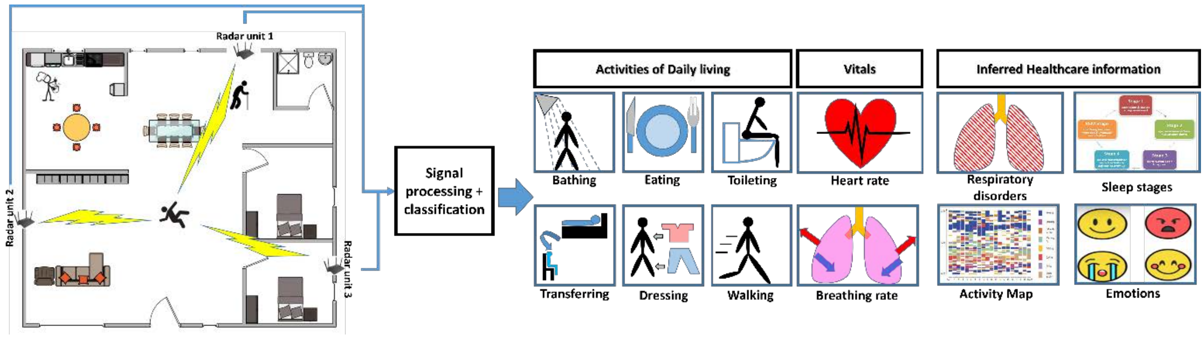


Figure 27: Assisted living scenario to follow-up patients with chronic diseases

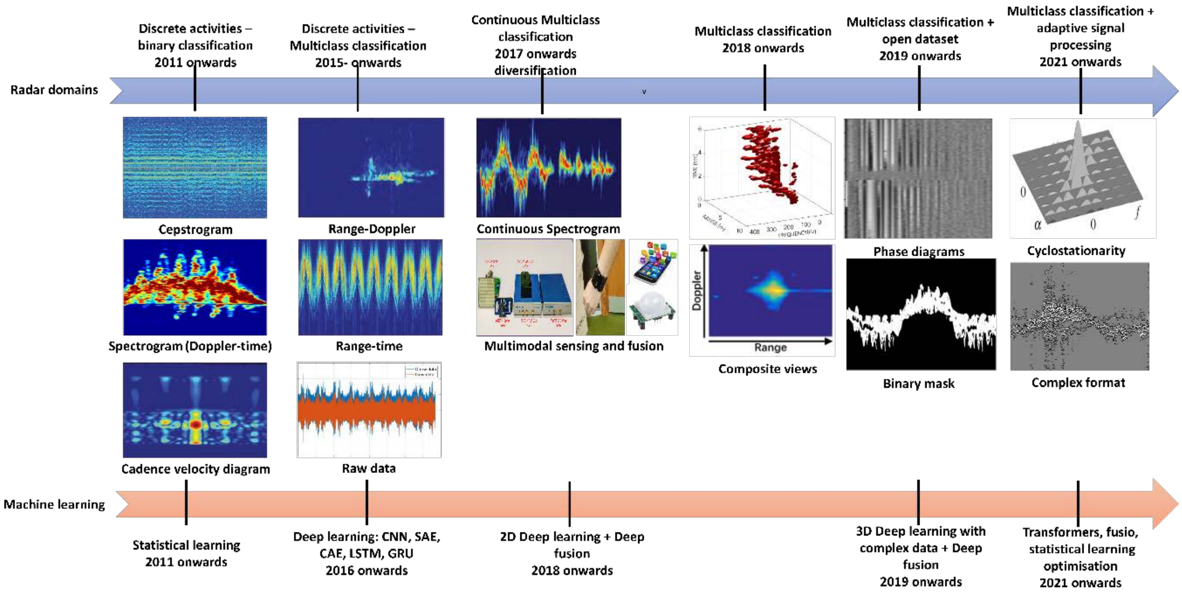


Figure 28: evolution of the state-of-the-art on human activity recognition

5.2.3 Simulation of Human activity Recognition

5.2.3.1 Publications

Journal articles

2. Zhou, B., Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Simulation framework for activity recognition and benchmarking in different radar geometries. IET Radar, Sonar and Navigation, 15(4), pp. 390-401. (doi: 10.1049/rsn2.12049)
3. Li, J., Shrestha, A., Le Kernec, J. and Fioranelli, F. (2019) From Kinect skeleton data to hand gesture recognition with radar. Journal of Engineering, 2019(20), pp. 6914-6919. (doi: 10.1049/joe.2019.0557)
4. Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2018) Human activity classification with radar: optimization and noise robustness with iterative convolutional neural networks followed with random forests. IEEE Sensors Journal, 18(23), pp. 9669-9681. (doi: 10.1109/JSEN.2018.2872849)

Book Sections

1. Fioranelli, F. and Le Kernec, J. (2020) Contactless radar and RF health monitoring. In: Imran, M. A., Ghannam, R. and Abbasi, Q. H. (eds.) Engineering and Technology for Healthcare.

Wiley-IEEE: Hoboken, NJ, pp. 29-59. ISBN 9781119644248 (doi: 10.1002/9781119644316.ch2)
2. Shrestha, A., Fioranelli, F. and Le Kernec, J. (2020) Multimodal sensing for assisted living using radar. In: Fioranelli, F., Griffiths, H., Ritchie, M. and Balleri, A. (eds.) Micro-Doppler Radar and its Applications. Institution of Engineering and Technology (IET): London, UK. ISBN 9781785619335

Conference Proceedings

1. Yang, K., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Bespoke Simulator for Human Activity Classification with Bistatic Radar. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 71-85. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_7)
2. Zhou, B., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Interferometric Radar for Activity Recognition and Benchmarking in Different Radar Geometries. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1515-1520. ISBN 9781839535406 (doi: 10.1049/icp.2021.0571)
3. Li, Z., Li, B. and Le Kernec, J. (2020) Activity Recognition System Optimisation Using Triaxial Accelerometers. In: International Conference on 3D Imaging Technology (IC3DIT2019), Kunming, Yunnan, China, 15-18 Aug 2019, ISBN 9789811538667 (doi: 10.1007/978-981-15-3867-4_15)
4. Lin, Y. and Le Kernec, J. (2018) Performance Analysis of Classification Algorithms for Activity Recognition using Micro-Doppler Feature. In: The 13th International Conference on Computational Intelligence and Security (CIS 2017), Hong Kong, China, 15-18 Dec 2017, ISBN 0769563414 (doi: 10.1109/CIS.2017.00111)

5.2.3.2 Contributors

Staff:

- Prof. Olivier Romain – University Cergy-Pontoise (CYU) (2016 – to date)
- Dr. Francesco Fioranelli – University of Glasgow (UoG)/TU Delft (TUD) (2016 – to date)
- Dr. Shufan Yang – UoG/Edinburgh Napier University (ENU) (2017 – to date)
- Prof. Zhao Zhiqin – University of Electronic Science and technology of China (2017 - 2020)

PhD student(s):

- Dr Yier Lin – UESTC (2017-2020)

Undergraduate and Postgraduate Students

- Yifei Jin – UESTC/UoG (2016-2017) – B.Eng EEE
- Jiang Haoyang UESTC/UoG (2017 - 2020) – Beng EEE / MSc EEE
- Shuting Huang – UESTC/UoG (2017-2018) – B.Eng EEE
- Jiayi Li – UESTC/UoG (2017-2018) – B.Eng EEE
- Jianfei Li –UoG (2018) – MSc EEE
- Zhenghui Li – UESTC/UoG (2018-2019) – B.Eng EEE
- Xinyu Hu – UESTC/UoG (2018-2019) – B.Eng EEE
- Boyu Zhou – UESTC/UoG (2018-2019) – B.Eng EEE
- Ruxue Yan – UESTC/UoG (2019-2020) – B.Eng EEE
- Jianwei Lai – UESTC/UoG (2019-2020) – B.Eng EEE
- Kai Yang – UESTC/UoG (2020-2021) – B.Eng EEE
- Kecheng Xing – UESTC/UoG (2020-2021) – B.Eng EEE
- Yuxiang Mao – UESTC/UoG (2021-2022) – B.Eng EEE

5.2.3.3 Contributions

One of the most effective tools, we have used to validate classification algorithms and radar signatures has been our simulator. I started developing it in 2016 as an evolution of the work presented in the seminal work on microDoppler effects in [136]. The limitations of the simulator were primarily in the provision of kinematic models for diversity in the activities as the book only included a parametric analytical model of walking [137]. I added the capability of using motion capture data files such as HDM05 database [138] or CMU [139]. The motion files capture 31 joints to form a skeleton (stickman) in three dimensions through a network of synchronised cameras at 120 frames per second (FPS). The number of FPS is important as in radar phenomenology this would correspond to the pulse repetition period (PRP) that dictates the Doppler unambiguous range ΔD. Interpolation was used to increase the sampling rate (typically 1 kHz at 5.8 GHz [80] or 2 kHz at 9.8 GHz [140] to accommodate the human Doppler) range and therefore observe the microDoppler phenomenon. This project was initiated with the help of Miss Yifei Jin (2016-2017) where the first version was produced capable of using Mocap files to generate signatures with custom code inspired from [136]. Miss Shuting Huang (2017-2018) and Mr Jiayi Li (2017-2018) continued this work with the addition of statistical classification and the use of data augmentation techniques (SMOTE [141]) to increase the size of the database for training and testing allowing reliable statistical learning after the classification accuracy was confirmed to be similar before and after data augmentation. We started to test the saliency of features coming from simulated signatures was tested in order to improve both the performances and the accuracy of classification from 30 to 60% over a very challenging gesture dataset as they were very similar in the microDoppler domain. Mr Xinyu Hu (2018-2019) investigated another augmentation technique for the simulator by modifying the morphology [142] of the subjects (thin/fat, short/tall) therefore providing more diversity in the signatures. Mr Boyu Zhou (2018-2019) in parallel worked on the development of radar signatures produced from different radar geometries (multistatic [143], interferometric[25]) with convolutional neural network for the analysis of the radar signatures (microDoppler and interferometric channel) followed by decision level fusion [75] in order to tackle the degradation in performance with varying aspect angle [144-146]. This method allowed us to find a suitable radar geometry for experimental test before purchasing the equipment therefore saving valuable resources. Boyu worked until 2021 on this topic to continue improving the simulator [140] as shown in Figure 29. The different steps of the radar simulation are shown and the interferometric and multistatic geometries as well as the effect of various aspect angles on the target. The results in [140, 147] show a robust implementation of both in-line multistatic and interferometric geometries to the target's aspect angle (Figure 31) as well as confirms the realism of the simulations compared to measured data.

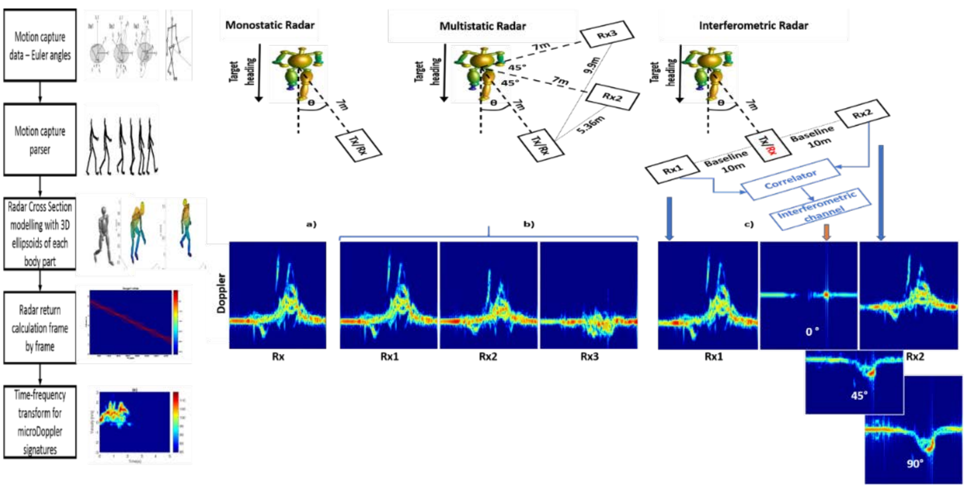


Figure 29: left) simulator steps from motion captured data to radar signatures, right) results for different radar architectures with a 9.8GHz carrier frequency a) monostatic radar, b) circular multistatic radar, c) interferometric radar and inline multistatic radar. [140, 147]

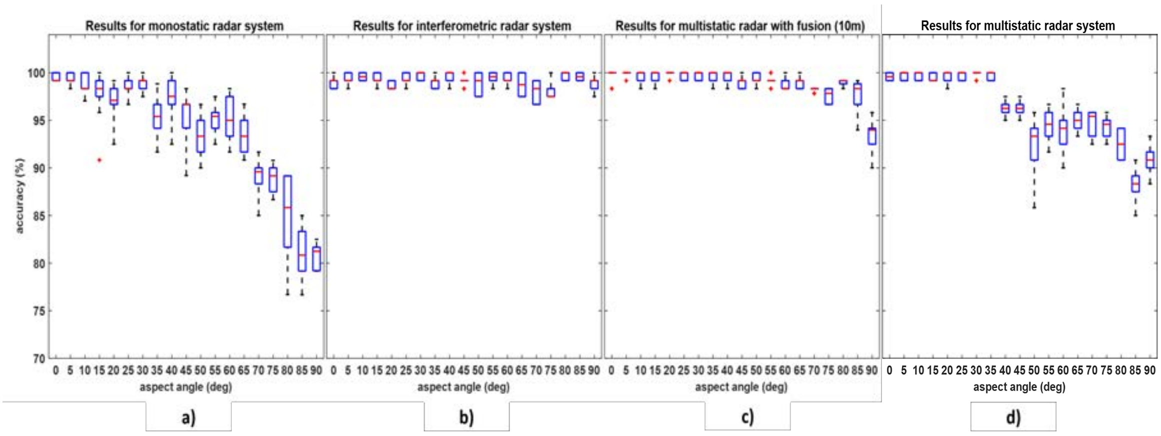


Figure 30: Boxplots for (a) monostatic radar system, (b) interferometric radar system with fusion – 10m baseline, c) multistatic radar system with fusion – in-line configuration -10m baseline, (d) multistatic radar system with fusion – circular configuration. In the boxplots, the central red mark indicates the median, and the bottom and top blue edges of the box indicate the first and third quartile, respectively. The black whiskers extend to the minimum and maximum values and the outliers are plotted with the red '+' symbol. [140, 147]

Mr Zhenghui Li (2018-2019) worked on adding a new sensing modality extracting acceleration data from the Mocap data using Mocap toolbox [148]. Since 31 joints are available, we were able to optimize the best placement of 1 (waist) and 2 sensors (waist+wrist – either left or right) for activity recognition and confirmed the results from the literature on the placement of the sensor on the waist for optimal human activity recognition. Mr Jianfei Li (2018) was working on the simulator but only produced results for the monostatic radar. Miss Ruxue Yan (2019-2020) worked on determining whether radar vision or Wi-Fi vision [149] was better for human activity recognition with the simulation of the Wi-Fi and radar signatures however only the radar vision simulation was achieved during her project. Mr Jianwei Lai (2019-2020) was tasked with further investigation of multistatic radar configurations for human activity recognition with respect to varying aspect angles but only completed monostatic and multistatic from the direct line of sight for classification purposes. This activity from the undergraduate projects was in support of the PhD study of Dr. Yier Lin (April 2017 – Jun 2020) who worked on "Non-linear parameter estimation and classification of radar microDoppler signatures" and simulations [80, 150] were used in support to develop classification algorithms before their application on measured data. This side of the activity included feature extraction robust to noise for varying SNR [150] and classifiers for human activity recognition [80]. Prof. Olivier Romain, Dr Francesco Fioranelli, Prof Zhiqin Zhao, Dr Shufan Yang were part of the supervisory team for Dr Yier Lin. They contributed in the guidance of the development of the simulations key performance indicators, classification algorithm techniques, research methods. Dr Yier Lin went to CYU for 1 year as a visiting PhD student as part of her PhD project to work on development of the algorithms for the measured data to validate her simulation results.

Mr Jiang Haoyang (2017-2020) has worked on the development of an advanced simulator to generate the other radar data domains from raw data, to range-time, range-Doppler, Spectrogram, and Cadence Velocity diagram for deformation monitoring initially with any kind of transmitted signals using matched filtering as opposed to stretch processing [151]. It was observed that the Spectrogram generated using this approach had richer information especially when sharp changes were observed in the spectrogram [11] for the application in deformation monitoring.

Mr Kecheng Xing (2020-2021) and Mr Kai Yang (2020-2021) continued exploring different radar geometries and moved from training one algorithm per angle to training one model for all angles. This work also looked at the robustness of feature extraction using principal component analysis and adding different key performance indicators to evaluate algorithms beyond the accuracy such as inference time, training time, and robustness/stability on a 10-fold cross-validation as shown in Figure 31.

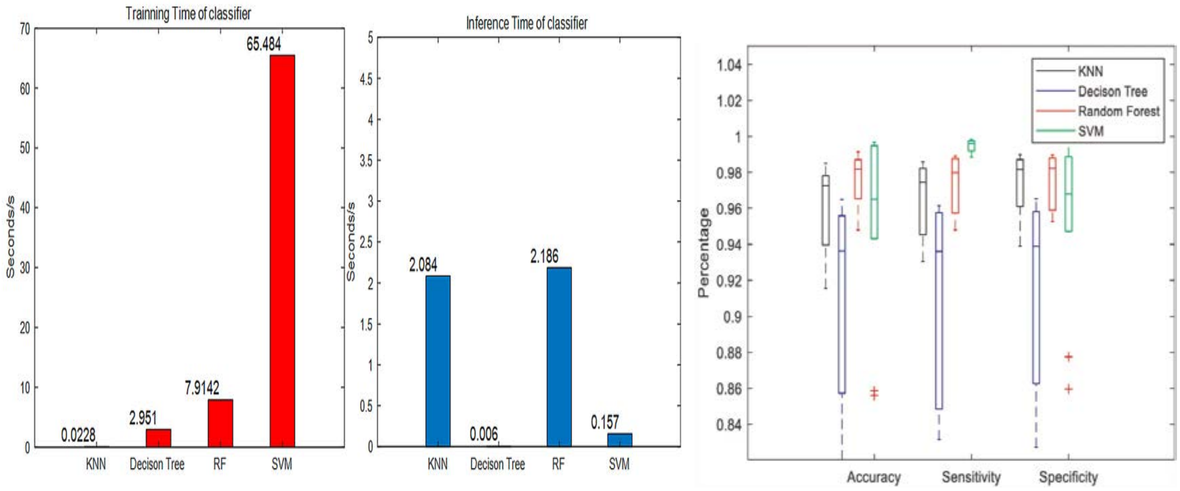


Figure 31: Average over 10-fold cross validation (left) training time (middle) inference time (right) Boxplot of accuracy, sensitivity and specificity.[152]

Mr Yuxiang Mao (2021-2022) has worked on adding realism to the simulations by adding beam pattern, noise, free space losses and multipath to the simulator. Furthermore, he tested the use of Histogram Oriented gradient [153] and Grayscale Co-Occurrence Matrix (GLCM) [154] with data augmentation techniques and interferometric geometries.

This activity continues and is essential to the development of new techniques for experiments. My new student in 2022-2023 will work on the integration of the various aforementioned techniques for the simulation of a 4D radar and will benefit from the refurbishment of the motion capture suite to enhance our simulation capabilities as well as being more in control of our databases.

5.2.4 Phenomenology

5.2.4.1 Contributors

Staff:

- Prof. Olivier Romain – CYU (2016 – to date)
- Dr. Francesco Fioranelli – UoG/TUD (2016 – to date)
- Prof. Qian He – UESTC (2020 – to date)
- Dr Bruno Philippe – GHT Novo (2018 – to date)

Undergraduate and Postgraduate StudentsStaff:

- Chen Yang - UESTC/UoG (2017-2018) – B.Eng EEE
- Xinyu Yang - UESTC/UoG (2017-2018) – B.Eng EEE
- Xuyu Fang - UESTC/UoG (2018-2019) – B.Eng EEE
- Tianxi Qi - UESTC/UoG (2018-2019) – B.Eng EEE
- Zhiling Peng - UESTC/UoG (2019-2020) – B.Eng EEE
- Tianhe Li - UESTC/UoG (2020-2021) – B.Eng EEE
- Wei Lai - UESTC/UoG (2020-2021) – B.Eng EEE
- Shuyi Ying - UESTC/UoG (2020-2021) – B.Eng EEE
- Zuo Chen – UoG (2021) – MSc Mechatronics
- Yifei Yao - UESTC/UoG (2016-2017) – B.Eng EEE
- Zhong. Yi - UESTC/UoG (2016-2017) – B.Eng EEE
- Yuxin Yang - UESTC/UoG (2016-2017) – B.Eng EEE
- Siwon Shin – Centrale/Supelec (2022) – Engineering degree

5.2.4.2 Contributions

This part is a little more diverse as it is exploring the phenomenology for human activity recognition as well as vital signs using other sensing modalities for an adaptation to radar monitoring. Prof. Olivier Romain works in embedded systems for health applied to polyp detection in the intestinal tract and spinal cord injuries. He has now extended his work to gait analysis as part of the work on radar in assisted living and has created a mobility lab in France constitute of a motion capture suite to capture 3D skeleton motions, a connected mat to measure foot falls and extract gait parameters, as well as radar and event camera sensing modalities. Dr Francesco Fioranelli has launched the activity on human activity recognition in Glasgow and pursues working on this field of research now focusing on continuous data streams and how to automate the transition from one activity to another as well as multistatic/MIMO configurations. Prof. Qian He is working on MIMO radar but has also an interest in traditional Chinese medicine which is an interesting take on health care monitoring, and we are working together to objectivise the diagnostic methods one student at a time. Dr Bruno Philippe is the head of the pneumology department, and his expertise helps us understand beyond the possibility of what can be done with human activity and vitals monitoring what movements are important to monitor and what conditions or difficulties patients will face at home. Dr Bruno Philippe has helped us from the beginning and has opened the links with the hospital, his rehabilitation clinic and helps us with volunteers to facilitate the research towards deployment.

The first implementation started with Chen Yang (2017-2018) in which he implemented a fall detection device based on accelerometers that would detect the fall based on a state machine and would send the GPS coordinates of the person using the mobile network to his phone. In parallel, Xinyu Yang (2017-2018) implemented the low cost UWB radar patented by McEwan [155] to work on activity and vital signs classification, the radar was built but the platform was not fully completed so we could not move to the experiments with humans. Xuyu Fang (2018-2019) continued the work from Chen Yang in which he realised an embedded platform to recognise fall detections but also when a person was walking to work towards gait parameter extraction based on a state machine. Tianxi Qi (2018-2019) worked on the development of a wrist worn embedded platform to measure the galvanic skin response in relation to the electrocardiogram. The galvanic skin response can be used to measured changed in the skin impedance. Understanding this phenomenology would then help track back to modelling the reflectivity changes in the chest caused by variations in the electric current when the heart beats. Zhiling Peng (2019-2020) worked on the implementation of an embedded platform based on accelerometers to monitor both activity recognition and vital signs. Unfortunately, this is when Covid hit in China, so we had to scale back to activity monitoring and because of lock down we changed it to hand gesture recognition. She constituted a database (600 samples) based on her measurements, and with some signal processing to smooth the signal, and a light neural network implementation the gestures “up”, “down”, “left”, “right”, “X” and “O” were recognised with 93.3% accuracy.

Tianhe Li (2020-2021) worked on the implementation of an electrocardiogram (ECG) embedded platform to study the heart rate variability and define rules to monitor this from the PQRST cycle in an ECG [156]. Wei Lai worked on the implementation of a multi-site breathing and heart rate monitoring (sternum, back, and side) system using accelerometers to construct a model of breathing and heart rate for simultaneous monitoring. The breathing rate and heart rate were extracted and compared against commercially available breathing rate and heart rate monitoring devices from Hefei Huake Electronic Technology Research Institute HKH-11C and HK-2000C, respectively. The breathing rate was extracted accurately but the heart rate had errors 7-8 beats per minutes because the ADXL355 was not resolving the peaks from the heartbeat impulses from the sternum, side or the back. It allowed to work out how to remove the baseline for monitoring the breathing rate to accurately estimate the changes. Shuyi Ying (2020-2021) worked on an electroencephalogram (EEG) database DEAP [157] to recognise emotions based on valence (pleasant/unpleasant) and arousal (calmness/excitement). The idea behind this was that arousal can be measured from the heart rate variations and arousal can be measured from the galvanic skin response. Because, this study happened during the pandemic, we reverted to the use of available databases in this case DEAP for the study. This however allowed to test the implementation of digital wavelet transforms to extract the features for classification but only reached 60% accuracy with statistical learning and handcrafted features. Zuo Chen (2021) continued this work and implemented deep learning techniques to extract features and classify the 4 emotional states with low/high valence and low/high arousal with over 90% accuracy.

Yifei Yao (2021-2022) worked on the digitisation of traditional Chinese medicine working on the 3 pressure points on the wrist used for diagnosis 'Chi', 'Guan', 'Cun' [158]. The project consisted of monitoring the 3 points pressure variations and recreating them remotely via haptic feedback for remote diagnosis. Yuxin Yang (2021-2022) continued on the work from Tianhe Li (2020-2021) and Tianxi Qi (2018-2019) to extract the exact timing of QRS waves from ECG [159] using adaptive thresholding and machine learning to distinguish sound heart beats from arrythmia with 99% accuracy for the QRS wave extraction and 98% accuracy in classification. Zhong Yi (2021-2022) continued on the work from Wei Lai (2020-2021) by selecting a more sensitive signal processing algorithm to extract the heart beat and breathing rate simultaneously using superlets [160]. The data is first filtered to extract the breathing rate using baseline removal and FFT to be subtracted from the overall measurement before applying the superlet analysis to extract the heartrate with ~1.2% error compared to the finger pressure heart monitor. This comes at the cost of a higher computational rate.

Investments were made in Glasgow to purchase a connected mat and refurbish the MAST lab with the motion capture equipment to turn it into a mobility lab. This took 12 months to have the connected mat and the motion capture working in the same room. Siwon Shin (2022) is working on developing an algorithm for the automatic extraction of gait parameters from the motion captured data in MATLAB to qualify the extracted parameters against the parameters obtained from the connected mat. The end game is to obtain a way to link the foot fall readings with the phenomenology of the radar reflectivity to extract the same parameters using the motion capture as an intermediate step. This consists in the detection of a stable phase of walk before starting the extraction. This project is still on-going.

The phenomenology strand advances the different future directions in human activity recognition, vital signs monitoring, and inference from vital signs toward an adaptation to radar monitoring.

5.2.5 Algorithms development

5.2.5.1 Publications

Journal/Magazine articles:

1. Shah, S. A., Tahir, A., Le Kernec, J., Zoha, A. and Fioranelli, F. (2022) Data portability for activities of daily living and fall detection in different environments using radar micro-doppler. Neural Computing and Applications, 34(10), pp. 7933-7953. (doi: 10.1007/s00521-022-06886-2)
2. Li, H., Le Kernec, J., Gurbuz, S. Z. and Fioranelli, F. (2021) Sequential human gait classification with distributed radar sensor fusion. IEEE Sensors Journal, 21(6), pp. 7590-7603. (doi: 10.1109/JSEN.2020.3046991)
3. Iloga, S., Bordat, A., Le Kernec, J. and Romain, O. (2021) Human Activity Recognition based on acceleration data from smartphones using HMMs. IEEE Access, 9, pp. 139336-139351. (doi: 10.1109/ACCESS.2021.3117336)
4. Shrestha, A., Li, H., Le Kernec, J. and Fioranelli, F. (2020) Continuous human activity classification from FMCW radar with Bi-LSTM networks. IEEE Sensors Journal, 20(22), pp. 13607-13619. (doi: 10.1109/JSEN.2020.3006386)
5. Li, H., Liang, X., Shrestha, A., Liu, Y., Heidari, H., Le Kernec, J. and Fioranelli, F. (2020) Hierarchical sensor fusion for micro-gestures recognition with pressure sensor array and radar. IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, 4(3), pp. 225-232. (doi: 10.1109/JERM.2019.2949456)

6. Li, X., Li, Z., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2020) Hierarchical radar data analysis for activity and personnel recognition. Remote Sensing, 12(14), 2237. (doi: 10.3390/rs12142237)
7. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2020) Bi-LSTM network for multimodal continuous human activity recognition and fall detection. IEEE Sensors Journal, 20(3), pp. 1191-1201. (doi: 10.1109/JSEN.2019.2946095)
8. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2019) Magnetic and radar sensing for multimodal remote health monitoring. IEEE Sensors Journal, 19(20), pp. 8979-8989. (doi: 10.1109/JSEN.2018.2872894)
9. Li, H., Shrestha, A., Fioranelli, F., Le Kernec, J. and Heidari, H. (2019) FMCW radar and inertial sensing synergy for assisted living. Journal of Engineering, 2019(20), pp. 6784-6789. (doi: 10.1049/joe.2019.0558)
10. Li, J., Shrestha, A., Le Kernec, J. and Fioranelli, F. (2019) From Kinect skeleton data to hand gesture recognition with radar. Journal of Engineering, 2019(20), pp. 6914-6919. (doi: 10.1049/joe.2019.0557)
11. Shrestha, A., Li, H., Fioranelli, F. and Le Kernec, J. (2019) Activity recognition with cooperative radar systems at C and K band. Journal of Engineering, 2019(20), pp. 7100-7104. (doi: 10.1049/joe.2019.0559)
12. Fioranelli, F., Shah, S. A., Li, H., Shrestha, A., Yang, S. and Le Kernec, J. (2019) Radar sensing for healthcare. Electronics Letters, 55(19), pp. 1022-1024. (doi: 10.1049/el.2019.2378)
13. Ding, C., Hong, H., Zou, Y., Chu, H., Zhu, X., Fioranelli, F., Le Kernec, J. and Li, C. (2019) Continuous human motion recognition with a dynamic range-Doppler trajectory method based on FMCW radar. IEEE Transactions on Geoscience and Remote Sensing, 57(9), pp. 6821-6831. (doi: 10.1109/TGRS.2019.2908758)
14. Fioranelli, F., Le Kernec, J. and Shah, S. A. (2019) Radar for healthcare: recognising human activities and monitoring vital signs. IEEE Potentials, 38(4), pp. 16-23. (doi: 10.1109/MPOT.2019.2906977)
15. Shrestha, A., Le Kernec, J., Fioranelli, F., Lin, Y., He, Q., Lorandel, J. and Romain, O. (2019) Elderly care: activities of daily living classification with an S band radar. Journal of Engineering, 2019(21), pp. 7601-7606. (doi: 10.1049/joe.2019.0561)
16. Le Kernec, J., Fioranelli, F., Ding, C., Zhao, H., Sun, L., Hong, H., Lorandel, J. and Romain, O. (2019) Radar signal processing for sensing in assisted living: the challenges associated with real-time implementation of emerging algorithms. IEEE Signal Processing Magazine, 36(4), pp. 29-41. (doi: 10.1109/MSP.2019.2903715)
17. Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2018) Human activity classification with radar: optimization and noise robustness with iterative convolutional neural networks followed with random forests. IEEE Sensors Journal, 18(23), pp. 9669-9681. (doi: 10.1109/JSEN.2018.2872849)
18. Shrestha, A., Loukas, C., Le Kernec, J., Fioranelli, F., Busin, V., Jonsson, N., King, G., Tomlinson, M., Viora, L. and Voute, L. (2018) Animal lameness detection with radar sensing. IEEE Geoscience and Remote Sensing Letters, 15(8), pp. 1189-1193. (doi: 10.1109/LGRS.2018.2832650)
19. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2018) A multi-sensory approach for remote health monitoring of older people. IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, 2(2), pp. 102-108. (doi: 10.1109/JERM.2018.2827099)
20. Le Kernec, J. and Romain, O. (2017) Performances of multitones for ultra-wideband software-defined radar. IEEE Access, 5, pp. 6570-6588. (doi: 10.1109/ACCESS.2017.2693300)

Book Sections

1. Fioranelli, F. and Le Kernec, J. (2020) Contactless radar and RF health monitoring. In: Imran, M. A., Ghannam, R. and Abbasi, Q. H. (eds.) Engineering and Technology for Healthcare. Wiley-IEEE: Hoboken, NJ, pp. 29-59. ISBN 9781119644248 (doi: 10.1002/9781119644316.ch2)
2. Shrestha, A., Fioranelli, F. and Le Kernec, J. (2020) Multimodal sensing for assisted living using radar. In: Fioranelli, F., Griffiths, H., Ritchie, M. and Balleri, A. (eds.) Micro-Doppler Radar and its Applications. Institution of Engineering and Technology (IET): London, UK. ISBN 9781785619335

Conference without proceedings or Workshop Items

1. Yang, S., Le Kernec, J. and Fioranelli, F. (2019) Action Recognition Using Indoor Radar Systems. IET Human Motion Analysis for Healthcare Applications, London, UK, 26 Jun 2019.
2. Du, Y., Li, B., Li, J., Fioranelli, F. and Le Kernec, J. (2022) A ViT Approach for Short-range Behaviour Recognition Using Radar Signals. In: 2022 IEEE Radar Conference (RadarConf22), New York, NY, USA, 21-25 Mar 2022.

Conference Proceedings

1. Zhang, X., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Elderly Care - Human Activity Recognition Using Radar with an Open Dataset and Hybrid Maps. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 39-51. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_4)
2. Fioranelli, F. and Le Kernec, J. (2021) Radar Sensing for Human Healthcare: Challenges and Results. In: IEEE Sensors 2021, Sydney, Australia, 31 Oct - 04 Nov 2021, ISBN 9781728195018 (doi: 10.1109/SENSORS47087.2021.9639702)
3. Le Kernec, J., Fioranelli, F. and Romain, O. (2021) Fusion of Radar Data Domains for Human Activity Recognition in Assisted Living. In: 14th International conference on Sensing Technology, Chennai, India, 17-19 Jan 2022.
4. Li, Z., Le Kernec, J., Fioranelli, F., Abbasi, Q., Yang, S. and Romain, O. (2021) Human Activity Classification with Adaptive Thresholding using Radar Micro-Doppler. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 - 19 December 2021.
5. Du, Y., Li, J., Li, Z., Yu, R., Napolitano, A., Fioranelli, F. and Le Kernec, J. (2021) Radar-based Human Activity Classification with Cyclostationarity. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 - 19 December 2021.
6. Guo, J., Shu, C., Zhou, Y., Wang, K., Fioranelli, F., Romain, O. and Le Kernec, J. (2021) Complex Field-based Fusion Network for Human Activities Classification With Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 68-73. ISBN 9781839535406 (doi: 10.1049/icp.2021.0572)
7. Jiang, H., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Human Activity Classification Using Radar Signal and RNN Networks. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1595-1599. ISBN 9781839535406 (doi: 10.1049/icp.2021.0556)
8. Li, X., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Radar-Based Hierarchical Human Activity Classification. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1373-1379. ISBN 9781839535406 (doi: 10.1049/icp.2021.0566)
9. Li, Z., Fioranelli, F., Yang, S., Zhang, L., Romain, O., He, Q., Cui, G. and Le Kernec, J. (2021) Multi-domains based Human Activity Classification in Radar. In: IET International

Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1744-1749. ISBN 9781839535406 (doi: 10.1049/icp.2021.0557)

10. Yang, F., Le Kernec, J., Fioranelli, F. and Liu, Q. (2021) Shape Feature Aided Target Detection Method for Micro-drone Surveillance Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 390-395. ISBN 9781839535406 (doi: 10.1049/icp.2021.0839)
11. Zhou, B., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Interferometric Radar for Activity Recognition and Benchmarking in Different Radar Geometries. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1515-1520. ISBN 9781839535406 (doi: 10.1049/icp.2021.0571)
12. Li, Z., Le Kernec, J., Fioranelli, F., Romain, O., Zhang, L. and Yang, S. (2021) A LSTM Approach to Short-Range Personnel Recognition Using Radar Signals. In: 2021 IEEE Radar Conference (RadarConf21), Atlanta, GA, USA, 7-14 May 2021, ISBN 9781728176093 (doi: 10.1109/RadarConf2147009.2021.9455218)
13. Li, H., Le Kernec, J., Mehul, A., Gurbuz, S. Z. and Fioranelli, F. (2020) Distributed Radar Information Fusion for Gait Recognition and Fall Detection. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266319)
14. Jia, M., Li, S., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Human Activity Classification With Radar Signal Processing and Machine Learning. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205461)
15. Li, S., Jia, M., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Elderly Care: Using Deep Learning for Multi-Domain Activity Classification. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205464)
16. Yang, S., Le Kernec, J., Fioranelli, F. and Romain, O. (2020) Human Activities Classification in a Complex Space using Raw Radar Data. In: 2019 International Radar Conference, Toulon, France, 23-27 Sept 2019, ISBN 9781728126609 (doi: 10.1109/RADAR41533.2019.171367)
17. Haider, D., Shah, S. Y., Romain, O., Farooq, M. M. U., Le Kernec, J. and Qadus, Z. (2019) Monitoring Body Motions Related to Huntington Disease by Exploiting the 5G Paradigm. In: UK-China Emerging Technologies Conference, Glasgow, UK, 21-22 Aug 2019, ISBN 9781728127972 (doi: 10.1109/UCET.2019.8881867)
18. Shrestha, A., Murphy, C., Johnson, I., Anbulselvam, A., Fioranelli, F., Le Kernec, J. and Gurbuz, S. Z. (2019) Cross-Frequency Classification of Indoor Activities with DNN Transfer Learning. In: IEEE Radar Conference, Boston, MA, USA, 22-26 Apr 2019, ISBN 9781728116792 (doi: 10.1109/RADAR.2019.8835844)
19. Le Kernec, J., Fioranelli, F., Ding, C., Zhao, H., Sun, L., Hong, H., Romain, O. and Lorandel, J. (2019) Radar Sensing in Assisted Living: An Overview. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777748)
20. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2019) Activities Recognition and Fall Detection in Continuous Data Streams Using Radar Sensor. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777855)
21. Le Kernec, J., Fioranelli, F., Yang, S., Lorandel, J. and Romain, O. (2019) Radar for Assisted Living in the Context of Internet of Things for Health and Beyond. In: 26th IFIP/IEEE/AICA International Conference on Very Large Scale Integration, Verona, Italy, 8-10 Oct 2018, ISBN 9781538647561 (doi: 10.1109/VLSI-SoC.2018.8644816)
22. Li, H., Fioranelli, F., Le Kernec, J. and Heidari, H. (2018) Hierarchical Classification on Multimodal Sensing for Human Activity Recogintion and Fall Detection. In: IEEE Sensors

2018 Conference, New Delhi, India, 28-31 Oct 2018, ISBN 9781538647073 (doi: 10.1109/ICSENS.2018.8589797)
23. Loukas, C., Fioranelli, F., Le Kernec, J. and Yang, S. (2018) Activity Classification Using Raw Range and I & Q Radar Data with Long Short Term Memory Layers. In: 1st International Workshop on Healthcare with Intelligent Sensing, System and Data (HISSD) in CyberSciTech2018, Athens, Greece, 12-15 Aug 2018, pp. 441-445. ISBN 9781538675199 (doi: 10.1109/DASC/PiCom/DataCom/CyberSciTec.2018.00088)
24. Shrestha, A., Le Kernec, J., Fioranelli, F., Cippitelli, E., Gambi, E. and Spinsante, S. (2018) Feature Diversity for Fall Detection and Human Indoor Activities Classification Using Radar Systems. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0381)
25. Li, H., Shrestha, A., Fioranelli, F., Le Kernec, J., Heidari, H., Pepa, M., Cippitelli, E., Gambi, E. and Spinsante, S. (2017) Multisensor Data Fusion for Human Activities Classification and Fall Detection. In: IEEE Sensors 2017, Glasgow, UK, 30 Oct - 01 Nov 2017, ISBN 9781509010127 (doi: 10.1109/ICSENS.2017.8234179)

Patents

1. Centre National de la Recherche Scientifique (2022), Method and Device for Human Activity Classification using Radar Micro-Doppler And Phase, EP21306742.
2. Centre National de la Recherche Scientifique (2021) Dispositif de caractérisation de l'actimétrie d'un sujet en temps réel = Device for Characterizing the Actimetry of a Subject in Real Time. . WO2021069518A1.

5.2.5.2 Contributors

Staff:

- Prof. Olivier Romain – CYU (2016 – to date)
- Dr. Francesco Fioranelli – UoG/TUD (2016 – to date)
- Prof. Qian He – UESTC (2020 – to date)
- Dr. Shufan Yang - UoG/ENU (2017 - to date)
- Dr. Qammer Abbasi – UoG (2020 – to date)
- Prof. Muhammad Imran - UoG (2019 – to date)
- Prof. Yi Zhang – UESTC (2020 – to date)
- Prof. Hong Hong – Nanjing University of Science and Technology (NJUST) (2018-2020)
- Prof. Antonio Napolitano – University of Napoli Parthenope (UNP) (2019 – to date)
- Dr Rebecca Killick – Lancaster University (LU) (2022 – to date)

PhD students:

- Dr Yier Lin – UESTC (2017-2020)
- Dr Aman Shrestha – UoG (2016-2021)
- Dr Haobo Li – UoG (2017-2021)
- Charalampos Louka – UoG (2017-2018)
- Dr Chuanwei Ding – NJUST (2018-2020)
- Zhenghui Li – UoG (2019 – to date)
- Weirong Sun – UoG/UESTC (2020 – to date)

Undergraduate and postgraduate students:

- Shaoxuan Li - UESTC/UoG (2019-2020) – B.Eng EEE
- Jia Mu - UESTC/UoG (2019-2020) – B.Eng EEE
- Xingzhuo Li - UESTC/UoG (2019-2020) – B.Eng EEE
- Chang Shu - UESTC/UoG (2019-2021) – B.Eng EEE

- Jiaqi Guo - UESTC/UoG (2019-2021) – B.Eng EEE
- Yan Peng - UESTC/UoG (2020-2021) – B.Eng EEE
- Xinyu Zhang - UESTC/UoG (2020-2021) – B.Eng EEE
- Zhouyixian Li - UESTC/UoG (2020-2022) – B.Eng EEE
- Jipeng Li - UESTC/UoG (2020-2022) – B.Eng EEE
- Yaxin Du - UESTC/UoG (2020-2022) – B.Eng EEE
- Haotian Xiang - UESTC/UoG (2021-2022) – B.Eng EEE
- Shiyuan Liu - UESTC/UoG (2021-2022) – B.Eng EEE
- Ran Yu - UESTC/UoG (2021-2023) – B.Eng EEE
- Jiuchuan Zhang - UESTC/UoG (2022-2023) – B.Eng EEE
- Hengxu Gong - UESTC/UoG (2022-2023) – B.Eng EEE
- Ruoyun Cheng - UESTC/UoG (2022-2023) – B.Eng EEE
- Shaowen Ma - UESTC/UoG (2022-2023) – B.Eng EEE
- Junyu Zhou - UESTC/UoG (2022-2023) – B.Eng EEE
- Pengzhao Liu - UESTC/UoG (2022-2023) – B.Eng EEE

5.2.5.3 Contributions

This activity has been running alongside the simulator's development evolving from binary discrete activity classification with statistical learning in 2016 to continuous activity classification using deep learning and fusion. Dr Fioranelli started this activity in 2016 when he was hired at University of Glasgow. We joined forces as I had more experience on signal processing and experimental trials and he had more experience on classification algorithms. Our research has contributed to the development of the state-of-the-art as it happened. Radar-based human activity recognition (HAR) was only starting then with Prof Moeness Amin's signal processing magazine paper in a special issue on assisted living "radar signal processing for elderly fall detection: the future of in-home monitoring" [85]. This paper presented a binary classification algorithm to distinguish fall events from other activities detailing the different signal processing approaches for microDoppler signatures: Fourier Transform, bi-linear time-frequency transforms, and wavelets.

This work was started with the recruitment of Mr Aman Shrestha (Oct 2016 - estimated completion date Oct 2020) as PhD student to work on "Radar microDoppler for healthcare applications". The work started with an Ancortek 580B monostatic radar operating at 5.8 GHz, with a 400 MHz bandwidth, a transmitted power of 19 dBm, 2 Yagi Uda antennas with a beamwidth in azimuth and elevation of 24deg with a gain of 17dBi. We started with discrete activities meaning that the subject would perform a specific activity in front of the radar and stop. There would only be one activity captured per file. The analysis of human activity recognition started from the microDoppler data representation domain from which handcrafted features were extracted for using statistical learning for classification.

In April 2017, we recruited another PhD student Mr Haobo Li to work on "Wearable devices and radar for human activities monitoring and classification". This PhD started with inertial motion units for activity classification and then quickly evolved to the fusion of sensing modalities for HAR [74].

After understanding the use of temporal connection in speech recognition for natural speech recognition, we recruited another PhD student Mr Charalampos Loukas to work on "Activities of Daily Life (ADL) classification in multi-occupancy scenarios with radar and deep learning" and veered further into assisted living. This PhD was supposed to develop algorithm exploiting discrete activities of daily living at first with Long-Short Term Memory (LSTM) [161] in different radar data domains, namely, raw data, range-time, spectrograms to activities of daily living. We enlisted the help of Dr Shufan Yang for more rigour with regard to machine learning algorithm. Our initial results on raw radar in-phase and in-quadrature (I&Q data) and range data [81] on binary classification data. This activity was moving on multi-class classification when the student left to do another PhD in electrical engineering in a competing university.

Since 2018, the activity developed with the help of undergraduate students working on the measured data that was released publicly in 2019 [162] and the two PhD students by continuing the development of multiclass, continuous, multidomain, multimodal classification algorithms for HAR.

In 2018, we started advising a PhD student Chuanwei Ding (2018-2020) in "Human Motion Recognition Theory and Technologies Based on Non-contact Bio-Radar" from Nanjing University of Science and Technology with Prof. Hong Hong for which we advised on continuous activity classification [163] and also on inattentive Driving Behaviour [164]. It consisted in a "dynamic range-Doppler trajectory (DRDT) method (Figure 32) based on the frequency-modulated continuous-wave (FMCW) radar system starting the exploitation of multidomain information for discrete activities and continuous activity classification.

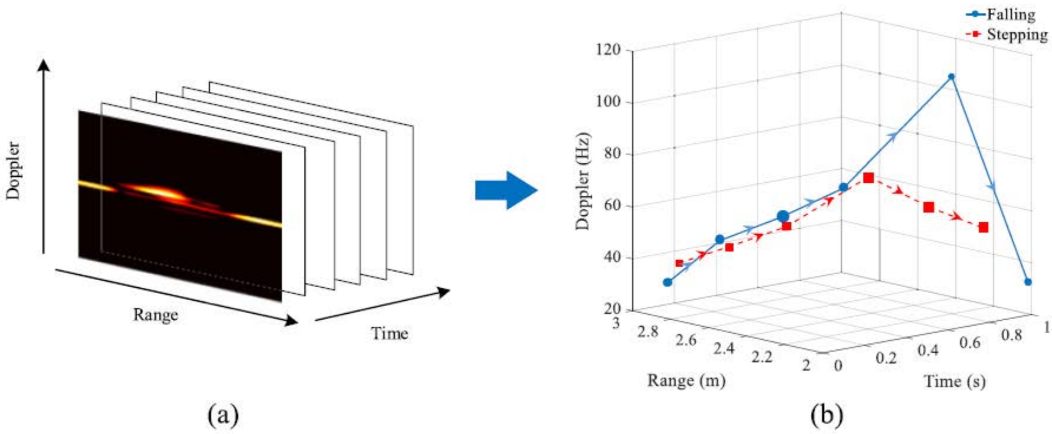


Figure 32: Illustration of DRDT processing. (a) Conventional range-Doppler frames. (b) DRDT of falling and stepping.[94, 163, 164]

In 2018, Yier Lin's work on s-band radar signatures [165] gave rise to further ideas using ideas derived from machine vision to extract geometric features from spectrogram images [166] resulting in over 90% accuracy with statistical learning.

The multidomain approach is booming since 2018-2019 and our review on the subject in signal processing magazine [93] alongside with Sevgi Gurbuz's piece in the same issue [167] set the tone for both supervised and unsupervised learning, respectively.

Historically, human activity recognition was viewed from the perspective of microDoppler signatures [168] as this was easily accessible with affordable RF equipment or a CW radar. Nowadays with the advent of automotive radar has significantly reduced the price of radar technology with enough instantaneous bandwidth for the range information to be exploited and much more as shown in Figure 33.

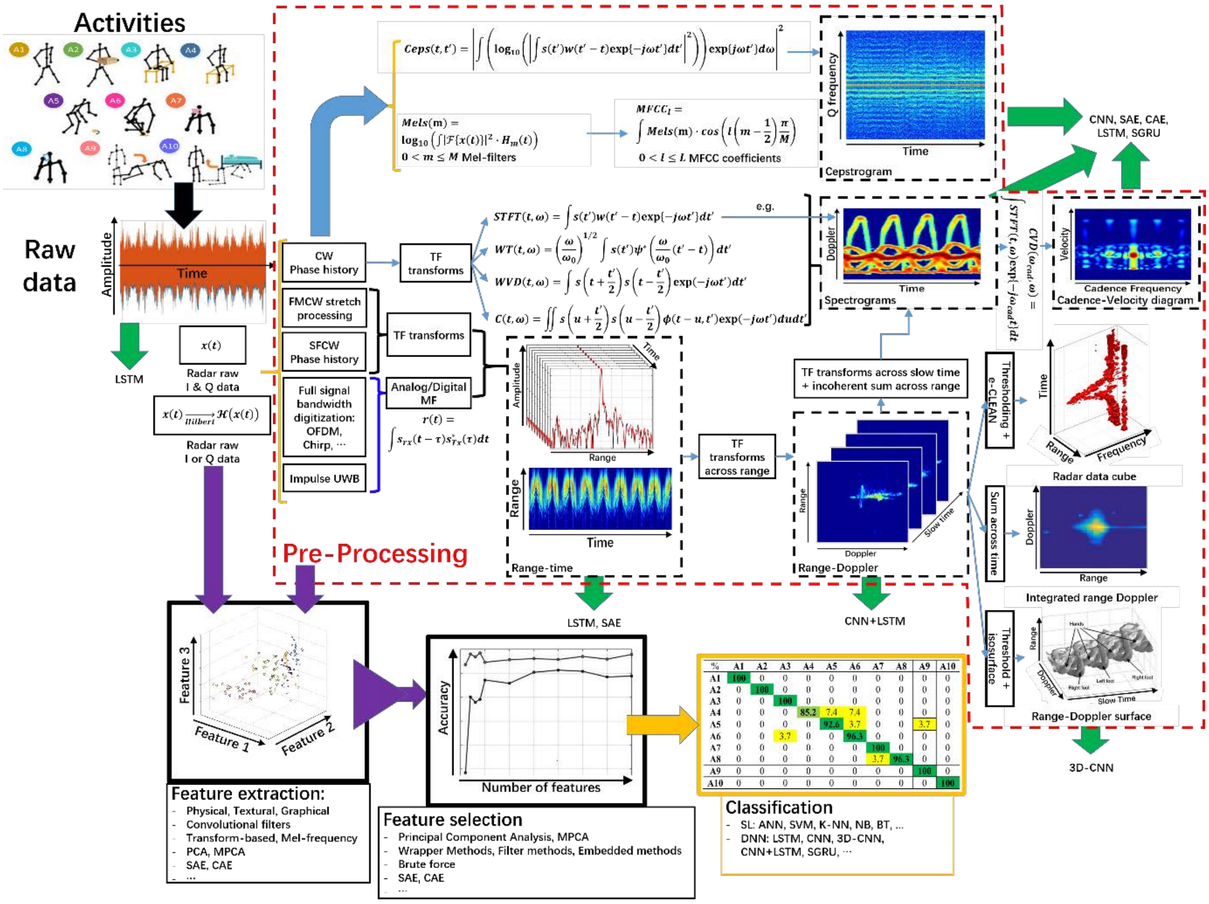


Figure 33: the different radar data domains and associated pre-processing operations

In Glasgow, we have been building a "large" (in radar terms 1000s of signatures) database that we published openly in 2019 with a companion article in IET electronic letters [162, 169]. The idea was to stimulate the field of radar-based classification like the release of open data for synthetic aperture radar images did in the 90s by ESA. The idea is to provide the raw material for research groups to develop algorithms for pre-processing and classification based on a common dataset which can therefore be benchmarked. This is the idea of the radar challenge organised for IET radar conference 2020 (http://www.ietradar.org/page.asp?id=202) and the associated leader board (https://humanactivitiyclassificationwithradar.grand-challenge.org/). We were the first to release an open dataset that was quickly followed by http://dop-net.com/ for human gestures.

In 2018, I started working on the training of Chang Shu (2018–2021) and Jiaqi Guo (2018–2021) on radar-based activity classification with the objective to tackle composite representation of range Doppler surfaces after I saw the article of [170] on simulated data based on the work in [171]. It works from a succession of Range-Doppler images treated as frames. Using a 2D- constant false alarm filter, the "target contributions" are extracted using a threshold the rest being considered noise to extract a range-Doppler surface. The 3D surface is much too voluminous for a machine learning algorithm and would result in much computation. It is therefore down sampled using Pointnet [172] to turn the surface in a point cloud before feeding it in a 3D classification algorithm. We adapted the technique to measured data which is noisy, imperfect and signatures of young and old people. Furthermore, we added the concept of using phase as a source of information for classification. We had noticed that 99% of the algorithms were using amplitude only for classification as most algorithms exploit images represented as amplitudes as they are much easier to interpret visually. However, the phase is very valuable as well. Phase was exploited using convolutional neural network for automated feature extraction as it is much harder to use handcrafted features using deep fusion [173] before classification for enhanced accuracy [174].

In 2019, I recruited Zhenghui Li to work on "Deep learning for multidomain radar-based continuous human activity recognition for multiple targets" supervised alongside Prof Muhammad Imran and Dr Shufan Yang and B.Eng. students, namely, Jia Mu (2019 – 2020), Xingzhuo Li (2019 – 2020), and Shaoxuan Li (2019 – 2020) to push forward the exploitation of multidomain. Where in 2016, we mainly focused on microDoppler signatures, now we exploit mainly range-time, range-Doppler, microDoppler, cadence velocity diagram and composite views from which we extract features and design feature-level and decision-level fusion alongside feature selection to maximize performances [175-178].

In parallel, the work from Aman Shrestha and Haobo Li have evolved to multimodal (radar, IMU, magnetic), exploiting different radar data domains and the classification of continuous data streams with the development of Bidirectional long short-term memory (LSTM) techniques for which we looked at optimising the classification and concluded a suboptimal initial learning rate can be as harmful to the classification accuracy as using a less suitable architecture or input domain [163]. In [89], the benefit of Bi-LSTM is studied against a sliding window using statistical learning for the classification of continuous data streams. This parametric study looked first at the effect of overlapping, the length of the sliding window of the spectrograms and Inertial Motion Unit (IMU) data (wrist, waist, ankle) on the classification accuracy. Generally, it appears that the classification accuracy is proportional to the overlapping factor, and the optimal point is typically with a medium-sized window. The best performance 89.8% was obtained with 3.5s sliding window, 90% overlap, with the feature-level fusion of radar and wrist IMU. A sequential backward selection is used to increase the performance to 92.9% by removing redundant features. The bi-LSTM framework and the proposed fusion schemes (soft, hard, and hybrid with a Naïve Bayes Combiner) were validated on data from FMCW radar and wearable sensors, corresponding to sequences of six human activities performed by 16 participants. Leave one person out validation approach was followed throughout, to demonstrate the approaches' performances when dealing with data of subjects "unknown to the classifier." The proposed hybrid approach is shown to yield an average classification accuracy of approximately 96% while improving performances and robustness across all participants (an increase of minimum value accuracy and a reduction of standard deviation).

Since the use of fixed threshold was limiting in performance as per the work of Jiaqi Guo and Chang Shu (2018-2021), Yan Peng (2020-2021) continued was working on developing adaptive thresholding methods to identify regions of interest in spectrograms. Furthermore, the realisation that closed sets would be limiting to the performances of a classifier, Xinyu Zhang (2020-2021) worked on methods to work on an open dataset to identify the activities of interest from a multitude of activities which was realised using a hybrid method including the phase and amplitude information form the spectrograms [179] reaching 86% accuracy using pretrained CNN algorithms. Zhenghui Li (2019 – to date) continued the work on the development of adaptive thresholding for classification [180] to isolate regions of interest and applied those on the spectrogram to extract features achieved 91.9% accuracy with a quadratic SVM. This also resulted in with further work on a patent application [180] in 2021 with the collaboration of Dr Shufan Yang, Dr Qammer Abbasi, Dr Francesco Fioranelli, Prof. Olivier Romain on the fusion of radar data domain in amplitude and phase with adaptive thresholding.

In 2019, I met Prof Antonio Napolitano (2019-to date) who is an expert in signal processing but more specifically cyclostationarity on which he wrote 2 books [181, 182]. Cyclostationary processes are normally used to recognise modulation in communication signals based on their statistical properties and the question arose from the observation that a human activity modulates the backscattered radar signal. So, could cyclostationary processes also help distinguish human activities from one another? We started to train 3 students Zhouyixian Li, Jipeng Li and Yaxin Du (2020-2022) and Ran Yu (2021 – to date) joined later to work on human activity recognition using cyclostationarity. Our initial results using handcrafted features and on our open dataset as shown up to 95.4% accuracy using real and imaginary handcrafted features on 13 cyclic frequencies [183].

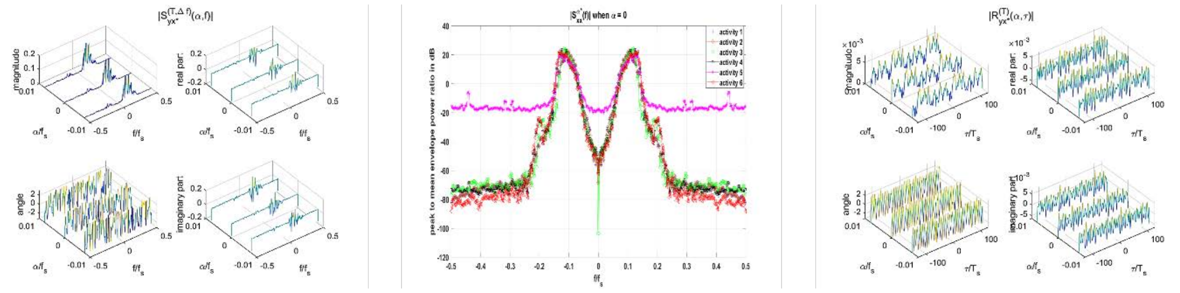


Figure 34: left) Estimated cyclic cross-spectrum for activity 1, middle) Comparison when α = 0 of the magnitude of the cyclic spectrum (with no conjugation) for 6 activities, right) Estimated cyclic cross-correlation for activity 1 [183]

We are continuing this work using deep learning methods such as transformers, principal component analysis and complex/multichannel CNN and variations of the cyclostationary pre-processing to boost the performances. Ran Yu (2021 – to date) will continue this project looking at the effect of different denoising approaches coupled with pre-processing of cyclostationary data to enhance the classification accuracy. Ruoyun Cheng (2022 – to date) will apply cyclostationarity and radon transform [184] to create specific patterns for data association in multi-subject radar recordings to ensure that the activities being monitored are associated to the right subject.

Haotian Xiang (2021-2022) worked on the adaptation of transformers in [185] to the open dataset of human radar signatures. The model was adapted to the change of input and to accept real and imaginary data as well as range-time and Doppler time data as to just I&Q raw data. The highest results were obtained using range-time data with 100% data with a reduced dataset as opposed to 86% with raw data. This suggests an overfitting in the network which will need to be revised for further development. Shiyuan Liu (2021-2022) worked on the reconstruction methods from compressed data to estimate the time of flight in a sonar application to map an oil well. This work is looking at orthogonal matching pursuit [186], compressive sensing matching pursuit [187], iterative shrinkage-thresholding algorithm [188], smoothed L_0-norm algorithm [189] and comparing the reconstruction error with against the computational time and the compression ratio. It was found that the orthogonal matching pursuit was the best trade-off as for similar reconstruction error provided much faster computational time. This work was running alongside Sun Weirong's (2020-to date) PhD project on "a robust high-resolution technology based on data compression" co-supervised with Prof. Muhammad Imran and Prof Yi Zhang of data and reconstruction applied to radar signature compression and classification for assisted living which is currently ongoing on static problems of beam pattern reconstruction and array antenna fault analysis before moving to dynamic reconstruction of data using tensor CUR algorithms [190]. Penzhao Liu (2022 – to date) will work on compression and denoising to enhance the classification accuracy in human radar signatures following the work of Shiyuan Liu (2021-2023) and in support of Sun Weirong's work.

Jiuchuan Zhang (2022 – to date) will work on the enhancement of pre-processing looking at different frequency transforms based on wavelet that will be advised jointly with Dr Rebecca Killick who is an expert in statistics and change detection to enhance classification accuracy compared to classic FFT-based pre-processing techniques. Hengxu Gong (2022- to date) will work on automatic detection methods to further advance the adaptive methods to isolate regions of interests from various radar data domains and determine their effects on classification accuracy.

Shaowen Ma (2022-to date) and Junyu Zhou (2022 – to date) will work on validating simulated data against measured data for realism and gauging the accuracy of methods to extract gait parameters from radar data using Motion capture as a reference and simulating the whole processing chain for a 4D radar based on motion capture data to be compared with our 24GHz Demorad platform from Analog Devices.

5.2.6 Platform development

5.2.6.1 Publications

International Journal/Magazine

1. Iloga, S., Bordat, A., Le Kernec, J. and Romain, O. (2021) Human Activity Recognition based on acceleration data from smartphones using HMMs. IEEE Access, 9, pp. 139336-139351. (doi: 10.1109/ACCESS.2021.3117336)

Conference Proceedings

1. Bordat, A., Dobias, P., Le Kernec, J., Guyard, D. and Romain, O. (2022) Towards Real-Time Implementation for the Pre-Processing of Radar-Based Human Activity Recognition. In: 2022 IEEE 31st International Symposium on Industrial Electronics (ISIE), Anchorage, AK, USA, 01-03 Jun 2022.

5.2.6.2 Contributors

Staff:

- Prof. Olivier Romain – CYU (2016 – to date)
- Dr. Francesco Fioranelli – UoG/TUD (2016 – to date)
- Dr Kayode Onireti – UoG (2021 – to date)
- Dr Wasim Ahmad – UoG (2021 – to date)
- Dr Qammer Abbasi – UoG (2020 – to date)
- Dr Hasan Abbas – UoG (2022 – to date)
- Dr Daniyal Haider – CYU (2019-2020)
- Dr David Guyard – Blulinea (2020 – to date)
- Dr Sylvain Iloga – University of Maroua (2018 – to date)

PhD students:

- Alexandre Bordat – CYU/Bluelinea (2020 – to date)
- Abdullah Akaydin – UoG (2021 – to date)
- Claire Beranger – CYU/Bluelinea (2022 – to date)
- Mostafa Elsayed – UoG (2022 – to date)

Undergraduate and Postgraduate students:

- Yunsong Zhang - UESTC/UoG (2019-2020) – B.Eng EEE
- Linfeng He - UESTC/UoG (2020-2021) – B.Eng EEE

5.2.6.3 Contributions

This platform development in the strand radar in assisted living is relatively new with respect to custom-built approaches. This stems from the simulation work on interferometric radar [140, 147, 152], experience with various components off the shelf and a desire to have bespoke platforms for radar in assisted living. This work started when we hired Dr Daniyal Haider (2019-2020) as a postdoctoral researcher at CYU to adapt the pre-processing algorithms from MATLAB to C++ on GPU platforms with Prof Olivier romain (2016 – to date). This work unfortunately did not come to fruition as the postdoc left for another position in the UK shortly after starting. Yunsong Zhang (2019-2020) and Linfeng He (2020-2021) worked on the adaptation of the cantenna radar [4] to be an interferometric radar for human activity recognition the work started in 2019 was interrupted by covid for Yunsong who finished the design work but could not get access to the lab to build the radar and Linfeng did the analysis of the performance of the radar using Simulink for the same reasons. This will be resumed once we can fly back to the campus in Chengdu with undergraduate students.

The work restarted with Alexandre Bordat (2020-to date) at ENSEA/CYU when he started his internship for his engineering degree and was then hired as an engineer on the project for 6 months before starting his PhD in 2021 with Bluelinea and CYU supervised by Prof Olivier Romain (2016 – to date) and Dr David Guyard (2020 – to date). The subject "Early estimation of signs of biomechanical failures by unconventional radar imaging. Applications to the robust prediction of falls in the elderly" consists in porting the pre-processing algorithm from MATLAB to GPU to FPGA for real-time processing of data streams from the radar platform towards in-home deployment. In [191], we have demonstrated the use of hidden Markov models to classify activities in a continuous data stream outperforming state-of-the-art techniques with 0.14% to 13.45% improvement in accuracy and the implementation implications in terms of power consumption, the number of operations required and the computational time based on human activity data captured by a mobile phone demonstrating it could be deployed on an Nvidia Jetson TX2 GPU. In [192], the implementation of the signal pre-processing chain from an FMCW radar Ancortek 980AD2 with 2 receiver channels with a carrier frequency of 9.8 GHz and 400 MHz bandwidth could be processed in 4.8 s for 10 s of recorded data on a Jetson Xavier card by parallelising the processing on the CPUs and GPUs available. This is the first intermediate step before an FPGA implementation by porting the MATLAB code in C and leveraging the parallelisation on GPUs and the optimisation of FFT processing with the FFTW3 libraries. Claire Beranger (2022-to date) started in June and will work on "the gait recognition and fall prediction with deep learning on microDoppler signatures". She will work on the embedded implementation of the classification algorithms following the work of Alexandre Bordat (2020- to date). This thesis is also in collaboration with Bluelinea and Prof. Olivier Romain (2016-to date). Prof Olivier Romain expertise in matching architectures with algorithms and Dr. David Guyard expertise in technology for the silver economy will bring us closer to in-home deployment for in-situ testing. In 2021, we also quantified the computational power requirements {Iloga, 2021 #1421} of a human activity recognition in a continuous data stream using Hidden Markov Models led by Sylvain Iloga using accelerometer data.

In UoG, Abdullah Akaydin (2021 – to date) is "working on the development of an Indoor Navigation System for Visually Impaired by Using Radar" and is co-supervised by Dr Wasim Ahmad who specialises in signal processing, navigation and assisted living, and Dr Kayode Onireti who specialises in 5G, propagation and channel modelling. This will be based on radar ego motion to create submaps which will help the visually impaired person to navigate the building. A 4D radar is being used to develop the platform and adapting automotive signal processing to indoor navigation. Mostafa Elsayed (2022 – to date) just started his PhD on "Enhancement of Weak Signal Detection in Radar Systems" co-supervised by Dr Qammer Abbasi who specialises in 5G, RF technology and propagation and Dr Hasan Abbas who specialises in RF platforms, plasmonics, and THz technology. Mostafa will design a bespoke platform for human activity recognition and vital signs monitoring that will adapt its processing based on the situation and switch from human activity classification to vital signs monitoring based on what it is sensing.

The field of radar in assisted living is booming worldwide due to an ageing population and finds broader applications in indoor monitoring, marketing (emotion recognition), surveillance which will continue to drive developments not only in this discipline but can be transposed to other research areas such a drone detection mentioned earlier following the discussion of implementations with digital radar but it also finds its way in more unusual spin-offs with animal welfare as this is using the same core technology as human for assisted living but with a twist.

5.3 Animal lameness

5.3.1 Context

Lameness is a very significant problem for farmed animals and performance horses. It has a negative impact on animal welfare and economically, both in terms of lost production and treatment costs. In dairy cattle, lameness is widely regarded as a major welfare problem. Difficulties with early identification of lameness in dairy cattle is a well-recognized issue [193]. Overall economic losses resulting from lameness have been estimated to be around $75 per cow per year [194]. The true extent of lameness in the UK dairy herds is unknown, but the herd level incidence has been estimated at 50 limb cases per 100 cows-years [195]. Sheep farmers are faced with a similar problem, with prevalence as high as 10% of the flock [196] and an estimated cost to the UK sheep industry of £24 million, for the most common cause of lameness in sheep [197]. For horses, the most frequent disease syndrome recorded in the UK in the 2016 was lameness, accounting for 33% of the reported issues [198].

The most common form of lameness identification is by subjective scoring method. While subjective gait assessment methods provide an immediate, on-site recognition and require no technical equipment, they show variation in reliability and repeatability of and between observers [199, 200]. More objective kinetic and kinematic methods to identify both lameness and limb abnormalities have been studied, such as force plate systems, 3D-accelerometers, infrared thermography and tracking mixed with modelling from vision-based and optoelectronic systems; these show promise when compared with more traditional methods [201, 202].

In this context, radar sensing can potentially enable contactless and automatic detection of lameness, with no additional sensors attached to the body of the animals under test, and sensing capabilities provided in any weather or lighting conditions, including outdoor farm environments. Extensive literature exists on the use of radar signatures to analyse human gait and activities in the assisted living context and security/surveillance [203, 204]. However, there is very limited work on radar for lameness detection of animals, to the best of our knowledge (with the exception of a few papers where the signature of quadrupeds is treated as a potential "confuser" for human detection [205, 206]). In this paper, we expand the preliminary results on our previous work [207] by providing an initial validation of the use of radar sensing to detect lameness in dairy cows, sheep, and horses. Experimental data were collected at the facilities of the Veterinary School at the University of Glasgow and analysed with techniques inspired from radar automatic target recognition (microDoppler signatures, feature extraction and supervised learning for classification). Promising results were achieved using very simple features (mean and standard deviation of the center of mass and bandwidth of the microDoppler signatures) and classifiers (such as SVM, Support Vector Machine, and KNN, K Nearest Neighbour), with 85% accuracy obtained for dairy cows, approximately 92% for horses, and 99% for sheep. The choice of features appears to have greater impact than the classifier, as similar accuracy is achieved with the same combinations of features for SVM and KNN. We now work on the evaluation of the reliability of the labelling for machine learning purposes in farm animals to ensure that the trained algorithms are learning from credible information and not from erroneous labels caused by subjectivity [208].

5.3.2 Horse Lameness

5.3.2.1 Publications

Journal articles:

1. Shrestha, A., Loukas, C., Le Kernec, J., Fioranelli, F., Busin, V., Jonsson, N., King, G., Tomlinson, M., Viora, L. and Voute, L. (2018) Animal lameness detection with radar sensing. IEEE Geoscience and Remote Sensing Letters, 15(8), pp. 1189-1193. (doi: 10.1109/LGRS.2018.2832650)

Conference Proceedings:

1. Shrestha, A., Le Kernec, J., Fioranelli, F., Marshall, J.F. and Voute, L. (2018) Gait Analysis of Horses for Lameness Detection with Radar Sensors. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0427)

5.3.2.2 Contributors

Staff:

- Dr Lance Voute – UoG (2016-2019)
- Dr John F. Marshall – UoG (2016-2018)
- Dr Francesco Fioranelli – UoG/TUD (2016 – 2019)

PhD students

- Dr Aman Shrestha – UoG (2016 – 2019)
- Dr Haobo Li – UoG (2017 – 2019)

5.3.2.3 Contributions

We have performed measurements on horses in Glasgow Weipers Equine hospital (x2), 2 private horse yards in Glasgow (x20) and the Warwickshire Moreton Morrell College (x14). We have collected a number of samples of lame and sound horses. Two scenarios were considered horses on a treadmill to optimize performances without the groom and groom-led straight-line test on a hard floor for a more realistic racetrack or training ground scenario.

We have done so with a gold standard on lameness detection – Equinosis [207, 209]. This apparatus measures acceleration on 3 locations on the horse (see Figure 35- the head, pelvis and right forehoof). This delivers a report on the “likely” problems with impact lameness or lameness as well as locating the leg (right/left hind, right/left fore). This technique suffers from synchronisation problems with the computer that collects the data even if this is a commercial product i.e. it does not always produce data. Furthermore, in Glasgow, a veterinarian accompanied us to assess the horses with a straight-line test as well to ensure the ground truth was reliable or not. The Equinosis system does not always provide the same result for successive tests on the same horse. Veterinarians’ subjective assessment is in line with the Equinosis system regarding the lameness classification (0 ((sound), 1 (inconsistent whatever circumstances), 2 (inconsistent/consistent depending on circumstances) ,3 (consistent) ,4 (lame at walk), 5 (non-weight bearing)). However, for the location of the lameness some concertation was needed to determine whether the machine was correct, or the veterinarian was needed. The conclusion is that we can reliably assume the lameness level from Equinosis but not necessarily the location of the lameness. This would normally require further tests for lameness assessment both with Equinosis and the veterinarian to ascertain the lameness level and location but due to limited resources, these were not conducted. They will be necessary however for the development of a more refined version. The horses, we worked with, only had lameness levels from 0 to 3. Levels 4 and 5 are usually obvious to professional staff and veterinarians and would not require use of a detection system.

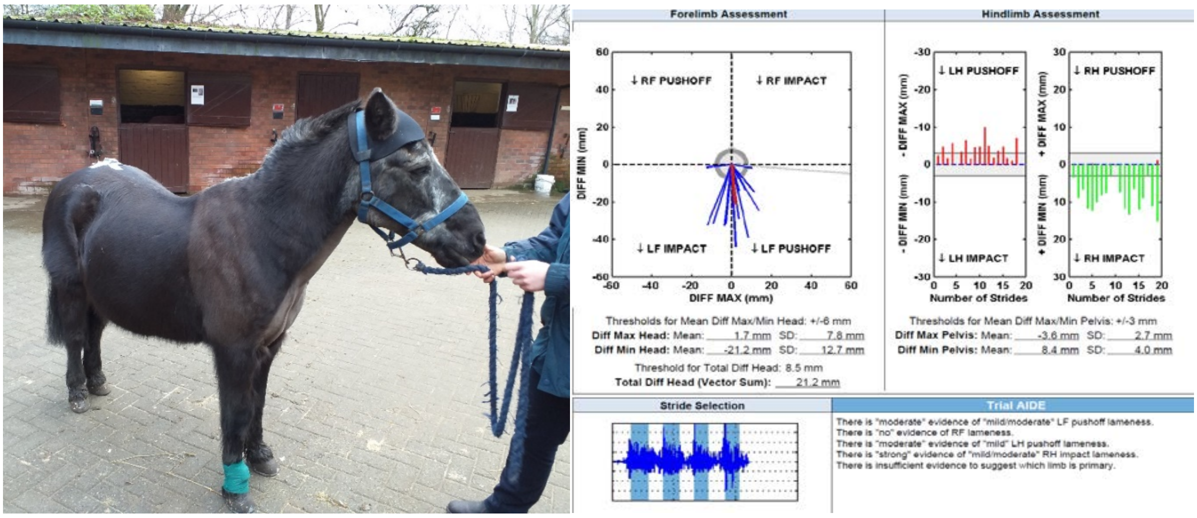


Figure 35: left) Horse equipped with Equinosis lameness detection system at one of the Glasgow private horse yards in January 2019. Right) example of the report given by the Equinosis system.

Figure 36: Radar equipment (Frequency Modulated Continuous Wave Radar) operated from a laptop for a straight-line test on hard surface in outside environment.

The data collected with radar (Figure 36) consisted of the straight-line test on a hard surface or on a treadmill (Figure 3). From the data collected, we used the process described in Figure 4.

Figure 37: left) straight-line test on hard surface, right) straight-line test on a treadmill at Moreton College (from [ITV.com](ITV.com))

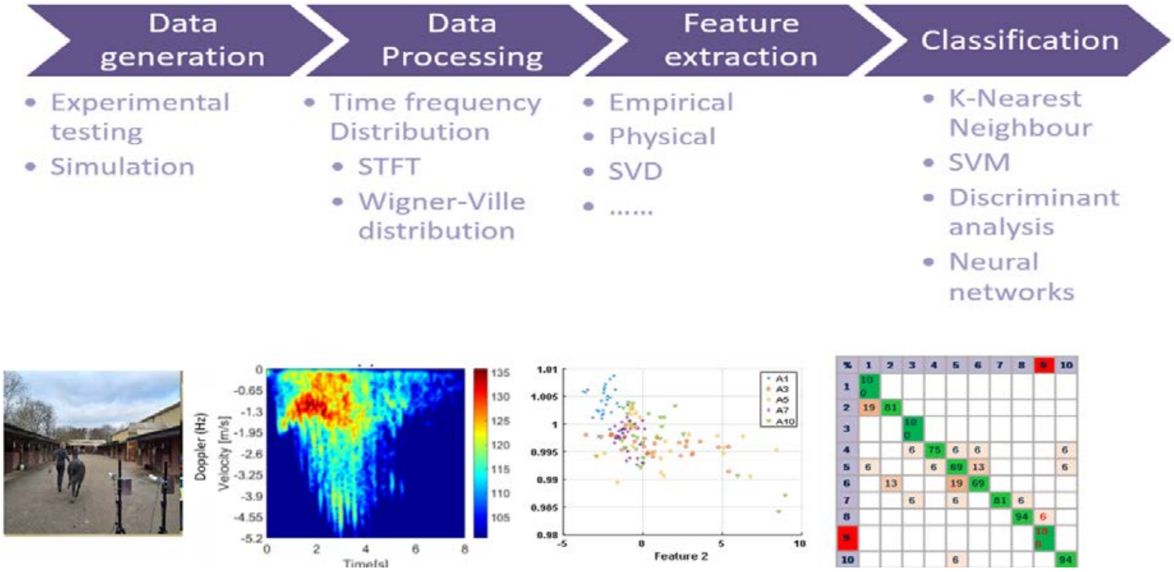


Figure 38: Signal processing chain for radar – 1st data collection using radar experimental setup or simulations – 2nd Data processing to obtain a spectrogram (Doppler/Speed against time graph) – 3rd feature extraction to get information from the processed data: centroid (centre of mass), Doppler bandwidth (spread), intensity, …) – 4th classification using machine learning to separate the samples in to classes.

The analysis of the classification data looking at a binary system lame vs sound horses shows that looking at a horse on a treadmill is much more reliable (10-20% higher) than on a hard surface in an outside environment. This conclusion is consistent for a range of parameter variations in the signal processing chain e.g., Figure 5.

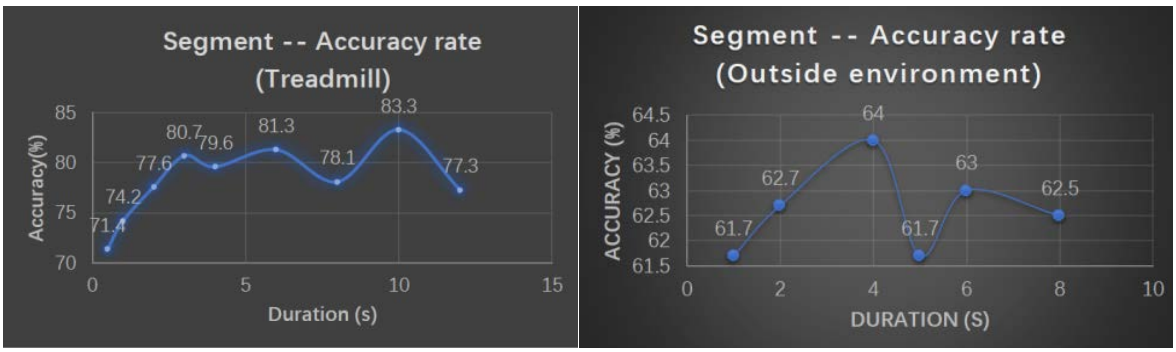


Figure 5: left) Classification results on a treadmill, right) classification results on a hard surface outside – for a variation on the length of the spectrogram segment for parameter extraction.

The issue with this conclusion is that a horse must be trained to run on a treadmill and treadmill availability is limited. This is an interesting result, but this is not feasible for what we are attempting to develop. Tweaking the parameters on a treadmill, we found that using a Cubic Kernel for Support Vector Machine Classifier, Length of Fourier Transform 2s, and overlap in data for spectrogram generation 50% using 4 parameters centroid (mean, standard deviation), and Bandwidth (mean and standard deviation), the classification accuracy reaches 91.3%.

Following the same process for horse data measured outdoors, we tried to adjust the number of features (2 to 4), the window length (0.2s to 2s) and the overlap factor (30% to 95%). We have found that a Quadratic Support Vector Machine using all four features with a window length of 2 s, and 50% accuracy could reach 89.8% accuracy. This has shown that higher overlap leading to smoother spectrograms from a visual standpoint are not suitable for good classification results. It is harder to recognise patterns visually, but the machine performs better. The reason why those signatures are harder to classify comes from the fact that horses need to be led by a groom and his/her radar signatures is entangled in the horse's signatures.

Dr Francesco Fioranelli (2016-2019), Aman Shrestha (2016-2019) and Haobo Li (2017-2019) worked on the algorithm development, feature extraction and classification as well as data collection. The equine vet surgeons Dr Lance Voute (2016-2019) and Dr John Marshall (2016-2018) were our experts in equine health who helped with data collection and assessing the lameness level (0-5) visually and using the Equinosis system.

The horse lameness work led to wider discussions within the veterinary school which started our work on cow lameness. The activity of horse lameness is currently on hold.

5.3.3 Cow Lameness

5.3.3.1 Publications

Journal articles:

1. Busin, V., Viora, L., King, G., Tomlinson, M., Le Kernec, J., Jonsson, N. and Fioranelli, F. (2019) Evaluation of lameness detection using radar sensing in ruminants. Veterinary Record, 185(18), 572. (doi: 10.1136/vr.105407) (PMID:31554712)
2. Shrestha, A., Loukas, C., Le Kernec, J., Fioranelli, F., Busin, V., Jonsson, N., King, G., Tomlinson, M., Viora, L. and Voute, L. (2018) Animal lameness detection with radar sensing. IEEE Geoscience and Remote Sensing Letters, 15(8), pp. 1189-1193. (doi: 10.1109/LGRS.2018.2832650)

Conference Proceedings

1. Linardopoulou, K., Viora, L., Fioranelli, F., Le Kernec, J., Abbasi, Q., King, G. and Jonsson, N. (2022) Time-series Observations of Cattle Mobility: Accurate Label Assignment from Multiple Assessors, and Association with Lesions Detected in the Feet. In: 31st World Buiatrics Congress, Madrid, Spain, 04-08 Sep 2022.
2. Linardopoulou, K., Viora, L., Abbasi, Q. H., Fioranelli, F., Le Kernec, J. and Jonsson, N. (2020) Lameness Detection in Dairy Cows: Evaluation of the Agreement and Repeatability of Mobility Scoring. 74th Annual AVTRW Conference, 14-15 Sept 2020.
3. Busin, V., Viora, L., King, G., Tomlinson, M., Le Kernec, J., Jonsson, N. N. and Fioranelli, F. (2019) Radar Sensing as a Novel Tool to Detect Lameness in Sheep. Ontario Small Ruminant Veterinary Conference, Ontario, Canada, 17-19 June 2019.
4. Fioranelli, F., Li, H., Le Kernec, J., Busin, V., Jonsson, N., King, G., Tomlinson, M. and Viora, L. (2019) Radar-based Evaluation of Lameness Detection in Ruminants: Preliminary Results. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777830)

5.3.3.2 Contributors

Staff

- Prof. Nicholas Jonsson – UoG (2017 – to date)

- Dr Lorenzo Viora – UoG (2017 – to date)
- Dr George King – UoG (2017 – to date)
- Dr Francesco Fioranelli – UoG/TUD (2017 – to date)
- Dr Qammer Abbasi – UoG (2019 – to date)
- Dr Valeir Busin – UoG (2016-2019)

PhD students

- Dr Aman Shrestha – UoG (2016 – 2019)
- Dr Haobo Li – UoG (2017 – 2019)
- Konstantina Linardopoulou (2020 – to date)
- Zhenghui Li (2019 – to date)

Undergraduate and Postgraduate students

- Yutong Fu – UESTC/UoG (2022-2023) – B.Eng EEE
- Chong Ren – UESTC/UoG(2022-2023) – B.Eng EEE

5.3.3.3 *Contributions*

We tested our algorithms on ruminants at the Cochno teaching farm in Glasgow (Figure 39).

Figure 39: A) exit of the milking parlour, B) Sheep running race at the University of Glasgow teaching farm (Cochno)

Dr Francesco Fioranelli (2016 – to date), Dr Qammer Abbasi (2020-to date), Aman Shrestha (2016-2019) and Haobo Li (2017-2019) developed the feature extraction and classification algorithms for ruminants and contributed to the data collection. Prof Nicholas Jonsson (2016 – to date), Dr George King (2016 – to date), and Dr Lorenzo Viora (2016 – to date), Dr Valerie Busin (2016-2019) are the veterinary surgeons for ruminants who are helping with the data collection, the statistical analysis of the lameness assessments and interpretation of the results in terms of animal health.

The animals were scored from 0 to 3 with 0 being not lame and 3 being severely lame. For classification, we used animals classified as 0 as healthy samples and 1, 2 and 3 as lame. This differs slightly from veterinarian practice where scores 2 and 3 would be considered lame and 0-1 not lame. This is because the radar is fulfilling another role as a screening system so that animals presenting early signs of lameness can be detected and then assessed or monitored more closely.

We have run similar tests for cows and sheep and found that the length of spectrogram depends on the animal. The optimum length for sheep is 1.5s for 95% accuracy whereas for cows it was 3s for 83% accuracy and for horses 2s for 89.8% accuracy.

We have demonstrated that this novel lameness detection method using radar has the potential for automatic discrimination between non-lame animals and lame animals, even of mild degree (score 1). The radar signatures were captured with a commercial off-the-shelf radar sensor and two antennas, while a supervised machine learning framework was developed to classify the animals. There was minimal setting-up time for the technology (radar and antennas), which worked well within normal farm settings. Short radar segment duration (3 seconds for cattle and 1.5 seconds for sheep) provided the best results, where rapid assessment is an important feature for the application of this technology on-farm. The selection of the minimum duration, indeed, could have a substantial operational impact because the time available for the radar to observe the animals is limited by the length of the passage in which the equipment is installed (milk parlour vs sheep race).

In [209-211], the overall performance of the proposed method for lameness detection was heavily influenced by operational parameters including the temporal duration of the spectrogram segment, and the implementation of the classification algorithm, both in terms of feature extraction and selection (e.g. what characteristics of the radar signatures are more suitable to capture the presence of lameness), as well as the classifier itself (as many different classifiers exist based on the supervised learning approach discussed here). Hence, considerable variation is reported in our results for the different segment durations, features, and classifier types, evidenced by the high range of performance between the best and worst classifier. The selection of the most suitable combination of features and classification algorithms to optimise performance across a range of conditions and environments remains a research challenge.

Sensitivity (85% for cattle and 96% for sheep) and specificity (81% for cattle and 94% for sheep) estimates for this novel system are encouraging. When compared to the "gold standard" of locomotion scoring, studies in dairy cattle have shown that lameness detection based on a series of lameness indicators in tied cows or free-stall barns can provide a sensitivity of around 50% and specificity of 86 to 93%. Similarly, when compared to other automated systems, such as infra-red technologies (sensitivity 74% and specificity 68%) or force plate system (sensitivity 24-35% and specificity 85-95%), our proposed method has either comparable or higher analytical performances to other potential alternative lameness detection methods. Similarly, in sheep, the performance was considerably better than obtained using infra-red technologies (sensitivity of 83% and specificity of 78%).

This method of lameness detection has the potential to be implemented as an automatic diagnostic tool for use in "precision farming" applications. Detection of lame animals would be by continuous, contactless and labour-free monitoring by placing the radar at strategic places (e.g. gates within adjacent fields for grazing animals or passageways for indoor systems). Coupled with electronic identification of individual animals, it would enable identification of lame individuals for treatment, also enabling the efficient reporting and robotic drafting out of animals for examination and treatment. Without individual animal identification, it would enable estimation of lameness prevalence within farms, which is increasingly important to livestock producers operating under quality-assurance programmes. The radar system would be expected to be cost-effective relative to accelerometer-based approaches because it does not require instrumentation of each animal. The initial capital cost might be high, but the cost per animal will be reasonable, and integration within automatic settings (precision farming) will considerably reduce labour requirements.

It is possible that the radar-based method of assessment was already an improvement over the visual locomotion scoring, which was used as the "gold standard" in this and other studies. The availability of well-labelled data for training of the algorithm is crucial at the testing stage and significantly affects the final performance of the algorithm. This had proven to be a challenge during our study because there were occasions when the veterinarian was unable to confidently assign a lameness score. This is not unexpected, as the limitations of visual assessment are well described in the literature, even for experienced observers. These uncertain classifications can have a significant cascade influence. In particular, for cases labelled as grade 1, they could have been erroneously misclassified by the observer as mildly lame, where the signatures of individual animals within this class would be more similar to grade 0-labelled cases or grade 2-labelled cases, leading to bias in the training and resulting in further erroneous classification by the algorithm. To overcome this issue, a panel of experts could be recruited to allow for uniform classification of lameness and reducing errors in the algorithm training. Once the algorithm has been provided with well-labelled and verified data, a more objective, reliable and repeatable system would be available.

This study further confirms the importance of getting reliable ground truth in order to refine the automatic detection of lameness in horses, cattle and sheep. It also demonstrates the feasibility of using it outdoors and its rapid deployment capabilities.

Following these findings, the veterinary school awarded a PhD scholarship to recruit Konstantina Linardopoulou (2019 – to date) to work on “Lameness detection using contactless radio-frequency radar”. We worked simultaneously on sheep [212] and cows [213, 214].

But we decided to focus on cows for the purpose of the study. Konstantina has worked simultaneously on the reliability of the cow mobility scoring in dairy cows from AHDB. [214]. The results from an extensive data collection using longitudinal study where multiple visits are done at the same farm collecting video data, visual assessments, and radar data. The reliability and agreement of the method were poor to moderate, but all measures were improved by the binary transformation, which is significant for future AI study. Zhenghui Li has worked on the signal processing and classification of the radar data based on the labels provided by the veterinarians but the initial encouraging results up to 91% on 1 visit fell to 52% including all the visits confirming the findings from the Konstantina about the reliability of the labelling process which hinders supervised machine learning.

In Figure 40, it can be observed that the radar signatures are varying in terms of speed between a sound and a lame cow, but it would be interesting to see if the symmetry is also affected that could also help in distinguishing the different levels of lameness.

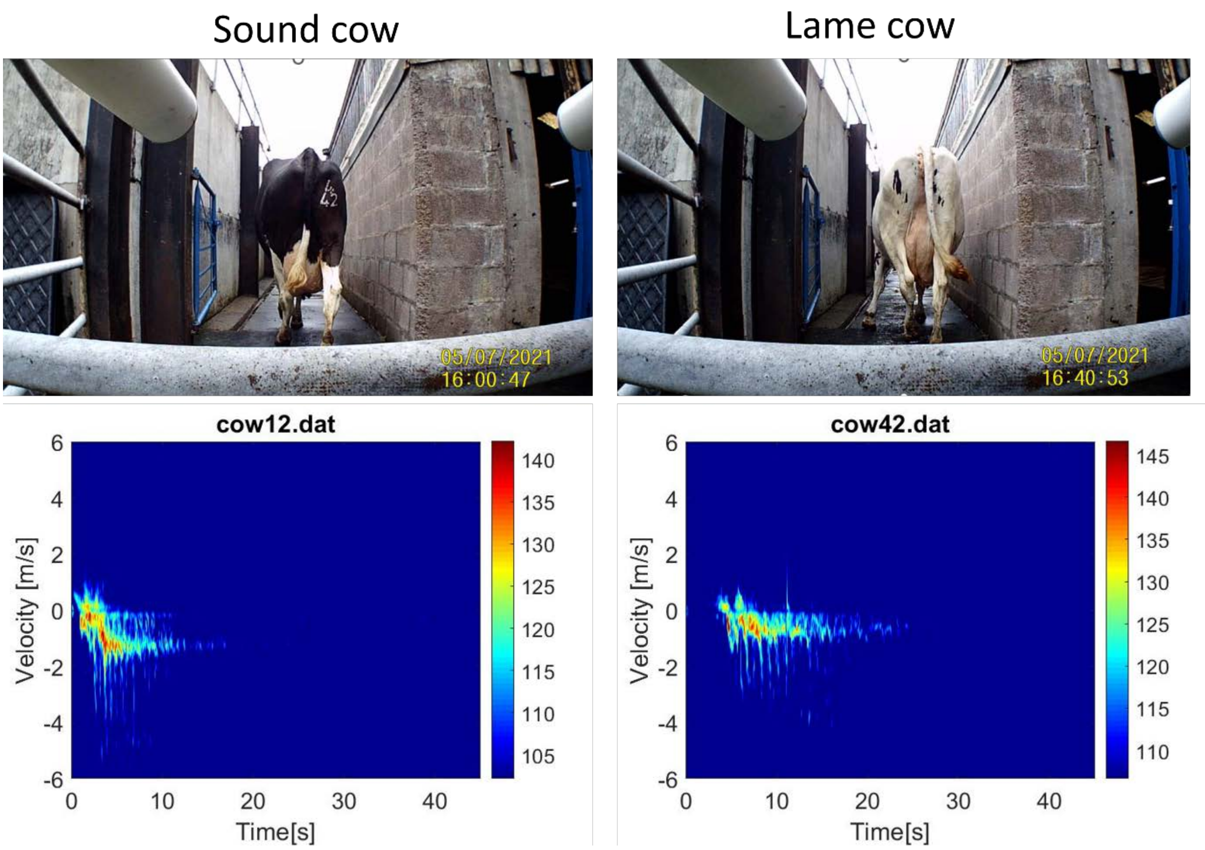


Figure 40: left) radar view of a sound cow and the associated spectrogram, right) radar view of a lame cow and the associated spectrogram.

Chong Ren (2022 – to date) will work on enhancing the pre-processing technique to extract gait parameters from the cow radar signatures automatically to study the difference between clearly identified sound and lame cows. Yutong Fu (2022 – to date) will work on unsupervised learning to understand whether the radar signatures can be organised according to the visual mobility scoring method, or the hoof trimming reports to find a correlation with the labelled data if any.

This work on animal welfare is very interesting as it challenges some of the assumptions made for radar in assisted living and there is feedback from both fields into one another progressing both at the same time. Furthermore, the requirements in animal lameness are also driving required development for bespoke platform developments.

The three research actions presented in this section on smart radar systems, radar in assisted living and radar for animal welfare are continuing and the next section will present my current vision to progress those strands.

6 Research vision

The theory and simulation are essential components in the context of identification. Indeed, understanding how radar works and the phenomenology of electromagnetic propagation will enable domain-knowledge-driven developments in elaborating future radar concepts and devise strategies for new algorithms in a cost-efficient way as well as augmenting datasets for training classification algorithms. The three-pillars of the research development simulation, algorithm, and experiment/applications are still the underlying driving thought behind the developments.

6.1 Simulations

The simulation in assisted living will need to integrate further modalities in the simulator [215]. This evolution in sensing also must be reflected in the development of future monitoring systems for in-home patient monitoring. The consequences from the perspective of radar and RF sensing are two-fold with respect to a paradigm change in radar sensing and multimodal sensing

Pervasive deployment of 5G/6G communications indoors, Wi-Fi access points, and miniature MIMO radar platforms radar opens new challenges for radar sensing. Classically radar is monostatic, new systems in millimetre wave offer miniaturized systems with multiple transmitters and multiple receivers, which allows enhancing spatial resolution beyond what the instantaneous bandwidth can offer. Despite radar units becoming more accessible, driven by the automotive industry, prototypes remain costly and usually do not fully match the application requirements. Wi-Fi and 5G access points are very good transmitters of opportunity that can be exploited for passive radar sensing. This will multiply the possible radar configurations and their diversity dramatically.

One way of testing various radar configurations in different situations would consist of simulating the environment, activities, and radar system to test its fitness for purpose as illustrated in Figure 41. Unlike experimental trials, simulation requires fewer resources in terms of equipment, manpower, and cost.

The model is configurable in terms of activity, human model, and sensor configuration. There are several kinematic models and motion-capture databases such as those described in [147, 150, 216, 217] that can be used to ensure the fidelity of the simulation to physical phenomena. With the addition of our Motion capture suite in-situ in Glasgow and its twin in Cergy-Pontoise. We will be able to expand the range of activities to suit the application requirements from human activity recognition, animal welfare to robotics, and UAV attitude simulations by capture the ground truth ourselves to simulate different sensing modalities but also to qualify the radar measurements at small to medium ranges before moving to medium to long range applications. For human activities, these can be configured to consider morphological changes and impaired movements. The radar sensing geometry or Wi-Fi or accelerometer for example can be defined within the model, considering the operating frequency, bandwidth, the transmitted signal (chirp, OFDM, 5G, etc.), the antenna beam patterns, and the placement among other possibilities. Furthermore, the realism of the simulations to obtain the raw data as you would in a radar is important to obtain a better fidelity of the expected measured performances and to expand the range of pre-processing and classification techniques available from different data representation domains and their fusion.

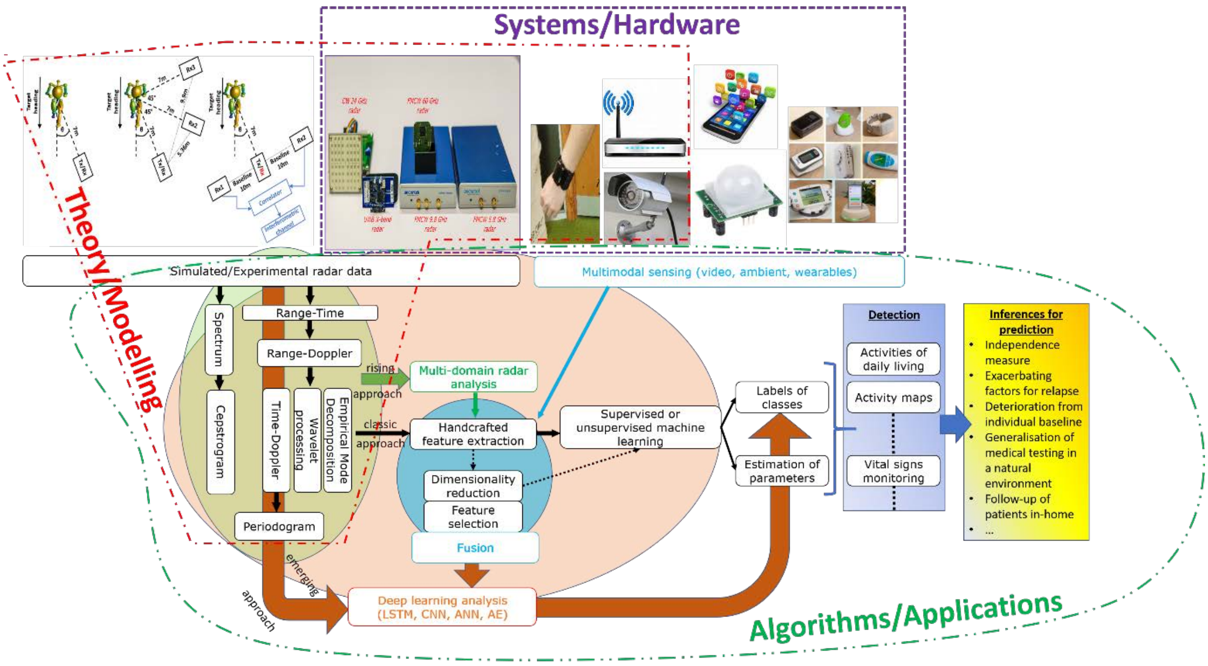


Figure 41: Radar simulation environment to design for paradigm shift.

For all the scenarios, the ground truth is available at all instants in time, which may not be possible for live experiments. By ground truth is meant the exact position from the sensor(s), trajectory, labels of the activities, and the possibility to get further sensing modalities by deriving acceleration at any point, for example. Furthermore, the simulator can be used to augment databases for limited datasets to increase performance by modifying the pace of the target and the physical traits of the human model, as well as synthetic sample generation [141, 218]. Simulations will never replace experimental measurements for validation of actual performances, but this allows dimensioning a system based on available information from limited resources. This is especially important when exploring future radar systems to develop new concepts especially when the technology does not currently exist, such as THz radar or 6G for receivers of opportunity.

In the context of assisted living, radar will become “a sensor in a suite of sensors” within the ambient space, more in general, a vulnerable subject at home. This means that other ambient sensors will be monitoring the environment of the patient, looking, for example, at thermal comfort, connected appliances with connected TVs, cooker sensors (on/off), communication devices (e.g., Wi-Fi, 5G access points), wearable sensors (smartphone, connected watches), implants for an ambient IoT environment specific to each home. As these devices will be providing different information at different data rates, their information will need to be properly fused to increase the accuracy of prediction models to infer health information.

Machine learning algorithms will need to become adaptive to consider sensors joining and leaving the ambient IoT sensing of the patient dynamically, and the need to consider diverse processing and features extraction/selection on the same sensor as the person monitored performs different activities. Furthermore, the adaptive capability will need to deal with sensors that stop working, sensors working in a synchronous or asynchronous manner, and sensors being moved, or wearables being worn or not. This changes the way algorithms are designed to predict a class of actions or estimate vital signs to infer information for prevention. Resorting to AI-driven design for the sensor placement, sensor hardware, signal processing , and classification/prediction is likely to emerge as a prevalent method given the multiplication of parameters in the same vein as demonstrated for antenna design in [219].

The work on the simulator continues as it is a valuable resource for future experiments and gives us freedom in setting different systems with different geometries [140] (bistatic, multistatic, interferometric, aspect angle), operating frequencies (S [165], C [169], X [220], Ku [96], mm wave [221]) and transmitted signals (FMCW [151], OFDM [42], MFSK [222]). Further developments will include the use of more realistic simulations by adding noise, clutter, antenna beampattern, masking of body parts depending on aspect angle for radar cross section variation [223], and electromagnetic coupling between the different body parts [224]. We plan to couple measurements with a radar with a motion capture suit in order to validate the fidelity [167] of the simulations with the experimental measurements.

The goal is to extend the functionalities of the simulator to include more realistic features (such as polarization, antenna beam pattern, waveforms) while ensuring fidelity by cross validating the concepts with measured data, when possible, to refine its realism. The added value is for the upcoming fusion of communication and sensing with 6G. The future simulator will also include different modalities that will be captured alongside a mocap and gold standard methods to progress both the realism of the simulation and steer the kinematic simulations towards the activities of interest for UAV detection and elderly care for example by driving jointly the measurements and the simulation environment.

How to obtain fidelity in simulations to develop multimodal sensing data from motion captured data while keeping the computational requirements down?

6.2 Vital signs monitoring

An extension of this work will dig deeper with vital signs monitoring. Signal processing to estimate health parameters is paramount for assisted living applications. The use of radar for vital signs monitoring has a long history as the first publications date from the 70s [225] first tested animals for breathing rate.

Vital signs are broader in sense today and include for the scope of this study gait analysis, heart and breathing rates.

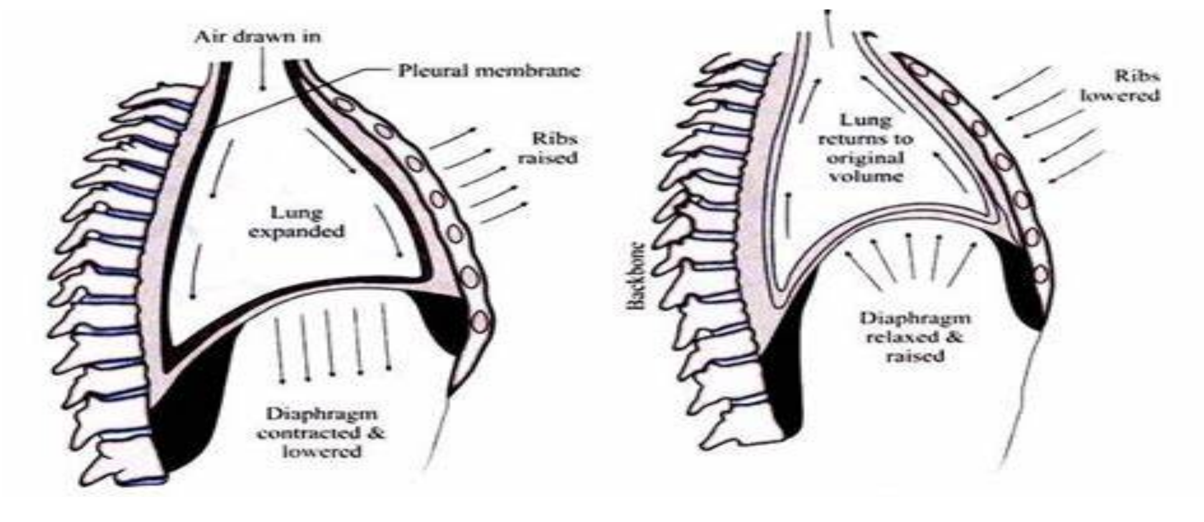


Figure 42: motion of the chest caused by the breathing process [226].

From Figure 42, we can see that when a person breathes in, the ribs are raised in all directions and the diaphragm goes down causing a swelling of the abdominal area. As the person breathes out, the ribs are lowered, and the diaphragm is raised causing the abdominal area to shrink. The displacement of the ribs and abdomen are measurable using radar and are centimetric in amplitude. The number of breath per minute for an adult at rest varies between 15 to 24 [226].

The heart a little eccentric to the left of the plexus and the apex tilts to the left as well. The heart pulses to pump blood to the body. This pulse causes a displacement of the ribs as the heart strikes the ribs and again when it retracts. This is an underlying motion that is superimposed to the breathing. The order of amplitude of the motion is millimetric. The number of heartbeats per minute for an adult at rest varies between 50-90 beats per minute [226].

Having understood the underlying physiological principles, we can now model the received signal modulated by the displacement caused by the breathing process and heartbeat. Assuming we use a Doppler radar, the received signal $R(t)$ will be modelled as shown in (1).

$$R(t) = A \cdot \cos\left(2\pi f t - \frac{4\pi d_0}{\lambda} - \frac{4\pi x(t)}{\lambda} + \theta_0 + \varphi(t)\right) \quad (1)$$

Where A is the signal amplitude, f is the signal carrier frequency and λ its associated wavelength, t is time, d_0 is the distance to the target, $x(t)$ is the displacement caused by the breathing process and heartbeat, $\varphi(t)$ is the phase noise and θ_0 is the phase offset.

The physiological motion $x(t)$ is often depicted as oscillatory signals as shown in (2) [124].

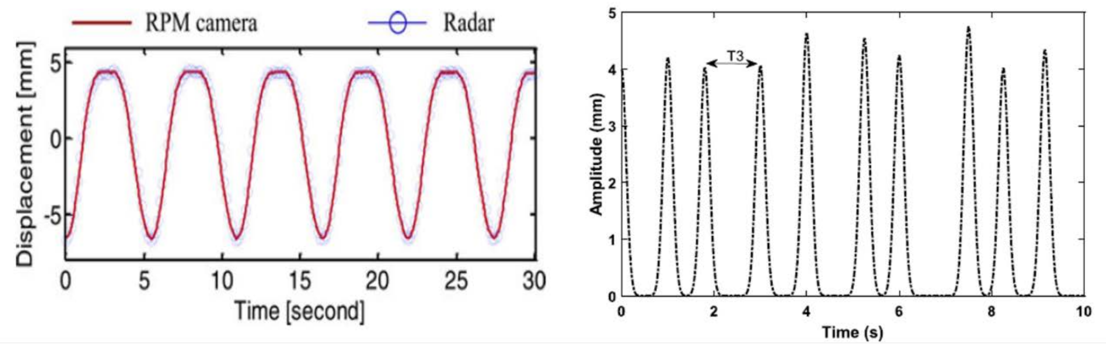
$$x(t) = m_b \cdot \sin(2\pi f_b t) + m_h \cdot \sin(2\pi f_h t) \quad (2)$$

Where m_b and m_h are the displacement amplitudes caused by breathing and heartbeat, f_b and f_h are the breathing and heartbeat frequencies, respectively.

In the literature, various techniques are used to estimate these frequencies ranging from different radar architectures to algorithmic solutions. To validate the different measurements, the ground truth is collected by respiration belts, pulse oximeter or other vital sign monitors to quantify the estimation error. This starts from spectrum estimation techniques with the classic FFT to finer estimation technique and super-resolution techniques. Dedicated algorithms and hardware for vital signs have been developed to directly extract the modulations from the received signals. Those algorithms have originally been developed for continuous-wave (CW) radar a.k.a Doppler radar but have been extended for some to UWB, FMCW and other radar architectures. The algorithms and hardware platforms from the state of the art Fast Fourier Transform [227-230], DC-coupled CW radar to improve accuracy [228, 231][176][232, 233], FMCW radar [122, 234], Super-resolution techniques [235-241][21], Arctangent demodulation [233, 242-249], Differentiate And Cross-Multiply (DACM) [249, 250], Extended DACM [246, 248], Kalman filters [221, 251, 252], Six-port interferometer [253-257], Self- and Mutual-Injection Locking [258-261][148], Complex Signal Demodulation [116] and State Space model [116, 262-265] to name a few.

The shortcomings in vital sign monitoring and applications need to be mentioned.

- The motion model for most of the designed algorithms is a sinewave for breathing and heartbeat which is inaccurate for two reasons. First, neither of the motions are sinusoidal as shown in Figure 43.



a) b)

Figure 43: a) amplitude of the displacement caused by breathing, b) amplitude of the displacement caused by the heart beating when the person is not breathing.

- Most works assume that heart rate and breathing rate are periodic, however they present variability from beat-to-beat both in breathing and the heart. Yet, the signal processing techniques mainly assume that the motions are periodic leading to imprecise reading when measuring patients' vitals. The breathing rate is usually captured accurately but the heart rate is not because it is a much smaller motion which is masked by the $3^{rd}/4^{th}$ harmonic of breathing and the inaccuracy of the model being estimated leading to errors.
- In an assisted living application, we cannot expect the person under test to always face the radar.

The orientation of the target is rarely considered and when it is front, left, right, and back only without considering the variations in the modelling of the motion. From the literature, we know that the displacement caused by the heart is much more pronounced when measuring the patient from the back or the top of their head.

- Finally, in a practical application the patients jittering during the measurement needs to be taken into account and compensated for so that the displacements caused by the jittering does not throw the measurements out or lose the signal completely as can be seen with different motion cancellation techniques in the literature [260, 261, 266-271]. Some solutions are software-based and may have limitations in that they cancel only well-defined motions or require long detection time. Some hardware-based studies presented vital signal sensors that cancel body motions by using two radars located on the opposite sides of body. Although these hardware-based random body motion (RBM) cancellation techniques can detect vital signals from a body with random motions in a particular direction, they are difficult to use practically [269]. A self and mutually injection-locked radar system using different gain antennas has also been proposed to cancel the effects of RBM from one side of a human body. However, this uses a tuneable phase shifter which must be properly adjusted according to the distance to the body being measured to cancel out symmetrical body motion artifacts [269] based on the principle of instrument amplifiers, common noise cancellation using this technique with the combination of 6 difference channels from 4 receivers. Vital signals are obtained by demodulating the phase difference signal with a weighted-sum algorithm which partially cancels random body motion. Something not often considered is that when compensating for body motion with the increased bandwidth in modern radar, range walk is likely to occur and range migration corrections will need to be employed in order to avoid losing energy when recovering vital signs [272, 273].

For the estimation of vital signs, there are 2 elements the rate and variability. The algorithms will therefore need ideally to capture every instance of a breath and heartbeat with a small number of data points. We will use the simulated model of vital signs at various aspect angles to gauge the accuracy of the algorithms in comparison to the model using the Bland-Altman plots [274] and other error measures like the mean square error. The algorithms will consider the computational load and practical application of the algorithm.

- It is important that every instance of heartbeat and breath are captured to get information on the variability which gives very precious information on the health condition for assisted living.
- Simulated electromagnetic model of the radar interaction with the body for vital signs monitoring from any aspect angle

The simulation of an electromagnetic model of the radar interaction with the torso/abdomen of the person under observation. The seminal work on the dielectric properties of biological tissues in [275, 276]. Electromagnetic simulation is very important in early stages of development to validate concepts before implementation. Numerous methods have been already investigated for fast and accurate computations of scattered fields for various subjects using techniques such as ray tracing and EM numerical techniques [260, 277, 278]. I propose to derive an EM model for heart rate and respiration rate. This will help devise appropriate estimation algorithms for the accurate extraction of the vitals from any angle. As we discussed earlier one of the goals of the classification task is also to determine the orientation of the person of interest. What a lot of the models proposed in the literature do not consider is the variations in the displacement when a target is under observation leading to large deviation in the estimation of the frequency of interest. The impact of the presence of more than one subject on the predicted accuracy of the results will be investigated using this developed EM model. The focus will be on modelling the human torso and abdomen, which are the areas that should be affected the most by respiratory and heartbeat motions. There is a fundamental part of the research here that will consist in modelling accurately the physical phenomenon prior to carrying simulations and experiments to design algorithms that will provide both the breathing/heart rate and variability.

How to accurately model the vital sign phenomenology to design algorithms to detect variability and not just means in multi-target scenarios and real environments that will yield accurate results with experimental platforms?

6.3 Algorithms

Optimising target identification is application dependent. Therefore, having a clear understanding of the application and its specificities helps understand how algorithms need to evolve to respond to the problematic.

This work continues evolving as we learn more in this area. New radar data domains are emerging to exploit with techniques such as Radon transforms [184], and also cyclostationarity [181] to widen the scope of classic techniques as aforementioned. The other path followed in the development is the design of machine learning algorithms able to handle complex data as in [279] or incorporating the phase as in [174, 177]. There is a saying in radar that "90% of detection capability of a radar is due to the quality of the frontend and 10% is signal processing". In machine learning, there is similar saying "garbage in, garbage out". I have a strong belief that the quality of the signal processing based on domain knowledge will further enhance performance as the selection of salient domains, features rely on how experienced the researcher is in his field. Building a strong understanding of the phenomenology as well as the design of algorithms both signal processing and machine learning is key to the optimisation of the human activity recognition. Furthermore, beyond just working on optimised classification, the notion of robustness to variations in experimental conditions subjects, noise, environment, clutter, attacks is going to be essential in getting such applications to market. In the context of assisted living, now that we have reached a certain maturity in classification, the next level is integrating vital signs monitoring (breathing, heart, gait analysis, activity pattern, …) to recognition to infer information from the data recorded on the patients' health and behaviour as variations in daily routines or a deviation from a pattern of vital signs may indicate a decline in health or cognition. This for example will mean the automatic extraction of gait parameters and defining a baseline for the patient to use statistical analysis on the evolution of that signature over time. This can be applied to the daily routine of a person, the vital sign variations during the day to move towards building a digital twin for the patient. All these techniques will need to be applied to a multi-occupancy scenario as people rarely live alone. They may have a companion or pets, live in a multigenerational home or a hospice. This will require the development of personnel recognition and tracking to associate data to the subjects under observation or single-out intruders.

For multi-occupancy, the literature is very scarce on the topic. In my earlier work, I was working on gait analysis with high-resolution radar [280]. I tested different scenarios with two people walking/running in opposite directions (Figure 44 to Figure 46).

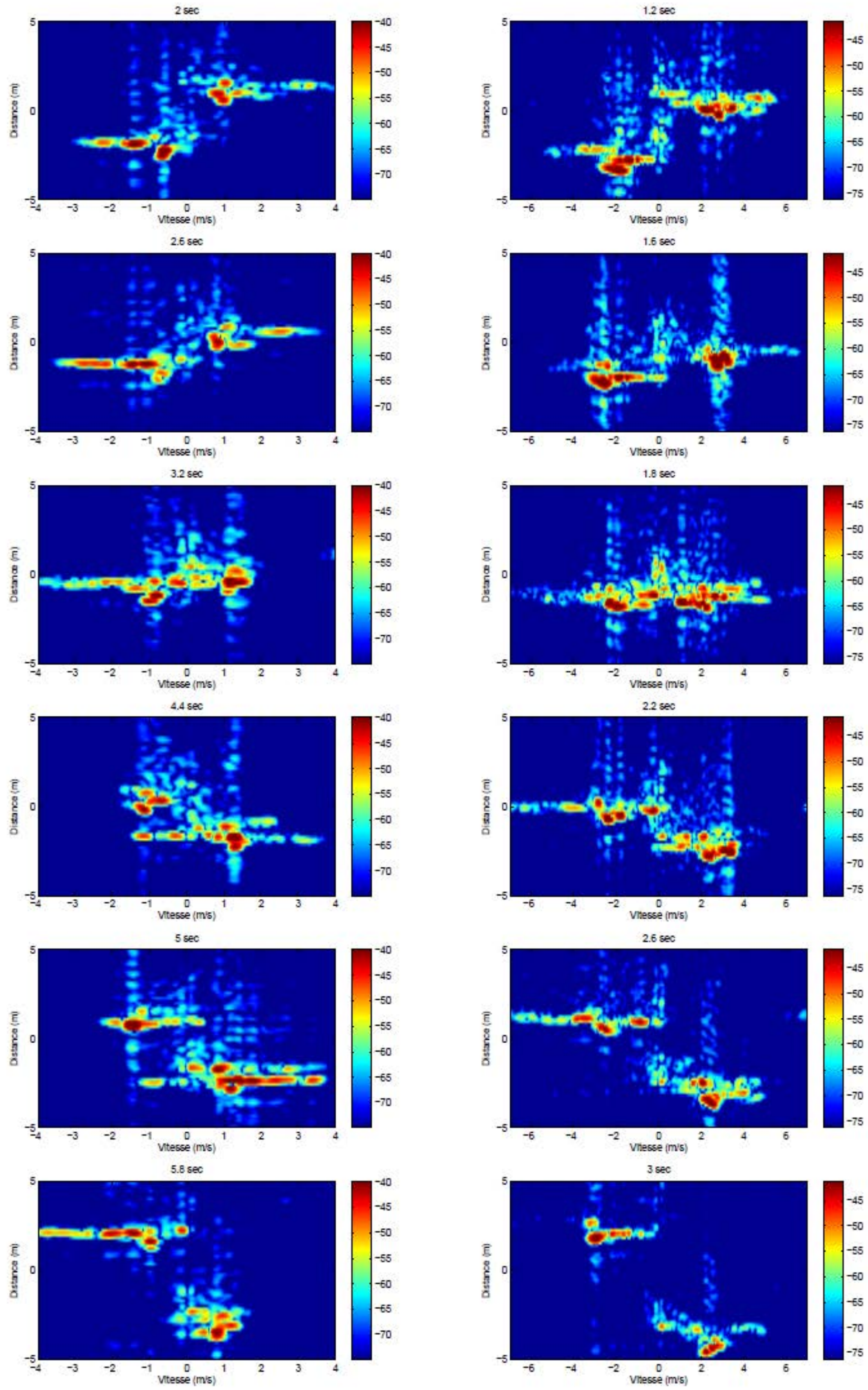


Figure 44: Range-Doppler representation decomposition of left) 2 people walk in opposite directions; right) 2 people running in opposite directions; with a high-range resolution radar. The labels are in French as I was working in Onera – the French Aerospace lab at the time – the abscissa is speed (m/s) and the ordinates distance (m).

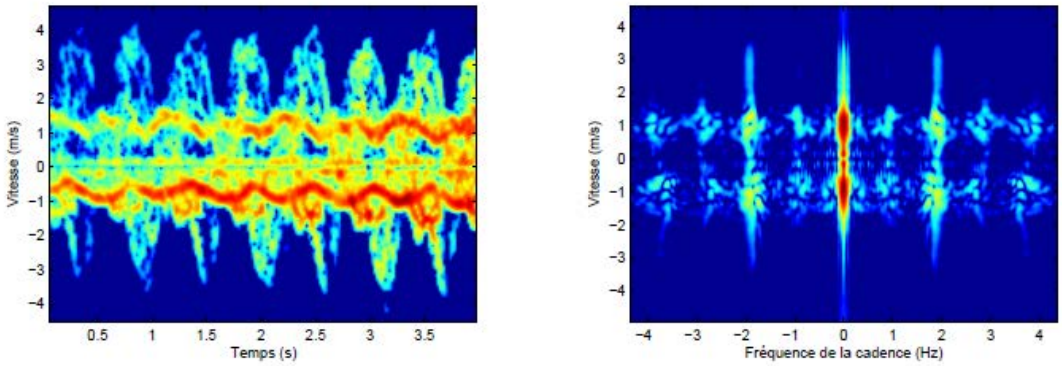


Figure 45: Two people walking in opposite directions left) Spectrogram (the labels are in French as I was working in Onera – the French Aerospace lab at the time – the abscissa is time (s) and the ordinates speed in (m/s)); right) Cadence velocity diagram (the labels are in French as I was working in Onera – the French Aerospace lab at the time – the abscissa is Q-frequency (s) and the ordinates speed in (m/s))

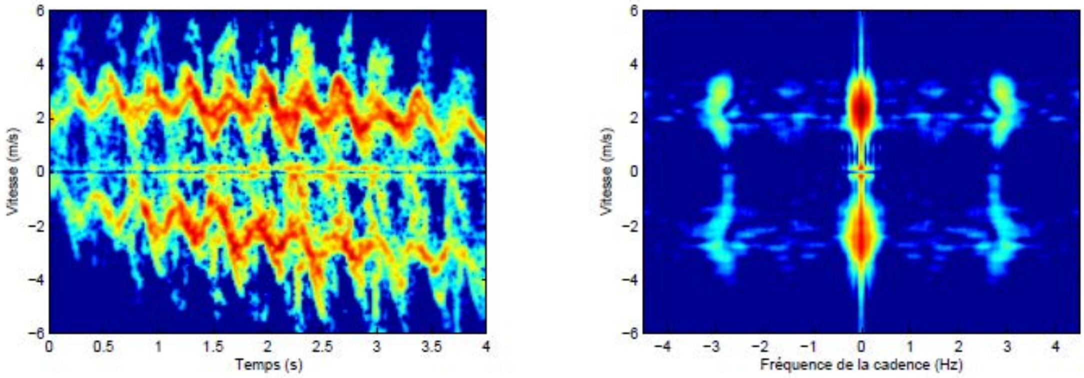


Figure 46: Two people running in opposite directions left) Spectrogram (the labels are in French as I was working in Onera – the French Aerospace lab at the time – the abscissa is time (s) and the ordinates speed in (m/s)); right) Cadence velocity diagram (the labels are in French as I was working in Onera – the French Aerospace lab at the time – the abscissa is Q-frequency (s) and the ordinates speed in (m/s)).

We will exploit multi-domain representations using a combination of radar data domains such as range-Doppler surface (Figure 47) [281] or compound views of radar data domains to separate up to 2 targets in the field of view of the radar.

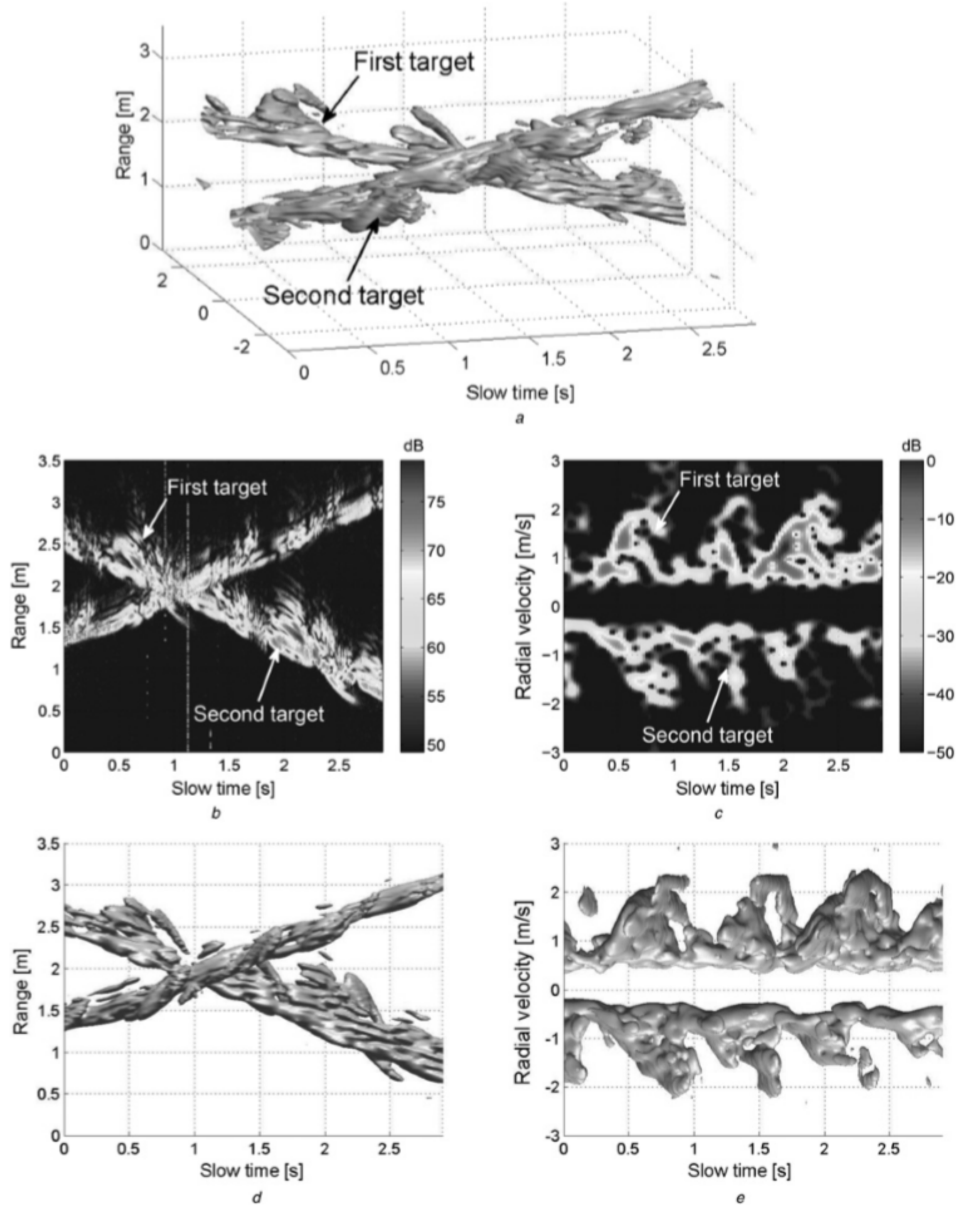


Figure 47: Range-Doppler surface of 2 human targets; a) range-Doppler surface in 3D; b) high-resolution range profiles; c) microDoppler image; d) time-range projection of Range-Doppler surface; e) time-Velocity projection of range-Doppler surface.

As can be seen from Figure 47, the 2 people could be separated if their tracks are separated enough to be isolated and dealt with individually. The tracking in multi-occupational can be simplified to 2 single target-tracking and to multi-target tracking when the targets are together before resuming single target tracking task. The challenge in this case is the data association in other words how do we know that the track of target 1 belongs to target 1 after the crossover and reciprocally for target 2. This is important to adopt an adaptive technique in this case as the use of multi-target tracking is taxing computationally. For the single target tracking case well known techniques like Kalman filters (KF) or their extensions with extended KF (EKF) or unscented KF (UKF) [282] for problems ranging from linear to non-linear or a particle filter [283] or other known techniques.

Associating targets to their track will require identification so if 1 target enters the radar field of view, we will need to be able to identify the person entering the field in a multi-occupancy scenario. Even if the person lives alone, it is very likely that they would have visitors. Indeed, maintaining people at home longer usually means that they may have carers visiting regularly for treatment and it will be important to distinguish their tracks from the patients' tracks. It is imperative that we maintain tractable problems for classification so these higher-order representations of data will need to be represented sparsely to limit the amount of data fed to machine learning network.

The data representation in Figure 47 for example having multiple targets will require the extraction of data within and across domain as well as only selecting the salient features with feature selection techniques. The number of dimensions of data representation for radar is not limited to 3. Objects of interest like the range-Doppler surface are naturally described as tensors or multilinear arrays. This data-representation is a sample of what can be done with multidimensional data representation and feature extraction/selection methods. The separation of the tracks will be further enhanced with radar systems with multi-static radar systems [145, 173, 204, 284-290] or interferometric radar [25, 291-295].

The main idea is to provide a method that can distinguish between the different scenarios and adopt adaptive signal processing to fit the scenario. As an example, we can imagine the radar working first as a presence detector when no-one is in the room initially thus reducing the energy consumption when the full capabilities of the radar are not necessary, then when a person is detected the pre-processing can then resume to normal operation, when a pet or another person is present then the radar will have to first discriminate between the signatures and then proceed to classification of activities. Multiple radar nodes will allow compensating for the shortcomings of individual nodes.

The future of this theme will lie in the development of strategies to merge various sensing modalities to enhance the accuracy of classification of algorithms moving from offline platforms to embedded systems that take into consideration the limited resources available such as power consumption, onboard computational power, AI topology for distributed sensors and how to split the algorithms to obtain the best trade-off between communication and processing loads. This must be performed while maintaining classification accuracy obtained with 64-bit floating-point precision with fixed precision or half-precision floating-point available on embedded platforms. The future algorithms will also need to consider the complex form of the data to boost classification accuracy by processing the complex data jointly in the machine learning algorithm. The next stage of this research will look at mix programming for the domain knowledge combined with AI-driven optimisation of both the signal processing chain, feature extraction, and classification algorithm by performing sensitivity analysis on the most sensitive parameters be they numerical (e.g., window size, short-time-Fourier transform length) or categorical (time-frequency transform: wavelet, fast Fourier transforms, or bilinear transforms e.g., Wigner-Ville, or machine learning algorithms e.g., Support Vector Machine with various kernels, Bagged Trees).

How to jointly tune the pre-processing, domain/sensing selection, feature selection and classification algorithm to find the optimal solution for a multi-objective problem?

6.4 Systems/Hardware

The radar sensor itself and its optimum radar geometry are being explored using our simulator but also via experimental validation. The multi-static/interferometric radar systems will then be used to collect an extensive dataset of activities with one person and with multi-occupancy scenarios to feed in the machine learning techniques for training and testing. We intend to deploy this in patients' homes for in-situ testing. The importance of using a software-defined radar is to use the waveform generator to generate specific signals (Table 12) suited for multi-target recognition.

Table 12: candidate multi-target waveforms

CW radar – frequent for the generation of radar microDoppler signatures	FMCW radar for multitarget – using 2 up-down chirps	MFSK CW Radar – intertwined stepped frequency continuous wave	Staggered Chirp sequence
Measurement of target velocity	Target resolution in range and velocity	Target resolution in range and velocity	Target resolution in range and velocity
No information about the target range	Simultaneous measurement of target and velocity	Ultra-short measurement time	Simultaneous measurement of target and velocity

	Ambiguities in multi-target situations	No Ghost targets	Unambiguous radial velocity measurement
	Long Measurement time	Resolution of stationary targets possible	High computational complexity
	Ghost targets		

One problem that is often forgotten in radar for assisted living is that living units may be close to one another and generate similar problems to what the automotive industry is faced with today: interferences from other radar units in the same band using the same signals. Therefore, we need to design as in communications waveforms that are robust to interference such as Coded Orthogonal Frequency Division Multiplexing (COFDM) waveforms.

The other aspect of system design is with the implementation of the classification algorithm. As we evolve towards a multimodal paradigm, we also need to consider how the system performs when one or more sensors are malfunctioning or disabled to maintain functionality even with slight degradation of performance. Systems need to be robust to the loss of sensing functions, noise and faults. Furthermore, the other issue revolves on where to implement the “intelligence” or where to split it. In other words, embedded systems have limited resources and will need to communicate their data with the classification algorithm. What data to be transmitted whether it is raw data, partially processed data, or fully processed data with some level of compression to reduce the amount transmitted are going to be central ideas to the development of smart living spaces in the future.

Radar sensing applications for assistive living can require real-time implementation of the signal processing. The challenge lies in designing parallel architectures under the constraints of low footprints (power consumption, area, and heterogeneous resources), and high input data throughput and processing time as shown in Figure 48. A typical radar-based classification system can be broken down in 3 steps: data acquisition/pre-processing, feature extraction, and classification. For data pre-processing, signal acquisition is a critical step strongly dependent on the ADC performance level, which can reach high sample rates (GS/s) for high resolution radar. Then, TF transforms have to be computed, requiring significant computational power. The number of Multiply-Accumulate per Second (MACS) can be used as a performance metric counted in GMACS/TMACS, and uses fixed-point rather than floating-point, which has a cascade effect on the performance of the following elements.

Massively parallel architectures can help achieve real-time performance, while approximate computing could be a solution to retain a good level of performance.

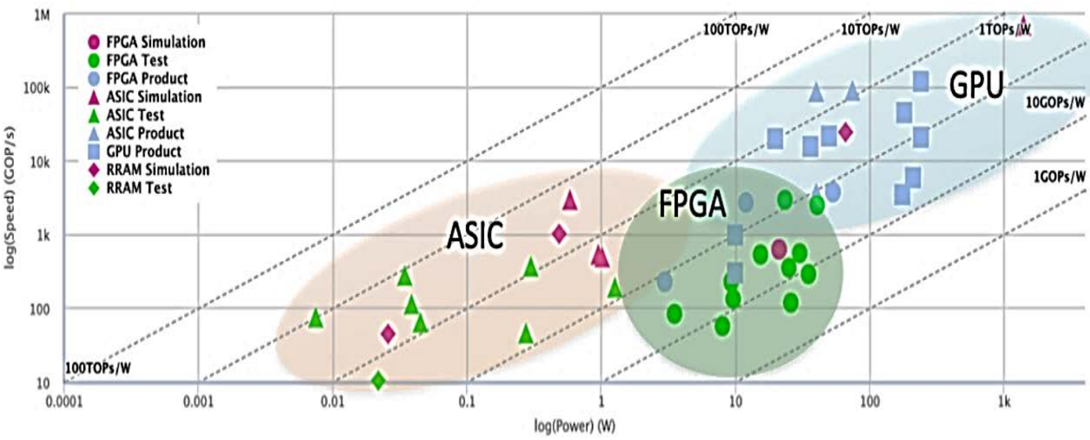


Figure 48: Comparison of neural network accelerators for FPGA, ASIC and GPU devices in terms of speed and power consumption; results obtained from [296].

Further challenges in implementing active learning techniques such as Reinforcement Learning (RL) on FPGA to make processing and computation adaptive, are still open and discussed below. RL and multimodal detection methods are likely to be widespread used in HAR in the near future to leverage on the increasing number of smart sensors in home environment and to enable robust classification algorithms across people and scenarios.

Regarding multimodal sensing, different types of sensing, computing and communication in embedded systems are required. The nature of the collected data has a significant impact on the computing architecture as well as if the sensing is continuous (gait analysis, video application for fall detection) or periodic e.g., triggered on time or events (sensors for smart home applications). Providing a fast and efficient reconfigurable architecture to adapt the processing locally or to self-organize the learning array [297], at low cost, with respect to the environment seems unavoidable.

Waveform design will be a challenge to support in the future both communication and sensing capabilities in high phase noise will be a challenge at (sub)THz frequency ranges spanning 10s of GHz. Switching times will need to be ultrafast and require the use of photonic switching to avoid getting high blind ranges/speeds in the massive MIMO receivers. In the 6G context, data will probably still be privileged against sensing so how to design for MIMO sensing in suboptimal configurations. With the multiplication of access points indoor, the field of multistatic and passive radar techniques will come at the forefront of development for assisted living.

Waveform design will also be of interest to detect new threats in civilian applications with UAVs using the 5G/6G network as illuminators of opportunity for multistatic passive detection using the base-stations' sensing capabilities themselves and passive receivers. The design of new waveforms especially in millimetre/THz region will prove more challenging because of the higher phase noise reducing the modulation capabilities and which might even require using non-coherent detection strategies.

The future challenge in this area will be to implement the RF platforms at high frequencies and deal with extremely large bandwidth of data. This has an impact on signal-processing as targets will appear as extended targets in most cases and require the implementation of high-resolution radar techniques for the compensation of the range walk before processing to Doppler processing. Going higher in frequency will also mean more integration and the multiplication of MIMO systems generating vast amounts of data and at the same time multiplying the signal processing variations per channel. Platforms to be 6G proof will need to implement hardware in the loop implementation and sense their environment to point beams towards the end-user as broadcasting would require too much power from base-stations in a broadcasting scenario.

How to design bespoke smart radcom systems when sensing is secondary to communications for optimal performances, resource allocation and adaptability?

6.5 Further development in the context of assisted living for precision medicine

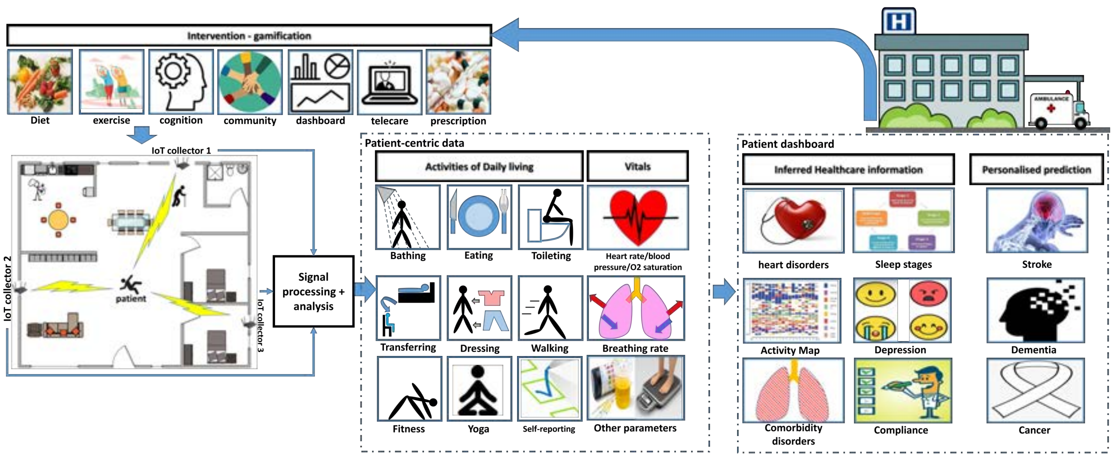


Figure 49: the future of assisted living

These future thoughts are just focusing on the sensing and collection of data, but this is part of a much wider problem that is multi-faceted and will require the involvement of Doctors, Big Data specialists, Secure communications with blockchain to ensure that patient data is protected and that patients retain the rights to their information. It is important as well to make sure that all the digital profile that is collected from the patient help produce precision prediction on their future medical outcome and design interventions appropriate to the patients that are administered to improve the health outcomes through gamification, a sense of ownership, community and this in turn will allow doctors to build an evidence-based practice to see how effective the different interventions are on their patients and whether or not they are compliant.

A lot of the thoughts for assisted living or transferrable to animal welfare, it can range from the application of those to your pet companion to precision farming.

We intend through our interaction with industry to have impact in the silver economy with our radar in assisted living strand which has started with our 2 PhD students with Bluelinea but also through other contacts in industry under development and leveraging the 2 patents filed in this area.

6.6 Spinout in lameness assessment

With the business development team and the veterinarian surgeons, we are working on a spin-off from the university on lameness detection in farm animals based on our core technology. The value proposition is based on the non-contact detection of lameness before it becomes visually obvious. Earlier detection of lameness result in Improved treatment options. The fact that animal welfare is a growing concern in society will influence the level of care standards farmers have to live up to sell their products with an improved welfare label for example. This will also result in an increase in milk yield per lactation per cow as well as reduce the number of culling increasing the number of lactation cycles per cow. Reduced lameness also increases fertility and birth which work to increase the revenue of the farm. With an automated approach, there is a higher objectivity and a lower cost of lameness scoring exercise which requires a veterinarian to come on sight to assess the herd. A single device in the milking parlour could cover a large herd and help sort the cows that present an impaired gait by analysing their signatures more precisely with respect to their baseline.

6.7 Diversification of portfolio

I am currently working on the diversification of my research portfolio by looking at the propagation effects in regolith for spacecraft landing on asteroids and exo-planets to avoid the browning effect of caused by the plume of the rocket when nearing ground level that creates a vortex lifting regolith from the ground and obscuring readings of the ground that could create altimetry issues that could cause a crash. This will be leveraging the ESA facility in Glasgow that can create a plume inside a vacuum chamber with regolith inside to recreate the conditions of landing.

Radar can be used in a multitude of different applications and with the advent of 6G. This will democratise it further. I am thinking of using radar in sport science for the improvement of performance as an extension of assisted living and rehabilitation to monitor the range of flexion a person can achieve with the rehabilitation exercises (and the monitoring of its completion) against the natural motion of a joint after rotator cuff surgery for example. This will leverage the mobility lab that has been created and developing its capabilities further to be used in aerospace engineering, robotics, and biomedical engineering.

6.8 Research Funding and impact

These research actions will be supported nationally by applications to:

- EPSRC (Engineering and Physical Sciences Research Council) for fundamental engineering research on smart radar systems, radar in animal welfare and radar in assisted living.

- BBSRC (Biotechnology and Biological Sciences Research Council) for the study of the outcome in improving patient/animal outcome for radar in animal welfare and radar in assisted living with joint applications with veterinarians and clinicians
- MRC (Medical Research Council) for interventions in clinical trials led by doctors for radar in assisted living

These will enable the purchase of equipment, access to patients/animals for experiments and enlisting research associates for future developments in those 3 research strands. To this end, I have started collaborations at the university with colleagues from the MVLS (Medical Veterinary and Life Science) College both in medical and veterinarian fields and within engineering to drive these research actions forward. Since January, I have finished capabilities for the mobility laboratory that will drive development for the simulations with motion capture and enable research collaborations with robotics, drone detection, joint communication/sensing. This has led to an invitation to be a co-investigator in a sarcopenia study with krill oil to study the patient outcomes through gait analysis.

I will be working also on the development of a doctoral training centre around defense technologies with Dr Dave Anderson as a lead to enable further the research on smart radar systems and translate the activities in radar in assisted living to surveillance and detection of threats. This will provide a sustainable base of PhD students to drive research in this area.

I am also intending to develop knowledge transfer activities with key partners using KTP (Knowledge Transfer Partnerships) and IAA (Impact Acceleration accounts) to form closer links with national industries to bring technology from TRL 3-4 up to commercialisation and generate impact both economic and societal. This also allows for much closer involvement of companies within the research development by understanding more in depth their expectations and challenges. I have initiated work on UAV detection and software-defined radar with industry in that vein to have research associates working within the company on these topics.

I also intend to grow the activity internationally with my existing collaborations in France, China, Japan, the Netherlands, and Italy to work on EU funding, bilateral funding, and international funds specially to drive the multifaceted aspects of the 3 research actions to pull teams together to tackle the various challenges. My PhD student already obtained an international postdoctoral fellowship to continue work on cow lameness between France and the UK for 18 months starting next year.

7 Appendices

7.1 Publications

7.1.1 International Journal and Magazine articles

https://www.scimagojr.com/

Q1 journals – scimago

Q2 journals – scimago

1. Yu, Z., Zahid, A., Taha, A. , Taylor, W., Le Kernec, J. , Heidari, H. , Imran, M. A. and Abbasi, Q. H. (2022) An intelligent implementation of multi-sensing data fusion with neuromorphic computing for human activity recognition. IEEE Internet of Things Journal, (doi: 10.1109/JIOT.2022.3204581)
2. Shah, S. A., Tahir, A., Le Kernec, J., Zoha, A. and Fioranelli, F. (2022) Data portability for activities of daily living and fall detection in different environments using radar micro-doppler. Neural Computing and Applications, 34(10), pp. 7933-7953. (doi: 10.1007/s00521-022-06886-2)
3. Tan, K., Bremner, D., Le Kernec, J., Sambo, Y., Zhang, L. and Imran, M. A. (2022) Intelligent handover algorithm for vehicle-to-network communications with double-deep Q-learning. IEEE Transactions on Vehicular Technology, (doi: 10.1109/TVT.2022.3169804) (Early Online Publication)
4. Tan, K., Bremner, D., Le Kernec, J., Zhang, L. and Imran, M. (2022) Machine learning in vehicular networking: an overview. Digital Communications and Networks, 8(1), pp. 18-24. (doi: 10.1016/j.dcan.2021.10.007)
5. Yang, F., Xu, F., Fioranelli, F., Le Kernec, J., Chang, S. and Long, T. (2021) Practical investigation of a MIMO radar system capabilities for small drones detection. IET Radar, Sonar and Navigation, 15(7), pp. 760-774. (doi: 10.1049/rsn2.12082)
6. Zhou, B., Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Simulation framework for activity recognition and benchmarking in different radar geometries. IET Radar, Sonar and Navigation, 15(4), pp. 390-401. (doi: 10.1049/rsn2.12049)
7. Li, H., Le Kernec, J., Gurbuz, S. Z. and Fioranelli, F. (2021) Sequential human gait classification with distributed radar sensor fusion. IEEE Sensors Journal, 21(6), pp. 7590-7603. (doi: 10.1109/JSEN.2020.3046991)
8. Iloga, S., Bordat, A., Le Kernec, J. and Romain, O. (2021) Human Activity Recognition based on acceleration data from smartphones using HMMs. IEEE Access, 9, pp. 139336-139351. (doi: 10.1109/ACCESS.2021.3117336)
9. Shrestha, A., Li, H., Le Kernec, J. and Fioranelli, F. (2020) Continuous human activity classification from FMCW radar with Bi-LSTM networks. IEEE Sensors Journal, 20(22), pp. 13607-13619. (doi: 10.1109/JSEN.2020.3006386)
10. Li, H., Liang, X., Shrestha, A., Liu, Y., Heidari, H., Le Kernec, J. and Fioranelli, F. (2020) Hierarchical sensor fusion for micro-gestures recognition with pressure sensor array and radar. IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, 4(3), pp. 225-232. (doi: 10.1109/JERM.2019.2949456)
11. Li, X., Li, Z., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2020) Hierarchical radar data analysis for activity and personnel recognition. Remote Sensing, 12(14), 2237. (doi: 10.3390/rs12142237)
12. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2020) Bi-LSTM network for multimodal continuous human activity recognition and fall detection. IEEE Sensors Journal, 20(3), pp. 1191-1201. (doi : 10.1109/JSEN.2019.2946095)

13. Rahman, M. A. et al. (2019) A secure occupational therapy framework for monitoring cancer patients' quality of life. Sensors, 19(23), 5258. (doi: 10.3390/s19235258) (PMID:31795384) (PMCID:PMC6928807)
14. Busin, V., Viora, L., King, G., Tomlinson, M., Le Kernec, J., Jonsson, N. and Fioranelli, F. (2019) Evaluation of lameness detection using radar sensing in ruminants. Veterinary Record, 185(18), 572. (doi: 10.1136/vr.105407) (PMID:31554712)
15. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2019) Magnetic and radar sensing for multimodal remote health monitoring. IEEE Sensors Journal, 19(20), pp. 8979-8989. (doi: 10.1109/JSEN.2018.2872894)
16. Li, H., Shrestha, A., Fioranelli, F., Le Kernec, J. and Heidari, H. (2019) FMCW radar and inertial sensing synergy for assisted living. Journal of Engineering, 2019(20), pp. 6784-6789. (doi: 10.1049/joe.2019.0558)
17. Li, J., Shrestha, A., Le Kernec, J. and Fioranelli, F. (2019) From Kinect skeleton data to hand gesture recognition with radar. Journal of Engineering, 2019(20), pp. 6914-6919. (doi: 10.1049/joe.2019.0557)
18. Ochieng, F. X., Jiang, H., Hancock, C. M., Roberts, G. W., Le Kernec, J., Tang, X. and de Ligt, H. (2019) Deflection characterisation of rotary systems using a ground-based radar. Journal of Engineering, 2019(20), pp. 7215-7219. (doi: 10.1049/joe.2019.0503)
19. Shrestha, A., Li, H., Fioranelli, F. and Le Kernec, J. (2019) Activity recognition with cooperative radar systems at C and K band. Journal of Engineering, 2019(20), pp. 7100-7104. (doi: 10.1049/joe.2019.0559)
20. Fioranelli, F., Shah, S. A., Li, H., Shrestha, A., Yang, S. and Le Kernec, J. (2019) Radar sensing for healthcare. Electronics Letters, 55(19), pp. 1022-1024. (doi: 10.1049/el.2019.2378)
21. Ding, C., Hong, H., Zou, Y., Chu, H., Zhu, X., Fioranelli, F., Le Kernec, J. and Li, C. (2019) Continuous human motion recognition with a dynamic range-Doppler trajectory method based on FMCW radar. IEEE Transactions on Geoscience and Remote Sensing, 57(9), pp. 6821-6831. (doi: 10.1109/TGRS.2019.2908758)
22. Fioranelli, F., Le Kernec, J. and Shah, S. A. (2019) Radar for healthcare: recognising human activities and monitoring vital signs. IEEE Potentials, 38(4), pp. 16-23. (doi: 10.1109/MPOT.2019.2906977)
23. Shrestha, A., Le Kernec, J., Fioranelli, F., Lin, Y., He, Q., Lorandel, J. and Romain, O. (2019) Elderly care: activities of daily living classification with an S band radar. Journal of Engineering, 2019(21), pp. 7601-7606. (doi: 10.1049/joe.2019.0561)
24. Le Kernec, J., Fioranelli, F., Ding, C., Zhao, H., Sun, L., Hong, H., Lorandel, J. and Romain, O. (2019) Radar signal processing for sensing in assisted living: the challenges associated with real-time implementation of emerging algorithms. IEEE Signal Processing Magazine, 36(4), pp. 29-41. (doi: 10.1109/MSP.2019.2903715)
25. Lin, Y., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2018) Human activity classification with radar: optimization and noise robustness with iterative convolutional neural networks followed with random forests. IEEE Sensors Journal, 18(23), pp. 9669-9681. (doi: 10.1109/JSEN.2018.2872849)
26. Ochieng, F.X., Hancock, C.M., Roberts, G.W. and Le Kernec, J. (2018) A review of ground-based radar as a non-contact sensor for structural health monitoring of in-field wind turbines blades. Wind Energy, 21(12), pp. 1435-1449. (doi: 10.1002/we.2252)
27. Shrestha, A., Loukas, C., Le Kernec, J., Fioranelli, F., Busin, V., Jonsson, N., King, G., Tomlinson, M., Viora, L. and Voute, L. (2018) Animal lameness detection with radar sensing. IEEE Geoscience and Remote Sensing Letters, 15(8), pp. 1189-1193. (doi: 10.1109/LGRS.2018.2832650)
28. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2018) A multi-sensory approach for remote health monitoring of older people. IEEE Journal of Electromagnetics, RF

and Microwaves in Medicine and Biology, 2(2), pp. 102-108. (doi: 10.1109/JERM.2018.2827099)

29. Le Kernec, J. and Romain, O. (2017) Performances of multitones for ultra-wideband software-defined radar. IEEE Access, 5, pp. 6570-6588. (doi: 10.1109/ACCESS.2017.2693300)

7.1.2 Book Sections

1. Fioranelli, F. and Le Kernec, J. (2021) Advanced classification techniques for drone payloads. In: Clemente, C., Fioranelli, F., Colone, F. and Li, G. (eds.) Radar Countermeasures for Unmanned Aerial Vehicles. The Institution of Engineering and Technology. ISBN 9781839531903 (In Press)
2. Fioranelli, F. and Le Kernec, J. (2020) Contactless radar and RF health monitoring. In: Imran, M. A., Ghannam, R. and Abbasi, Q. H. (eds.) Engineering and Technology for Healthcare. Wiley-IEEE: Hoboken, NJ, pp. 29-59. ISBN 9781119644248 (doi: 10.1002/9781119644316.ch2)
3. Shrestha, A., Fioranelli, F. and Le Kernec, J. (2020) Multimodal sensing for assisted living using radar. In: Fioranelli, F., Griffiths, H., Ritchie, M. and Balleri, A. (eds.) Micro-Doppler Radar and its Applications. Institution of Engineering and Technology (IET): London, UK. ISBN 9781785619335
4. Ochieng, F. X., Hancock, C. M., Roberts, G. W. and Le Kernec, J. (2020) Optimal design and operational monitoring of wind turbine blades. In: Maalawi, K. Y. (ed.) Optimization of Wind Energy Conversion Systems. IntechOpen. ISBN 9781789844085 (doi: 10.5772/intechopen.90258)
5. Le Kernec, J. and Romain, O. (2015) Multitones' performance for ultra wideband software defined radar. In: Radhakrishnan, S. (ed.) Applications of Digital Signal Processing through Practical Approach. Intech. ISBN 9789535121909 (doi: 10.5772/60804)

7.1.3 Conference without proceedings or Workshop Item

1. Yang, S., Le Kernec, J. and Fioranelli, F. (2019) Action Recognition Using Indoor Radar Systems. IET Human Motion Analysis for Healthcare Applications, London, UK, 26 Jun 2019.
2. Levrai, P., Bolster, A. and Le Kernec, J. (2014) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical Engineering Students. ICED 2014: International Consortium for Educational Development, Stockholm, Sweden, 16-18 June 2014.
3. Levrai, P., Bolster, A. and Le Kernec, J. (2013) Mixed Panel Oral Presentation Assessment: Preparing Electrical & Electronic Engineering Students for Work. In: 11th Biennial Conference of the Association for Academic Language and Learning, Melbourne, Australia, 13-15 Nov 2013, (Unpublished)
4. Waliwander, T., Rulikowski, P., Le Kernec, J. and Sokol, V. (2005) The Experimental UWB Link. In: 15th International Traveling Summer School on Microwaves and Lightwaves, L'Aquila, Italy, 9-15 July 2005.
5. Du, Y., Li, B., Li, J., Fioranelli, F. and Le Kernec, J. (2022) A ViT Approach for Short-range Behaviour Recognition Using Radar Signals. In: 2022 IEEE Radar Conference (RadarConf22), New York, NY, USA, 21-25 Mar 2022.

7.1.4 Conference Proceedings

1. Linardopoulou, K., Viora, L., Fioranelli, F., Le Kernec, J., Abbasi, Q., King, G. and Jonsson, N. (2022) Time-series Observations of Cattle Mobility: Accurate Label Assignment from Multiple Assessors, and Association with Lesions Detected in the Feet. In: 31st World Buiatrics Congress, Madrid, Spain, 04-08 Sep 2022.

2. Bordat, A., Dobias, P., Le Kernec, J., Guyard, D. and Romain, O. (2022) Towards Real-Time Implementation for the Pre-Processing of Radar-Based Human Activity Recognition. In: 2022 IEEE 31st International Symposium on Industrial Electronics (ISIE), Anchorage, AK, USA, 01-03 Jun 2022.
3. Gray, D., Thornton, J. and Le Kernec, J. (2022) Homogeneous Spherical Lens for Marine Retro-reflector Application, Part 3. In: IEICE Technical Committee on Antennas and Propagation (AP), Kobe, Japan, 19-20 May 2022.
4. Taylor, W., Shah, S. A., Dashtipour, K., Le Kernec, J., Abbasi, Q. H., Assaleh, K., Arshad, K. and Imran, M. A. (2022) Wireless Sensing for Human Activity Recognition using USRP. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 52-62. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_5)
5. Yang, K., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Bespoke Simulator for Human Activity Classification with Bistatic Radar. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 71-85. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_7)
6. Zhang, X., Abbasi, Q. H., Fioranelli, F., Romain, O. and Le Kernec, J. (2022) Elderly Care – Human Activity Recognition Using Radar with an Open Dataset and Hybrid Maps. In: 16th EAI International Conference on Body Area Networks (EAI BODYNETS 2021), Glasgow, UK, 25-26 Oct 2021, pp. 39-51. ISBN 9783030955922 (doi: 10.1007/978-3-030-95593-9_4)
7. Fioranelli, F. and Le Kernec, J. (2021) Radar Sensing for Human Healthcare: Challenges and Results. In: IEEE Sensors 2021, Sydney, Australia, 31 Oct – 04 Nov 2021, ISBN 9781728195018 (doi: 10.1109/SENSORS47087.2021.9639702)
8. Le Kernec, J., Fioranelli, F. and Romain, O. (2021) Fusion of Radar Data Domains for Human Activity Recognition in Assisted Living. In: 14th International conference on Sensing Technology, Chennai, India, 17-19 Jan 2022.
9. Li, Z., Le Kernec, J., Fioranelli, F., Abbasi, Q., Yang, S. and Romain, O. (2021) Human Activity Classification with Adaptive Thresholding using Radar Micro-Doppler. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 – 19 December 2021.
10. Du, Y., Li, J., Li, Z., Yu, R., Napolitano, A., Fioranelli, F. and Le Kernec, J. (2021) Radar-based Human Activity Classification with Cyclostationarity. In: 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15 – 19 December 2021.
11. Guo, J., Shu, C., Zhou, Y., Wang, K., Fioranelli, F., Romain, O. and Le Kernec, J. (2021) Complex Field-based Fusion Network for Human Activities Classification With Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 68-73. ISBN 9781839535406 (doi: 10.1049/icp.2021.0572)
12. Jiang, H., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Human Activity Classification Using Radar Signal and RNN Networks. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1595-1599. ISBN 9781839535406 (doi: 10.1049/icp.2021.0556)
13. Li, X., Fioranelli, F., Yang, S., Romain, O. and Le Kernec, J. (2021) Radar-Based Hierarchical Human Activity Classification. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1373-1379. ISBN 9781839535406 (doi: 10.1049/icp.2021.0566)
14. Li, Z., Fioranelli, F., Yang, S., Zhang, L., Romain, O., He, Q., Cui, G. and Le Kernec, J. (2021) Multi-domains based Human Activity Classification in Radar. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1744-1749. ISBN 9781839535406 (doi: 10.1049/icp.2021.0557)
15. Yang, F., Le Kernec, J., Fioranelli, F. and Liu, Q. (2021) Shape Feature Aided Target Detection Method for Micro-drone Surveillance Radar. In: IET International Radar

Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 390-395. ISBN 9781839535406 (doi: 10.1049/icp.2021.0839)
16. Zhou, B., Le Kernec, J., Yang, S., Fioranelli, F., Romain, O. and Zhao, Z. (2021) Interferometric Radar for Activity Recognition and Benchmarking in Different Radar Geometries. In: IET International Radar Conference 2020, Chongqing City, China, 4-6 Nov 2020, pp. 1515-1520. ISBN 9781839535406 (doi: 10.1049/icp.2021.0571)
17. Li, Z., Le Kernec, J., Fioranelli, F., Romain, O., Zhang, L. and Yang, S. (2021) A LSTM Approach to Short-Range Personnel Recognition Using Radar Signals. In: 2021 IEEE Radar Conference (RadarConf21), Atlanta, GA, USA, 7-14 May 2021, ISBN 9781728176093 (doi: 10.1109/RadarConf2147009.2021.9455218)
18. Bennett, C., Jahangir, M., Fioranelli, F., Ahmad, B. I. and Le Kernec, J. (2020) Use of Symmetrical Peak Extraction in Drone Micro-Doppler Classification for Staring Radar. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266702)
19. Li, H., Le Kernec, J., Mehul, A., Gurbuz, S. Z. and Fioranelli, F. (2020) Distributed Radar Information Fusion for Gait Recognition and Fall Detection. In: 2020 IEEE Radar Conference (RadarConf20), Florence, Italy, 21-25 Sep 2020, ISBN 9781728189420 (doi: 10.1109/RadarConf2043947.2020.9266319)
20. Linardopoulou, K., Viora, L., Abbasi, Q. H., Fioranelli, F., Le Kernec, J. and Jonsson, N. (2020) Lameness Detection in Dairy Cows: Evaluation of the Agreement and Repeatability of Mobility Scoring. 74th Annual AVTRW Conference, 14-15 Sept 2020.
21. Jia, M., Li, S., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Human Activity Classification With Radar Signal Processing and Machine Learning. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205461)
22. Jiang, H., Song, Q. and Le Kernec, J. (2020) Searching the Adversarial Example in the Decision Boundary. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205320)
23. Li, S., Jia, M., Le Kernec, J., Yang, S., Fioranelli, F. and Romain, O. (2020) Elderly Care: Using Deep Learning for Multi-Domain Activity Classification. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205464)
24. Tan, K., Bremner, D., Le Kernec, J. and Imran, M. (2020) Federated Machine Learning in Vehicular Networks: a Summary of Recent Applications. In: 5th International Conference on the UK-China Emerging Technologies (UCET 2020), Glasgow, UK, 20-21 Aug 2020, ISBN 9781728194882 (doi: 10.1109/UCET51115.2020.9205482)
25. Gray, D. and Le Kernec, J. (2020) Scan Performance of Small Spherical Retro-Reflectors. In : 2019 International Radar Conference, Toulon, France, 23-27 Sept 2019, ISBN 9781728126609 (doi : 10.1109/RADAR41533.2019.171391)
26. Yang, S., Le Kernec, J., Fioranelli, F. and Romain, O. (2020) Human Activities Classification in a Complex Space using Raw Radar Data. In : 2019 International Radar Conference, Toulon, France, 23-27 Sept 2019, ISBN 9781728126609 (doi : 10.1109/RADAR41533.2019.171367)
27. Li, Z., Li, B. and Le Kernec, J. (2020) Activity Recognition System Optimisation Using Triaxial Accelerometers. In: International Conference on 3D Imaging Technology (IC3DIT2019), Kunming, Yunnan, China, 15-18 Aug 2019, ISBN 9789811538667 (doi: 10.1007/978-981-15-3867-4_15)
28. Haider, D., Shah, S. Y., Romain, O., Farooq, M. M. U., Le Kernec, J. and Qadus, Z. (2019) Monitoring Body Motions Related to Huntington Disease by Exploiting the 5G Paradigm. In:

UK-China Emerging Technologies Conference, Glasgow, UK, 21-22 Aug 2019, ISBN 9781728127972 (doi: 10.1109/UCET.2019.8881867)
29. Tan, K., Le Kernec, J., Imran, M. and Bremner, D. (2019) Clustering Algorithm in Vehicular Ad-hoc Networks: A Brief Summary. In: UK-China Emerging Technologies Conference, Glasgow, UK, 21-22 Aug 2019, ISBN 9781728127972 (doi: 10.1109/UCET.2019.8881833)
30. Busin, V., Viora, L., King, G., Tomlinson, M., Le Kernec, J., Jonsson, N. N. and Fioranelli, F. (2019) Radar Sensing as a Novel Tool to Detect Lameness in Sheep. Ontario Small Ruminant Veterinary Conference, Ontario, Canada, 17-19 June 2019.
31. Shrestha, A., Murphy, C., Johnson, I., Anbulselvam, A., Fioranelli, F., Le Kernec, J. and Gurbuz, S. Z. (2019) Cross-Frequency Classification of Indoor Activities with DNN Transfer Learning. In: IEEE Radar Conference, Boston, MA, USA, 22-26 Apr 2019, ISBN 9781728116792 (doi: 10.1109/RADAR.2019.8835844)
32. Fioranelli, F., Li, H., Le Kernec, J., Busin, V., Jonsson, N., King, G., Tomlinson, M. and Viora, L. (2019) Radar-based Evaluation of Lameness Detection in Ruminants: Preliminary Results. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777830)
33. Le Kernec, J., Fioranelli, F., Ding, C., Zhao, H., Sun, L., Hong, H., Romain, O. and Lorandel, J. (2019) Radar Sensing in Assisted Living: An Overview. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777748)
34. Li, H., Shrestha, A., Heidari, H., Le Kernec, J. and Fioranelli, F. (2019) Activities Recognition and Fall Detection in Continuous Data Streams Using Radar Sensor. In: IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May 2019, ISBN 9781538673959 (doi: 10.1109/IMBIOC.2019.8777855)
35. Le Kernec, J., Fioranelli, F., Yang, S., Lorandel, J. and Romain, O. (2019) Radar for Assisted Living in the Context of Internet of Things for Health and Beyond. In: 26th IFIP/IEEE/AICA International Conference on Very Large Scale Integration, Verona, Italy, 8-10 Oct 2018, ISBN 9781538647561 (doi: 10.1109/VLSI-SoC.2018.8644816)
36. Bremner, D. J., Le Kernec, J., Fioranelli, F. and Dale, V. H. M. (2019) The Use of Multiple Choice Questions in 3rd year Electronic Engineering Assessment: a Case Study. In: IEEE TALE 2018, Wollongong, Australia, 4-7 Dec 2018, pp. 887-892. ISBN 9781538665220 (doi: 10.1109/TALE.2018.8615153)
37. Li, H., Fioranelli, F., Le Kernec, J. and Heidari, H. (2018) Hierarchical Classification on Multimodal Sensing for Human Activity Recogintion and Fall Detection. In: IEEE Sensors 2018 Conference, New Delhi, India, 28-31 Oct 2018, ISBN 9781538647073 (doi: 10.1109/ICSENS.2018.8589797)
38. Loukas, C., Fioranelli, F., Le Kernec, J. and Yang, S. (2018) Activity Classification Using Raw Range and I & Q Radar Data with Long Short Term Memory Layers. In: 1st International Workshop on Healthcare with Intelligent Sensing, System and Data (HISSD) in CyberSciTech2018, Athens, Greece, 12-15 Aug 2018, pp. 441-445. ISBN 9781538675199 (doi: 10.1109/DASC/PiCom/DataCom/CyberSciTec.2018.00088)
39. Gray, D. and Le Kernec, J. (2018) Aluminium Feeds for Reflector for NadirSAR. In: 2018 IEEE EMC and APEMC Symposium, Singapore, 14-17 May 2018, ISBN 9781509039555 (doi: 10.1109/ISEMC.2018.8393966)
40. Gray, D. and Le Kernec, J. (2018) Structural Antennas for 3cm Radar Onboard Multi-Rotor UAV. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0394)
41. Shrestha, A., Le Kernec, J., Fioranelli, F., Cippitelli, E., Gambi, E. and Spinsante, S. (2018) Feature Diversity for Fall Detection and Human Indoor Activities Classification Using Radar

Systems. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0381)

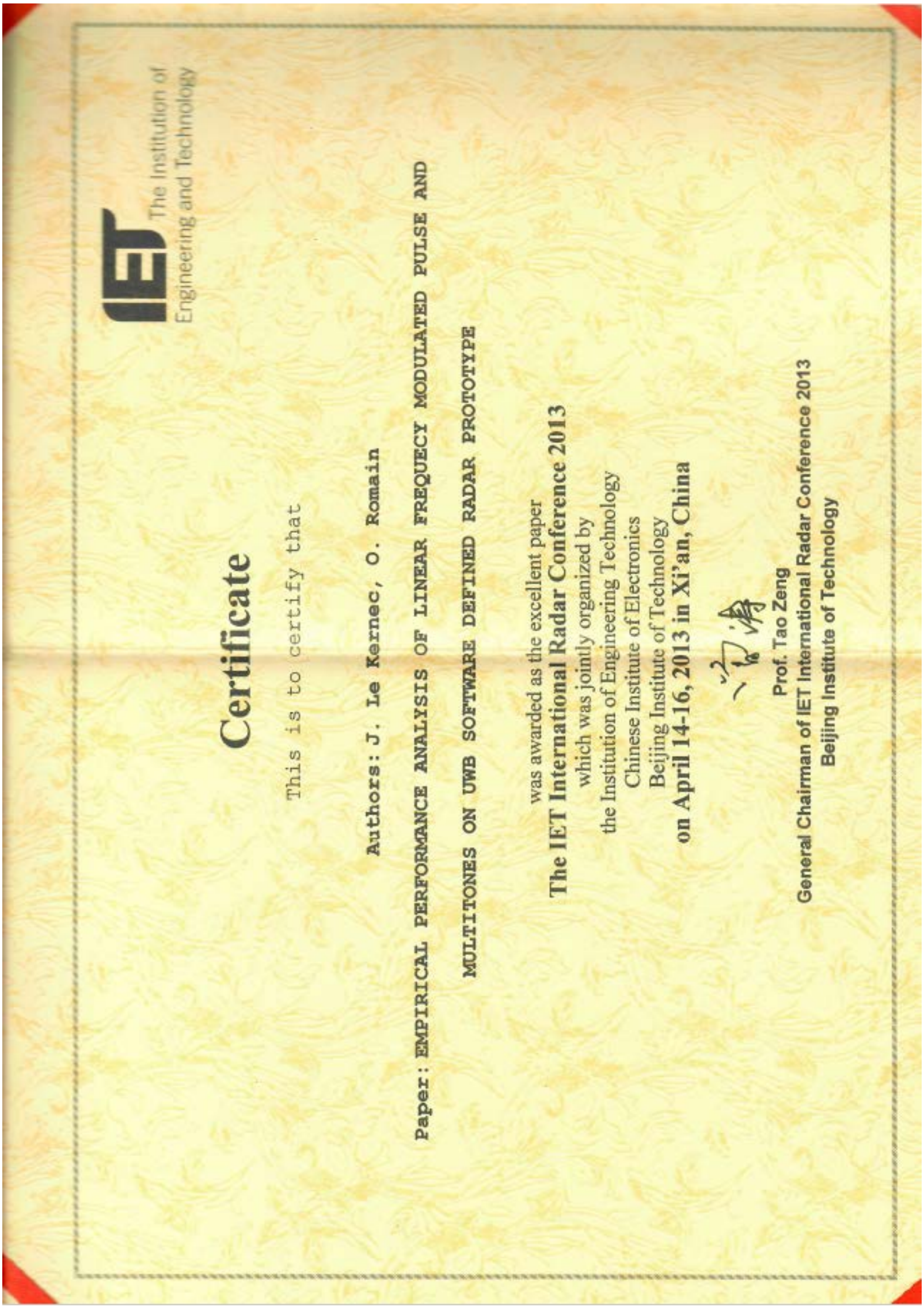
42. Shrestha, A., Le Kernec, J., Fioranelli, F., Marshall, J.F. and Voute, L. (2018) Gait Analysis of Horses for Lameness Detection with Radar Sensors. In: RADAR 2017: International Conference on Radar Systems, Belfast, UK, 23-26 Oct 2017, ISBN 9781785616730 (doi: 10.1049/cp.2017.0427)
43. Lin, Y. and Le Kernec, J. (2018) Performance Analysis of Classification Algorithms for Activity Recognition using Micro-Doppler Feature. In: The 13th International Conference on Computational Intelligence and Security (CIS 2017), Hong Kong, China, 15-18 Dec 2017, ISBN 0769563414 (doi: 10.1109/CIS.2017.00111)
44. Ochieng, F. X., Hancock, C. M., Roberts, G. W., Le Kernec, J. and Tang, X. (2018) Novel Non-contact Deformation Health Monitoring of Towers and Rotating Composite Based Wind Turbine Blades Using Interferometric Ground Based Radar. In: FIG Congress 2018, Istanbul, Turkey, 06-11 May 2018, ISBN 9788792853783
45. Li, H., Shrestha, A., Fioranelli, F., Le Kernec, J., Heidari, H., Pepa, M., Cippitelli, E., Gambi, E. and Spinsante, S. (2017) Multisensor Data Fusion for Human Activities Classification and Fall Detection. In: IEEE Sensors 2017, Glasgow, UK, 30 Oct – 01 Nov 2017, ISBN 9781509010127 (doi: 10.1109/ICSENS.2017.8234179)
46. Le Kernec, J. (2017) Inter-Range-Cell Interference Free Compression Algorithm: Performance in Operational Conditions. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059232)
47. Zhou, X., Le Kernec, J. and Gray, D. (2017) Vivaldi Antenna for Railway Cutting Monitoring. In: 2016 CIE International Conference on Radar (Radar 2016), Guangzhou, China, 10-13 Oct 2016, (doi: 10.1109/RADAR.2016.8059180)
48. Le Kernec, J., Levrai, P. and Bolster, A. (2016) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical and Electronic Engineering Students. In: IEEE TALE2016, Bangkok, Thailand., 7-9 Dec 2016, ISBN 9781509055982 (doi: 10.1109/TALE.2016.7851761)
49. Melnikov, A., Le Kernec, J. and Gray, D. (2015) Porting Spotlight Range Migration Algorithm Processor from Matlab to Virtex 6. In: 2015 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Turin, 7-11 Sept. 2015, pp. 1429-1432. ISBN 9781479978090 (doi: 10.1109/APWC.2015.7300214)
50. Ren, C., Le Kernec, J., Galy, J., Chaumette, É., Larzabal, P. and Reneaux, A. (2015) Borné de Cramér-Rao sous contraintes pour l’estimation simultanée de paramètres aléatoires et non aléatoires. GRETSI, Lyon, France, Sept. 2015.
51. Ren, C., Le Kernec, J., Galy, J., Chaumette, E., Larzabal, P. and Renaux, A. (2015) A Constrained Hybrid Cramér-Rao Bound for Parameter Estimation. In: 2015 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), South Brisbane, QLD, 19-24 Apr 2015, pp. 3472-3476. ISBN 9781467369978 (doi: 10.1109/ICASSP.2015.7178616)
52. Gray, D., Xin, X., Zhu, Y. and Le Kernec, J. (2014) Structural Slotted Waveguide Antennas for Multirotor UAV Radio Altimeter. In: 2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Guilin, 5-8 Aug. 2014, pp. 819-824. ISBN 9781479952724 (doi: 10.1109/ICSPCC.2014.6986311)
53. Gray, D., Le Kernec, J. and Thornton, J. (2014) Assessment of Sochacki Lenses for Autonomous Maritime Patrol FLAR. In: 2014 International Radar Conference (Radar), Lille, 13-17 Oct. 2014, pp. 1-6. ISBN 9781479941957 (doi: 10.1109/RADAR.2014.7060439)
54. Le Kernec, J., Gray, D. and Romain, O. (2014) Empirical Analysis of Chirp and Multitones Performances with a UWB Software Defined Radar: Range, Distance and Doppler. In: 3rd Asia-Pacific Conference on Antennas and Propagation (APCAP), Harbin, China, 26-29 Jul 2014, pp. 1061-1064. ISBN 9781479943548 (doi: 10.1109/apcap.2014.6992691)

55. Melnikov, A., Le Kernec, J. and Gray, D. (2014) A Case Implementation of a Spotlight Range Migration Algorithm on FPGA Platform. In: 2014 International Symposium on Antennas and Propagation (ISAP), Kaohsiung, 2-5 Dec. 2014, pp. 177-178. (doi: 10.1109/isanp.2014.7026588)
56. Melnikov, A., Le Kernec, J. and Gray, D. (2014) FMCW rail-mounted SAR: Porting spotlight SAR imaging from MATLAB to FPGA. In: 2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), Guilin, 5-8 Aug. 2014, pp. 780-785. ISBN 9781479952724 (doi: 10.1109/ICSPCC.2014.6986303)
57. Le Kernec, J. and Romain, O. (2013) Empirical Performance Analysis of Linear Frequency Modulated Pulse and Multitones on UWB Software Defined Radar Prototype. In: IET International Radar Conference 2013, Xian, 14-16 April 2013, 0440-0440. ISBN 9781849196031 (doi: 10.1049/cp.2013.0228)
58. Le Kernec, J., Romain, O., Garda, P. and Denoulet, J. (2012) Empirical Comparison of Chirp and Multitones on Experimental UWB Software Defined Radar Prototype. In: 2012 Conference on Design and Architectures for Signal and Image Processing (DASIP), Karlsruhe, 23-25 Oct. 2012, pp. 1-8. ISBN 9781467320894
59. Terosiet, M., Feruglio, S., Vallette, F., Garda, P., Romain, O. and Le Kernec, J. (2011) A Self-Sufficient Digitally Controlled Ring Oscillator Compensated for Supply Voltage Variation. In: 18th IEEE International Conference on Electronics, Circuits and Systems (ICECS), 2011, Beirut, 11-14 Dec. 2011, pp. 484-487. ISBN 9781457718458 (doi: 10.1109/icecs.2011.6122318)
60. Le Kernec, J., Klepal, M. and Sokol, V. (2010) 3D Directional Coupler for Impulse UWB: 3D Electromagnetic Simulation and Prototyping. In: C2I 2010: 5th Colloquium Interdisciplinary in Instrumentation, Le Mans, France, Jan 2010, ISBN 9782746225169
61. Le Kernec, J., Dreuillet, P., Bobillot, G., Garda, P., Romain, O. and Denoulet, J. (2009) Case Study Analysis of Linear Chirp and Multitones (OFDM) Radar Signals Through Simulations and Measurement with HYCAM-Research Test Bench. In: Radar 2009 Surveillance for a Safer World, Bourdeaux, France, 12-16 Oct 2009,
62. Vignaud, L., Ghaleb, A., Le Kernec, J. and Nicolas, J.-M. (2009) Radar High Resolution Range & Micro-Doppler Analysis of Human Motions. In: International Radar Conference – Surveillance for a Safer World, 2009, Bordeaux, 12-16 Oct. 2009, ISBN 9782912328557

7.1.5 Patents

1. Centre National de la Recherche Scientifique (2022), Method and Device for Human Activity Classification using Radar Micro-Doppler And Phase, EP21306742.
2. Centre National de la Recherche Scientifique (2021) Dispositif de caractérisation de l’actimetrie d’un sujet en temps reel = Device for Characterizing the Actimetry of a Subject in Real Time. . WO2021069518A1.

7.2 Awards



The Institution of Engineering and Technology

Certificate

This is to certify that

Authors: J. Le Kernec, O. Romain

Paper: EMPIRICAL PERFORMANCE ANALYSIS OF LINEAR FREQUECY MODULATED PULSE AND MULTITONES ON UWB SOFTWARE DEFINED RADAR PROTOTYPE

was awarded as the excellent paper

The IET International Radar Conference 2013

which was jointly organized by

the Institution of Engineering Technology

Chinese Institute of Electronics

Beijing Institute of Technology

on April 14-16, 2013 in Xi'an, China

Prof. Tao Zeng

General Chairman of IET International Radar Conference 2013

Beijing Institute of Technology

Figure 50: Excellent paper award IET international radar conference 2013

7.3 Grants

Table 13: Details on awards (AP: associate professor, AsP: Assistant Professor, P: Professor, SES: Senior Equine Surgeon)

	PHC XU GUANGQI	PHC CAI YUANPEI	PHC ALLIANCE	SEEDS MEETING	SANDPIT	IPDF FRANCE CHINA	CHANCELLOR FUND: WELL	SPE ONERA	INEX CARING	DIM-RSI	PETPLAN: LAMENESS LOCATOR	HBLB: ATLAS	RGC COLLAB. RESEARCH FUND
TYPE	Mobility	Mobility	Mobility	Mobility	Internal (UNNC)	Internal (UoG)	Internal (UoG)	Internal (UoG)	Internal (UPS)	Public funding	Public funding	Public funding	Public funding
START	04/2017	07/2018	01/2019	03/2020	01/2015	12/2017	05/2018	01/2019	10/2019	01/2021	10/2017	05/2018	01/2021
END	12/2017	12/2020	12/2021	03/2020	12/2015	06/2018	04/2020	06/2019	09/2021		09/2018	09/2019	12/2022
DURATION	7 months	2 years	2 years	2 days	1 year	7 months	2 years	6 months	2 years	Punctual captical eqpt	1 year	16 months	2 years
AWARD	6,540€	38k€	£7,500	£10,000	100kCNY	£3k	£5,125	£3k	106k€	42k€	£9,800	£9,961.28	HKD6,849,390
MY ROLE	PI (UESTC)	PI (UESTC)	PI (UoG)	PI (UoG)	Co-I (UNNC)	PI (UoG)	PI (UoG)	PI (UoG)	PI (UoG)	Co-I (CYU)	Co-I (UoG)	PI (UoG)	Co-I (UoG)
PI-CO-I	Olivier Romain (P-UCP) Jordane Lorandel (AP-UCP) Xiaozhang Zhu (AP-UESTC)	Olivier Romain (P-UCP) Qian He (P-UESTC) Yier Lin (PhD student – UESTC)	Olivier Romain (P-UCP) Daniyal Haider (Postdoc – UCP) Francesco Fioranelli (AsP-UoG)	Olivier Romain (PI – P-UCP) + 12 collaborators (UoG, TUD, UoLisboa-UFM, UoLisboa-UFM, GHT Novo, Bluelinea, USMB, KCL)	Gethin Roberts (P-UNNC) Xu Tang (Postdoc-UNNC)				Olivier Romain (P-UCP) Francesco Fioranelli (AsP-UoG)	Olivier Romain (P-UCP)	Francesco Fioranelli (AsP-UoG) Lance Voute (SES-UoG) John Marshall (SES-UoG)	Francesco Fioranelli (AsP-UoG) Lance Voute (SES-UoG) John Marshall (SES-UoG)	Xi Ning PI (P-HKU), Roy Vellaisamy (P-UoG), Hadi Heidari (AP-UoG), Sajjad Hussain (AP-UoG), Muhammad Imran (P-UoG), Qammer Abbasi (AP-UoG), Guodong Zhao (asP-UoG) and team members in HK

*PHC: Projet Hubert Curien, PI: Principal Investigator, Co-I: Co-Investigator, UCP: University Cergy-Pontoise, UoG: University of Glasgow, UNNC: University Nottingham Ningbo China, UPS: University Paris-Seine, GHT Novo: Groupement Hospitalier de Territoire – Val d'Oise, USMB: Universite de Savoie-Mont-Blanc, KCL: Kings College London.

Table 14: Details on awards – continued (AP: associate professor, AsP: Assistant Professor, P: Professor, R: Reader)

	SCOTLAND 5G CENTRE – PHASE 2	**TURKISH GOVERNMENT PHD+RESEARCH COST**	**EGYPTIAN GOVERNEMENT PHD+RESEARCH COST**	**GLASGOW FUNDING**	**UESTC FUNDING**	**GLASGOW FUNDING**
TYPE	Public funding	Public funding	Public funding	Internal funding	Internal funding	Internal funding
START	10/2021	10/2021	07/2022	06/2022	05/2021	06/2021
END	09/2022	09/2024	06/2025	06/2022	05/2021	06/2021
DURATION	12 months	36 months	36 months	1 months	1 months	1 months
AWARD	£250k	£75k (tuition fees) +£15k (research cost)	£75k (tuition fees) +£15k (research cost)	£6.2k	£36k	£6.5k
MY ROLE	Co-I (UoG)	PI (UoG)	PI (UoG)	PI (UoG)	PI (UoG)	PI (UoG)
PI-CO-I	Muhammad Imran (P-UoG), and co at UoG and US	Oluwakayode Onireti (AsP-UoG) Wasim Ahmad (AsP-UoG), Muhammad Imran (P-UoG).	Hasan Abbas (AsP-UoG) Qammer Abbasi (R-UoG), Muhammad Imran (P-UoG).	CSI group	CSI group	CSI group

*UoG: University of Glasgow, US: University of Strathclyde, UESTC: University of Electronic Science and Technology of China, CSI: Communication, Sensing and Imaging, PI: Principal Investigator, Co-I: Co-Investigator.

- **Turkish Government**

Indoor Navigation System for Visually Impaired by Using Radar

A study indicates that there were 36 million blind and 253 million visually impaired people in the World in 2015, and this number is growing at an alarming rate. As many visually impaired people have difficulty navigating in public spaces, frequently feeling totally disorientated or even isolated, supportive navigational guidance is very important for them. The main goal of supportive navigational guidance is to allow visually impaired and blind people to walk in real world environment without bumping into the surrounding objects. Many of the existing navigation tools (GPS, etc.) provide navigation information required to travel from one point to another. Despite their utility as a global navigation tool, they do not provide information about indoor environment, which is also variable and unpredictable. In this PhD project, an approach for detecting collisions from a radar system that can predict and give warnings about impending collisions while walking indoors will be investigated. The central question this project asks, then, is: How an indoor navigation system for the visually impaired by using a radar system operating in a noisy environment can be constructed?

- **Scotland 5G Centre – Phase 2**

The Scotland 5G Centre is the national centre for accelerating the deployment and adoption of 5G and realising its economic and societal potential for Scotland.

We're here to enable businesses to reap the benefits of this new technology, bringing together entrepreneurs with a network of small businesses, larger corporates and government bodies.

My role is to focus on radio frequency sensing for healthcare applications within this project.

- **Egyptian Government**

Enhancement of Weak Signal Detection in Radar Systems for Assisted Living

This research will focus on the development of radar systems (hardware and algorithms) to enhance weak signal detection in the context of assisted living.

There is a growing need worldwide to enable the elderly to live at home independently as long as possible. This will only be possible if we are able to monitor their health continuously especially to manage chronic diseases.

In this work, it is proposed to co-design the radar hardware and algorithm in order to have a low-cost, low computation and accurate platform for human activity recognition for the detection of activities of daily living essential for assess the capacity of a person to live independently. Jointly, strategies will be developed to detect the vital signs of the person in a home environment e.g (gait pattern, breathing, heartbeat) which are weak signals in radar in order to infer information on their health status.

- **Glasgow Funding – £6.2k – Mobility and vital signs lab development – continued**

This is an upgrade to the Mocap suite in the MAST lab that includes the software license renewal, the upgrade from a 18 camera fixed system to a 24 camera adjustable with railing in the same room to make the space more flexible and also increase the maximum capture volume. The applications for the motion capture was justified with its applications in healthcare, 3D motion tracking, sport science, flight dynamics, and human robot interface to benefit the engineering community in university of Glasgow as well as attract funding. The accessories being ordered are to enhance the base of reflectors for the capture of body motions and objects with the motion capture suite.

- **Glasgow Funding – £6.5k – Mobility and vital signs lab development**

This was to reactivate the Mocap lab by buying a license that incorporates rigis bodies and soft bodies (e.g., humans) capture, calibrating the suite and train the staff and students in its usage. The money was also used to buy suits for body captures as well as reflectors for 2 people. This was to support the healthcare activity in the Communications, Sensing and Imaging group in University of Glassgow.

- **UESTC funding – £36k – Mobility lab development**

With an ageing population, the development of new in-home sensing modalities is becoming a priority. The mobility lab will enable cross-disciplines to work on assisted living, sports and rehabilitation by developing high-fidelity simulation models for sensor developments. This project will focus on frailty to determine prediction factors leading to frailty that can be observed over time by adapting clinical tests to home environments within daily routines. The mobility/vital signs lab will be used to regularly capture patients to build a database that will be used for research, student projects, and to disseminate the data to a larger public for health technology development.

The mobility/vital signs lab will be a platform for health technology development involving mobility ranging from human activity recognition, vital signs monitoring, rehabilitation and sports science to behavioural research and human-machine interface. For teaching, this will be used for the transnational education program for summer projects, final year project, PhD students locally and in UESTC, and in my course for wireless and biomedical engineering programs. When students are at Glasgow, they will use the mobility lab to capture data for their projects, if off site they will be users of the models stored in the database that we will curate for simulations. The aim will be to provide Glasgow College-UESTC students and our home student facilities to develop sensors safely and get high-fidelity data for exploring new sensing modalities design and ensuring repeatability of experiments for instrumentation and simulations.

The capacity building with the acquisition of a connected mat will allow ground truthing our various sensing modalities against a commercial reference and integrate this sensing modality in clinical practices for us to liaise with them more easily and promote joint funding applications. This will open new collaborations within and outwith the university ranging from engineering with biomedical and medical.

- **RGC Collaborative Research Fund (01/2021 – 01/2023)**

super reality for hands-on online education

Older the effectiveness of two different psychosocial interventions (i.e. telephone-delivered behavioral activation, and telephone-delivered mindfulness interventions) by comparing with telephone-delivered befriending intervention in a 3-arm randomized controlled trial (RCT) of community-dwelling older adults who are living in poverty, living alone and digitally excluded.

- **DIM-RSI (01/2021)**

This grant paid for a connected mat as part of the mobility lab being built at University Cergy-Pontoise for gait analysis and frailty modelling as part of the assisted living research strand.

- **Seeds meeting (12/2019)**

This 2-day meeting is financed by the French Embassy of London to coordinate research actions at the National level (France:ANR, UK: EPSRC) and European level to bid for research projects. This is in support of a project in healthcare for a H2020 on assisted living supporting 12 collaborators from European institutions to join in London for 2 days with flights, meals, accommodation and venue paid for.

- **PHC Xu Guangqi (04/2017 – 12/2017)**

This project will develop remote sensing systems to monitor elderly and vulnerable people and promptly alert carers and emergency services in case of fall events, as well as provide invaluable diagnostic information following fall events, which can cause immediate physical consequences and psychological trauma and reduce the life expectancy of the patients due to the long involuntary time spent on the floor.

One of the great challenges in China is the aging population and associated increased spending for providing healthcare, combined with fewer earnings from active individuals. The transformation of Chinese society and the single child policy is putting strain on the sustainability of healthcare with growing urbanization, lifestyle diseases, and increased demand for better health coverage.

The healthcare spending in China will reach 892b USD by 2018, with predicted growth of 12% a year and one of the 5 priority areas for improvement by 2020 is in medical-service provision. France has similar issues, with increasing elderly population due to longer life expectancy and falling birth rate, and strict cost constraints on the sustainability of the healthcare system.

Inequalities in healthcare provision in urban and rural areas are growing and the healthcare infrastructures are not ready to handle the incoming wave of elderly by 2050. Falls are serious and costly events, therefore an automatic, non-intrusive remote monitoring system allowing faster response time to fall accidents would drastically reduce their consequences. This would also provide 24/7 monitoring capabilities, invaluable diagnostic information following fall events which would be particularly effective in rural areas where healthcare provision is lower than in urban areas.

The main innovation is combining microDoppler and range spread feature extractions with non-intrusive, contactless monitoring capabilities that works night and day to detect fall events and monitor gait to inform diagnosis of degrading physical health and cognition abilities. The system is seamless, and the elderly wouldn't have to learn to use it, it will automatically alert relevant responders to tend to situations.

Neuropathy translates into gait anomaly and increases the risk of falling as it progresses. After a fall, doctors will check gait and balance, as well as ask for the frequency of the falls. This system will provide information on gait and the number of times the person fell before. This would reduce the amount of unreported falls to the doctors.

The outcomes will be

- Technical specifications for the monitoring system development
- Suitable signal processing algorithms to detect falls and signs of degrading health conditions

A Software Defined Radar will be used for experimental tests to determine the appropriate technical parameters and data processing routines to identify fall events and characterise effectively people gait to inform diagnosis such a neuropathy or irregularities in gait pattern which may be a sign of deteriorating health conditions. Initial experiments will be conducted on adult volunteers from the project team.

We will work and test the platform with healthy adults emulating elderly frailty and falls in China with the radar system.

Both ETIS and the University of Electronics Science and Technology of China have significant expertise in signal processing, hardware implementation, microDoppler gait analysis, electromagnetic propagation modelling and state-of-the-art measurement facilities.

Real-time Implementation of radar signal processing for range compression, imaging, feature extraction and classification need to be developed on heterogeneous platforms with parallel processor arrays (PPA) and Field Programmable Gate Arrays (FPGA) however implementation strategies need to be developed to meet the high processing requirements.

The collaboration will build on previous work conducted by Olivier Romain and Julien Le Kernec on the radar platforms and the signal processing algorithms. Using the experience of ETIS with the project surf-on-hertz for signal processing and pattern recognition and the expertise in signal processing, EM modelling and state of that art anechoic chambers from UESTC, the development of a fall detection and gait changes system to care for the elderly can be developed. In the long term, it is intended that UoG, UESTC and ETIS form a consortium applying this technology for the development of Heath Technology development to care tackle frailty and multimorbidity issues in retirement homes and to provide home care.

- **<u>PHC Cai Yuanpei (07/2018 – 12/2020)</u>**

One of the great challenges in China is the aging population and associated increased spending for providing healthcare, combined with fewer earnings from active individuals. The transformation of Chinese society and the single child policy (now 2 children policy) is putting strain on the sustainability of healthcare with growing urbanization, lifestyle diseases, and increased demand for better health coverage.

That means that atop aging, there will also be more people sufferering from multimorbidity (multiple chronic diseases: arthritis, asthma, cancer, chronic obstructive pulmonary disease, diabetes, …) and a rise in the number of people recovering from strokes.

The world health organization reports that approximately 28-35% of people aged of 65 and over fall each year increasing to 32-42% for those over 70 years of age. The frequency of falls increases with age and frailty level. Frailty is accentuated by multimorbidity and stroke recovery. Older people who are living in nursing homes fall more often than those who are living in community. Approximately 30-50% of people living in long-term care institutions fall each year, and 40% of them experienced recurrent falls.

The healthcare spending in China will reach 892b USD in 2018, with predicted growth of 12% a year and one of the 5 priority areas for improvement by 2020 is in medical-service provision. France has similar issues, with increasing elderly population due to longer life expectancy and falling birth rate, and strict cost constraints on the sustainability of the healthcare system.

Inequalities in healthcare provision in urban and rural areas are growing and the healthcare infrastructures are not ready to handle the incoming wave of elderly by 2050. Critical events (Falls, Strokes, …) are both serious and costly but also if a 122ctivity122nerative disease or physical decline is caught early the symptoms and consequences of the ailment can be managed much better therefore alleviating the weight of institutionalizing someone on the infrastructure and keeping people autonomous longer in their own homes.

Current radar systems can be used to monitor users, but it has the potential to enable a step change by making them intelligent enough to learn and categorize the regular activity pattern of an individual user, and then identify subtle anomalies linked to deteriorating health conditions and predict possible critical events (e.g. falls, strokes). This technology will become an enabler for prompt intervention of carers or family following critical events (detection), for monitoring data for health professionals to improve their diagnostic capabilities and provide individualized treatment (prediction), but also provide persuasive feedback to end-users to advise and influence behaviours for safer and better practice, when anomalies in their routine are identified (prevention & assistance). This will transform the current paradigm of technologies from “reactive” to “proactive” monitoring systems.

A novel approach has been recently developed and shows that 90% of sensibility can be reached with cubic SVM from features extracted on the spectrum. This approach allowed to class in several categories (fall, walk, walk carry, etc.) the spectrum delivered by the software radar system that we designed. Although these results are encouraging, these ones must be improved to reach 99% by the identification of new features and benchmarked on a real-time platforms, in many configuration (one to N people). In comparison to the state-of-the-art, this new approach allows to expand the number of activities that are usually classified by adding activities of daily living and gait analysis, these directly relate to diagnostic tools to assess a person's ability to live independently. The other advantage of this approach lies in the multistatic approach where most publications rely on the radial variations to measure the signatures, the fact is that people won't always be moving in the pointing direction of the radar that affects the intensity of the Doppler spread. A multi-static radar would allow to capture signals whichever way the person is performing his/her activities. Finally, most published works only deal with one person. We propose here to develop strategies to deal with multi-occupancy by isolating and classifying the activities of different people/animals simultaneously.

Based on these first results, we propose in this project to extend the software designed radar – INSHAPE (Intelligent radio-frequency Sensing for falls and HeAlth PrEdictions) to the early detection of diseases that introduce progressively hindrances in activities of daily living (ADL) like Parkinson, epilepsy, dementia, etc... The entire machine learning algorithms will be integrated in hardware in the INSHAPE system both for the benchmarking in real-time and for active learning approach. For this purpose, some physicians will be included during the project (in France and in China).

- **PHC Alliance (01/2019 – 12/2021)**

The project Intelligent radio-frequency sensing for assisted living aims to tackle the societal issue of in-home care for elderly and patient follow up after being released from hospital. The increase in elderly population with the added chronic diseases caused by changes in living habits will create a strain on the economic system and hospitals to keep up. By developing a biomedical multimodal sensing system (radar + event camera), we aim to enable personalized care for patients by providing medical practitioners a tool that better informs them about the status of their patients. The objectives of this study will be to provide daily activity maps of patients with human activity recognition and vital signs monitoring with biomedical multimodal sensing. The breakdown of these objectives into research directions is as follows:

1- Classify human activities by exploiting multiple domains of data representations and enhance performance with multimodal data fusion.
2- Separate individual activities from a continuum of activities
3- Extract biomedical information and activity maps from multimodal sensing data

Leveraging on machine learning techniques, we will push the boundaries of assisted living by adding contactless sensing modalities to the suite of sensors already available. This ambient sensing for assisted living will open new alleys for precision medicine by aiding medical practitioners in forming a prognosis with enhanced information including biomedical information and activity maps.
Biomedical information used to aid in forming a medical prognosis and patient follow-up care:

- Respiration rate: measured at rest and on the go (essential for pulmonary diseases)
- Heart rate: measured at rest.
- Gait metrics: Time-up and go (linked with functional mobility), gait speed (ambulation metric).
- Activity maps: they are used to assess the level of independence of a person as part of the functional independence measure.
- Time stamp activities and produce daily activity maps
- Activities of daily living (ADLs) consist of fundamental self-care tasks that include:

Bathing/showering, grooming, dressing, toileting, transferring, self-feeding. Fall detection and near fall detection.

- **Sandpit (01/2015 – 12/2015)**

Using GNSS to monitor deflections of bridges, has been an ongoing area of research in civil engineering for almost 30 years. Both the magnitudes and frequencies, using simple FFT and PSD approaches, can be measured. This project brings together expertise in GNSS, structural engineering, signal processing, electronic engineering and mechanical engineering to research into other methods of signal analysis and using these to create a Structural Health Monitoring system.

The researchers will bring together ideas, and incorporate on the extensive data set already gathered on the Severn Bridge in the UK in 2010, whereby 9 GNSS receivers were attached at various locations, gathering data at 20Hz for 3 days, as well as temperature, wind and traffic information. Such approaches include those used in radar development such as joint time frequency transforms, Gabor transforms, continuous wavelet transform, Winger-Ville distribution or Cohen's time frequency distribution series.

All these data will be used in a numerical model of the bridge, evaluating its dynamic motion, determining its structural mode shape.

This will then be used in a SHM, looking at the changes in characteristics over time, caused by deterioration and damage.

- **IPDF: France, China (12/2017 – 06/2018)**

This project was funding mobility to develop a partnership between University of Glasgow, University of Science and Electronic of China and University Cergy-Pontoise. This allowed the establishment of MoU between Cergy-Pontoise and University of Glasgow and a round of funding applications between UESTC and Cergy-Pontoise.

- **Chancellor Fund: Well (05/2018 – 05/2020)**

We will develop a novel lameness detection method working at any pace with low-power COTS radar and innovative algorithms as trialled in [11]. To quantify reliability, a dataset of sound and lame horses will be collected with radar at all paces. Deep learning and clinical statistical analysis will be used to train classifiers for automatic identification of lameness. To quantify reliability, the results will be checked against clinical information and the gold-standard system for walk and trot [9,10,12]. Radar can operate 24/7 in all weather conditions [13] and is contactless which is ideal for in-situ assessment as evidenced in [11].

- **SPE: Onera (12/2018 – 06/2019)**

This seed fund was attributed to develop a research collaboration between the James Watt School of Engineering and the French Aerospace Lab – Onera. It funded mobility to organise meetings in UK and in France with representatives from the university and Onera.

- **INEX Caring (10/2019 – 10/2021)**

The automatic detection of postures has given rise in recent years to intense research activity and major economic spin-offs. Kinect 3D sensors in particular have reinvented gaming by offering the possibility of taking into account the depth information and thus effectively discriminating typical movements. The challenges still recently organized on this theme nevertheless show the limitations of the current sensors, especially for the recognition of posture in various situations and in particular falls. Fall detection of people and the elderly is a public health issue. One in two seniors falls at least once. Of the 450,000 falls of elderly persons surveyed annually, 37% lead to hospitalization after a visit to the emergency department, with an average length of stay of between 12 and 14 days. Every year, more than 12,000 people die from a direct fall or the consequences of these falls. To respond to these public health issues, solutions based on sensors embedded on the person, sensors integrated in places of life or even cameras have been developed in recent years. These solutions are still limited by the ergonomics, the clutter, the invasion of the privacy (taking plain images), the sensitivity to acceleration, the consumption, the precision of recognition, the discrimination of the situations.

In this context, this project proposes to study a new paradigm based on the use of a software radar. Unlike conventional video sensors, the use of a radar solution can deliver rich information while respecting privacy. This project paves the way for a new mode of early detection of falls of elderly people in specialized institutions (EHPAD). CARING is based on the processing of microDoppler signatures of a software radar. The project aims to define the characteristics of a biomechanical change in behaviour, to process them with artificial intelligence and to validate the performance in EHPAD in real time. The CARING project is supported by a consortium made up of the UCP (ETIS UMR8051), the University of Glasgow, the UESTC in Chengdu and the EPINOMIS company (management of three nursing homes, Neuville, Herblay and Compiègne). A first laboratory prototype was produced as part of a PHC Xu Guanqgi in 2017 to detect a fall with an average recognition rate of 96%, offline. A second prototype in real time must now be developed to perform real-life tests in EHPAD and verify hypotheses.

- **Petplan: lameness locator (12/2017 – 09/2018)**

This project proposed to explore the possibility of using radar sensors to detect signs of lameness or other irregularities is horses' gait. Lameness is a significant problem for performance horses and farmed animals, with severe impact on animal welfare and treatment costs. Lameness is commonly diagnosed through subjective scoring methods performed by trained veterinary clinicians, but automatic methods using suitable sensors would improve efficiency and reliability. In this project, we proposed the use of radar microDoppler signatures for contactless and automatic identification of lameness, and obtained preliminary results for dairy cows, sheep, and horses. These proof-of-concept results are promising, with classification accuracy above 85% for dairy cows, around 92% for horses, and close to 99% for sheep.

- **HBLB: ATLAS (05/2018 – 09/2019)**

The project looked at the automatic detection of lameness using radar. The accuracy of the method is about 90% on a treadmill or outdoors. Because of some hindrances outside of our control in procurement, personnel and data acquisition. Therefore, the method is validated for automated detection and is much more reliable than veterinary observations (~50% accuracy). This method permits the sorting of animals reliably and requires little setting-up time. From our side studies on ruminants, we now know that the size of the animal influences the classification algorithm parameters for best performance. Further work is required to guarantee the ground truth as this may affect performance results negatively. Additionally, future research directions should investigate locating the lame leg (left/right, hind/fore) by exploring future multiple receiver radar systems.

7.4 Student supervision

7.4.1 Supervised Final Year Projects

First name	Last name	Programme	University	Subject	Academic Year	Currently	Publications
Chengfeng	Yue	Beng EEE	UoG/UESTC	Waveform design for radcomm	2022-2023	N/A	
Jiuchuan	Zhang	Beng EEE	UoG/UESTC	Elderly care : Human activity recognition using radar - pre-processing techniques to enhance classification accuracy	2022-2023	N/A	
Ran	Yu	Beng EEE	UoG/UESTC	Elderly care : Human activity recognition using radar – pre-processing techniques to enhance classification accuracy with cyclostationarity	2022-2023	N/A	[CP-10]
Hengxu	Gong	Beng EEE	UoG/UESTC	Elderly care : Human activity recognition using radar - detection algorithms to enhance the isolation of activities in signals	2022-2023	N/A	
Ruoyun	Cheng	Beng EEE	UoG/UESTC	Biometric identification of a person using cyclostationarity - radon and radar data domains to develop a unique signature	2022-2023	N/A	
Shaowen	Ma	Beng EEE	UoG/UESTC	Elderly care Human activity recognition using radar - extracting a walking signature from mocap data and testing it on measured data	2022-2023	N/A	
Junyu	Zhou	Beng EEE	UoG/UESTC	Elderly care Human activity recognition using radar - 4D radar based on mocap data	2022-2023	N/A	
Chong	Ren	Beng EEE	UoG/UESTC	Cow lameness - pre-processing technique to enhance classification accuracy	2022-2023	N/A	
Yutong	Fu	Beng EEE	UoG/UESTC	Cow lameness - unsupervised learning vs human classification	2022-2023	N/A	
Pengzhao	Liu	Beng EEE	UoG/UESTC	Elderly care : Human activity recognition using radar - compression and denoising for	2022-2023	N/A	

				efficient classification			
Siwon	Shin	Engineering degree	Centrale-Supelec	Gait analysis with motion capture – ground truthing	2021-2022	N/A	
Yifei	Yao	Beng EEE	UoG/UESTC	Elderly care：Linking Traditional Chinese Medicine to modern sensing	2021-2022	N/A	
Zhong	Yi	Beng EEE	UoG/UESTC	Elderly care：Breathing/heart rate monitoring.	2021-2022	MSc EEE – University of Glasgow	
Yuxin	Yang	Beng EEE	UoG/UESTC	Elderly care：ECG monitoring	2021-2022	N/A	
Jipeng	Li	Beng EEE	UoG/UESTC	Human Activity Classification Based on a Complex Architecture for Classification or Complex Feature Extraction	2021-2022	Master degree at Tsinghua-Berkeley Shenzhen Institute.	[CNP-5], [CP-10]
Shiyuan	Liu	Beng EEE	UoG/UESTC	Application of Compressed Sensing in Ultrasonic Signal Processing and TOF determination	2021-2022	MSc EEE, University of Stanford	
Yaxin	Du	Beng EEE	UoG/UESTC	Radar-based human activity classification in transformer model with cyclostationary approach	2021-2022	Shanghai Jiao Tong University for a PhD degree in high-order graph learning	[CNP-5], [CP-10]
Yuxiang	Mao	Beng EEE	UoG/UESTC	Using machine learning for human activity classification testing radar geometries	2021-2022	MSc communication system, KTH royal institute of technology, Sweden	
Haotian	Xiang	Beng EEE	UoG/UESTC	Elderly care on the usage of transformers for radar-based human activity classification	2021-2022	N/A	
Zhouyixian	Li	Beng EEE	UoG/UESTC	Elderly care cyclostastionarity for human activity classification with radar – compression of feature space	2021-2022	MSc ECE, University of Pennsylvania	[CNP-5], [CP-10]
Shuyi	Ying	Beng EEE	UoG/UESTC	Elderly care：Emotion detection	2020-2021	MSc EE, University of Pennsylvania	
Kai	Yang	Beng EEE	UoG/UESTC	Elderly care – Using machine learning for human activity classification testing radar geometries	2020-2021	MSc Computer Control and Automation, Nanyang Technological University	[CP-5]
Linfeng	He	Beng EEE	UoG/UESTC	Elderly care – adapting an existing radar prototype for activity recognition	2020-2021	MSc Computer Control and Automation, Nanyang Technological University	
Yan	Peng	Beng EEE	UoG/UESTC	Elderly care：Human activity	2020-2021	MSc Integrated Circuit Design, TUM Asia, NTU	

				recognition using radar – adaptive			
Wei	Lai	Beng EEE	UoG/UESTC	Elderly care：Breathing/heart rate monitoring using radar	2020-2021	MSc EEE, Nanyang Technological University	
Kecheng	Xing	Beng EEE	UoG/UESTC	Elderly care – Using machine learning for human activity classification with radar interferometry	2020-2021	MSc EEE, University of Glasgow	
Tianhe	Li	Beng EEE	UoG/UESTC	Elderly care：ECG using radar	2020-2021	N/A	
Jiaqi	Guo	Beng EEE	UoG/UESTC	Elderly care ：Using Machine Learning on multiple radar data domains exploiting fusion	2020-2021	MSc in EE, Northwestern University	[CP-11]
Chang	Shu	Beng EEE	UoG/UESTC	Elderly care ：Using Machine Learning on multiple radar data domains exploiting time series for classification	2020-2021	King Abdullah University of Science and Technology – fully funded MSc/PhD ECE 5 years	[CP-11]
Xinyu	Zhang	Beng EEE	UoG/UESTC	Elderly care ：Human activity recognition using radar – open dataset	2020-2021	MSc ECE, University of Michigan	[CP-6]
Xingzhuo	Li	Beng EEE	UoG/UESTC	Elderly care – human activity recognition and gait analysis with radar	2019-2020	MSc TU Delft in EEE	[IJM-11], [CP-13]
Jia	Mu	Beng EEE	UoG/UESTC	Elderly care – deep learning for human activity recognition on optimizing data pre-processing for high accuracy	2019-2020	MSc HIT Shenzhen in EEE	[CP-21, 23]
Yunsong	Zhang	Beng EEE	UoG/UESTC	Elderly care – adapting an existing radar prototype for activity recognition	2019-2020	MSc in ECE, Georgia Tech-Shenzhen Campus in China..	
Shaoxuan	Li	Beng EEE	UoG/UESTC	Elderly care ：Using Machine Learning on multiple radar data domains.	2019-2020	MSc in Signal processing an communication – University of Edinburgh	[CP-23]
Zhiling	Peng	Beng EEE	UoG/UESTC	Elderly care – design a wearable sensor for the monitoring of activities and vital signs.	2019-2020	Msc in Computer Control & Automation at NTU Singapore	
Jianwei	Lai	Beng EEE	UoG/UESTC	Elderly care – Using machine learning for human activity classification with multistatic radar	2019-2020	Applying for further studies	
Ruxue	Yan	Beng EEE	UoG/UESTC	Elderly care：is Wifi vision better than radar vision for 128 ctivity recognition?	2019-2020	MSc in EE – University of Pennsylvania, USA	
Muhammad Iqbal Bin	Sapii	Beng Mechatronics	UoG/SIT	Design and Development of a	2019-2020	Looking for a job as Mechatronic	

				Reliable and Robust FMCW Radar System		engineer in Singapore	
Boyu	Zhou	Beng EEE	UoG/UESTC	Elderly care – Using machine learning for human activity classification with radar interferometry	2018-2019	MSc in Computer Science – University of Hong Kong	[IJM-6], [CP-16]
Tianxi	Qi	Beng EEE	UoG/UESTC	Elderly care – design of a wearable sensor for health monitoring: temperature, galvanic skin response, heart rate, fall detection.	2018-2019	MSc in signal and image processing as a graduate student in the George Washington University, USA.	
Xinyu	Hu	Beng EEE	UoG/UESTC	Elderly care – on the effect of morphology on human activity classification with radar with machine learning	2018-2019	MSc in Communication engineering, NTU Singapore.	
Xuyu	Fang	Beng EEE	UoG/UESTC	Elderly care : Using Machine Learning with accelerometers for activity recognition	2018-2019	Master's degreeField Of StudyGreen Electronics, NTU, Singapore	
Zhenghui	Li	Beng EEE	UoG/UESTC	Elderly care : Using Machine Learning with wearable sensors to optimize the activity recognition accuracy	2018-2019	PhD in EEE- University of Glasgow	
Jun Qi	Ng	Beng Mechatronics	UoG/SIT	Design and Development of Low-Cost FMCW Radar System	2018-2019	N/A	
Kit Wa	Li	Beng Mechatronics	UoG/SIT	FPGA Based Signal Generator and PC Interface for Low-Cost Radar System	2018-2019	N/A	
Yiming	Lyu	B.Eng EEE	UoG/UESTC	Automotive anti-collision radar: exploring new radar waveforms	2017-2018	MSc in Electromagnetic field and microwave technology, UESTC, China	
Jiayi	Li	B.Eng EEE	UoG/UESTC	Kinect-based skeleton extraction for human motion recognition	2017-2018	Software Engineer – Apple – USA	[IJM-17]
Shuting	Huang	B.Eng EEE	UoG/UESTC	Elderly care: fall detection with radar	2017-2018	Msc in data analysis and statistics, California Lutheran University, USA	
Xinyu	Yang	B.Eng EEE	UoG/UESTC	Everything you always wanted to know about UWB radar	2017-2018	MSc in Management Science and engineering – UESTC, China	
Yixiao	Huang	B.Eng EEE	UoG/UESTC	Digital core implementation for automotive anti-collision radar	2017-2018	N/A	
Chen	Yang	B.Eng EEE	UoG/UESTC	Elderly care: fall detection with remote access to	2017-2018	Technology Development- NAND CMOS	

				3D accelerometers and GPS		Process Integration-Engineer, Micron Technology Singapore	
Yifei	Jin	B.Eng EEE	UoG/UESTC	microDoppler analysis in high range resolution radar – human gait	2016-2017	School of Visual Arts School of Visual Arts Master of Fine Arts – MFA Field Of StudyComputer Arts	
Zhiyi	Yang	B.Eng EEE	UoG/UESTC	Design and implementation of a robotic car controlled by a smart phone: robotic car	2016-2017	Storage Software Engineer at Dell EMC, USA	
Yi	Li	B.Eng EEE	UoG/UESTC	multi-target detection using Linear Frequency Shift Keying	2016-2017	PhD in Computer Science,Newcastle University, UK	
Yucheng	Xia	B.Eng EEE	UoG/UESTC	Digital Audio Broadcasting receiver with an FPGA	2016-2017	Research intern, Institute of Optoelectronic Technology, Chinese Academy of Sciences, China	
Chuncheng	Wu	B.Eng EEE	UoG/UESTC	Design and implementation of a robotic car controlled by a smart phone: smart phone app	2016-2017	MSc in Electronics and Electrical Engineering. University of Glasgow, UK	
Yinghao	Li	B.Eng EEE	UoG/UESTC	FPGA based signal generator – digitizer – PC interface	2016-2017	N/A	
Zhi Xuan	Loh	Beng Mechatronics	UoG/SIT	Design and development of a small low-cost FMCW radar system	2016-2017	Onboard lead engineer in navigation system readiness in the Republic of Singapore Navy.	
Yash	Anil Singh Shikarwar	B.Eng EEE	UNNC	Airplane blackbox prototyping for radar phase compensation for SAR applications	2014-2015	Network Engineer at KDC technologies, USA	
Pin	Zeng	B.Eng EEE	UNNC	Signal generation and signal acquisition with a digital core FPGA for a DIY radar	2014-2015	Senior Application Engineer at Nexperia	
Alexander	Melnikov	B.Eng EEE	UNNC	Real-time implementation of radar signal processing on FPGA and DIY radar prototyping	2013-2014	PhD Student in the Department of Electronic and Information Engineering at The Hong Kong Polytechnic University	[CP-49, 55, 56]
Chen	Shen	B.Eng EEE	UNNC	Performance analysis of OFDM and Chirp for Software-Defined radar on a USRP	2013-2014	Senior Physical Design Engineer – Sondrel Ltd – China	

7.4.2 Supervised M.Sc./M.Eng. students

First name	Last name	Programme	University	Subject	Academic Year	Supervision load	Currently	Publications
Jueluo	Asha	M.Sc. EEE	University of Glasgow	Experimentation on polarisation and interferometry in drone HERM lines	2021-2022	J. Le Kernec 80%, D. Anderson 20%	N/A	
Adam	Thorburn	M.Eng. Mechanical Engineering	University of Glasgow	Additive Manufacturing of a Bearing Cooling Fin	2021-2022	Douglas Thomson 80% J. Le Kernec 20%	N/A	
Zuo	Chen	MSc Mechatronics	University of Glasgow	Emotion recognition using EEG	2021-2022	J. Le Kernec 100%	N/A	
Cameron	Bennett	M.Eng. Electrical and Electronic Engineering	University of Glasgow	Classification of UAVs in holographic radar	2019-2020	F. Fioranelli 50% J. Le Kernec 50%	Knowledge-to-Practice Engineer at Aveillant, UK	[CP-18]
Joe	Walker	M.Eng. Electrical and Electronic Engineering	University of Glasgow	Digital electronics (confidential) – @Cirrus Ltd	2018-2019	D. Bremner 50% J. Le Kernec 50%	Digital Design Engineer at Cirrus Logic, UK	
Conor	McHarg	M.Eng. Electrical and Electronic Engineering	University of Glasgow	ADAS radar – beamforming and detection performance evaluation @p	2018-2019	F. Fioranelli 50% J. Le Kernec 50%	Financial Modelling Analyst at KPMG UK	
Jianfei	Li	M.Sc. Electrical and Electronic Engineering	University of Glasgow	Human activity classification from MicroDoppler Radar Signatures	2017-2018	100%	N/A	
Jian	Li	M.Sc. Electrical and Electronic Engineering	University of Glasgow	Piggy-backing 131 ommunication on top of radar signals " learning lessons from passive radar for active radar waveform design	2017-2018	100%	N/A	
Vlad	Coman	M.Eng. Electrical and Electronic Engineering	University of Glasgow	Radar absorbing metamaterials: active vs passive @Onera	2017-2018	F. Fioranelli 50% J. Le Kernec 50%	Intern, Information Security Department for Raiffeisen Bank, Romania	
Charlie	Owens	M.Eng. Electrical and Electronic Engineering	University of Glasgow	Processor Architecture Analysis of Task-Based Scheduling for Airborne Radar – Leonardo	2017-2018	F. Fioranelli 50% J. Le Kernec 50%	Graduate Digital Hardware Engineer – Leonardo, UK	
Harmony Kerry	Ojehomon	M.Sc. Electrical and Electronic Engineering	University of Nottingham	Empirical Analysis of Chirp and Multitones Performances with a UWB Software Defined Radar	2014-2015	100%	Project Engineer at Marks and Spencer, UK	
Yanis-Sofiane	Hamma	M.Sc. SESI – Embedded	University Pierre and	Radar waveform	2010-2011	O. Romain 50%	Hardware Electronic	

	Systems and Computer Systems	Marie Curie	performance evaluation for OFDM and Chirp		J. Le Kernec 50%	Engineer – Mentor Graphic – France	

7.4.3 PhD Students

First name	Last name	Programme	University	Subject	Academic Year	Supervision load	Currently	Publications
Mostafa	Elsayed	• PhD in EEE	UoG	Enhancement of Weak Signal Detection in Radar Systems	08/2022	J. Le Kernec 40%, Q. Abbasi 30%, H. Abbas 20%, M.Imran 10%	N/A	N/A
Claire	Beranger	PhD in EEE	ETIS/CYU	Gait recognition and fall prediction with deep learning on microDoppler signatures	06/2022	O. Romain 30%, Son Vu 30%, Amine Khelif 30%, J. Le Kernec 10%	N/A	N/A
Abdullah	Akaydin	PhD in EEE	UoG	Indoor Navigation System for Visually Impaired by Using Radar	10/2021	J. Le Kernec 40%, O. Onireti 30%, W. Ahmad 20%, M. Imran 10%	N/A	N/A
Alexandre	Bordat	PhD in EEE	ETIS/CYU	Early estimation of signs of biomechanical failures by unconventional radar imaging. Applications to the robust prediction of falls in the elderly.	07/2021 – to date	O. Romain 50%, P. Dobias 30%, J. Le Kernec 20%	N/A	[IJM-8][CP-2]
Weirong	Sun	PhD in EEE	UoG/UESTC	A robust high-resolution technology based on data compression	09/2020 – to date	M. Imran (40%), Y. Zhang (40%), J. Le Kernec (20%)	N/A	
Fawei	Yang	PhD in EEE	BIT (visiting UoG)	MIMO radar and wideband arrays techniques for the detection, tracking and classification of low, slow, and small targets	10/2019-03/2020 (visiting) Advising 04/2020 to date	F. Fioranelli (50%), J. Le Kernec (50%)	N/A	[IJM-5][CP-15]
Zhenghui	Li	PhD in EEE	UoG	Deep learning for multidomain radar-based continuous human activity recognition for multiple targets	10/2019 – to date	J. Le Kernec (50%), Lei Zhang (30%), S. Yang (20%)	N/A	[CP-9, 10, 14, 17, 27]; [P-2]
Shuojie	Wang	PhD in EEE	UoG	Robotic arm wireless system control based on 5G Control Systems.	10/2019 – to date	G. Zhao (60%), J. Le Kernec (40%)	N/A	N/A

Kang	Tan	PhD in EEE	UoG	Machine learning in vehicular networks	10/2019 – to date	D. Bremner 60%, J. Le Kernec 30%	N/A	[IJM-3, 3], [CP-24, 29]
Konstantina	Linardopoulou	PhD Veterinary Science	UoG	Lameness detection using contactless radio-frequency radar	10/2019 – to date	N. Jonsson (40%), F. Fioranelli (20%), J. Le Kernec (20%), L. Viora (20%)	N/A	[CP-1, 20]
Chuanwei	Ding	PhD in EEE	NJUST	Human Motion Recognition Theory and Technologies Based on Non-contact Bio-Radar	10/2018-10/2020	Hong Hong (80%), J. Le Kernec (10%), F. Fioranelli (10%)	Assistant Professor in EEE, Nanjing University of Science and Technology, China	[IJM-21, 24], [CP-33]
Jarez	Patel	PhD in EEE	UoG	Innovative radar detection & classification of small UAVs or drones	10/2017 – to 03/2023 (incomplete to date – student on indefinite sick leave)	F. Fioranelli 50%, Dave Anderson 30% (50 since 10/2019), J. Le Kernec 20% (1st since 10/2019 and 50% loading)	N/A	
Haobo	Li	PhD in EEE	UoG	Wearable devices and radar for human activities monitoring and classification	04/2017-01/2021	F. Fioranelli 50%, J. Le Kernec 30% (1st since 10/2019 and 50% loading), Hadi Heidari 20%	Postdoc in Physics department, University of Glasgow, UK	[IJM-7, 9, 10, 12, 15, 16, 19, 20, 28], [CP-19, 32, 34 ,37, 45]
Yier	Lin	PhD in EEE	UESTC	Non-linear parameter estimation and classification of radar microDoppler signatures	04/2017-06-2020	Z. Zhao 50% J. Le Kernec 50%	Postdoc Scholar CRRC Corporation Ltd, Beijing, China	[IJM-6, 23, 25], [CP-43]
Aman	Shrestha	PhD in EEE	UoG	Radar microDoppler for healthcare applications	10-2016-09/2021	F. Fioranelli 50% J. Le Kernec 50% (1st since 10/2019)	Assistant researcher, Hitachi, Japan	[IJM-9, 10, 12, 15, 16, 17, 19, 20, 23, 27, 28], [BC-3]. [CP-31, 34, 41, 42, 45]
Charalampos	Loukas	PhD in EEE	UoG	Activities of daily life (ADL) classification in multi-occupancy scenarios with radar and deep learning	10/2017-09/2018 (terminated)	J. Le Kernec 50% F. Fioranelli 50%	Unknown	[IJM-27], [CP-38]
Petros	Hadjichristodopoulou	PhD in EEE	UoG	RF waveforms for simultaneous applications	09/2017-09/2018 (terminated)	F. Fioranelli 60% M. Imran 30%	Unknown	

				in radar and communication domains		J. Le Kernec 10%		
Francis Xavier	Ochieng	PhD Civil Engineering	UNNC	The use of ground-based radar to monitor the deflections of wind turbine masts and blades	10/2016-04/2019	C.M. Hancock 50% G.W. Roberts 30% J. Le Kernec 20%	Research Fellow in Energy at Institute of Energy & Environmental Technology - Jomo Kenyatta University of Agriculture and Technology – Juja, Kenya	[IJM-18, 23], [BC-4], [CP-44]
Chengfang	Ren	PhD in Signal Processing	ENS Cachan visiting UNNC	Lower bounds on the mean square error: theory and applications in signal processing field	09/2014-11/2014	J. Le Kernec (100% UNNC visit)	Researcher, SONDRA, Centrale-Supelec, Gif s/ Yvette, France	[CP-50, 51]

7.4.3.1 Current PhD students

- Mr Mostafa Elsayed – "Enhancement of Weak Signal Detection in Radar Systems for Assisted Living"

Summary:

This research will focus on the development of radar systems (hardware and algorithms) to enhance weak signal detection in the context of assisted living.

There is a growing need worldwide to enable the elderly to live at home independently as long as possible. This will only be possible if we are able to monitor their health continuously especially to manage chronic diseases.

In this work, it is proposed to co-design the radar hardware and algorithm in order to have a low-cost, low computation and accurate platform for human activity recognition for the detection of activities of daily living essential for assess the capacity of a person to live independently. Jointly, strategies will be developed to detect the vital signs of the person in a home environment e.g (gait pattern, breathing, heartbeat) which are weak signals in radar in order to infer information on their health status.Indoor Navigation System for Visually Impaired by Using Radar"

==

- Miss Claire Beranger – "Gait recognition and fall prediction with deep learning on microDoppler signatures"

Summary:

The automatic detection of postures has given the rise in recent years to intense research activity and significant economic spin-offs. Kinect 3D sensors, in particular, have reinvented gaming by offering the possibility of taking into account the depth information and thus effectively discriminating typical movements. The challenges recently organized on this theme nevertheless show the limitations of the current sensors, especially for the recognition of posture in various situations and critical events such as falls. Fall detection of people and the elderly is a public health issue. One in two seniors falls at least once. Of the 450,000 falls of elderly persons surveyed annually, 37% lead to hospitalization after a visit to the emergency department, with an average length of stay of between 12 and 14 days. Every year, more than 12,000 people die from a direct fall or the consequences of these falls. To address these public health issues, solutions based on worn embedded sensors, ambient sensors or even cameras have been developed in recent years. These solutions are still limited by the ergonomics, the clutter, the invasion of privacy (taking plain images), the sensitivity to acceleration, the consumption, the precision of recognition, the discrimination of the situations. Unlike conventional video sensors, the use of a radar solution can deliver rich information while respecting privacy. Radar paves the way for a new sensing modality of early detection of frailty in elderly people in specialized institutions (nursing houses) or in a home environment. The processing of raw data produced by an FMCW radar allows to produce microDoppler images. By using handcrafted features and statistical learning (i.e., image processing coupled with a low foot-print machine learning), the recognition off-line of the gait in the radar image can be done with a high rate (96% for the fall, for example). Currently, a real-time implementation on an embedded platform (e.g. GPU, FPGA, DSP) is in progress.

Objectives:

In this context, the main challenge is to monitor a patient in daily life to produce a reference biomechanical "signature". Deviations from that reference over time represents an interesting solution to identify early signs of frailty, to prevent a fall. This challenge addresses several scientific issues:

1. Find out the action recognition algorithms that are robust to the patient's movement with respect to the radar. Indeed, the shapes in the radar images are distorted according to the orientation of the person in front of the radar. To this end, one can consider to use large-scale dataset to train deep neural networks but collecting such a large annotated radar dataset is too expensive. One possible research direction is to use many unlabeled data by following the last trends of self-supervised learning and self-training that are successfully used for natural language processing, visual recognition [1] as well as for mobile sensor-based human action recognition [2, 3, 4].

2. How to follow-up of activities over time and to define strong features for early fall prediction and prevention? Several works have been carried out in the literature [5] and a recent series of Precognition workshop has been organized [6] to promote the advanced research on visual and sensor-based forecasting or precognition.

3. The algorithms being developed will be first evaluated on lab-based dataset and then on real-life data with elderly patients in a nursing home or hospital environment. On that stage, domain adaption and knowledge distillation techniques can be applied [7].

[1] T. Chen et al., "A simple framework for contrastive learning of visual representations". In International conference on machine learning 2020.

[2] A. Saeed et al., « Multi-task self-supervised learning for human activity detection ». Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 3, 2 (2019).

[3] C. I. Tang et al., "SelfHAR: Improving Human Activity Recognition through Self-training with Unlabeled Data", In Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (IMWUT), 2021

[4] Y. Jain et al. "ColloSSL: Collaborative Self-Supervised Learning for Human Activity Recognition", Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2022

[5] M. Hemmatpour et al. "A review on fall prediction and prevention system for personal devices: Evaluation and experimental results". Adv. Hum. Comput. Interact. 2019.

[6] https://sites.google.com/view/ieeecvf-cvpr2022-precognition/

[7] Z. Cao et al., "Towards Cross-Environment Human Activity Recognition Based on Radar Without Source Data" IEEE Transactions on Vehicular Technology 2021.

==

- Mr Abdullah Akaydin – “Indoor Navigation System for Visually Impaired by Using Radar”

Summary: A study indicates that there were 36 million blind and 253 million visually impaired people in the World in 2015, and this number is growing at an alarming rate. As many visually impaired people have difficulty navigating in public spaces, frequently feeling totally disorientated or even isolated, supportive navigational guidance is very important for them. The main goal of supportive navigational guidance is to allow visually impaired and blind people to walk in a real-world environment without bumping into the surrounding objects. Many of the existing navigation tools (GPS, etc.) provide navigation information required to travel from one point to another. Despite their utility as a global navigation tool, they do not provide information about indoor environment, which is also variable and unpredictable. In this PhD project, an approach for detecting collisions from a radar system that can predict and give warnings about impending collisions while walking indoors will be investigated. The central question this project asks, then, is: How an indoor navigation system for the visually impaired by using a radar system operating in a noisy environment can be constructed?

==

- Mr Alexandre Bordat – “Early estimation of signs of biomechanical failures by unconventional radar imaging. Applications to the robust prediction of falls in the elderly.”

Summary: The main contribution of this thesis is to propose a novel framework of observations improving the reinforcement of the prevention of “falls” by repeated daily measures on targeted populations (multifactorial prevention). The originality of the approach lies in the observation and characterization of the person's behavior through non-conventional imagery (radar-based system), which does not impose any particular protocol, specific action or device. Observation tools and techniques are therefore required to capture extended execution traces of the activities in order to fully understand deviations of behavior or failures that may happen during daily life. The failures (fall, stumbling, night fall, …) may represent a small proportion of the amount of recorded data. So, such tools must be robust as is must identify falls in all circumstances; easy to setup as it is used by physician; easy to integrate in commercial set up; and autonomous. This thesis is a multidisciplinary project: combining hardware and software expertise applied to the health sector.

==

- Mr Sun Weirong – “A robust high-resolution technology based on data compression”

Summary: Radar has been used in a wide range of applications, such as target identification, assisted living and other fields. This research aims to explore sampling optimisation to build a robust (self-diagnosis of failure), high-resolution (virtual UWB) framework for assisted living utilising little channel capacity and reducing the amount of intelligence required near the sensor and reducing the load on edge computing with data compression (skeletonisation). Experimental instrumentation will include sub-GHz, 1-6GHz and mm-wave bands radar for human target measurements and array testing. Results from experimental measurements will be used to develop a robust (self-diagnosis of failure), high-resolution (virtual UWB) framework for assisted living.

==

- Mr Shuojie Wang – “Robotic arm wireless system control based on 5G.”

Summary: This Research Proposal considers control and communication co-design to achieve ultra-reliable and low latency in wireless networks to control a robotic arm. As the main communication scenario in 5G technology, URLLC is promising to realize real-time wireless control function with high reliable and extremely low delay. The objective is to minimize the transmission latency under power constraints and reduce the resource consumption. In this research, the proposed method is to co-design the communication protocol to dynamically adapt the signal to control a fleet of robotic arms in an industry 4.0 scenario based on task requirements to maintain QoS, throughput, latency, energy, and resources.

==

- Mr Kang Tan – "Machine learning in vehicular networks"

Summary: According to the literature review, vehicular networks have become vital important for enabling intelligent transportation systems (ITS) applications via information sharing. However, the application requirement and heterogeneous nature of vehicular networks introduce new challenge in both communication and networking aspects. Machine Learning (ML), a powerful tool for adaptive and predictive system development, has emerged in both vehicular and conventional wireless networks, providing data-centric methods to tackle the challenges faced by traditional solutions. For this project, on Machine Learning methods application in vehicular networking, three research topics have been identified, including 'deep reinforcement learning enabled handover optimisation', 'distributed spectrum resource management', and 'energy efficiency via intelligent cell switching'. The report covers both background and experimental detail for the ongoing topic 1 demonstrating the progress already achieved, while for the other two topics, background and motivation is introduced, with. In addition, other accomplishments throughout the second year and a plan for the next 12 months with a rough thesis plan are also covered in this report. Due to the impact of COIVD-19, the project experienced moderate impact, and the related information is also recorded in this document for reference

---

- Miss Konstantina Linardopoulou – "Lameness detection using contactless radio-frequency radar"

Summary: Lameness in productive animals could be considered as one of the major issues. Often the problem cannot be recognised on time due to the impassivity of the animals and then the treatment could be estimated as delayed. The process of finding out lameness requires either experienced and trained personnel or technological equipment that can be proved extremely uneconomical.

Nowadays, there are methods based on radio-frequency radar sensors that offer several advantages as regard the costs and labour on detection of lameness. Through this study beyond the fact that welfare and wellness of the animals are going to be better off, farmer's job is also going to be improved, be faster and more inexpensive.

The main purpose of this pioneering study is the establishment of radar signtures as an automatic diagnostic tool for precision veterinary medicine, development of innovative algorithms that will provide information about the animal's condition without the requirement of direct contact with the animal, the effect of the surgical parameters to the total performance of the system and finally the quantification of the output of the method.

Research Objectives:

Lameness of ruminants influence the health and welfare of animals, also affects their productivity therefore the farmers, too. Impact of lameness can be observed on milk yield, on animal's weight and in carcass quality, on nutrition and reproduction.

The vulnerability of the method that is being used until today for recognition and detection of lameness is the fact that is based on the experience and training of the human resources or the cost of the expensive technological equipment that should be operated which occasionally requires the binding and restraint of the animal.

Using radar signatures alleviate all the vulnerabilities that have been mentioned above will be avoided. Experience and long training will not be a necessity anymore neither high expenditure is going to be required or animal welfare will be jeopardized.

Specifically, the project will deal with the following questions:

- What are the ways of modelling, testing and classifying animal's locomotion?
- How can radar data be processed and used through machine-learning methods to automate lameness detection?
- How robust the labelling through visual inspection is to train supervised machine learning algorithms?

==

- Mr Zhenghui Li – "Deep learning for multidomain radar-based continuous human activity recognition for multiple targets"

<u>Summary</u>: Activity classification can help individuals to monitor dangerous events such as fall. In this plan, deep learning-based approach such as convolutional neural network, is proposed to investigate activity classification in a variety of domains such as range Doppler image and microDoppler spectrogram. In addition, further study would focus on the continuum and multi-occupancy problem. People's activity is continuous under living condition, and it is likely to have more than one target (pets, other person) in the view of radar system. Data obtained by radar is used for developing methods to separate a series of continuous activities into single activity. Besides, radar signatures are deployed to identify people under multi-targets situation. Other categories of sensors can also be utilized, and data fusion method is implemented to achieve a more accurate result.

The objectives are to:

- Design human activity classification algorithms using multi-domain information
- Design a radar system for multi-occupancy scenarios to discriminate people and animals for multi-occupancy scenarios
- Design human activity classification algorithms for multi-occupancy scenarios

==

- Mr Jarez Patel – "Innovative Radar Detection & Classification of Small UAVs or Drones"

<u>Summary</u>: Micro-Drones or Unmanned Aerial Vehicles (UAVs) have become increasingly popular amongst many communities such as hobbyists, professional photographers and potentially Amazon, one of the biggest online corporations. Amazon have recently announced plans to test drone delivery systems in the UK, which could fulfil up to 90% of their orders, increasing low altitude air traffic enormously. There is also a great potential for these systems to aid in search and rescue, agricultural maintenance and even policing monitoring. Drones are well suited to undertake this task as these environments consist of a large functioning volume, dismissing the need for land vehicles or helicopters to be deployed, hence reducing operational costs tremendously.

However, there have also been a significant number of cases where these readily available platforms have been exploited for crime, such as: the trafficking of illegal substances, spying on individuals and the disruption of commercial flights through operation in reserved airspace. There is also the potential for these systems to carry dangerous payloads or chemical agents which could be released in targeted areas with devastating consequences. In all these cases, the misuse of these platforms has proven to be a significant danger and has caused severe confusion amongst authorities as they are not trained to deal with these threats and do not have the appropriate systems in place to counter such intrusions.

Radar sensors have been shown to have the capability to actively detect and track such platforms; in addition to this they have the advantage of operating at long ranges, in poor visibility conditions and in darkness. In order to safely integrate these new aerial vehicles into low altitude airspace, further research must be conducted to understand the characteristic signatures produced, to successfully detect and to verify their presence.

This PhD has 3 objectives:

- Design, simulate and prototype a flexible multiband FMCW radar system (hardware and signal processing) capable of accurately measuring the radar signatures produced by a drone, through a range of different radar parameters.
- Implement automatic classification algorithms and potentially integrate payload detection techniques.
- Identify and evaluate suitable waveforms for each radar task and if time allows make it intelligent and automatic through reinforcement learning.

==

7.4.3.2 Completed PhDs

- Dr Aman Shrestha – "Radar microDoppler for healthcare applications"

Summary: With an increasing global population who continue to live to a longer age, challenges in the form of multi-morbidity conditions are arising in the forms of multi-morbidity conditions. These conditions correlate with age and present severe consequences to the individual and the supporting societal and economic systems.

Falls are the singular risk leading to many multi-morbidity conditions. Their effect is recognised in the UK as the National institute for health and care excellence UK (NICE) estimates a cost of $2.3 billion per year is incurred due to falls. Severe consequences to mental well-being which falls can cause is another consideration which needs to be made.

NICE recommend a risk prediction tool which predicts the likelihood or risk of a person falling and this is the key reason why monitoring activities beyond falls is important. This tool should predict falls by measuring parameters which can detect pre-existing conditions which can indicate a high risk of falls.

The project's main objective involves classifying activities with radar signatures from human movement which relies on the microDoppler effect. This is observed in joint-time frequency representations of radar returns, as minute frequency modulations caused by rotational or oscillatory movements alongside the central Doppler shift caused by the traversal main motion.

The finer objectives are:

- The design and analysis of classification methods for discrete human activity classification
- The design and analysis of classification methods for continuous human activity classification
- The design and analysis of methods to extract breathing rate from subjects under observation

==

- Dr Haobo Li - Wearable devices and radar for human activities monitoring and classification

Summary: Numerous sensing technologies have been employed in the field of assisted living. Each of them has pros and cons. Our concern is combining different sensors to achieve better performance than using them individually. In the case that one sensor loses the quality of data or simply can't provide enough information, another sensor is acted as an 'Enhancer' to complement with the weaker one by its strength. Even in the best case scenario (each sensor is working properly), we have proved multimodal sensing still outperforms than single sensor.

Information fusion aims to explain the multi-dimensional data matrix by producing a more representative model to characterize the user's behaviour. It can take place at three different levels, notably, signal, feature and decision level. Signal level fusion requires the joint sensor data with high compatibility, for instance, accelerometer and gyroscope. Feature level fusion is usually combined with feature selection algorithm to reduce the dimension of the feature subset and achieve subsequent improvement. Decision level fusion is typically a voting system (e.g. majority voting, weighted voting), if we add any preference on the classifiers according to their classification performance of certain classes, they it becomes a Naïve Bayes Combiner or Recall Combiner. Apart from that, decision fusion also includes the combination of confidence levels of each classifier to generate a new output.

The objectives are to:

- Design fusion techniques (signal-, feature- or decision-level) to optimize human activity recognition leveraging multimodal sensing
- Design human activity classification algorithms for continuous actions using soft and hard fusion
- Design feature selection techniques and analyze the saliency of features and their effects on classification

==

- Dr Chuanwei Ding – "Human Motion Recognition Theory and Technologies Based on Non-contact Bio-Radar"

<u>Summary:</u> Human motion recognition has attracted great interest for different purposes, such as surveillance, search and rescue operations, smart home, and senior people care in assisted living facilities. Various methods for human motion recognition have been proposed. Radar-based human motion recognition may complement the conventional technologies because of its potential for high accuracy, robustness, and privacy preservation. The thesis considers all information provided by radar regarding time, range, Doppler and Radar Cross-Section (RCS) features of different body parts to recognize various human activities. New techniques for feature extraction are proposed under both individual and continuous motion detection.

A multiple-layer classification method is introduced for comprehensive human motion recognition, including the largest number of motion types ever studied. First, in the pre-screening layer, range information from binary images is used to divided them into in-situ motions and non-in-situ motions, according to which physical empirical features and principal component analysis (PCA) based features are extracted based on a proposed weight range time frequency transform (WRTFT) spectrogram.

A novel dynamic range-Doppler trajectory (DRDT) method is applied to recognize continuous human motions with various conditions emulating real-living environment. This method can separate continuous motions and process them as single events. First, range-Doppler frames consisting of a series of range-Doppler maps are obtained from the backscattered signals. Next, the DRDT is extracted from these frames to monitor human motions in time, range and Doppler domains. Then, a peak search method is applied to locate and separate each human motion form the DRDT map. Finally, time, range, Doppler, RCS and dispersion features are extracted and combined in a multi-domain fusion approach for the following classification.

Extensive experiments based on both Impulse Radio Ultra-Wideband (IR-UWB) and Frequency Modulated Continuous Wave (FMCW) radar systems are conducted and demonstrated their feasibility and high performance in human motion recognition, especially in distinction between fall and fall-similar motions.

==

- Dr Yier Lin – “Non-linear parameter estimation and classification of radar microDoppler signatures”

Summary: With increasing numbers of terror attacks and their diversity, automating the detection and classification of "normal behavior" against anomalous behavior has never been more important. Security systems for mass surveillance need to be able to identify and learn what "normal" behavior is, in order to isolate anomalous behaviors or threats from a crowd of people moving in an area or building. Therefore, first and foremost, accurate classification of activities or individuals is a key enabler. Although classification could be performed with video or images, for the sake of protecting privacy, cameras are not allowed in many places, and furthermore might be sensitive to lighting and weather conditions especially outdoors. However, radar is an interesting sensing modality to investigate as an alternative or complementary tool as it can operate night and day and in all weather.

Classically, activities or individuals are distinguished with methods based on microDoppler radar signatures. The relative motion of structural components of an object/body generates unique patterns in the time-frequency domain of the radar returns. Therefore, different activities are generating uniquely distinctive features in microDoppler signatures - a.k.a. spectrograms - that can be used for classification. This kind of technique relies on features that are either formulaic (e.g. centroid, skewness) or handcrafted. The best set of parameters for optimal classification accuracy is usually determined by trial and error, and requires significant effort in fine-tuning the values of the input features. When activities are similar in nature like walk, fast walk and running, the classifier will be faced with “confusers” that drastically reduce accuracy and re quires new strategies to deal with those. This PhD will explore how novel approaches to classification and estimation can optimize the performances of human activity classification compared to classic microDoppler. The objectives of this thesis are:

- The design of a radar simulator to generate radar signatures for human activity classification
- The design of novel classification algorithms based on deep learning
- The design of novel estimation techniques to extract features to optimize classification.

==

- Dr. Francis Xavier Ochieng – “The use of ground-based radar to monitor the deflections of wind turbine masts and blades”

Abstract: Metrological features like vertical gradients in wind speeds, wind direction and turbulence intensity are becoming more decisive in design and deployment of wind turbines (WT). This has fuelled a need for new measurements techniques to collect the specific parameters for structural health monitoring (SHM) of the wind mast and blades. Importantly it has led to an increase in non-contact measurement techniques as well as need for better validated modelling techniques that address problems of (a) flutter and (b) type and component certification of WT blades and masts. One such novel approach is the use of Ground-Based Radar (GBR) as a non-contact SHM sensor.

GBR are increasingly being used either as a vibration-based or as guided-wave-based SHM sensors for monitoring of WT blades and masts. The study contributes to the monitoring of blades and masts during design, testing, and in-field operation. The optimal monitored condition parameters (CP’s) that the GBR can utilise are identified as the component modal frequencies and deflection at blade tips and tower nacelle.

The research gap and subsequently novelty being addressed include: First, the apparent lack of singular studies that consider a portable GBR for SHM of in-field blades and masts of level 1 damage detection while the WT is operating normally under international IEC standards 61400-1 Design load conditions (DLC) 1.1. to 1.5. Secondly, the apparent lack of studies for utilising GBR under SHM framework for WT operating in actual conditions. Previous studies (and not under SHM framework) focussed on WT in a parked position or under laboratory set-ups.

This research thus sought two main objectives (a) GBR determination of the two SHM Condition Parameters (CP), modal frequencies and flapwise deflection, for an operating in-field wind turbine blade and masts and (b) Integration of GBR into the 3-tier framework and its validation thereof. In achieving this research objectives and answering the research questions, a conceptual framework cognisant with type and component certification for blade and mast design (IEC 61400-1, IEC 61400-2) and full blade SHM under IEC 61400-23.

Using simplified Sammon mapping, 2D visualization techniques, Operational Modal Analysis (OMA's) and three set of multi-sensor experiments the objectives of the research were progressively achieved. The first experiment involved GBR determination of the frequency on a Steel I-beam hit by an impact hammer with accelerometer as the ground-truth. The second involved use of a custom-made rotating arm to acquire deflection of a beam structure in a rotating motion. Third experiments focussed on the CP acquisitions from an operating in-field WT. The main WT components being the WT blades and tower.

The GBR results were in first experiment validated using a Geographical Positioning System (GPS). The aim of these 2 experiments were primarily to assess the capability of the GBR to acquire CP's, the accuracy of the acquired values and most importantly CP's acquisitions by GBR within a 3-tier SHM framework. Correction of the GBR results were also undertaken using Welch Power Spectrum estimation and Group delay response for the frequencies results. The third experiment had its resulted validated using a OMA's in form of a Campbell diagram under a 3-tier SHM framework.

The key results from the 3 cluster experiments were as follows:

1. I-Beam experiment: - Comparisons between the GBR results with those of an accelerometer indicated a divergence of 0.1% from accelerometer results when a correction was applied, and 3.5% without correction.

2. Rotating arm experiment: - Employing a rotating beam structure with GPS Leica AR 25 choke antenna attached at the tip, the system was used to model a rotary structure. The deflection characterization was done using a portable GBR and the output from the GPS. Using Sammons mapping, GBR results were processed and thereafter compared those of a GPS, which indicated a divergence ± 3.12%

3. Operational in-field WT: - The GBR was able to acquire both the both CP's (modal frequencies and flap wise deflections) for the blade and mast. The validation results were obtained from OMA Campbell diagram. An accuracy of 2% was achieved when the GBR results were compared WT design parameters as provided by the Campbell diagram. This experiment, was the focus of this thesis, by demonstrating the actual deployment of a GBR for WT blade and mast monitoring

The above three sets of experiments were thus able to demonstrate the ability of GBR for SHM of WT blades and masts, while also enabling its integration as a 3-tier SHM framework. Thus, providing significance of this research to the wider wind energy industry and monitoring world for

(a) Flutter through acquisition of SHM condition parameters (CP's) that can be used to verify the results of flutter design process for optimization of WT blades.

(b) Easing the Type and component certification process for WT blades and masts by implementation of 3-tier SHM framework to address the

(i). Deficiency of current fatigue damage metrics in blade-tip monitoring as well as,

(ii). Insufficient understanding of the structural behaviour of FRPC materials under long-term real operating conditions.

In conclusion, using GBR for on-shore infield WT during real time operations provides data to enable validation and improvement of current aeroelastic models for flutter analysis. Thus, providing significant information towards flutter analysis and improvement of future flutter models. The thesis also entrenches the use of GBR as a non-contact sensor in level 1 damage detection for infield WT composite blades within a 3-tier SHM framework.

This work suggests additional work be done regarding whirling mast movements monitoring using GBR. This will particularly support the development of a flutter analysis model. Further work may also need to be done in the application of GBR monitoring within a 3-tier SHM framework for off-shore WT where vertical subsidence of the sea plays a key role.

7.4.3.3 Visiting PhD students

- Mr Fawei Yang – "MIMO radar and wideband arrays techniques for the detection, tracking and classification of low, slow, and small targets"

Summary: The detection of low, slow and small (LSS) targets has always been a research hotspot in the field of radar. It has great research significance and application value in many aspects such as urban security, anti-terrorism, aircraft bird strike prevention and so on. As civilian drone technology continues to mature, small drones are getting more and more available to the general public. In recent years, sales of consumer drones have increased significantly due to cheap price and ease of use, and the applications of these unmanned aerial vehicles (UAVs) has become more widespread. The most common use of UAVs including surveillance and reconnaissance missions, agriculture and environmental monitoring, disaster response as well as private leisure use such as aerial photography and filming. Besides the positive aspects of small UAVs, however, small drones can be also misused to conduct dangerous activities or even terrible crimes, such as privacy violation, illegal monitoring of restricted areas, collision hazard with people, buildings, and larger aircrafts. Furthermore, small drones can carry cameras, toxic chemicals or explosives and can be deployed for spying, smuggling or even terrorist attacks. As for LSS targets like birds, they may cause birds strikes near the airport and have great potential risks to the safety of civil aviation. Thus, there is a strong demand on developing new technologies for LSS targets detection and starting appropriate intervention procedures in advance.

LSS targets are targets with low flight altitude, slow speed, and small radar-cross section (RCS). These targets are quite challenging for radar systems to detect and track. The main reason is the low flight altitude, and when it is observed by radar, a large amount of ground clutter will enter the receiver at the same time. Meanwhile, the shielding, attenuation, and multipath effects of electromagnetic waves in complex terrain environments have increased the difficulty of ground-based radars to detect low-altitude targets. Secondly, due to the slow flying speed, the Doppler shift of the echo signal itself is small, and the clutter spectrum broadening caused by the random Doppler component generated by the surrounding environment, such as trees or grasses, will adversely affect the detection of slow moving targets. Thirdly, many LSS targets consist of non-metallic materials with very small RCS, which leads to low signal-to-noise ratio (SNR) or signal-to-clutter ratio (SCR). The target is easily submerged by clutter and noise, affecting radar detection performance. In addition, the radar tracking problem appears more difficult as the highly varied motion of small drones makes it impossible to make assumptions about the expected motion.

Multiple-input multiple-output (MIMO) radar systems have many advantages compared to mechanical scanning systems or fully filled phased array systems, and it can be used in LSS target detection. In a MIMO system, orthogonal waveforms are transmitted to form a low-gain wide transmit beam.

This visit will explore signal processing and classification techniques for LSS targets with MIMO radar.

==

- Dr. Chengfang Ren – “Lower bounds on the mean square error : theory and applications in signal processing field”

Abstract: The aim of this thesis is to evaluate the theoretical optimal performance for hybrid estimation problems (i.e. when parameters to estimate are random for one part and non-random for the other part) in signal processing applications. In statistical estimation context, the performance of an estimator is generally characterized by its Mean Square Error (MSE). In order to quantify the MSE of an estimator, the classical approach is to resort to Monte-Carlo simulations. These simulations are time consuming depending on estimator’s complexity. Therefore, lower bounds on the MSE are developed to quantify the optimal estimator’s MSE. These bounds require less computing time and allows to predict the optimum region of operation of estimators for a given observation model. Indeed, when the observation model is not linear with respect to the parameters to estimate, it is well known that a signal-to-noise ratio (SNR) threshold occurs leading to large estimation errors. Consequently, the knowledge of this particular value for which this threshold appears is fundamental. There is a plethora of lower bounds on the MSE in the literature (Cramér-Rao bound, Barankin Bound, Ziv-Zakaï bound, Weiss-Weinstein bound ...) that have been derived using different mathematical inequalities such that: Cauchy-Schwartz inequality, Hölder inequality, covariance inequality. The goal is to predict accurately the threshold and to have a tight bound able to approximate as closely as possible the optimal estimator’s MSE.

During his visit he worked on a constrained hybrid Cramér-Rao bound for parameter estimation applied to radar Doppler estimation.

7.4.3.4 Discontinued PhD students

- Mr Charalampos Loukas (Oct 2017- Sept 2018) – “Activities of Daily Life (ADL) classification in multi-occupancy scenarios with radar and deep learning”

Summary: Automatic monitoring, to discriminate between different activities of daily life (ADL) and especially to identify critical events, such as falls, attracted signi_cant interest in the research community due to rising of the old-age dependency ratio and the demand for improved living conditions. The percentage of 65+ years old will reach 30% by 2050 in the European Union according to projections. Hence, increased spending towards healthcare has to be provided, which comes in contrast with the reduced economic resources from less active employees.

This problem stems from Ambient Assisted Living (AAL) concept, which aims to provide a useful bridge of communication, between carers and vulnerable people, patients at medical places or elders at home, making use of a plethora of devices, such as wearable, camera based, RGB-depth and radar sensors. Among these devices, radar is a promising candidate due to its attributes. It supports contactless and nonintrusive monitoring capabilities, with no requirement needed from the elders to carry or wear sensors during their daily life, which can cause stigmatisation, frustration and anxiety. Besides, radar technology reduces to the minimum the security of human privacy life as no optical images of the end users are recorded. Hence, it is important to approach human monitoring, prioritizing the human privacy to avoid legal issues for image rights.

Monitoring activities of daily life can range from walking, jogging which show an active person up to crawling or standing still which can indicate that the person present a health problem or is at risk. In addition, monitoring activities of daily living patterns can cover anomalies as deviation of the `normal' behaviour such as the degradation of human health, providing the carer/medical stu_ with useful data to act accordingly.

Moreover, critical events such as falls is of special concern since they can lead to injuries, reduced physical activity or even to death, especially for the elders. According to World Health organisation the percentage of people above 65 that fall, accounts to 28-35%. Therefore, an active scheme has to be researched which will eliminate the total time needed to collect data using radar sensors, provide the

outcome about the presence of a critical event and reduce to the minimum false alarms. In that way, the response of families and health professionals to people at risk will be immediate.

The aim of this PhD project is to enable the automatic monitoring of vulnerable people (older people and people with physical and cognitive impairments) to support caregivers, families, and health professionals making use of radar sensors. In that way the conventional healthcare model directly connected with the hospital will be centred around the home and provide medical care using state-of-the -art technologies. Experience obtained in that field, will be complemented with the design of a reliable solution for the end users, acting as the main monitoring system. Auxiliary sensors such as wearables or camera based will compensate for false alarms resulting in a more stable
and reliable solution.
The objectives are to:

- Conduct a systematic investigation of deep learning methods to process assisted living data, not only for short-term activity classification and fall detection, but also for longer-term discovery of anomalies in users' behaviour and daily activity patterns.
- Integrate deep learning techniques with multistatic radar around multi-occupancy scenarios. These scenarios will include the presence of more than one individual to the field of observation, using multiple radar nodes to address problems of occlusions of the monitored subject.

==

- Mr_Petros_Hadjichristodopoulou (Sept 2017- Aug 2018) – "RF waveforms for simultaneous applications in radar and communication domains"

Summary: Frequency spectrum is increasingly becoming an expensive and rare commodity, as the number of mobile users and provided services increases worldwide. This creates a "crunching" effect, potentially detrimental for telecommunication applications (cap to the number of users, need for additional infrastructures, increased latency unsuitable for real- time multimedia services), and even more for radar applications (the narrower allocated frequency bandwidth reduces resolution to sense targets of interest, and restricts the possibility of using different parts of the spectrum for different radar tasks, for example detection vs tracking). Hence this project investigates the integration of radar and communication systems. The two systems use very similar hardware. However, a good communication system requires maximising the entropy embedded in the transmitted waveform, while, a good radar system requires coherent waveforms to maximise detection performance. Consequently, a good radar-communication system results by compromising between the two.

The radar-communications convenience is a complicated problem widely researched. According to Chiriyath et al. waveform diversity is a dominant research area in the field of radar and communication integration. Signals such as Orthogonal frequency division multiplex (OFDM), spread spectrum (Direct sequence spread spectrum DSSS) waveforms and multiple input multiple output (MIMO) techniques have been extensively examined. The work of Sturm et al. emphasizes on the waveform design for fusion of wireless communications and radar sensing. During this study, the basic radar waveforms have been identified (FMCW, LFM, pseudorandom, phase and frequency coding) together with the basic communication waveforms and digital modulation techniques (OFDM, BPSK, QPSK, 8 PSK, 16 QAM 64 QAM) [3]. Hence, the first objective of the project is the understanding of the above-mentioned signals and modulation techniques. Secondly, the work done the last decade in the joint radar/communication systems must be investigated in order to establish the state of art of the radar/communication system research area. For the conduction of a more comprehensive study, the work done on this field should be categorized. Thus, a clearer view is obtained, where all the signals used as well as the parameters used are listed in a comprehensive form. The primary objective of the project is to generate, transmit and receive the found signals by RF hardware. Seemingly, before the hardware operation, simulations must be conducted to create a "control group", so we can compare the results obtained by the RF hardware with the "control group". After the successful operation of the desired system, machine learning techniques is planned to be applied in order to select different parameters, dependent on the environment that the system is used.

The objectives of this project are:

- to design a system capable of generating, transmitting and receiving waveforms capable of combining radar signals and communication data.
- to design the performance metrics for the evaluation of radar/communication wavefroms into a figure of merit
- to implement strategies for the adaptive use of the spectrum and task scheduling for optimized use of resources

7.4.4 Postdoctoral staff

First name	Last name	University	Subject	Period	Supervision load	Currently	Publications
Daniyal	Haider	University Cergy-Pontoise	Design of a Software Radar for the Early Identification of Gait Failure in EHPAD: Application to Fall Detection	10/2019-02/2020	O. Romain (50%) J. Le Kernec (50%)	Lecturer in Games & AI, De Montfort University, UK	CP-28
Xu	Tang	University of Nottingham Ningbo	Design of time-frequency transform algorithms for the analysis of bridge deformation based on GNSS data	01/2015-12/2015	G. Roberts (50%), C.M. Hancock (25%) J. Le Kernec (25%)	Lecturer at Nanjing University of Information Science & Technology	N/A

- Dr. Daniyal Haider – "Design of a Software Radar for the Early Identification of Gait Failure in EHPAD: Application to Fall Detection" – (Oct 2019 – Feb 2020) – INEX Caring

Summary: Design of a Software Radar for the Early Identification of Gait Failure in EHPAD: Application to Fall Detection The automatic detection of postures has given rise in recent years to intense research activity and major economic spin-offs. Kinect 3D sensors in particular have reinvented gaming by offering the possibility of taking into account the depth information and thus effectively discriminating typical movements. The challenges still recently organized on this theme nevertheless show the limitations of the current sensors, especially for the recognition of posture in various situations and in particular falls. Fall detection of people and the elderly is a public health issue. One in two seniors falls at least once. Of the 450,000 falls of elderly persons surveyed annually, 37% lead to hospitalization after a visit to the emergency department, with an average length of stay of between 12 and 14 days. Every year, more than 12,000 people die from a direct fall or the consequences of these falls. To respond to these public health issues, solutions based on sensors embedded on the person, sensors integrated in places of life or even cameras have been developed in recent years. These solutions are still limited by the ergonomics, the clutter, the invasion of the privacy (taking plain images), the sensitivity to acceleration, the consumption, the precision of recognition, the discrimination of the situations. In this context, this project proposes to study a new paradigm based on the use of a software radar. Unlike conventional video sensors, the use of a radar solution can deliver rich information while respecting privacy. This project paves the way for a new mode of early detection of falls of elderly people in specialized institutions (EHPAD). CARING is based on the processing of microDoppler signatures of a software radar. The project aims to define the characteristics of a biomechanical change in behaviour, to process them with artificial intelligence and to validate the performance in EHPAD in real time. The CARING project is supported by a consortium made up of the UCP (ETIS UMR8051), the University of Glasgow, the UESTC in Chengdu and the EPINOMIS company (management of three nursing homes, Neuville, Herblay and Compiègne). A first laboratory prototype was produced as part of a PHC Xu Guanqgi in 2017 to detect a fall with an average recognition rate of 96%, offline. A second prototype in real time must now be developed to perform real-life tests in EHPAD and verify hypotheses. In this context, the objectives are to:

• Design an FPGA architecture for the real-time processing of spectrograms

• Develop a hardware solution for extracting and classifying spectrograms.

• Develop an operational prototype for EHPAD tests.

• Evaluate and analyze the performances the performances of the developed system against the state-of-the-art.

==

- Dr Xu Tang – "Design of time-frequency transform algorithms for the analysis of bridge deformation based on GNSS data" – (Jan 2015 – Dec 2015) – Sandpit UNNC

Summary:

Using GNSS to monitor deflections of bridges, has been an ongoing area of research in civil engineering for almost 30 years. Both the magnitudes and frequencies, using simple FFT and PSD approaches, can be measured. This project brings together expertise in GNSS, structural engineering, signal processing, electronic engineering and mechanical engineering to research into other methods of signal analysis and using these to create a Structural Health Monitoring system.

The researchers will bring together ideas, and incorporate on the extensive data set already gathered on the Severn Bridge in the UK in 2010, whereby 9 GNSS receivers were attached at various locations, gathering data at 20Hz for 3 days, as well as temperature, wind and traffic information. Such approaches include those used in radar development such as joint time frequency transforms, Gabor transforms, continuous wavelet transform, Winger-Ville distribution or Cohen's time frequency distribution series.

All these data will be used in a numerical model of the bridge, evaluating its dynamic motion, determining its structural mode shape.

This will then be used in a SHM, looking at the changes in characteristics over time, caused by deterioration and damage.

7.5 PhD Viva and mini-viva participation

7.5.1 Context

All PhD and MSc by research students, whether part-time or full-time, must carry out an annual progress review in all years following first registration.

The purpose of the annual progress review is to:

• Determine whether a student should progress to the following year of research study and gauge the feasibility of completion within the timescale allotted (3.5 years with a maximum of 4 years from start date).

• Provide an opportunity for the student to present aspects of their work and achievements for the session.

• Provide an opportunity for the student to raise any issues about their research experience.

• Provide feedback to the student on their research, personal development and performance.

• Set clear goals for the following year.

• Support supervisors and students to maintain and develop a dynamic research community.

7.5.2 For year 1, 2, and 3 students

The student writes a Technical Report the content of which may vary depending on whether the student is in their first, second or third year. The type of work that the student is expected to submit may include a selection from:

• an analysis of the literature (students in first year);

• a description of any preparatory work or familiarization with the relevant equipment/software (mainly students in first year);

• a description of the research carried out (students in first year and second year);

• a rough plan of the thesis (students in second year and third year);

• a Gantt chart of the work planned for the following 12 months

The length of the Technical Report should be about 4000 words long (excluding references).

The content of the Technical Report must be discussed with supervisors before submission.

Submission or presentation of work which is not one's own, without acknowledgement of the sources, is considered plagiarism and may be subject to severe sanctions (see http://www.gla.ac.uk/services/plagiarism/).

Following the uploading of the technical report and Gantt chart to the online system (https://webapps.eng.gla.ac.uk/progress/login), the student completes parts A and B of the Annual Review Form and the Training Analysis form.

Upon submission the supervisor(s) will be requested to complete part C of the Annual Review Form, including a recommendation as to the student's future registration.

The system then alerts the student to confirm acceptance of the comments made by the supervisor(s). This should be done as soon as possible otherwise the miniviva team will be unable to view the report. If students have any issue with the supervisor(s) comments, they should contact the PGR Administrator for further advice.

The representative from each research division who sits on the PGR Committee will be responsible for setting the Examining Committee comprising an examiner with knowledge of the area of work of the student but not involved in the supervision, and a convener whose role is that of ensuring consistency across the student cohorts.

The student attends a meeting (mini-viva)2 conducted by the Examining Committee to discuss the submitted Annual Review Form, Training Analysis form and Technical Report. By default, supervisors are not present at the mini-viva but students can ask them to attend. The meeting starts with a brief introduction by the student about their work, followed by questioning of the student from the Examining Committee. The mini-viva is expected to last between 30 and 45 minutes. Students will be informed by the Convener beforehand should a short presentation be required. Biomedical Engineering students are expected to prepare a presentation (please contact Dr Alasdair Clark for more information).

At the end of the mini-viva, the Examining Committee completes the Outcome of Review Form. It is the responsibility of the Examining Committee Convener to make sure that the form is completed online not later than 3 working days after the mini-viva has taken place. Only in special cases where disagreement exists between the recommendation of the Examining Committee and the recommendation of the supervisor(s), completion of the form can be postponed so to allow consultation between the Examining Committee, the supervisor(s) and the PGR convener. Upon submission both the student and their supervisor(s) receive an alert that the outcome is available to view.

7.5.3 For year 4 students

The technical report should be the thesis/chapters outline and/or the contents page, showing a clear understanding of what the finished thesis will look like. The Gantt chart should indicate the number of chapters that will make up the thesis and how many are completed. Of the incomplete ones the % of completion and the agreed submission date should be included. Once submitted online the supervisor will have the opportunity to comment and make a recommendation. Approval and recommendation from the Convener of PGR Studies completes this process.

Those who have completed their viva or have a viva date that will not allow for graduation in June/July must complete the Thesis Pending Form to allow their record to roll into the new session come August. Only registered students with no debt to the University will have an automatic right to enroll for graduation.

The thesis is expected to be submitted in 3.5 years with an absolute maximum of 4 years from the PhD start date. Please note that there is no automatic right for an extension and that delaying moving to thesis pending does not give extra time to complete the thesis.

7.6 Teaching practice

7.6.1 Details of teaching activities

7.6.1.1 Teaching pre-academic posts

7.6.1.1.1 Course 2005-2006 – Cork Institute of Technology

In these courses, I was the module convenor and created the courses from scratch. I developed the course material, teaching activities (lectures, labs), and assessments. I reported directly to the Head of the department as a part-time Lecturer.

History of Computer Science and Office Automation- Engineer Level 1 8h of Lectures and 16h of labs

I prepared a course for chemistry L1 engineering students on the basics of computer science:
- History of computer science and components
- Windows Features
- Desktops: Word, Excel, PowerPoint

Operational Systems Architecture – 2nd Year Technicians 18h course – 8h TP

I prepared a course for technicians in the 2nd year in Computer Science. The goal was to teach them the essentials about Windows and Linux operating systems.
- Linux and Windows architecture
- Linux installation and configuration
- Basic command on Linux

In this course, I was the module convenor and created the course from scratch. I developed the course material, teaching activities (lectures, labs), and assessments.

7.6.1.1.2 Course 2007-2008 – UPMC- Polytech' Paris

In these courses, I carried out the labs provided by the lead academic of the course and was in charge of ensuring the labs could be conducted and modify them if necessary as well as marking .

Programmable Board Design - M2-ACSI - Architecture and Integrated Systems Design 12h of labs

The purpose of these labs was to upgrade new students entering the 2nd year of master's degrees on VHDL programming and the bases of NIOS on FPGA platforms.
- VHDL
- Creating digital block libraries
- Nios I
- Nios II
- SOPC-Builder

Digital Electronics - ELI3 - Electronics and Computing 8h of labs – 16h of projects

This 3rd year engineer course was intended to cover the basics of VHDL programming on Quartus:
- VHDL programming - text and graphics
- Use of chronograms
- Setting up and programming of FPGA cards

7.6.1.1.3 Course 2008-2009 – UPMC- Polytech' Paris

In these courses, I carried out the labs provided by the lead academic of the course and was in charge of ensuring the labs could be conducted and modify them if necessary as well as marking .

Programmable Board Design - M2-ACSI - Architecture and Integrated Systems Design
12h of labs

Idem

Digital Electronics - ELI3 - Electronics and Computing
8h of labs and 16h of projects

Idem

Digital Telecommunications - ELI4 - Electronics and Computing
16h of labs

The aim of this course was to give the 4^{th} year engineers the basics of modulation and demodulation techniques in digital telecommunications. The labs were made on the FPGA card for the base band and analog for the Radio Frequency part.

7.6.1.1.4 Course 2009-2010 – UPMC – Polytech'Paris

I was an ATER (Attaché Temporaire d'Enseignement et de Recherche) at University Pierre and Marie Curie and Polytech'Paris. I was in charge of delivering the teaching activities labs, tutorials and projects and ensuring the material could be run with the equipment. I had for system architecture to design the labs and carry them out as the lead academic delegated this work to me. For Electronic components, I was in charge of designing the tutorial questions for distance learning.

Digital Electronics - ELI3 - Electronics and Computing
15h of tutorials + 8h of labs

Tutorials were used to reinforce the concepts taught about VHDL in the Quartus environment, including differences between sequential and simultaneous programming and the basics of digital architecture.

labs – same as previous year

Digital Telecommunications - ELI4 - Electronics and Computing
16h of tutorials + 16h of labs

The tutorials were intended to reinforce the concepts taught in parallel by simulating modulation and demodulation techniques with Matlab

labs – same as last year

CoDesign - ELI4 - Electronics and Computing
48h project

The goal of this 24-hour mini-project was to create a digital thermometer displaying the data on a VGA screen. This project was done on FPGA with the implementation of a NIOS.

Digital Signal Processing - ELI4 - Electronics and Computing

12h of projects

The 12-hour project was designed to design a sound equalizer using a blackfin DSP card in Visual DSP. Students had to implement audio stream acquisition, filtering and volume adjustment before applying sound equalizer options using interruptions.

Sequential Electronics - ELI4 - Electronics and Computing
12h Project

The goal was to implement a digital FPGA calculator that includes addition, subtraction, multiplication and 16-bit division operations with ALU and RAM.

VHDL - E2I3 - Electronics and Industrial Computing
4h Tutorial

Bases for using Quartus.

System architecture - E2I3 - Electronics and Industrial Computing
44h of labs

The goal was to teach students how to create digital system architectures. The labs covered state machines, simple systems architectures, and pipeline multiplication implementation with Keil Vision and Quartus.

SOCMP - E2I4 - Electronics and Industrial Computing
32h of labs

The goal was to teach students how to create digital system architectures with Modelsim and System C-AMS. TPs were used to reinforce the concepts learned in class by implementing a BCD converter, a custom square root IP and modeling an 8051 Controller.

7.6.1.1.5 Course 2010-2011 - Conservatoire National des Arts et Métiers

I was an ATER (Attaché Temporaire d'Enseignement et de Recherche) at Conservatoire National des Arts et Métiers. I was in charge of delivering the material as specified by the lead academic. In analog electronics, I had to redesign the labs as the students did not cover the theory to carry the labs in good condition. Therefore, I changed the labs into lectures/tutorials/labs to consider the students' learning needs.

Digital Electronics - L1 - Microprocessor Architecture and Programming
45h lectures/Tutorials/Labs

The goal was to teach first-year engineering students the general architecture of a microprocessor, instructions, address modes, assembler programming, function writing, battery management and real-time interruptions on a 68HC11 and 68HC12 microprocessor.

Microwave signal transmission - ET2
14h of tutorials + 40h of labs

Tutorials and labs were used to reinforce the concepts of microwave signal transmission learned in class. Labs were performed on ADS Agilent for simulations and on network analyzer to measure components.

- Coaxial cable line constants
- Reflectometry
- Smith's Abacus: Impedance, Admittance and Impedance Adaptation

- Microstrip components: Wilkinson filter, coupled lines and couplers

Microwave Systems - M1
27h lectures/tutorials

The goal was to teach theory about active components with transistors on ADS Agilent. The course covered the static and dynamic characteristics of transistors, dual grid mixers and distributed amplifiers. 2 hours were devoted to spectrum analyzer practice for the study of gain, compression point at 1dB and 3dB, harmonics and passive components.

Analog Electronics - L1
21.5h of labs

These labs were used to apply basic electronics learned in class such as the characterization of a diode, bipolar transistor, astable multivibrator circuit and an R-2R analog digital converter.

Electronic components - L2
30 hours distance learning

These distance courses concerned the physics of the components:

- Materials, insulators, conductors and semiconductors
- Balanced semiconductors
- Electron dynamics: unbalanced semiconductors
- Elemental components: PN, PIN, MS, MIS, heterojunctions, bipolar transistors and field effects.

7.6.1.2 Assistant Professor at the University of Nottingham Ningbo China (Courses 2012-2015)

I was a lecturer at the University of Nottingham Ningbo China between 2012-2015. I will detail my role in each of the items below.

Electronic construction project – 3rd year Engineer EEA – Course Convenor
2h of lectures - 30h of projects

- The goal was to develop the analytical and problem-solving capabilities in the field of electronic design and realization. The students analyzed, built and adapted an audio amplifier and its power supply from project specifications.

In this course, I had within a month to prepare a lab with all the necessary equipment to carry out the lab as there were no oscilloscopes, power supplies, soldering irons, or components to carry out the module. I had to prepare a bid for tender to procure the equipment and get the material ready for the course to design an audio amplifier and its power supply.

Introduction to Real-Time Systems - 2nd Year EEA Engineer – Course convenor
2h of lecturer and 30h of projects

- This project was based on the implementation of a digital processing of a Microprocessor audio signal in C to learn the basics of real-time systems. The students made the circuit and software part in pairs.

In this course, I had to procure the cards from Microsim and develop the courses from scratch as well as the project at the end of the semester. This included procuring equipment for a second lab as our student numbers had increased. This meant putting together a proposal to the faculty for a budget to increase the capacity by incorporating the occupancy rates of the labs and the student numbers to justify the expenditure.

Foundation in Physics – 1st year engineer - (2012-2013) Teacher

5h of lectures - 30h of tutorials – 16h of labs

- This module introduced the foundations in physics:
  - Basics in magnetism and electricity
  - Scalars and vectors for the study of forces applied to rigid structures.
  - The physical explanation of light and electrons, from modeling to applications.
  - Dimensional analysis and similarity.

In this course, I was a co-teacher I had to design 5h of lectures in physics as well as tutorials accompanying those, online activities for revisions and running the lab experiments in association with the lectures.

Laboratory techniques and presentation -2nd year Engineer EEA (2013 to 2015) Course Convenor
10h of lectures - 39h of labs - 24h of projects

- This module covered laboratory techniques for electronics that complemented the other more theoretical electronics modules taught simultaneously. This included TP and a project to carry out a pairing with a report writing for each TP and for the project (a presentation).
  - Instrumentation, Matlab (basic commands and communications), alternative signals, Introduction to OrCAD, Single Phase Transformer, Three-phase induction engine, electronics (diode, transistor and amplifier)
  - Project: signal generator, signal selector and active rectifier filter
  - Presentation: report writing, poster, presentation with slides and bibliographic research.

This new course further stretched our capabilities to get students in labs in concurrently with physics. So I had to write another proposal to turn another room in the building in a new lab space for electronics by putting in a proposal with the faculty reviewing the entire curriculum and other curricula in the faculty making use of our lab facilities. This course was imported from the UK and only required adjustment for lab procedures in relation to the differences in equipment between the UK campus and the Chinese campus.

Business planning for engineers – 4th year Engineer EEA (2013 to 2015) – Course convenor but not teacher - exam writing, course organization and speakers, administration, presentation reviewer)
20h of lectures (N/A)

- This module presents a diverse set of topics that a qualified engineer is likely to encounter in the world of work. This will allow them to acquire the knowledge they need to write and evaluate rudimentary business plans and make informed decisions about product and business development. It includes various common models, tools and concepts within the business community, including: the Belbin team training model, the appropriate use of PEST and SWOT analyses, marketing bases, product lifecycle, audits sources of finance, intellectual property, ethics and product design. Creating an idea for a new product and developing it in a business plan is both the primary means of evaluation and a way to discuss the above topics in a meaningful context.

Microwave communications - 4th year engineer. (2013-2014) Course convenor
16h of lectures

- This module provides an overview of microwave telecommunications systems. Topics cover the characteristics of the atmosphere and ionosphere, microwaves in open space (link equation, satellite communications, wireless links, radar), microwave guides and filters, circuits equivalent of microwave transmission lines, matrix representation of microwave networks (transfer matrix, diffusion matrix) and impedance adaptation.

For this course, I imported the material from the UK and updated the material especially as most of the content had not been updated in 20 years.

Business awareness in technical education – 3rd and 4th year of science and engineering. (2014 to 2015) Course convenor but not teaching - exam writing, reviewer, course and stakeholder organization, administration) extracurricular
20h of lectures

- This module aims to improve business education and personal development for engineering and science students for their work experience, postgraduate studies and future careers. It includes:
    - Business acumen
    - Presentation skills
    - Entrepreneurship
    - Intellectual property/patents, warranty, reliability, product life, entrepreneurship, product design, technology management, accounting and product/manufacturing cost, product/positioning marketing, project management and risk assessment, innovation, foresight, project financing and expressing complex ideas to a non-expert audience, operations management.

I designed this course from scratch and proposed its addition for the Nottingham Advantage Award which are extra credits that the students can take at their leisure during the course of their study. From my own experience, I learned the hard way that business awareness for an engineer is quite important and I wished my engineering education would have incorporated those and better explained its relevance to engineering careers. I designed the module and liaised with academics in the business school, the university lawyer, the Academic Support Unit to provide a semester's worth of lectures evaluated by a student competition in which they have to come up with a business plan within a day and present their work in the evening in front of a panel of 5 academics.

Professional Skills for EEA Engineers – 2nd Year Engineer (2014-2015) Course Convenor and teacher
6h of lectures course (extracurricular but mandatory)

- This module aims to improve the education of EEA engineers with academic support on the subjects taught during the year and also to help them with their careers. It includes:
    - Advice and support on writing technical reports and presenting technical data using the MS Office suite
    - Career and employability advice on careers and employability
    - Advice on job search skills and postgraduate opportunities
    - Advice on academic skills for Level 1 modules undertaken in the EEA department

I designed this course from scratch and proposed its addition for the Nottingham Advantage Award which are extra credits that the students can take at their leisure during the course of their study. This was a year-long module for year 2 students. Based on the tutoring programme in UK and the time students took to complete it. I incorporated some lectures from the careers office, the academic support unit and all the academics in the EEE department had to provide every week academic support covering all subjects (this was imposed by the UK campus). I had to organise the tutorial material by liaising with all staff in the EEE department for each of the courses to prepare material to distribute to all staff to carry small group academic support. I also had to organise the progress tests using the virtual learning environment to record the students' scores as they counted as continuous assessment for all the modules running in 1 semester.

7.6.1.3 Assistant/Associate Professor at the University of Glasgow (2016- to date)

I am since 2016 a lecturer at the University of Glasgow (20%) and seconded at the University of Electronic Science and Technology of China (80%). I will detail my role in each of the items below.

Dynamics and Control – 3rd year Engineer EEE –
32h of lectures - 80h of labs (2015-2018) Course convenor
16h of lectures – 24h of labs (2018-2020) Course convenor/co-taught

- This course introduces the general behaviour of second-order dynamic systems with examples from electrical and mechanical systems, and shows how systems can be described by block diagrams and transfer functions. It goes on to analyse the behaviour of these systems using

Laplace transforms, examine their transient behaviour and stability, and show how they can be controlled.

As the course convenor, I imported the lectures from UK. However, as in the UK they used very specific lab benches for that module. All the lab procedures had to be rewritten to reduce the cost of the labs as imposed by procurement rules in UESTC. In this course, I have experimented a few times on the lab and have found that active learning in the labs work very effectively. For labs, I prepare an answer sheet that requires students to present their work and findings during the lab time to check that they have understood the work. The questions are aimed to see if they have understood what they are doing as opposed to just reporting the measurements they obtained from following the instructions. This makes for hectic lab sessions but the reward is that I can eliminate misconceptions for most students by linking the teaching material and the labs constructively.

Electronic system design – 3rd year Engineer EEE – Course convenor
24h of lectures - 80h of labs (2016-2017) and 6h of lectures – 20h of labs (2018-2019)

- This course presents an introduction to specification driven design of analogue systems. Topics covered are low frequency precision design, design of ground and differential signals and low noise design.

In this course, the lectures were imported from UK. However, the lab sessions had to be written from scratch as there were no labs for this course in the UK. This also included the preparation of a theoretical design assignment.

Circuit Analysis and Design – 2nd year Engineer EEE –
6h of lectures - 20h of labs (2017-2018) co-taught

- This course provides the skills and understanding required to analyse the behaviour of electrical circuits containing inductors, capacitors, resistors and operational amplifiers when dc, ac and transient dc signals are applied to the circuits. It develops insight into the relationship between the ac and transient solution and the impedance representation of an electrical circuit.

In this course, I was filling in as my colleagues were unable to come to China. So, I carried out the teaching activities lectures and labs as instructed.

Professional practice – 3rd year Engineer EEE and CE –Co-taught
32h of lectures (2017-2018)

- This course is designed to introduce the concepts of Professional Practice to Engineers in line with the accreditation requirements for either ABET or Engineering Council (UK). The course also covers additional material for engineers on effectively contributing to new organisations after graduation.

In this course, I was given half the course to teach by the module convenor that he developed the previous year. I incorporated new materials relative to ethics and in -class debates about case-studies as well as updating some of the material.

Team Design Project and Skills – 3rd year Engineer EEE and CE –Co-taught
20h of project (2017-2019)

- Students divide into teams of 8-10 members to design and construct electronic and electrical systems (typically autonomous vehicles) which perform assigned tasks on time and within budget. Students make oral and written presentations of their work, and also give demonstration of their final design.

In this course, I was in charge of guiding 7-8 teams per year for their projects. This included project meetings where we discussed their ideas and ways forward as a facilitator.

Engineering and the law – 3rd year Engineer EEE and CE – Course convenor/Co-taught
32h of lectures (2018- to date)

- This course introduces students to the practice of engineering within a commercial environment so that they will contribute effectively to new organisations after graduation.

I designed this course when professional practice was split in 2 (Engineering and the law / Engineering Finance and Management). I proposed a split of the material by reviewing the module content and linking material together. I prepared the course proposal to Senate for approval and modified the course material to incorporate Health and Safety, the differentiation of engineering ethics and business ethics as well as research methods to prepare the students for the expectations of the written assignment. The product requirement document required the students to come up with a project and provide a document at stage 2 of the stage-gate process for review by their manager (me in this context) with sales projections for three years around a technical product or service.

Digital Circuit Design – 2nd year Engineer EEE –
6h of lectures - 20h of labs (2018-2019) co-taught

- This course introduces the basics of digital electronics and Hardware Description Languages, developing the skills necessary to design complex digital systems that are made up from a mix of subsystems including state machines, counters, multi-function registers, memory and data processing units.

In this course, I was filling in as my colleagues were unable to come to China. So, I carried out the teaching activities lectures and labs as instructed.

Wireless Sensor Network – 4th year Engineer EEE - –Co-taught 8h of lectures (2020- 2021)

- The aim of this course is to provide participants with an understanding of the sensor network concepts and practical aspects of wireless sensor networks and an appreciation of their wide application area.

I introduced the basic principles of a wireless sensor node, simple scheduling on a processor or multiple processors with the concepts of adaptive voltage and frequency scaling as well as some concepts of control engineering with respect to the dynamic changes within the chip to avoid damages.

Signal Processing in Wireless Sensor Network – 1st year PhD Electronic Engineering – Course convenor/Co-taught 20h of lectures / 20h of labs (2020- to date)

- The purpose of this course is to enable postgraduate students to master the basic theories and methods of signal processing in wireless sensor network including Mathematical Model of the Time-Varying Wireless Channel, Detection Theory and Estimation Theory for Wireless Communication, Modulation techniques in Wireless Sensors, and Wireless sensor network beamforming technology. To enable students to master understand the versatility of signal processing and modeling through practical implementation in the fields of radar and communications applied to distributed sensor networks.

This course was designed from scratch for the new PhD cohort starting in academic year 2020-2021. I had to develop the module for the doctoral training programme as there is a taught element for the first year and 3-4 years of research after that, have it approved by the school of Engineering in Glasgow, the School of information and communication engineering in UESTC, and the programme including all courses and the proposal validated by the Ministry of education in China. The doctoral programme was approved this February. I will design the lecture and lab material specifically for that course.

Digital Circuit Design – 3rd year Engineering –Co-taught 12h of lectures / 8h of labs (2021- to date)

- The aim of this course is to provide a broad grounding in digital electronic systems, leading from basic gates to design at Medium- and Large Scale Integration (MSI/LSI) functional block level aided by a hardware description language.

I have been added to the teaching team to cover 25% of the course this year and teach the basics of Boolean logic/algebra and logic gates as well as minimisation techniques and the implementation of simple designs, We emphasise in this course the notion of constraints and focus notably on energy consumption and timing issues.

7.6.2 Academic statement

This statement is written against the UK Professional Standards Framework as shown in

Figure 51. The dimensions within the framework are organised as areas of activity (A), core knowledge (K), and Professional Values (V).

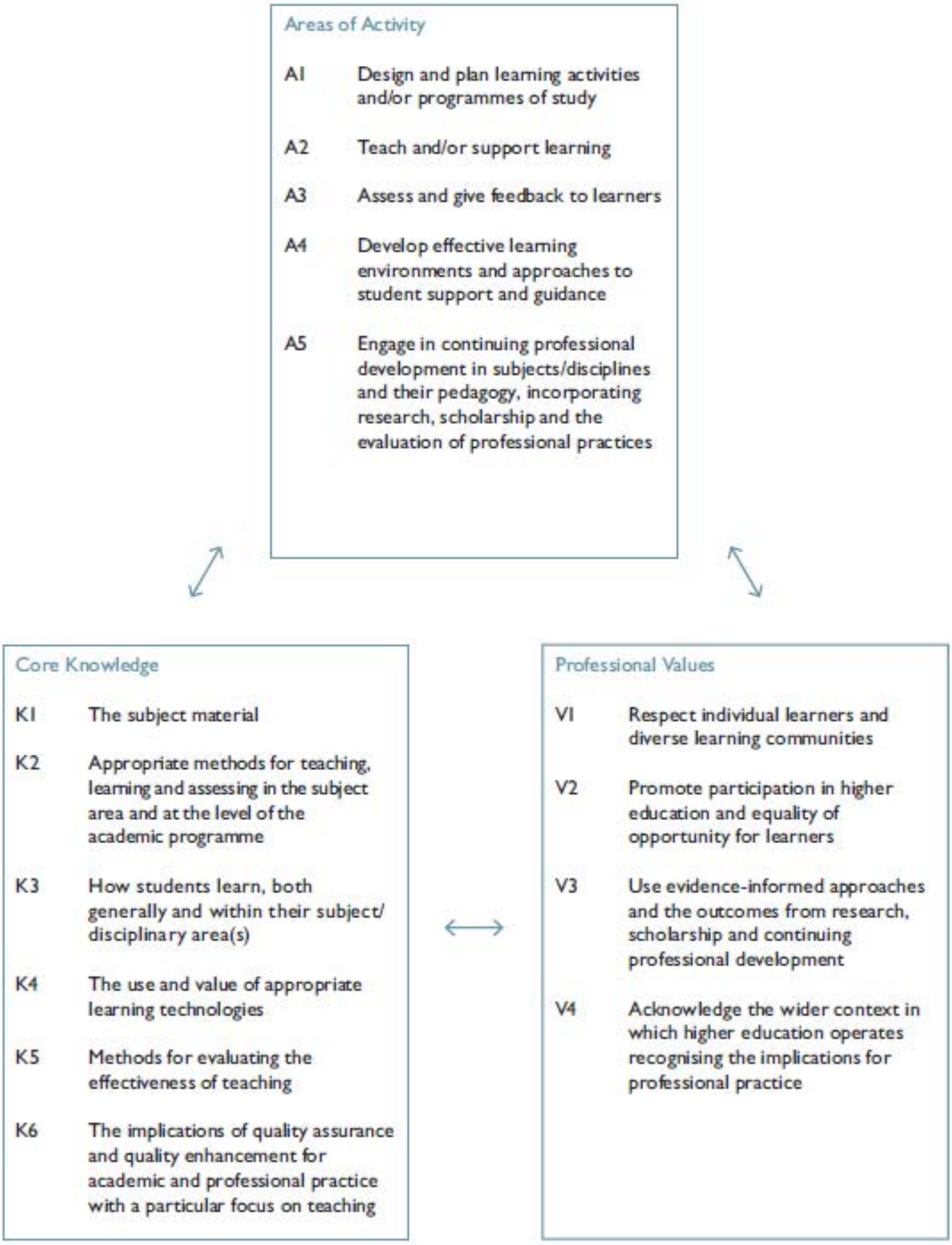


Figure 51: [UK Professional Standards Framework – Higher Education Academy]

Engineering curricula are continuously being updated to follow evolutions and new developments in engineering (A1). After I run a course, I critically reflect on what went well, what needs improving and where students had difficulties in my course. I use the student evaluations of the course, my own reflection and refer to existing literature from the IET, our accreditation body and the traits they expect future engineers to have, the engineering professors' Council, and at times draw ideas from the literature. This allows a gradual improvement of the course and consolidating things that work well and improving on things that do not while evolving with accreditation requirements. These include evolutions of knowledge in the field, following research, and business trends such as EDI (equality, diversity and inclusion), sustainability energy and embedded computing. New facets of engineering training have also emerged in the past decade, such as the incorporation of ethics, management, entrepreneurship, and international profiles are now required to work in the global economy with sustainability, equality, diversity, and inclusion and is also an integral part of the Washington accord (Ko, 2010) and the IET accreditation requirements (IET, 2017) (V4, K6). Where 50 years ago, the technical aspect of the field was sufficient, nowadays, an engineer must be technically competent but also an able communicator to share ideas, manage projects, work in an international setting to integrate the global economy and have some level of understanding of business models. (Fry, Ketteridge, & Marshall, 2009).

In my current job post, I am part of the transnational education program between UESTC in China and the University of Glasgow, and therefore most of the undergraduate students enrolled in that programme are Chinese (V1). I have also taught Indonesians, Indians, Russians, French, Irish, Africans and Europeans (V1) in my previous employments. In the context of my current job, for my students, English is their second language as it is for me, but most importantly, we have vastly diverse cultures and have gone through different education systems (V1). The new challenges are to integrate this mixture of backgrounds into the teaching delivery. From Gestalt psychology (Brown, 2004), "what you see and hear is determined in part by what you already know" and "Insight into a problem springs from the juxtaposition of precepts or ideas" (V1, K3). It is thus important to set a clear and meaningful context for the learning to be effective and how the material being taught is linked to their previous knowledge and how it will be used in the future. In my courses, I draw from the curriculum the course is embedded in and the material taught before, in parallel and in future courses to put my material into context to emphasize the importance of the material and how their past knowledge contributes to the apprenticeship of this new knowledge and how it will apply in further learning. With a diverse student audience, it is important to interact with them to gauge what their individual difficulties may be, so an alignment of the exercises and experiments with the course linked with in-class/lab feedback enables this feedback loop to ensure that everybody can improve and that allows to identify difficulties and resolve them quickly. People learning in a language that is not always their mother tongue can prove difficult, so a climate of trust and respect is upheld, and I ensure that all questions are welcome and no students get berated when they ask questions or participate, I also make sure that I pause and check if everybody understood what I meant or if they understood new vocabulary I introduce in the course.

I have taught for 17 years from postgraduate days as a Master and PhD student at Cork Institute of Technology for an undergraduate program in computer science, UPMC/Polytech' Paris for undergraduate and postgraduate students in electronic engineering with computer science and CNAM for undergraduate part-time distance learners, engineer apprentices, and mature students (A1, A2, A4, V1, V2, K1). Then, as a full-fledged lecturer in UNNC where I taught undergraduate Electrical and Electronic Engineering and Business awareness for technical education considering developments in the industry and the Washington accord (A1, K6, V4, K1). I now teach in Electrical and Electronic Engineering at Glasgow College UESTC, the courses "Digital Circuit Design," "Professional Practice (now Engineering and the Law)," for level 3 students and Signal Processing for Wireless Sensor Networks for 1st year PhD students primarily (K1). I also contribute to various courses when needed. I have been involved in "Dynamics and Control," "Electronic System Design," "Circuit Analysis and Design," "Introductory Programming" to teach a quarter of a semester to replace staff with extenuating circumstances (replacing someone with one week in our TNE context means teaching 25% of the semester as we are block teaching). This also happened in 2021 because I was on site for face-to-face teaching during Covid in 2021, and my colleagues were not to maximise the student experience across all years as much as possible with the allotted time in China.

The difficulty in it is to get the students from any year to go from seeing learning as an increase in knowledge, memorizing or acquiring facts to making sense of what they learnt and putting it into practice (K2) (Brown, 2004) which has been even more challenging with Covid and teaching remotely via zoom/teams. For labs, students must prepare to complete the tasks before coming, and I encourage discussions between students and between groups (A1, A2) for peer learning in and out of class (A3). Also, during the session, I take the time to ask each one of them what they understand from the lab sheets and how they work on the various issues that need to be tackled (V1, A4, A3). From those discussions often, arise an issue that I did not explain, and I would cover for all the class or individual misconceptions that I resolve by scaffolding (Vygotski, 1978) on their previous knowledge or, in certain cases, an explanation as a last resort. It is important to me to link schemata based on experience and schemata based on theories and practice (Brown, 2004) as I do in my research on radar systems (K1, V3).

In my research, I engage in future radar system design, telecommunications, and its applications in target detection for airborne drones and healthcare/veterinary applications. So, I also must engage with my postgraduate students who come from non-specialist courses into my realm of research and support them in the development of their own while interacting with cross-disciplinary academics and students (V1, V2, A5, A2, K1, V3). I also engage in teaching scholarship and continuous development with PGCAP (completed 60 credits) and PGCHE (completed 30 credits). I worked on Bringing the outside world in with mixed panel presentations while in UNNC ("Bringing the outside world in: using mixed panel assessment of oral presentations with electrical and electronic engineering students," 2016), and I am engaging now on scholarship in remote supervision and assessment and feedback ("The use of multiple-choice questions in 3rd-year electronic engineering assessment: A case study", 2018). (V4, A5, K2, V3)

The other aspect is the interest of the students in the various modules depending on their aims and personal preferences (Biggs, 2012) (K3). Also, the integration of non-technical modules in engineering usually meets incomprehension from the students. Soft skills are now more than ever as important as hard skills, and it is supported by literature including but not limited to (Baren & Watson, 1993; Darling & Dannels, 2003; Stephens, 2013). The lecturer has an active role to play in getting the students engaged in the module and trying to inspire them or at least to get them to look at your module as relevant to improve their skills and knowledge (A2, A4). This will avoid strategic learning behaviours and students' disengagement (V1, V2). As for the soft skills, I link them to technical modules so that students understand the importance it plays in daily company operations, such as ethics, law, regulations, intellectual property, project planning, literature research methods and report writing, planning and communication skills (A2, K6, V4).

Personally, I like this quote: "Give a man a fish; you have fed him for today. Teach a man to fish, and you have fed him for a lifetime." Indeed, teaching is not just about making students learn lessons by heart but more meta-learning, seek out relevant information, analyse, synthesize ideas, evaluate relevant issues, make informed decisions, and think critically that is what higher education is all about going from observations to explaining why going through all the intermediate stages and make sense of what they learn and obtain transferrable skills and knowledge. Also, as Albert Einstein said "Learning is experience. Everything else is just information." The course material will be applied through tutorials, labs, and projects to put the course content into action. *This is the experiential.* (Mcleod, 2013) (A4). In my lab sessions, they get feedback during and at the end of the lab session when seeking the GTAs or my signature after having a conversation about the exercise they just completed and whether they understood the concepts are not. That has so far sparked quite a few "penny-dropping" moments. (A3).

For assessment, I design assessments so that they evaluate the intended learning outcomes either through lab, projects, homework, presentations and/or exams. I am currently working on turning "engineering and the law" into 100% coursework, with no exams engaging in different subthemes of the course for each assignment under the same umbrella topic. This is to provide more authentic assessment tasks that are meaningful to the students and promote deep learning. This assessment design deters plagiarism rather than encourages them as they are working in teams with a workload spread out the semester as opposed to cramming at the end of the semester just before the exams. Working in teams makes it less likely for individuals to share their work as it is not just theirs, and it promotes their sense of competition. So less is more in that case. Fewer assignments but designed so that they are achievable yet challenging and done in pairs/small groups to encourage collaborative work. The assessments are designed to put the student in real-life conditions for homework and contextualisation for exams. The course is aligned with the assessments and is a natural development integrating the different parts of the course, testing basic knowledge, and moving into higher cognition levels with design exercises and open-ended questions to evaluate if they can transfer the skills they learned to a new problem (A3). When several markers are involved, the question of standardising marks is particularly important as marking is subjective and depends on people's own experience and expectations. Usually, for coursework and presentations marking descriptors are better to reduce the complexity and subjectivity of marking and significantly reduce variance amongst markers.

I also incorporate double marking when several markers are included to ensure consistent marking across large cohorts of students. For exams and lab procedures, a detailed solution will help make sure the work/results are gauged against a reference and thoroughly checked by the course convenor prior to conducting the lab and delivering the exam so that the marking is objective and marks are given for the completion or partial completion of tasks. (A3)

As an educator and researcher, I pursue knowledge, and address issues to further understand and develop future technology. Personally, I believe in excellence, rigour, honesty, respect, and tolerance. So, I will strive to pass on those values to the students in all aspects, personal and professional, as they are traits of good engineers (V4)

I also encourage them to be rigorous regarding safety issues (V4, K6), electronic construction and measurement protocols to work safely and induce rigorous behaviours in approaching circuit analysis and problem-solving as well as understanding why various circuits have been used and not just how they work. (A4, A2)

Also, I see teaching as a two-way street. The students are learning, and I learn too. I learn and improve based on my teaching experience, the advice from my peers and students' feedback (student evaluation of modules and teaching that we get from UESTC, random deep stick in class, personal tutees) (K5). I learn from the coursework from my students and identify where there are weaknesses, and try to identify if it comes from my practice or students' misunderstandings/misconceptions (K5). The quality of both the course material and the delivery are essential to facilitate the learning process of all students. The courses' content should evolve with the current state-of-the-art in technology and the emerging activities to match the students' toolbox to the current and future demands on the job market and research. (V4, V3)

The use of technology as envisioned by (Flavin, 2016) might be still a bit further down the road but bringing your own devices to the classroom opens potential use of these devices to enhance participation and engagement. Prensky's view on the coming generation (Prensky, 2001b, 2001a, 2009) is interesting because it looks at it from a divide between the old generation and the new generation. From that perspective, I am a hybrid (Rafael Tercarolli, 2017), the hinge generation that separates the two. I agree technology is important, but they need to be used efficiently and with measure. Barr's view on this is appealing to the gamification of learning but then a counter point is life is not a game although used sparingly that may help, that article also forgets to mention the huge resources required to deploy this at the university level or even just at a module level (Barr, 2017). Fuchs' idea of introducing padlet – a cloud-based software-as-a-service, hosting a real-time collaborative web platform in which users can upload, organise, and share content to virtual bulletin boards called "padlets" – in the classroom is interesting, and I think that might be a promising idea when seeking debate or idea generation in the classroom for engineering and the law mostly but sparingly in tech courses as well when asking for meaning in what is being taught (Fuchs, 2014). This type of technology is inclusive as you enable reflective students or students who do not have as much confidence to participate in the class debate while staying anonymous, which they may not be doing if they must speak aloud. I think the approach I feel is more appropriate to the way things need to be taken in is described in (Ryan, 2013). There, an emphasis on aligning ILOs (Intended Learning Outcomes), teaching with the assessment and continuously assessing the students through the semester does help to make sure they learn as it goes along. I have found that collaborative learning is powerful for them to learn concepts as observed in project-based courses like "Team Design Project and Skills," "Electronic Construction Project," and "Introduction to Real-time systems" but so far, my attempts with Peerwise and contributing to wiki have been unsuccessful. I found out that students prefer to interact face-to-face rather than online when they can. Knowing that there is a platform out there that the University supports will encourage the use of that peer knowledge building platform in the future. (K4)

To help inclusiveness with regards to teaching with English as a second language, I started doing some videos pre-Covid for my course "Dynamics and Control", especially for threshold concepts necessary for the understanding of the course. I had noticed that students had a tough time understanding that part. This was appreciated by the students, and the average in that course on the exam questions was significantly better (+15%) on average than in previous years. (A4, V1, K3, K4). The Covid-19 outbreak disrupted our way of teaching dramatically. We had overnight to teach everything remotely and run exams online. I am part of the Covid-19 committee for online teaching provision. As I was on the ground in China when it happened and knew what technology worked and did not work in China to communicate with headquarters (A1) effectively. Spring semester 2019-2020, all courses were taught online, from lectures to labs and even projects, and this I still ongoing. This means that all courses are video recorded in chunks of 10-20 mn maximum with the threshold concepts. They are also given live with the students in the classroom. We provide subtitles for the videos as, again, students with English as a second language need this to fully understand the content of the videos, especially those with weaker language skills and accessibility (A2, A4. K2, K4, V1, V2). The labs were turned to simulations only as the students did not have access to the lab until June 2021 (A4, K2, K4). Now, the students in China are back on campus, but our administration, given the quarantine conditions in China and the large overhead costs, prevents us from travelling. So, we have mainly kept the same model of tuition for labs. The exams will be run as open book exams from their homes with a time limit for each question to avoid chances to use technology, and invigilation will take place through remote video conference to observe students while taking the exams but also intervene when there is a technical difficulty or answer questions if needed (K4, K6). This is a game-changer as now the world has turned to online teaching, and students will now expect this to be the norm as well as providing live classes. This will support the widespread use of blended learning with online classes and in-person content to access higher levels of cognition while teaching with interactive activities. These will need to be planned carefully as we do not want to overload the students with content. For "engineering and the law", we have designed a virtual learning environment that tracks the progress of students and delivers badges when they complete units of learning as well as the formative assessment associated with them. This has increased the engagement with this course, with 70% of 500 students completing all learning units on time based on weekly schedules at the end of the semester.

Further to that, in labs for engineering, we have used and continue to use a range of technologies for learning: computers, embedded microcontrollers, and measuring equipment (oscilloscopes, voltmeters, vector network analysers, spectrum analysers, ….). (K4, A2, A4). I have coordinated the development of a lab around radiofrequency and communications that will be used both for research and teaching to initiate students to the use of state-of-the-art technology and to invite more research-led teaching into the courses at UESTC.

Baren, M. R., & Watson, J. (1993). Developing communications skills in engineering classes. In *IEEE International Professional Communication Conference* (pp. 432–437).

Barr, M. (2017). Video games can develop graduate skills in higher education students: A randomised trial. *Computers and Education*, *113*, 86–97. https://doi.org/10.1016/j.compedu.2017.05.016

Biggs, J. (2012). What the student does: Teaching for enhanced learning. *Higher Education Research and Development*, *31*(1), 39–55. https://doi.org/10.1080/07294360.2012.642839

Bringing the outside world in: using mixed panel assessment of oral presentations with electrical and electronic engineering students. (2016). In *2016 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (pp. 1–8). https://doi.org/10.1109/TALE.2016.7851761

Brown, G. (2004). How Students Learn: A supplement to the RoutledgeFalmer Key Guides for Effective Teaching in Higher Education series. *Social Sciences*, *5*, 1–57. Retrieved from http://media.routledgeweb.com/pdf/seriesinfo/how_to_learn.pdf

Darling, A. L., & Dannels, D. P. (2003). Practicing engineers talk about the importance of talk: A report on the role of oral communication in the workplace. *Communication Education*, *52*(1), 1–16. https://doi.org/10.1080/03634520302457

Flavin, M. (2016). Technology-enhanced learning and higher education. *Oxford Review of Economic Policy*, *32*(4), 632–645. https://doi.org/10.1093/oxrep/grw028

Fry, H., Ketteridge, S., & Marshall, S. (2009). *A Handbook for Teaching and Learning in Higher Education*. *A Handbook for Teaching and Learning in Higher Education*. https://doi.org/10.1080/03075079312331382498

Fuchs, B. (2014). The Writing is on the Wall : Using Padlet for Whole-Class Engagement. *LOEX Quarterly*, *40*(4), 7.

IET. (2017). IET - The Institution of Engineering and Technology. *IET Website*, 2015–2017. Retrieved from http://www.theiet.org/

Ko, E. (2010). The washington accord on engineering curriculum. In *International Encyclopedia of Education* (pp. 209–215). https://doi.org/10.1016/B978-0-08-044894-7.01507-4

Mcleod, S. (2013). Kolb - Learning Styles The Experiential Learning Cycle. *Simply Psychology*, 1–7. Retrieved from http://www.simplypsychology.org/learning-kolb.html

Prensky, M. (2001a). Digital Natives, Digital Immigrants Part 2: Do They Really Think Differently? *On the Horizon*, *9*(6), 1–6. https://doi.org/10.1108/10748120110424843

Prensky, M. (2001b). Digital Natives,Digital Immigrants Part 1. *On the Horizon*, *9*, 1–6. https://doi.org/10.1108/10748120110424816

Prensky, M. (2009). H. sapiens digital: From digital immigrants and digital natives to digital wisdom. *Innovate: Journal of Online Education*, *5*(3), 1–9. https://doi.org/www.innovateonline.info/index.php?view=article&id=705

Rafael Tercarolli. (2017). If you were born between 1977 and 1983, there's a new name for you. Retrieved May 9, 2018, from https://www.linkedin.com/pulse/you-were-born-between-1977-1983-theres-new-name-rafael-tercarolli/

Ryan, B. J. (2013). Line up, line up: using technology to align and enhance peer learning and assessment in a student centred foundation organic chemistry module. *Chemistry Education Research and Practice*, *14*(3), 229–238. https://doi.org/10.1039/C3RP20178C

Stephens, R. (2013). Aligning engineering education and experience to meet the needs of industry and society. *The Bridge*, *43*(2), 31–34.

Vygotski, L. S. (1978). Mind in Society. The Development of Higher Psychological Processes. *Year 1978*, 159. Retrieved from http://www.hup.harvard.edu/catalog.php?isbn=9780674576292&content=reviews

7.6.3 PGCAP (Postgraduate Certificate in Academic Practice)

7.6.3.1 Introduction to Learning and Teaching in Higher Education (30 credits)

I had to repeat this module as the PGCHE is English and the PGCAP is Scottish therefore the credits were not transferrable. This course was similar to the teaching dialogue and individual pathway I did in Nottingham for the PGCHE. The course aims to introduce you to the UK Professional Standards Framework for Teaching and Supporting Learning (UKPSF), which sets out the knowledge, activities and values expected of higher education teachers. The half-day trainings covered Learning and Teaching in Higher Education, Evaluating Teaching in Higher Education, Understanding Student Learning, Course Design, Assessment and Feedback, Effective Lecturing, Small Group Teaching, and Technology Enhanced Learning and Teaching. Essentially looking through key research literature and concepts underpinning higher education. The end goal was to develop our teaching philosophy that you read earlier that I updated again as my teaching practice evolved since I wrote it in Nottingham and in Glasgow 2 years ago. The second element is a development of a teaching activity where I chose enabling a class discussion for 240 students on ethics case within the context of Engineering and the law. Chinese students are usually quite shy and getting them to engage openly on a case study as they do not want to lose face or appear impolite (cultural bias) which made my first attempt live in class quite frustrating for them and me. I now use an online discussion board that is anonymous and blog like that the students are used to deal with in social media called Padlet. Padlet gives a voice to every student and allows them to discuss in English although it is online, in written form and it is very demanding for me to follow the flow of information as a lot comes in from 240+ students at the same time. I was able to engage with them online and respond to some comments to give more perspective or intervene to the whole class by bringing up ways to contribute. Being able to observe what the whole class contributes in is very invaluable as you can steer discussions and actively elicit more in depth understanding of the topic. This was continued beyond PGCAP in the following years by adding some roles in the discussions by assigning different stakeholder roles: firm, competitors, customers, shareholders, suppliers, government, employee, civil society … The students manage well the perspectives of engineers, employees in general, but struggle to give perspectives as a manager, government, etc… which makes sense given the lack of experience the students have with politics as it is seldom discussed in China. The last piece of the assignment was on teaching observation. The first one I was observed during a new lecture I developed on conducting a literature review and presenting data and the second was around the intervention with Padlet for class discussion. These teaching observations are useful to get a fresh pair of eyes to give a critical view on what went well and what can be improved as well as suggestions for new developments which is where I got the tip for stakeholder assignment to different groups to change the point of views in the class debates.

7.6.3.2 Course design in your discipline (10 credits)

This course aims to focus the teaching development more strongly with our own discipline. We are asked to develop and design a course in our discipline involving constructive alignment of intended learning outcomes and assessments, down to the details of some specific learning activities.

For this activity, I reworked the module Engineering and the law to incorporate I would like to change as this is a theoretical exercise but could not in effect because of guidelines on course assessment weighting.

The course aims were changed and the intended learning outcomes to better align the assessment on what the students need to learn in Engineering and the law.

- Previous: "This course introduces students to the practice of engineering within a commercial environment so that they will contribute effectively to new organisations after graduation"
- New: "Modern engineers need to be able to function within an interdisciplinary environment and make decisions on engineering based on other disciplines in a company affecting their work such

as: ethics, business ethics, marketing, market forces, product development, health and safety and legal drawing from the literature and other information sources. This course introduces students to the practice of engineering within a commercial environment so that they will contribute effectively to new organisations after graduation."

The intended learning outcomes are as follows:

- Engineering and the Law
    - describe liabilities and responsibilities, Health & Safety, Corporate responsibility, ethical issues in relation to engineering practice
    - categorise types of regulations as applied to engineering, such as IET, H&S, environmental regulations
    - explain the standardisation process and its importance as well as read and summarise standards
    - explain what is meant by Intellectual Property (IP) and distinguish between different protection options (patents, trademarks etc)

- New product creation and business plan
    - explain the process of product approval and the process of innovation including its importance and its impact on the customer
    - evaluate the potential of a product/market opportunity.
    - understand the role of different actors in a company setting to carry out your role as an engineer in order to reflect on the analysis of their own strengths and weaknesses and those of their colleagues in the process of product development and its life cycle
    - survey the existing body of knowledge and summarize the research findings and graph the data.

The proposed assessments

	Previous	New
Exam	Formal Examination (75%) – MCQ 18% Essay 19.5% 2 Questions on e.g. marketing, and product life cycle 18.75% each	Formal Examination (20%) – MCQ
Written assessment	Written assignment of a product requirement document and presentation slides (20%) – 10-page document constructed in teams of 2 with the submission of individual contributions.	Written assignment of a business plan and presentation slides (75%) – 30-40 page document constructed in teams of 4 with the submission of individual contributions.
Peer assessment	Peer assessment of above product requirement document (PRD) (5%) – mark 3 other PRDs with the same criteria as I use.	Peer assessment of above business plan (BP) document (5%) – mark 3 other BPs with the same criteria as I use.

The draft business plan would be peer-evaluated so the students engage with the marking descriptors and learn from what others are doing so as to enrich their knowledge of the course and broaden their horizons.

This exercise took into account the incorporation of the accreditation body requirements as well as the global governing body the Washington accord for the framework in the context of teaching at the University of Glasgow following the University code of assessment and regulations. Furthermore, the students were consulted as they are the most affected by these changes.

7.6.3.3 Technology Enhanced Learning (10 credits)

This course aims to provide the opportunity to consider how technologies might be used to enhance learning. It will explore the efficacy of learning with technologies and whether technologies might engender different approaches to learning and teaching. We were required to consider how learning with technology might apply to your own context. We were tasked to design an intervention within our courses and implement it.

The target audience was the 3rd year cohort of Electrical and Electronic Engineering in Glasgow College – University of Electronic Science and Technology (UESTC). In this degree program, they follow a mixture of University of Glasgow and UESTC courses. All of them are Chinese nationals with English as their second language. "Dynamics and control" is an abstract course where the concepts relating to analogue control engineering require the mastery of time-domain and frequency-domain analysis to assess the stability of a system. Historically, students in that course did well with the time-domain concepts as they overlap a lot with another course "Signal and Systems" which look at feedback systems for signal processing which also need to be stable. Therefore, I focus my innovation on the part students have been consistently struggling with by offering more resources to the students for revision and assimilate the threshold concepts:

- Online lectures (enhance) using Camtasia software suite which provides an information-focused strategy with the intention of providing up to date/quality teaching materials.
- Participative Multiple-Choice Questions (Empower) using Peerwise as a participative platform to create MCQs from scratch and challenge their peers which provides a collaborative-focused strategy with the intention of providing an online space for building knowledge.

I would use PeerWise to enable students to create MCQs relating to the course in order to enhance their understanding and challenge their peers in finding the right answers or getting corrections if it has not been done properly. I would ask them to categorize these into 4 sections which correspond to the split in the course roughly to enable chapter specific questions that would be easier to assess whether a unit has been assimilated or not. The problem is that the last chapter will likely be forgotten towards revision time.

I would further record lectures with Camtasia and demonstrations to make sure students can review them offline. This would offer more flexibility for students for whom English is a second language and to go over the class material again. This material could be broken down in text, speech, followed by MCQ questions for them to test their knowledge. I would concentrate for this on the 2nd part of the course I am responsible and to test it first.

7.6.3.4 Supervising Students (10 credits)

This course aims to provide an opportunity to evaluate and reflect on supervision practices and develop an evidence-based understanding of approaches to supervision of students. The course covered supervision at undergraduate, postgraduate taught, PhD, and professional doctoral levels. This is an opportunity to compare practice against both institutional requirements and recent literature on effective supervision as well as confronting ideas with colleagues from different colleges. What I have learned from reading quite a few wikis is the importance of the supervisor-student relationship, and that different styles and attitudes should be applied from one supervisee to the next depending on their personality, learning style, aptitude and your own style. In (Akerlind, 2017), they highlight the change in paradigm in PhD studies reflecting the fact that it is now just another degree which is somewhat difficult to come to terms for people who did their PhDs some ten years ago or more. This creates different motivations for pursuing a PhD that may differ from the supervisor's personal beliefs, and that needs to be addressed. Where having 2-3 PhD students overall with one at every stage of their PhDs was enough before, now we are pushed to get at least at the median of 4 including when co-supervising which brings the total number of managed students in the region of 10 which challenges us. This links well with the paper stating that ties between supervisors and supervisees become fragile because the master-apprentice relationship is fading away against higher demands of productivity.

In (Gatfield, 2005), the identified styles are: Laissez-faire, Pastoral, Directorial, and Contractual. These are an interpretation of factors contributing to PhD completion. I would have to say that this changes from student to student and also depending on the situation. The supervisor needs to adapt to the situation and also maintain his own sanity with relation to work. I tend to be directorial/contractual with the students at least until now. This is good to have a list of factors and behaviours appropriate for support to a PhD completion. I have seen from the Wikis that there are more than one model looking at different aspects of supervision which is interesting to look at for an introspection into my own practice.

For this course, I chose to study remote supervision. I finished my PhD in 2011, and then did one year as a project manager in a start-up company in China. I have worked 3.5 years as a lecturer at the University of Nottingham Ningbo China (UNNC) (2012-2016) where I could only supervise final year project students. I, then joined the University of Glasgow (UoG) and was directly seconded to the University of Electronic Science and Technology of China (UESTC) since January 2016 – I am also an adjunct associate professor at the University of Cergy-Pontoise (UCP) in February 2018. In this atypical context, I directly supervise Final Year Project students locally in UESTC, remotely supervise M.Sc. and M.Eng Students in UoG, and I remotely supervise PhD students in UoG, UNNC, UCP, and Nanjing University of Science and Technology. They are from different horizons Chinese, Kenyan, British, Greek, and Cypriot. This has proven quite challenging as PhD supervision was new to me and remote supervision takes a lot of my personal time as I have tried to be directional, and I was also looking at meetings at reasonable hours for both parties: supervisor and supervisee. I have been doing too much in directions which led to unwanted behaviours from some such as over reliance on supervisor. I have now shifted my supervision practice to empower students although I retain that need to control quality. This is their thesis/manuscript not mine and that they need to grow and become full-fledged researchers/engineers. My job is to shape their minds, give them opportunities, support, be a sounding board, a guide, grow their critical thinking, while ensuring quality work.

I focused mainly on PhD supervision as this was the most challenging given the involvement a supervisor has in shaping someone towards completing a PhD. In (Mainhard, 2009), the authors look at a model for supervisor-PhD student relationship. I sent the questionnaire in the article to all my students and self-assessed (see Fig. 1).

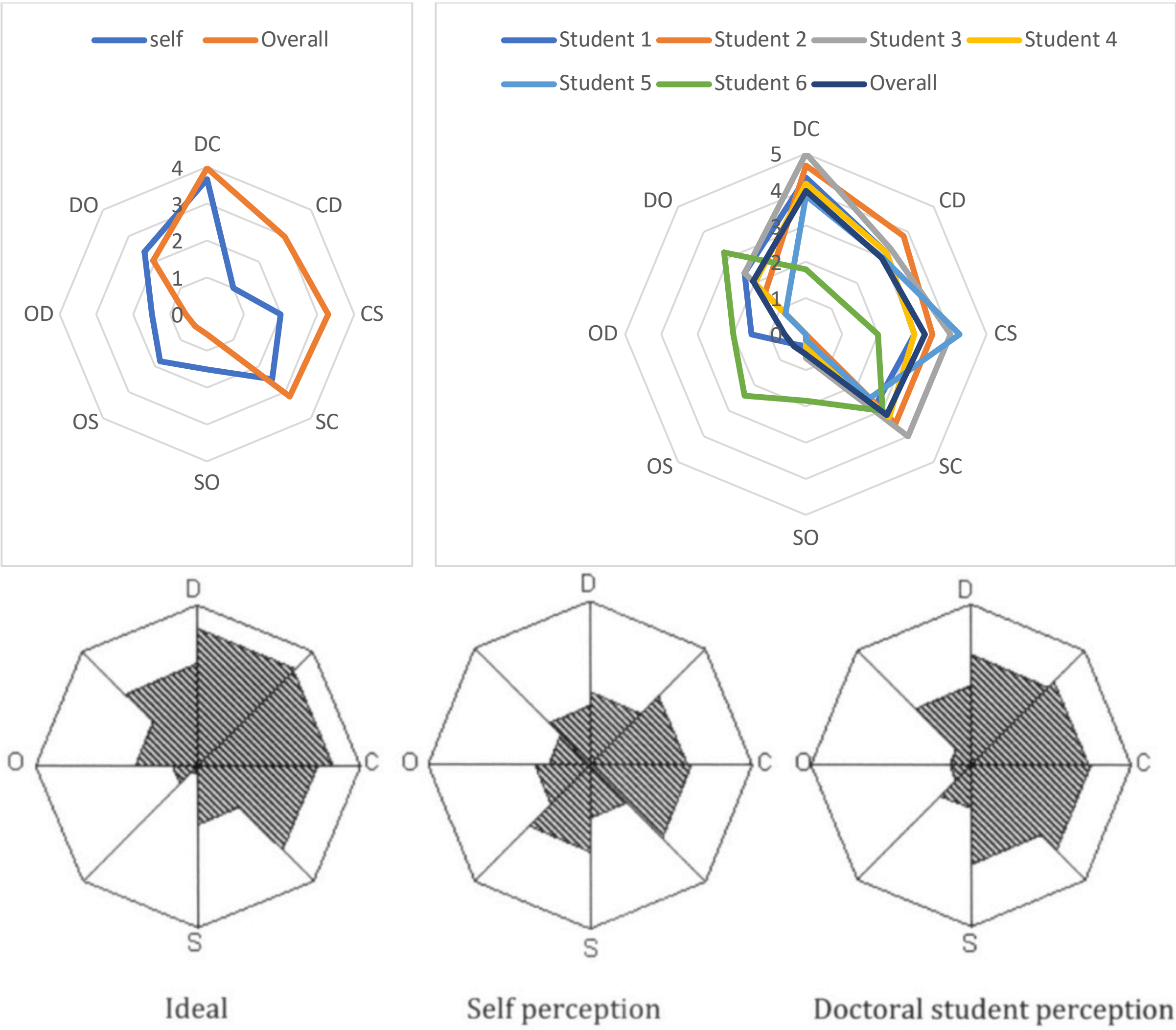


Fig. 1: top-left) Student average vs self-assessment, top-right) individual results from students, bottom) extract from (Mainhard, 2009) of the ideal, self-perception, and doctoral student perception of the supervisor-PhD student relationship.

It can be seen from the results that my perception of the relationship differs from what my students experience in general. Overall, they see me as Dominative-Cooperative (DC) primarily, but they also experience a spectrum of Cooperative-Dominative (CD), see that I confront them to their responsibility freedom (Submission-Cooperation), and I am understanding (CS). One of them sees me more on the side of opposition because it is a difficult PhD as he is treading on a subject, I was brought in late to advise on and the learning curve is high, and some concepts are still hard to grasp so there is opposition in demands for higher standards in the thesis writing stage that the student is eager to finish. Having said that he was also very appreciative of the support I give in his thesis. This questionnaire was a snapshot in time. As he himself told me a lot of questions in there could be answered by it depends.

I consider them as adults and working with them to shape research, but I am very strict on quality and discussions on the chosen topic. My self-assessment is out of sync with what students perceive and this might be the position I assume as a supervisor makes me dominant predominantly and I also support them as I try to provide them with the supervisory support I did not have during my PhD. I think being in opposition is part of my role to challenge their ideas as well as encourage them. I think this owes to the duality of the supervisory role being guide and assessor.

Looking at the (PGR code of practice, 2018) research progress is largely the responsibility of the students. The duties of the supervisory team are to provide guidance (standards, direction, support services), being accessible, the timely delivery of the thesis, opportunities to interact with the research community, student continuous Professional Development training in general and subject-specific areas, pastoral care, and check on absences. In the case of remote supervision, it is important that students have support locally as well as the remote provision. I believe that my colleagues and I (I am not allowed to supervise on my own postgraduate school rules) do provide on all accounts. These are responsibilities.

To align views on responsibilities, the questionnaire on expectations in supervision (Griffith University, 1997) is useful to initiate the discussion on expectations and beliefs and make sure to manage any differences through dialogue and to explain, if necessary, the contractual expectations set by the PGR code of practice.

In (Gatfield, 2005), supervision is looked at through a 2D grid with structural and support as the axis which vaguely resembles the dominance-submission and opposition-cooperation in (Mainhard, 2009). A third dimension is identified as being external factors but is considered fixed and intrinsic to the parties involved and therefore are not variables but rather fixed unknowns coming into the blend of the supervisor-PhD student relationship. From this 2D frame, 4 supervision styles are identified: Laissez-faire (low support, low structure), pastoral (high support, low structure), directorial (low support, high structure), and contractual (high support, high structure). My preferred style from the description is contractual which matches the findings from the previous articles and the feedback from students which is characterized with being provided with as much support as I can give them but on the other hand, they must hit the goal posts in return.

An analysis of the most successful supervisors shows a contractual style is most adapted. My supervision style is in opposition to what I experienced whereas I had equipment but no support other than that and I had 6 supervisors that never agreed on anything so meaning no direction. I intrinsically have a very high personal drive that pushed me through my studies despite very difficult times. I believe my students deserve better than that and from Fig. 1 above they feel they are being supported in their studies. The paper continues into implementing flexibility in the supervisory style. Different stages of PhD require different styles. Often in Engineering, there is a preformed thesis topic as they are mostly funded unless the student is self-funded and, in that case, we offer them more freedom to define their own topics. We still tend to be quite contractual even from the start because the engineering discipline demands it. Most of my students were currently in phase 2 (research generation) or 3 (writing up). If we see a student is quite autonomous, we release a bit more on direction. We usually expect a change in direction around mid-point in the PhD where students would be expected to drive the topic. When a student is in difficulty, we may adopt a style appropriate with the situation: pastoral when problems of a personal nature appear and directorial when the student is not finding ground. When it comes to supervision, I find the Goldilocks Rule (Clear,2019) quite useful to get students and supervisors alike motivated on a topic. If the task is too easy or too hard, people will lose focus. But if you put the goal post at the right level then you get very motivated individuals. For research supervision, I have been quite involved and I found it challenging, I have now found a middle ground where I am involved in guidance more than in the detailed inspection of everything. Other publications like (Murphy, 2007), (Lee, 2018) the recurring themes of structure and support although phrased differently here come as the tenets of PhD supervision.

In (McCulloch, 2016), the excellence in research supervision lauded UK Higher education against Australia, New Zealand, and South Africa's framework for excellence. Our excellence framework is driven by the Quality Assurance Agency (QAA) and since the PGR code of practice is derived from the QAA. So, this is a good place to start for support and structure instructions. In (Lee, 2018), the modern supervisor needs to embrace five dimensions to develop a doctoral student successfully, I need to work on how to better help students to emancipate (gaining in autonomy) and better provide for enculturation (academic writing style) remotely. Looking at (Nasiri,2014) on PG supervision at a distance (even though it is for students being supervised at a distance from the Uni mothership), I recognise a lot of the challenges there as the ones I live and for the most part I think I have addressed those as per my students' responses. One of the strategies mentioned is to use bubble comments on the side of the text as opposed to track changes to enable the conversation as opposed to the student accepting directly track changes and not discussing the point being raised or not understanding it. Having a research community at hand can be useful when supervising from a distance, I always put in place a local supervisory team and a PhD community around for support and exchange as even though the subjects are different being able to talk about your research is paramount in conducting a PhD. I will keep working on this in the future to incorporate sharing platforms to create a small community of research students so that they can exchange between themselves and myself to provide an alternative for scientific advice.

(Spear, 2000) In order to improve contact with students, we are moving the weekly group meeting to a monthly group meeting and ad-hoc conversation on dedicated topics with the individuals. In another aspect for timely response to written work, I have been struggling to keep up with these because of the level of scrutiny I put in the review and track changes. I found from my co-supervisor that timely comments with deep analysis can be better to empower the students and get them to learn from their mistakes rather than working for them. This would be both time-saving and instructional for students as well as meeting their expectations of timeliness. And avoid the Goldilocks rule of doing too much for them.

For the future, I will strive to stay in the contractual scheme for supervision which is from the literature and the PGR code of practice the way forward while implementing flexibility based on the different stages of a PhD. My supervision practice evolves with experience, and I am glad to see that I'm heading in the right direction with the takeaway messages below:

1) Contractual supervision model with flexibility
2) More interaction to bring a sense of community in the research group
3) Keep working on better ways to provide remote supervision and see how technology could enhance the experience for sharing knowledge between students
4) Participating in supervisory development training to keep up to date with education theories and ways to improve practice
5) Work on feedback on written work to enable discussions and improve timeliness

When I wrote this, I was managing 3 students and I graduated 5 students since then 2 from UoG and 3 from other universities. Now, I am supervising 9 PhD students (7 in Glasgow, 1 in China, and 1 in France). I am the PI for 5 PhD students and Co-I for 4 students. This has been a steep learning curve to work on all fronts, but this has helped me tremendously in improving handling remote supervision and providing feedback timely with enough details but sufficiently high-level so that the student work for themselves more and become more independent.

7.6.4 PGCHE (Postgraduate Certificate in Higher Education)

7.6.4.1 Teaching Dialogue – 10 credits

This module aims to create an exchange of teaching philosophy statements with two colleagues by provide feedback on two other teaching philosophy statements and using the feedback from the others to critically reflect on it. My original teaching philosophy started there and has evolved into the piece shown in 7.6.2 over the years as my own practice evolved.

Another part of this module was the establishment of a teaching discussion partnership and reflection on teaching activities both as an observer and as an actor. This is an opportunity to get critical feedback on one own teaching and observe someone else's practice by identify an appropriate focus for teaching and learning discussions by having a pre-teaching discussion to explain what the person is trying to achieve in the teaching, the observation, and the post-observation feedback on what went well and what could be improved. For this I elected to observe a business lecture implementing active learning in class where students were given a short lecture, followed by a case study where students were asked to engage with in class participation was elicited by marks where the participation of the students is assessed throughout the semester both in terms of engagement and the relevance of their answers. This is interesting to embed in engineering but this is hard to translate in engineering as is unless it is a project-based module or problem-based learning which is not adapted to traditional UK style lecturing and style which is rigid because of accreditation bodies. I managed to introduce this year project electronic design project where I set a 1-week challenge over the semester for students to find out a problem in the design collaboratively beyond the project task for fun and the students engaged. The second activity I chose this time for being observed was running an authentic assessment. An authentic assessment is a life-like viva where students were put in front of a panel of engineers, a businessperson, and an English tutor to present their technical report. This was a break from traditional practice in the UK where the VIVA was done with one engineer and for a relatively short time. The students were forced to translate their work so that the non-experts would get the gist of the technical content and pitch a business aspect of the project. They also had to satisfy experts with enough technical depth for us to assess the proficiency in the subject. The English tutor was there to assess the English proficiency as all our students had English as their second language. I would then provide detailed feedback combined from different angles business, language proficiency, and proficiency in the subject.

Then, a qualified observer would do a teaching appraisal to assess my proficiency in teaching: preparation, delivery, and use of effective learning resources.

Finally, an action plan is provided covering a students' learning needs, how this was identified, future actions, and a period for completion in other words SMART objectives for teaching development. I worked on project-based learning as I oversaw 2 project-oriented modules and improved on the provision in the UK by leading changes in the modules in China that were then later adopted in the UK. The projects were designed with guidelines that were sufficiently helpful for beginners in electronics yet vague enough to leave room for creativity. This was a guided-project approach that helped break the students' training of follow the rules in China to think about why you are doing this and try to produce a solution that will address the objectives which was well received by the students.

7.6.4.2 Individual pathway – 20 credits

The individual pathway offers a structured route for participants with taught sessions on the principles of course design, marking and assessing, developing your teaching and related reading "Key aspects of teaching and learning in engineering," "assessing student learning", and "how students learn". Based on those, a teaching project has to be carried out. First, we need to provide a proposal supported by a literature review and explaining the relevance of the teaching development. I chose to pursue on the authentic assessment by embedding this to my modules in 2nd and 3rd year. I also asked my colleagues if I could use their modules to run the experiment as well so the students would have 6 semesters to improve their technical presentation skills based on the Kolb's cycle of learning [1]. This a constructive cycle of experiential learning and reflection the students would do a presentation get feedback and then the following semester they would get a similar assignment. This turned into Business Awareness in Technical Assessment in the end which was embedded within the engineer curriculum and led to 3 publications in conferences.

Le Kernec, J. , Levrai, P. and Bolster, A. (2016) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical and Electronic Engineering Students. In: IEEE TALE2016, Bangkok, Thailand., 7-9 Dec 2016, ISBN 9781509055982 (doi:10.1109/TALE.2016.7851761)

Levrai, P., Bolster, A. and Le Kernec, J. (2014) Bringing the Outside World In: Using Mixed Panel Assessment of Oral Presentations with Electrical Engineering Students. ICED 2014: International Consortium for Educational Development, Stockholm, Sweden, 16-18 June 2014.

Levrai, P., Bolster, A. and Le Kernec, J. (2013) Mixed Panel Oral Presentation Assessment: Preparing Electrical & Electronic Engineering Students for Work. In: 11th Biennial Conference of the Association for Academic Language and Learning, Melbourne, Australia, 13-15 Nov 2013

A summary of the research and results is given below:

"Engineering students have been portrayed as having poor oral communication skills despite oral communication competence being a key factor in future career success. With the aim of equipping students with attributes identified as important for Engineering graduates this paper presents a research project carried out at the University of Nottingham Ningbo China in the Division of Science & Engineering with Electrical and Electronic with undergraduate students, focusing on the use of a mixed specialist and non-specialist audience for students' end of semester oral presentations assessment. It is known that oral presentations are an important academic genre developing communication skills and confidence in students, but it is an area which has been found to be lacking in traditional engineering courses. The innovation of the mixed panel was to help prepare students for life after university by giving them experience of pitching technical material appropriate to the knowledge of the audience, which is something they will have to do when working in companies or on projects. This paper outlines the experience from the perspective of the assessors from different disciplines who were interviewed to determine what they were looking for in the presentations. It will also review the experience of the students themselves, based on a survey which considered the impact the mixed audience had on their presentation preparation in terms of language, presenting skills and content. This innovation in assessment encourages multi-disciplinary thinking in students and the impact of audience on presentation content and delivery is something which could be explored across different academic fields."

For this project, I coordinated the project with the centre for English learning, the business school, and engineering in order to have 5 assessors (3 engineers, 1 business and 1 English tutor) for every assessment in 6 modules. This is a tough ask at universities as every staff is stretched with their own activities already and they did not get any benefit other than coffee, lunch and biscuits but they bought in the concept and were quite pleased with the assessments and the student performances. Because all the modules were not mine, I also had to convince my colleagues to buy in this project for it to be successful and we managed to provide students with 5 semesters of training before they got to their final year project presentation which is a major assessment representing 30% of their final year project mark and also prepares them for life in industry and presenting their work effectively in general. The viva format and assessment criteria over the years evolved in order to improve the student presentations by devising support workshops in between repeats to upgrade the student skills in presentation, translation, and most importantly business acumen which turned into a new module of extra-curricular activities "business awareness in technical education". For staff, improvement went through designing marking criteria that helped to standardize marking between markers from multiple disciplines. The standard deviation was reduced to 1 grade point as opposed to 3 in the past by simplifying the marking descriptors and the granularity for an ease in gauging the level of achievement. This was done in concertation with English tutors, Business tutors and Engineers to find the right formula.

The students found the experience of presenting to a mixed audience challenging as they had to adapt their speech to cater for specialists and non-specialists. The presentation had to be technical as well as dealing with a business element involving their project such as coming up with a product using their project or focusing on costing for example. Even though, they found the task difficult as it is a hard balancing-act, their feedback was very positive on the experience and one the fact that they felt better prepared to present their work in the future.

By embedding presentations through each academic semester appropriate presentation skills and oral fluency and competence can be developed. The use of mixed panel assessment of oral presentations has been successfully piloted in UNNC and can become fully embedded in the EEE curriculum, with a view to the assessment task being adopted in other schools within the Science and Engineering Division and, potentially, beyond. Such a presentation task speaks directly to the competencies most often found to be wanting in engineering graduates.

Bibliography

[1] "Bringing the outside world in: using mixed panel assessment of oral presentations with electrical and electronic engineering students," in *2016 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 7-9 Dec. 2016 2016, pp. 1-8, doi: 10.1109/TALE.2016.7851761.

[2] A. S. e. al., "Microrail - monitoring vegetated road and railway cuttins using radar interferometry," University of Nottingham, 2010.

[3] F. T. Ulaby, R. K. Moore, and A. K. Fung, *Microwave Remote Sensing*. Norwood, MA: Artech House, 1986.

[4] G. L. Charvat, A. J. Fenn, and B. T. Perry, "The MIT IAP radar course: Build a small radar system capable of sensing range, Doppler, and synthetic aperture (SAR) imaging," in *2012 IEEE Radar Conference*, 7-11 May 2012 2012, pp. 0138-0144, doi: 10.1109/RADAR.2012.6212126.

[5] A. Melnikov, J. L. Kernec, and D. Gray, "FMCW rail-mounted SAR: Porting spotlight SAR imaging from MATLAB to FPGA," in *2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, 5-8 Aug. 2014 2014, pp. 780-785, doi: 10.1109/ICSPCC.2014.6986303.

[6] A. Melnikov, J. L. Kernec, and D. Gray, "A case implementation of a spotlight range migration algorithm on FPGA platform," in *2014 International Symposium on Antennas and Propagation Conference Proceedings*, 2-5 Dec. 2014 2014, pp. 177-178, doi: 10.1109/ISANP.2014.7026588.

[7] A. Melnikov, J. L. Kernec, and D. Gray, "Porting spotlight range migration algorithm processor from Matlab to Virtex 6," in *2015 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, 7-11 Sept. 2015 2015, pp. 1429-1432, doi: 10.1109/APWC.2015.7300214.

[8] F. X. Ochieng, C. M. Hancock, G. W. Roberts, and J. L. Kernec, "Optimal Design and Operational Monitoring of Wind Turbine Blades," in *Design Optimization of Wind Energy Conversion Systems with Applications*, K. Y. Maalawi Ed.: Intechopen, 2020.

[9] F. X. Ochieng, C. M. Hancock, G. W. Roberts, and J. Le Kernec, "A review of ground-based radar as a noncontact sensor for structural health monitoring of in-field wind turbines blades," *Wind Energy,* vol. 21, no. 12, pp. 1435-1449, 2018, doi: https://doi.org/10.1002/we.2252.

[10] F. X. Ochieng, C. M. Hancock, G. W. Roberts, J. Le Kernec, and X. Tang, "Novel Non-contact Deformation Health Monitoring of Towers and Rotating Composite Based Wind Turbine Blades Using Interferometric Ground Based Radar," in *FIG Congress 2018*, Istanbul, Turkey, 06-11 May 2018.

[11] F. X. Ochieng *et al.*, "Deflection characterisation of rotary systems using ground-based radar," *The Journal of Engineering*, vol. 2019, no. 20, pp. 7215-7219. [Online]. Available: https://digital-library.theiet.org/content/journals/10.1049/joe.2019.0503

[12] D. Gray, N. Nikolic, and J. L. Kernec, "Scan performance of small spherical retro-reflectors," in *2019 International Radar Conference (RADAR)*, 23-27 Sept. 2019 2019, pp. 1-5, doi: 10.1109/RADAR41533.2019.171391.

[13] D. Gray, X. Xin, Y. Zhu, and J. l. Kernec, "Structural slotted waveguide antennas for multirotor UAV radio altimeter," in *2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*, 5-8 Aug. 2014 2014, pp. 819-824, doi: 10.1109/ICSPCC.2014.6986311.

[14] D. Gray and J. L. Kernec, "Structural antennas for 3cm radar onboard multi-rotor UAV," in *International Conference on Radar Systems (Radar 2017)*, 23-26 Oct. 2017 2017, pp. 1-6, doi: 10.1049/cp.2017.0394.

[15] D. Gray and J. L. Kernec, "Aluminium feeds for reflector for NadirSAR," in *2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility (EMC/APEMC)*, 14-18 May 2018 2018, pp. 1140-1144, doi: 10.1109/ISEMC.2018.8393966.

[16] D. Gray, J. Thornton, and J. Le Kernec, "Homogeneous Spherical Lens for Marine Retro-reflector Application, Part 3. ," presented at the IEICE Technical Committee on Antennas and Propagation (AP), Kobe, Japan, 19-20 May, 2022.
[17] C. Ren, J. Le Kernec, J. Galy, É. Chaumette, P. Larzabal, and A. Reneaux, "Borné de Cramér-Rao sous contraintes pour l'estimation simultanée de paramètres aléatoires et non aléatoires," presented at the GRETSI, Lyon, France, Sep, 2015.
[18] C. Ren, J. Le Kernec, J. Galy, E. Chaumette, P. Larzabal, and A. Renaux, "A Constrained Hybrid Cramér-Rao Bound for Parameter Estimation," presented at the IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), South Brisbane, Australia, 2015.
[19] J. S. Patel, F. Fioranelli, and D. Anderson, "Review of radar classification and RCS characterisation techniques for small UAVs ordrones," *IET Radar, Sonar & Navigation*, vol. 12, no. 9, pp. 911-919. [Online]. Available: https://digital-library.theiet.org/content/journals/10.1049/iet-rsn.2018.0020
[20] M. Ritchie, F. Fioranelli, H. Griffiths, and B. Torvik, "Micro-drone RCS analysis," in *2015 IEEE Radar Conference*, 27-30 Oct. 2015 2015, pp. 452-456, doi: 10.1109/RadarConf.2015.7411926.
[21] F. Yang, J. L. Kernec, F. Fioranelli, and Q. Liu, "Shape feature aided target detection method for micro-drone surveillance radar," in *IET International Radar Conference (IET IRC 2020)*, 4-6 Nov. 2020 2020, vol. 2020, pp. 390-395, doi: 10.1049/icp.2021.0839.
[22] F. Yang, F. Xu, F. Fioranelli, J. Le Kernec, S. Chang, and T. Long, "Practical Investigation of a MIMO radar system capabilities for small drones detection," *IET Radar, Sonar & Navigation,* https://doi.org/10.1049/rsn2.12082 vol. 15, no. 7, pp. 760-774, 2021/07/01 2021, doi: https://doi.org/10.1049/rsn2.12082.
[23] C. Bennett, M. Jahangir, F. Fioranelli, B. I. Ahmad, and J. L. Kernec, "Use of Symmetrical Peak Extraction in Drone Micro-Doppler Classification for Staring Radar," in *2020 IEEE Radar Conference (RadarConf20)*, 21-25 Sept. 2020 2020, pp. 1-6, doi: 10.1109/RadarConf2043947.2020.9266702.
[24] M. Jahangir and C. J. Baker, "CLASS U-space drone test flight results for non-cooperative surveillance using an L-band 3-D staring radar," in *2019 20th International Radar Symposium (IRS)*, 26-28 June 2019 2019, pp. 1-11, doi: 10.23919/IRS.2019.8768155.
[25] J. A. Nanzer and V. C. Chen, "Microwave interferometric and Doppler radar measurements of a UAV," in *2017 IEEE Radar Conference (RadarConf)*, 8-12 May 2017 2017, pp. 1628-1633, doi: 10.1109/RADAR.2017.7944468.
[26] G. Wunder *et al.*, "5GNOW: non-orthogonal, asynchronous waveforms for future mobile applications," *IEEE Communications Magazine,* vol. 52, no. 2, pp. 97-105, 2014, doi: 10.1109/MCOM.2014.6736749.
[27] G. R. Al-Juboori, A. Doufexi, and A. R. Nix, "System level 5G evaluation of GFDM waveforms in an LTE-A platform," in *2016 International Symposium on Wireless Communication Systems (ISWCS)*, 20-23 Sept. 2016 2016, pp. 335-340, doi: 10.1109/ISWCS.2016.7600925.
[28] F. Schaich and T. Wild, "Waveform contenders for 5G — OFDM vs. FBMC vs. UFMC," in *2014 6th International Symposium on Communications, Control and Signal Processing (ISCCSP)*, 21-23 May 2014 2014, pp. 457-460, doi: 10.1109/ISCCSP.2014.6877912.
[29] Y. L. Sit, C. Sturm, T. Zwick, L. Reichardt, and W. Wiesbeck, "The OFDM Joint Radar-Communication System: An Overview," in *The Third International Conference on Advances in Satellite and Space Communications, SPACOMM 2011, April 17-22, 2011 - Budapest, Hungary*, 2011// 2011, pp. 69-74.
[30] C. Sturm and W. Wiesbeck, "Waveform Design and Signal Processing Aspects for Fusion of Wireless Communications and Radar Sensing," *Proceedings of the IEEE,* vol. 99, no. 7, pp. 1236-1259, 2011, doi: 10.1109/JPROC.2011.2131110.
[31] C. Sturm, Y. L. Sit, M. Braun, and T. Zwick, "Spectrally interleaved multi-carrier signals for radar network applications and multi-input multi-output radar," *IET Radar, Sonar & Navigation,* vol. 7, no. 3, pp. 261-269, 2013, doi: 10.1049/iet-rsn.2012.0040.

[32] D. Garmatyuk and K. Kauffman, "Radar and data communication fusion with UWB-OFDM software-defined system," in *2009 IEEE International Conference on Ultra-Wideband*, 9-11 Sept. 2009 2009, pp. 454-458, doi: 10.1109/ICUWB.2009.5288748.
[33] G. Fettweis, M. Krondorf, and S. Bittner, "GFDM - Generalized Frequency Division Multiplexing," in *VTC Spring 2009 - IEEE 69th Vehicular Technology Conference*, 26-29 April 2009 2009, pp. 1-4, doi: 10.1109/VETECS.2009.5073571.
[34] M. Bică and V. Koivunen, "Generalized Multicarrier Radar: Models and Performance," *IEEE Transactions on Signal Processing,* vol. 64, no. 17, pp. 4389-4402, 2016, doi: 10.1109/TSP.2016.2566610.
[35] G. Lellouch, A. K. Mishra, and M. Inggs, "Design of OFDM radar pulses using genetic algorithm based techniques," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 52, no. 4, pp. 1953-1966, 2016, doi: 10.1109/TAES.2016.140671.
[36] J. Le Kernec, P. Dreuillet, G. Bobillot, P. Garda, O. Romain, and J. Denoulet, "Case Study Analysis of Linear Chirp and Multitones (OFDM) Radar Signals Through Simulations and Measurement with HYCAM-Research Test Bench," presented at the Radar 2009 Surveillance for a Safer World, Bordeaux, France, 12-16 Oct, 2009.
[37] J. L. Kernec, "Contribution of Multitones for Ultra-Wide Band Software Defined Radar," Ph.D., EDITE de Paris – Ecole Doctorale Informatique, Télécommunication et Électronique, L'Université Pierre et Marie Curie, 2011.
[38] J. L. Kernec, O. Romain, P. Garda, and J. Denoulet, "Empirical comparison of Chirp and Multitones on experimental UWB software defined radar prototype," in *Proceedings of the 2012 Conference on Design and Architectures for Signal and Image Processing*, 23-25 Oct. 2012 2012, pp. 1-8.
[39] J. L. Kernec and O. Romain, "Empirical performance analysis of Linear Frequency Modulated pulse and Multitones on UWB software defined radar prototype," in *IET International Radar Conference 2013*, 14-16 April 2013 2013, pp. 1-6, doi: 10.1049/cp.2013.0228.
[40] J. L. Kernec, D. Gray, and O. Romain, "Empirical analysis of chirp and multitones performances with a UWB software defined radar: Range, distance and Doppler," in *Proceedings of 2014 3rd Asia-Pacific Conference on Antennas and Propagation*, 26-29 July 2014 2014, pp. 1061-1064, doi: 10.1109/APCAP.2014.6992691.
[41] J. L. Kernec and O. Romain, "Multitones' Performance for Ultra Wideband Software Defined Radar," in *Applications of Digital Signal Processing through Practical Approach*, S. Radhakrishnan Ed.: Intech open, 2015, ch. 3.
[42] J. Le Kernec and O. Romain, "Performances of multitones for ultra-wideband software-defined radar," *IEEE Access,* vol. 5, pp. 1-1, 2017, doi: 10.1109/access.2017.2693300.
[43] X. Lin and N. Lee, Eds. *5G and Beyond: Fundamentals and Standards*, 1 ed. Springer International Publishing, 2021.
[44] A. Goldsmith, *Wireless Communications*, Draft of Second Edition ed. 2020.
[45] Ofcom, "The award of 800 MHz and 2.6 GHz spectrum," 2012. [Online]. Available: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/32872/im.pdf
[46] S. Peng, S. Li, G. Han, X. Xue, and X. Zheng, "High-resolution imaging of a high-speed target based on a reconfigurable photonic fractional Fourier transformer," *Opt. Express,* vol. 29, no. 13, pp. 19985-19997, 2021/06/21 2021, doi: 10.1364/OE.430630.
[47] X. Li, Y. He, and X. Jing, "A Survey of Deep Learning-Based Human Activity Recognition in Radar," *Remote Sensing,* vol. 11, no. 9, p. 1068, 05/06 2019, doi: 10.3390/rs11091068.
[48] S. Mazahir, S. Ahmed, and M.-S. Alouini, "A Survey on Joint Communication-Radar Systems," (in English), *Frontiers in Communications and Networks,* Review vol. 1, no. 9, 2021-February-25 2021, doi: 10.3389/frcmn.2020.619483.
[49] Andre Bourdoux *et al.*, "6G White Paper on Localization and Sensing," 2020. [Online]. Available: arXiv:2006.01779v1
[50] C. Sahin, J. Jakabosky, P. M. McCormick, J. G. Metcalf, and S. D. Blunt, "A novel approach for embedding communication symbols into physical radar waveforms," in *2017 IEEE Radar Conference (RadarConf)*, 8-12 May 2017 2017, pp. 1498-1503, doi: 10.1109/RADAR.2017.7944444.
[51] N. Levanon and E. Mozeson, *Radar Signals*. Hoboken, New Jersey: John Wiley & Sons, 2004.

[52] M. Kronauge and H. Rohling, "New chirp sequence radar waveform," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 50, no. 4, pp. 2870-2877, 2014, doi: 10.1109/TAES.2014.120813.
[53] WHO, "Noncommunicable Diseases (NCD) Country Profiles, 2018 - China," 2018.
[54] H. Liu, "Chart: China's Aging Population," Caixin, Ed., ed, 2018.
[55] J. Smyth, X. Wang, and T. Hancock, "China's ageing population lures foreign operators into care market," F. Times, Ed., ed, 2019.
[56] "Embrace Healthcare Revolution - Strategically moving from volume to value," RITM0144070, 2018. [Online]. Available: https://www2.deloitte.com/cn/en/pages/life-sciences-and-healthcare/articles/embrace-healthcare-revolution.html
[57] (2016). *The 13th Five-Year Plan for economic and social development of the people's republic of china*. [Online] Available: http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf
[58] X. Tan, X. Liu, and H. Shao, "Healthy China 2030: A Vision for Health Care," *Value in Health Regional Issues,* vol. 12, pp. 112-114, 2017/05/01/ 2017, doi: https://doi.org/10.1016/j.vhri.2017.04.001.
[59] P. a. S. J. A. Equality. "Equality Evidence Finder." Scottish government. https://scotland.shinyapps.io/sg-equality-evidence-finder/ (accessed 10 Oct, 2019).
[60] (2014). *China and the UK: Partners in healthcare*. [Online] Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/271480/Healthcare_UK_China_and_the_UK.pdf
[61] N. Blanpain and O. Chardon, "Population projections for 2060: one-third of the population aged over 60," INSEE, 27/10 2010. [Online]. Available: https://www.insee.fr/en/statistiques/1281152
[62] WHO. "the top 10 causes of death - fact sheet." http://origin.who.int/mediacentre/factsheets/fs310/en/ (accessed 2019/02/25.
[63] X. Zhang and H. Xiao, "Development and evaluation of a WeChat-based life review programme for patients with cancer: protocol for a randomised controlled trial," *BMJ open,* vol. 8, no. 12, pp. e020239-e020239, 2018, doi: 10.1136/bmjopen-2017-020239.
[64] O. Ciani *et al.*, "Lung Cancer App (LuCApp) study protocol: a randomised controlled trial to evaluate a mobile supportive care app for patients with metastatic lung cancer," *BMJ Open,* vol. 9, no. 2, p. e025483, 2019, doi: 10.1136/bmjopen-2018-025483.
[65] M. Abdur Rahman *et al.*, "A Secure Occupational Therapy Framework for Monitoring Cancer Patients' Quality of Life," *Sensors,* no. 19(23):5258, 2019, doi: https://doi.org/10.3390/s19235258.
[66] S. N. W. Vorrink, H. S. M. Kort, T. Troosters, P. Zanen, and J.-W. J. Lammers, "Efficacy of an mHealth intervention to stimulate physical activity in COPD patients after pulmonary rehabilitation," *European Respiratory Journal,* vol. 48, no. 4, p. 1019, 2016, doi: 10.1183/13993003.00083-2016.
[67] B. Philippe, "House of Therapeutic education and Health prevention - internal document," Groupement Hospitalier de Territoire du Val d'Oise, 2019.
[68] (2012). *Report to Congress: Aging services Technology Study*.
[69] T. He, "China's Silver Consumers: Growing Opportunities for UK Companies " China Britain Business Council, 2015.
[70] "National strategy for Health 2018-2022," French Ministry of solidarity and health, 2017.
[71] NHS, "NHS long term plan," January 2019.
[72] H. Aykan, "Report to Congress: Aging Services Technology Study," Washington, 2012.
[73] J. Le Kernec, F. Fioranelli, S. Yang, J. Lorandel, and O. Romain, "Radar for Assisted Living in the Context of Internet of Things for Health and Beyond," in *26th IFIP/IEEE Int. Conf. Very Large Scale Integr. VLSI-SOC*, Verona, 8-10 Oct 2018, pp. 1-5.
[74] H. Li, A. Shrestha, F. Fioranelli, J. L. Kernec, and H. Heidari, "Multisensory Data Fusion for Human Activities Classification and Fall Detection," presented at the IEEE Sensors 2017, Glasgow, UK, 30 Oct - 1 Nov, 2017.

[75] H. Li *et al.*, "Multisensor data fusion for human activities classification and fall detection," in *IEEE sensors*, Glasgow, Scotland, Oct 29 - Nov 1 2017, pp. 1-3, doi: 10.1109/ICSENS.2017.8234179.
[76] H. Li, A. Shrestha, F. Fioranelli, J. Le Kernec, and H. Heidari, "FMCW Radar and Inertial Sensing Synergy for Assisted Living," presented at the IET Int. Radar Conf., Nanjing, China, 17-19 Oct, 2018.
[77] H. Li, A. Shrestha, H. Heidari, J. L. Kernec, and F. Fioranelli, "A Multisensory Approach for Remote Health Monitoring of Older People," *IEEE J. of Electromagn., RF and Microw. in Med. and Biol.,* vol. 2, no. 2, pp. 102-108, 2018, doi: 10.1109/JERM.2018.2827099.
[78] H. Li, A. Shrestha, H. Heidari, J. L. Kernec, and F. Fioranelli, "Magnetic and Radar Sensing for Multimodal Remote Health Monitoring," *IEEE Sensors J.,* pp. 1-1, 2018, doi: 10.1109/JSEN.2018.2872894.
[79] J. Li, A. Shrestha, J. Le Kernec, and F. Fioranelli, "From Kinect Skeleton Data to Hand Gesture Recognition with Radar," presented at the IET Int. Radar Conf., Nanjing, China, 17-19 Oct, 2018.
[80] Y. Lin and J. L. Kernec, "Performance Analysis of Classification Algorithms for Activity Recognition using Micro-Doppler Feature," presented at the The 13th International Conference on Computational Intelligence and Security (CIS 2017), Hong Kong, China, 15-18 December, 2017.
[81] C. Loukas, F. Fioranelli, J. Le Kernec, and S. Yang, "Activity Classification Using Raw Range and I & Q Radar Data With Long Short Term Memory Layers," in *3rd IEEE Cyber Sci. Tech. Congr.*, Athens, 12-15 Aug 2018, pp. 441-445, doi: doi:10.1109/DASC/PiCom/DataCom/CyberSciTec.2018.00088.
[82] A. Shrestha, J. L. Kernec, F. Fioranelli, E. Cippitelli, E. Gambi, and S. Spinsante, "Diversity for fall detection and human indoor activities classification using radar systems," presented at the Radar 2017: international conference on radar systems, Belfast, UK, 23-26 Oct, 2017.
[83] A. Shrestha *et al.*, "Elderly Care: Activities of Daily Living Classification with an S Band Radar," presented at the IET Int. Radar Conf., Nanjing, China, 17-19 Oct, 2018.
[84] A. Shrestha, H. Li, F. Fioranelli, and J. Le Kernec, "Activity recognition with cooperative Radar systems at C and K band," in *IET Int. Radar Conf.*, Nanjing, China, 2018 2018, pp. 1-6.
[85] M. G. Amin, Y. D. Zhang, F. Ahmad, and K. C. D. Ho, "Radar Signal Processing for Elderly Fall Detection: The future for in-home monitoring," *IEEE Signal Processing Magazine,* vol. 33, no. 2, pp. 71-80, 2016, doi: 10.1109/MSP.2015.2502784.
[86] F. Ahmad, A. E. Cetin, K. C. D. Ho, and J. Nelson, "Signal processing for Assisted Living: Developments and Open Problems [From the Guest Editors]," *IEEE Signal Processing Magazine,* vol. 33, no. 2, 2016.
[87] C. Debes, A. Merentitis, S. Sukhanov, M. Niessen, N. Frangiadakis, and A. Bauer, "Monitoring Activities of Daily Living in Smart Homes: Understanding human behavior," *IEEE Signal Processing Magazine,* vol. 33, no. 2, pp. 81-94, 2016, doi: 10.1109/MSP.2015.2503881.
[88] F. Erden, S. Velipasalar, A. Z. Alkar, and A. E. Cetin, "Sensors in Assisted Living: A survey of signal and image processing methods," *IEEE Signal Processing Magazine,* vol. 33, no. 2, pp. 36-44, 2016, doi: 10.1109/MSP.2015.2489978.
[89] H. Li, A. Shrestha, H. Heidari, J. Le Kernec, and F. Fioranelli, "Bi-LSTM Network for Multimodal Continuous Human Activity Recognition and Fall Detection," *IEEE Sensors Journal,* vol. 20, no. 3, pp. 1191-1201, 2020, doi: 10.1109/jsen.2019.2946095.
[90] H. Li, A. Shrestha, F. Fioranelli, J. Le Kernec, and H. Heidari, "FMCW radar and inertial sensing synergy for assisted living," *The Journal of Engineering,* vol. 2019, no. 20, pp. 6784-6789, 2019, doi: 10.1049/joe.2019.0558.
[91] A. Shrestha *et al.*, "Cross-Frequency Classification of Indoor Activities with DNN Transfer Learning," in *2019 IEEE Radar Conference (RadarConf)*, 22-26 April 2019 2019, pp. 1-6, doi: 10.1109/RADAR.2019.8835844.
[92] J. L. Kernec *et al.*, "Radar Sensing in Assisted Living: an Overview," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, 6-8 May 2019 2019, vol. 1, pp. 1-4, doi: 10.1109/IMBIOC.2019.8777748.

[93] J. Le Kernec *et al.*, "Radar Signal Processing for Sensing in Assisted Living: The Challenges Associated With Real-Time Implementation of Emerging Algorithms," *IEEE Signal Processing Magazine,* vol. 36, no. 4, pp. 29-41, 2019, doi: 10.1109/msp.2019.2903715.

[94] C. Ding *et al.*, "Continuous Human Motion Recognition With a Dynamic Range-Doppler Trajectory Method Based on FMCW Radar," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 57, no. 9, pp. 6821-6831, 2019, doi: 10.1109/tgrs.2019.2908758.

[95] H. Li, A. Shrestha, H. Heidari, J. Le Kernec, and F. Fioranelli, "Magnetic and Radar Sensing for Multimodal Remote Health Monitoring," *IEEE Sensors Journal,* vol. 19, no. 20, pp. 8979-8989, 2019, doi: 10.1109/jsen.2018.2872894.

[96] A. Shrestha, H. Li, F. Fioranelli, and J. Le Kernec, "Activity recognition with cooperative radar systems at C and K band," *The Journal of Engineering,* vol. 2019, no. 20, pp. 7100-7104, 2019, doi: 10.1049/joe.2019.0559.

[97] H. Li, A. Shrestha, H. Heidari, J. L. Kernec, and F. Fioranelli, "Activities Recognition and Fall Detection in Continuous Data Streams Using Radar Sensor," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, 6-8 May 2019 2019, vol. 1, pp. 1-4, doi: 10.1109/IMBIOC.2019.8777855.

[98] F. Fioranelli, J. Le Kernec, and S. A. Shah, "Radar for Health Care: Recognizing Human Activities and Monitoring Vital Signs," *IEEE Potentials,* vol. 38, no. 4, pp. 16-23, 2019, doi: 10.1109/mpot.2019.2906977.

[99] A. Mishra, W. McDonnell, J. Wang, D. Rodriguez, and C. Li, "Intermodulation-Based Nonlinear Smart Health Sensing of Human Vital Signs and Location," *IEEE Access,* vol. 7, pp. 158284-158295, 2019, doi: 10.1109/access.2019.2950347.

[100] J. Yan *et al.*, "The Development of Vital-SAR-Imaging with an FMCW Radar System," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, 6-8 May 2019 2019, vol. 1, pp. 1-4, doi: 10.1109/IMBIOC.2019.8777881.

[101] J. Wang, T. Karp, J. Muñoz-Ferreras, R. Gómez-García, and C. Li, "A Spectrum-Efficient FSK Radar Solution for Stationary Human Subject Localization Based on Vital Sign Signals," in *2019 IEEE MTT-S International Microwave Symposium (IMS)*, 2-7 June 2019 2019, pp. 140-143, doi: 10.1109/MWSYM.2019.8700837.

[102] G. Zhang *et al.*, "Phase-demodulation based Human Identification for Vital-SAR-Imaging in Pure FMCW Mode," in *2019 IEEE MTT-S International Microwave Symposium (IMS)*, 2-7 June 2019 2019, pp. 152-155, doi: 10.1109/MWSYM.2019.8700958.

[103] A. Mishra and C. Li, "A Low Power 5.8-GHz ISM-Band Intermodulation Radar System for Target Motion Discrimination," *IEEE Sensors Journal,* vol. 19, no. 20, pp. 9206-9214, 2019, doi: 10.1109/jsen.2019.2926189.

[104] H. Zhang, L. Zhang, Q. Gao, Y. Xiao, H. Hong, and X. Zhu, "Body Movement Cancellation Based on Hybrid Radar-Webcam Sensing System," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, 6-8 May 2019 2019, vol. 1, pp. 1-3, doi: 10.1109/IMBIOC.2019.8777873.

[105] J. Muñoz-Ferreras, J. Wang, Z. Peng, C. Li, and R. Gómez-García, "FMCW-Radar-Based Vital-Sign Monitoring of Multiple Patients," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, 6-8 May 2019 2019, vol. 1, pp. 1-3, doi: 10.1109/imbioc.2019.8777845. [Online]. Available: https://ieeexplore.ieee.org/document/8777845/https://ieeexplore.ieee.org/ielx7/8766265/8777735/08777845.pdf?tp=&arnumber=8777845&isnumber=8777735&ref=

[106] G. Diraco, A. Leone, and P. Siciliano, "Radar Sensing of Vital Signs in Assisted Living Applications," in *Ambient Assisted Living*, Cham, N. Casiddu, C. Porfirione, A. Monteriù, and F. Cavallo, Eds., 2019// 2019: Springer International Publishing, pp. 3-22.

[107] X. Hui and E. C. Kan, "No-touch measurements of vital signs in small conscious animals," *Science Advances,* vol. 5, no. 2, p. eaau0169, 2019, doi: 10.1126/sciadv.aau0169.

[108] Q. Lv *et al.*, "Doppler Vital Signs Detection in the Presence of Large-Scale Random Body Movements," *IEEE Transactions on Microwave Theory and Techniques,* vol. 66, no. 9, pp. 4261-4270, 2018, doi: 10.1109/tmtt.2018.2852625.

[109] J. Muñoz-Ferreras, J. Wang, Z. Peng, R. Gómez-García, and C. Li, "From Doppler to FMCW Radars for Non-Contact Vital-Sign Monitoring," in *2018 2nd URSI Atlantic Radio Science*

Meeting (AT-RASC), 28 May-1 June 2018 2018, pp. 1-4, doi: 10.23919/ursi-at-rasc.2018.8471575. [Online]. Available: https://ieeexplore.ieee.org/document/8471575/https://ieeexplore.ieee.org/ielx7/8457680/8471271/08471575.pdf?tp=&arnumber=8471575&isnumber=8471271&ref=

[110] M. Mercuri *et al.*, "A Direct Phase-Tracking Doppler Radar Using Wavelet Independent Component Analysis for Non-Contact Respiratory and Heart Rate Monitoring," *IEEE Trans Biomed Circuits Syst,* vol. 12, no. 3, pp. 632-643, Jun 2018, doi: 10.1109/TBCAS.2018.2813013.

[111] X. Hui and E. C. Kan, "Accurate Extraction of Heartbeat Intervals with Near-Field Coherent Sensing," in *2018 IEEE International Conference on Communications (ICC)*, 20-24 May 2018 2018, pp. 1-6, doi: 10.1109/ICC.2018.8423000.

[112] M. Nosrati, S. Shahsavari, and N. Tavassolian, "Multi-Target Vital-Signs Monitoring Using a Dual-Beam Hybrid Doppler Radar," in *2018 IEEE International Microwave Biomedical Conference (IMBioC)*, 14-15 June 2018 2018, pp. 58-60, doi: 10.1109/IMBIOC.2018.8428942.

[113] F. Zhu, K. Wang, and K. Wu, "A Fundamental-and-Harmonic Dual-Frequency Doppler Radar System for Vital Signs Detection Enabling Radar Movement Self-Cancellation," *IEEE Transactions on Microwave Theory and Techniques,* vol. 66, no. 11, pp. 5106-5118, 2018, doi: 10.1109/TMTT.2018.2869591.

[114] A. E. Fathy, L. Ren, S. Nahar, and O. Kilic, "Overview of human vital signs detection using radar techniques," in *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 9-14 July 2017 2017, pp. 1229-1230, doi: 10.1109/APUSNCURSINRSM.2017.8072657.

[115] C. Hsu, C. Chuang, F. Wang, T. Horng, and L. Hwang, "Detection of vital signs for multiple subjects by using self-injection-locked radar and mutually injection-locked beam scanning array," in *2017 IEEE MTT-S International Microwave Symposium (IMS)*, 4-9 June 2017 2017, pp. 991-994, doi: 10.1109/MWSYM.2017.8058756.

[116] L. Ren, H. Wang, K. Naishadham, O. Kilic, and A. E. Fathy, "Phase-Based Methods for Heart Rate Detection Using UWB Impulse Doppler Radar," *IEEE Transactions on Microwave Theory and Techniques,* vol. 64, no. 10, pp. 3319-3331, 2016, doi: 10.1109/tmtt.2016.2597824.

[117] L. Ren, S. Nahar, A. E. Fathy, T. Phan, N. Tran, and O. Kilic, "Investigation of vital signs monitoring errors due to subject's orientation, clothing and distance from a SFCW radar," in *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, 26 June-1 July 2016 2016, pp. 1171-1172, doi: 10.1109/APS.2016.7696293.

[118] L. Ren, H. Wang, K. Naishadham, O. Kilic, and A. E. Fathy, "Phase-Based Methods for Heart Rate Detection Using UWB Impulse Doppler Radar," *IEEE Trans. Microw. Theory Tech.,* vol. 64, no. 10, pp. 3319-3331, 2016, doi: 10.1109/TMTT.2016.2597824.

[119] M. Tang, C. Kuo, D. Wun, F. Wang, and T. Horng, "A Self- and Mutually Injection-Locked Radar System for Monitoring Vital Signs in Real Time With Random Body Movement Cancellation," *IEEE Transactions on Microwave Theory and Techniques,* vol. 64, no. 12, pp. 4812-4822, 2016, doi: 10.1109/TMTT.2016.2623612.

[120] L. Sun, Y. Li, H. Hong, F. Xi, W. Cai, and X. Zhu, "Super-resolution spectral estimation in short-time non-contact vital sign measurement," *Rev Sci Instrum,* vol. 86, no. 4, p. 044708, Apr 2015, doi: 10.1063/1.4916954.

[121] L. Ren, Y. S. Koo, Y. Wang, and A. E. Fathy, "Noncontact heartbeat detection using UWB impulse doppler radar," in *2015 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS)*, 25-28 Jan. 2015 2015, pp. 1-3, doi: 10.1109/BIOWIRELESS.2015.7152128.

[122] G. Wang, J. Muñoz-Ferreras, C. Gu, C. Li, and R. Gómez-García, "Application of Linear-Frequency-Modulated Continuous-Wave (LFMCW) Radars for Tracking of Vital Signs," *IEEE Transactions on Microwave Theory and Techniques,* vol. 62, no. 6, pp. 1387-1399, 2014, doi: 10.1109/TMTT.2014.2320464.

[123] P. Bechet, R. Mitran, and M. Munteanu, "A non-contact method based on multiple signal classification algorithm to reduce the measurement time for accurately heart rate detection," *Rev Sci Instrum,* vol. 84, no. 8, p. 084707, Aug 2013, doi: 10.1063/1.4818974.

[124] A. Lazaro, D. Girbau, and R. Villarino, "Analysis of Vital Signs Monitoring Using an IR-UWB Radar," *Progress In Electromagnetics Research,* vol. 100, pp. 265-284, 2010, doi: doi:10.2528/PIER09120302.

[125] Y. Yan, C. Li, X. Yu, M. D. Weiss, and J. Lin, "Verification of a non-contact vital sign monitoring system using an infant simulator," in *2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 3-6 Sept. 2009 2009, pp. 4836-4839, doi: 10.1109/IEMBS.2009.5332668.

[126] B. Lohman, O. Boric-Lubecke, V. M. Lubecke, P. W. Ong, and M. M. Sondhi, "A digital signal processor for Doppler radar sensing of vital signs," *IEEE Engineering in Medicine and Biology Magazine,* vol. 21, no. 5, pp. 161-164, 2002, doi: 10.1109/MEMB.2002.1044188.

[127] A. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, and L. Jenshan, "0.25 /spl mu/m CMOS and BiCMOS single-chip direct-conversion Doppler radars for remote sensing of vital signs," in *2002 IEEE International Solid-State Circuits Conference. Digest of Technical Papers (Cat. No.02CH37315)*, 7-7 Feb. 2002 2002, vol. 1, pp. 348-349 vol.1, doi: 10.1109/ISSCC.2002.993075.

[128] A. König *et al.*, "Validation of an Automatic Video Monitoring System for the Detection of Instrumental Activities of Daily Living in Dementia Patients," *Journal of Alzheimer's Disease,* vol. 44, no. 2, pp. 675-685, 2015.

[129] R. Igual, C. Medrano, and I. Plaza, "Challenges, issues and trends in fall detection systems," *BioMedical Engineering OnLine,* journal article vol. 12, no. 1, p. 66, July 06 2013, doi: 10.1186/1475-925x-12-66.

[130] P. Calyam, I. Jahnke, A. Mishra, R. B. Antequera, D. Chemodanov, and M. Skubic, "Toward an ElderCare Living Lab for Sensor-Based Health Assessment and Physical Therapy," *IEEE Cloud Computing,* vol. 4, no. 3, pp. 30-39, 2017, doi: 10.1109/MCC.2017.46.

[131] S. Wang, M. Skubic, and Y. Zhu, "Activity Density Map Visualization and Dissimilarity Comparison for Eldercare Monitoring," *IEEE Transactions on Information Technology in Biomedicine,* vol. 16, no. 4, pp. 607-614, 2012, doi: 10.1109/TITB.2012.2196439.

[132] E. Cippitelli, F. Fioranelli, E. Gambi, and S. Spinsante, "Radar and RGB-Depth Sensors for Fall Detection: A Review," *IEEE Sensors Journal,* vol. 17, no. 12, pp. 3585-3604, 2017, doi: 10.1109/JSEN.2017.2697077.

[133] C. Li *et al.*, "A Review on Recent Progress of Portable Short-Range Noncontact Microwave Radar Systems," *IEEE Trans. Microw. Theory Tech.,* vol. 65, no. 5, pp. 1692-1706, 2017, doi: 10.1109/TMTT.2017.2650911.

[134] M. Amin, Ed. *Radar for Indoor monitoring*, 1st edition ed. CRC Press, 2017.

[135] V. Nathan *et al.*, "A Survey on Smart Homes for Aging in Place: Toward Solutions to the Specific Needs of the Elderly," *IEEE Signal Process. Mag.,* vol. 35, no. 5, pp. 111-119, 2018, doi: 10.1109/MSP.2018.2846286.

[136] V. Chen, *The Micro-Doppler Effect in Radar*, 2nd edition ed. London, Boston: Artech House, 2011.

[137] R. Boulic, N. M. Thalmann, and D. Thalmann, "A global human walking model with real-time kinematic personification," *The Visual Computer,* vol. 6, no. 6, pp. 344-358, 1990/11/01 1990, doi: 10.1007/bf01901021.

[138] M. Muller, T. Roder, M. Clausen, B. Eberhardt, B. Kruger, and A. Weber, "Documentation Mocap Database HDM05," Institut fur informatik II Universitat Bonn D-53117 Bonn, Germany, CG-2007-2, 2007 2007.

[139] *CMU Graphics Lab Motion Capture Database*. [Online]. Available: http://mocap.cs.cmu.edu/

[140] B. Zhou, J. L. Kernec, S. Yang, F. Fioranelli, O. Romain, and Z. Zhao, "Interferometric radar for activity recognition and benchmarking in different radar geometries," presented at the IET international radar conference, Chongqing, China, 4-6 Nov, 2020.

[141] N. V. Chawla, K. W. Bowyer, L. O. Hall, and W. P. Kegelmeyer, "SMOTE: synthetic minority over-sampling technique," *J. Artif. Int. Res.,* vol. 16, no. 1, pp. 321–357, 2002.

[142] M. S. Seyfioglu, B. Erol, S. Z. Gurbuz, and M. G. Amin, "Diversified radar micro-Doppler simulations as training data for deep residual neural networks," in *2018 IEEE Radar Conference (RadarConf18)*, 23-27 April 2018 2018, pp. 0612-0617, doi: 10.1109/RADAR.2018.8378629.

[143] K. D. Trott, "Stationary Phase Derivation for RCS of an Ellipsoid," *IEEE Antennas and Wireless Propagation Letters,* vol. 6, pp. 240-243, 2007, doi: 10.1109/lawp.2007.891521.

[144] Q. Chen, Y. Liu, F. Fioranelli, M. Ritchie, and K. Chetty, "Eliminate Aspect Angle Variations for Human Activity Recognition using Unsupervised Deep Adaptation Network," in *2019 IEEE Radar Conference (RadarConf)*, 22-26 April 2019 2019, pp. 1-6, doi: 10.1109/RADAR.2019.8835756.

[145] F. Fioranelli, M. Ritchie, and H. Griffiths, "Aspect angle dependence and multistatic data fusion for micro-Doppler classification of armed/unarmed personnel," *IET Radar, Sonar & Navigation,* vol. 9, no. 9, pp. 1231-1239, 2015, doi: 10.1049/iet-rsn.2015.0058.

[146] C. Karabacak, S. Z. Gürbüz, M. B. Guldogan, and A. C. Gürbüz, *Multi-aspect angle classification of human radar signatures* (SPIE Defense, Security, and Sensing). SPIE, 2013.

[147] B. Zhou *et al.*, "Simulation framework for activity recognition and benchmarking in different radar geometries," *IET Radar, Sonar & Navigation,* vol. 15, no. 4, pp. 390-401, 2021, doi: https://doi.org/10.1049/rsn2.12049.

[148] B. Burger and P. Toiviainen, "MoCap Toolbox – A Matlab toolbox for computational analysis of movement data," in *Proceedings of the 10th Sound and Music Computing Conference, (SMC)*, Stockholm, Sweden, R. Bresin, Ed., 2013.

[149] M. Zhao *et al.*, "Through-Wall Human Pose Estimation Using Radio Signals," in *2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 18-23 June 2018 2018, pp. 7356-7365, doi: 10.1109/CVPR.2018.00768.

[150] Y. Lin, J. Le Kernec, S. Yang, F. Fioranelli, O. Romain, and Z. Zhao, "Human Activity Classification With Radar: Optimization and Noise Robustness With Iterative Convolutional Neural Networks Followed With Random Forests," *IEEE Sensors Journal,* vol. 18, no. 23, pp. 9669-9681, 2018, doi: 10.1109/jsen.2018.2872849.

[151] G. W. Stimson, *Introduction to Airborne Radar*. Institution of Engineering and Technology, 1998.

[152] K. Yang, Q. H. Abbasi, F. Fioranelli, O. Romain, and J. Le Kernec, "Bespoke Simulator for Human Activity Classification with Bistatic Radar," in *Body Area Networks. Smart IoT and Big Data for Intelligent Health Management*, Cham, M. Ur Rehman and A. Zoha, Eds., 2022// 2021: Springer International Publishing, pp. 71-85.

[153] X. Wang, T. X. Han, and S. Yan, "An HOG-LBP human detector with partial occlusion handling," in *2009 IEEE 12th International Conference on Computer Vision*, 29 Sept.-2 Oct. 2009 2009, pp. 32-39, doi: 10.1109/ICCV.2009.5459207.

[154] P. Mohanaiah, P. Sathyanarayana, and L. GuruKumar, "Image Texture Feature Extraction Using GLCM Approach," *International Journal of Scientific and Research Publications,* vol. 3, no. 5, 2013.

[155] T. McEwan, "Body monitoring and imaging apparatus and method," Patent Appl. 747,131, 1998.

[156] P. Madona, R. I. Basti, and M. M. Zain, "PQRST wave detection on ECG signals," *Gaceta Sanitaria,* vol. 35, pp. S364-S369, 2021/01/01/ 2021, doi: https://doi.org/10.1016/j.gaceta.2021.10.052.

[157] S. Koelstra *et al.*, "DEAP: A Database for Emotion Analysis ;Using Physiological Signals," *IEEE Transactions on Affective Computing,* vol. 3, no. 1, pp. 18-31, 2012, doi: 10.1109/T-AFFC.2011.15.

[158] J. Ren, *Diagnostics of traditional Chinese Medicine*. Jinan: Shandong Technology Press, 2020.

[159] H.-M. D. o. H. S. a. Technology. *MIT-BIH Database Distribution*. [Online]. Available: https://ecg.mit.edu/

[160] V. V. Moca, H. Bârzan, A. Nagy-Dăbâcan, and R. C. Mureşan, "Time-frequency super-resolution with superlets," *Nature Communications,* vol. 12, no. 1, p. 337, 2021/01/12 2021, doi: 10.1038/s41467-020-20539-9.

[161] S. Hochreiter and J. Schmidhuber, "Long short-term memory," *Neural Comput,* vol. 9, no. 8, pp. 1735-80, Nov 15 1997, doi: 10.1162/neco.1997.9.8.1735.

[162] F. Fioranelli, S. A. Shah, H. Li, A. Shrestha, S. Yang, and J. Le Kernec. *Radar signatures of human activities*, doi: 10.5525/gla.researchdata.848.

[163] A. Shrestha, H. Li, J. L. Kernec, and F. Fioranelli, "Continuous human activity classification from FMCW radar with Bi-LSTM networks," *IEEE Sensors Journal,* pp. 1-1, 2020, doi: 10.1109/JSEN.2020.3006386.
[164] C. Ding *et al.*, "Inattentive Driving Behavior Detection Based on Portable FMCW Radar," *IEEE Transactions on Microwave Theory and Techniques,* vol. 67, no. 10, pp. 4031-4041, 2019, doi: 10.1109/tmtt.2019.2934413.
[165] A. Shrestha *et al.*, "Elderly care: activities of daily living classification with an <i>S</i> band radar," *The Journal of Engineering*, vol. 2019, no. 21, pp. 7601-7606. [Online]. Available: https://digital-library.theiet.org/content/journals/10.1049/joe.2019.0561
[166] O. Romain, J. LEKERNEC, J. LORANDEL, and F. FIORANELLI, "Dispositif de caracterisation de l'actimetrie d'un sujet en temps reel = Device for Characterizing the Actimetry of a Subject in Real Time.," Patent WO2021069518A1, 2019. [Online]. Available: https://patents.google.com/patent/WO2021069518A1/en
[167] S. Z. Gurbuz and M. G. Amin, "Radar-Based Human-Motion Recognition With Deep Learning: Promising Applications for Indoor Monitoring," *IEEE Signal Processing Magazine,* vol. 36, no. 4, pp. 16-28, 2019, doi: 10.1109/msp.2018.2890128.
[168] V. C. Chen, D. Tahmoush, and W. J. Miceli, *Radar Micro-Doppler Signature: Processing and Applications*. IET, 2014.
[169] D. F. Fioranelli, D. S. A. Shah, H. Li, A. Shrestha, D. S. Yang, and D. J. L. Kernec, "Radar sensing for healthcare," *Electronics Letters,* vol. 55, no. 19, pp. 1022-1024, 2019, doi: 10.1049/el.2019.2378.
[170] H. Du, T. Jin, Y. Song, Y. Dai, and M. Li, "A Three-Dimensional Deep Learning Framework for Human Behavior Analysis Using Range-Doppler Time Points," *IEEE Geoscience and Remote Sensing Letters,* pp. 1-5, 2019, doi: 10.1109/lgrs.2019.2930636.
[171] Y. He, T. Sakamoto, P. Molchanov, A. Yarovoy, F. Le Chevalier, and P. Aubry, "Range-Doppler surface: a tool to analyse human target in ultra-wideband radar," *IET Radar, Sonar & Navigation,* vol. 9, no. 9, pp. 1240-1250, 2015, doi: 10.1049/iet-rsn.2015.0065.
[172] C. R. Qi, H. Su, K. Mo, and L. J. Guibas, "PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation," ed, 2016.
[173] Z. Chen, G. Li, F. Fioranelli, and H. Griffiths, "Personnel Recognition and Gait Classification Based on Multistatic Micro-Doppler Signatures Using Deep Convolutional Neural Networks," *IEEE Geoscience and Remote Sensing Letters,* vol. 15, no. 5, pp. 669-673, 2018, doi: 10.1109/lgrs.2018.2806940.
[174] J. Guo *et al.*, "Complex Field-based Fusion Network for Human Activities Classication With Radar," presented at the IET international radar conference, Chongqing, China, 4-6 Nov, 2020.
[175] X. Li, Z. Li, F. Fioranelli, S. Yang, O. Romain, and J. L. Kernec, "Hierarchical Radar Data Analysis for Activity and Personnel Recognition," *Remote Sensing,* vol. 12, no. 14, p. 2237, 2020. [Online]. Available: https://www.mdpi.com/2072-4292/12/14/2237.
[176] S. Li, M. Jia, J. L. Kernec, S. Yang, F. Fioranelli, and O. Romain, "Elderly Care: Using Deep Learning for Multi-Domain Activity Classification," presented at the 5th international conference on the UK-China Emerging Technologies (UCET) 2020, Glasgow, UK, 20-21 Aug, 2020.
[177] M. Jia, S. Li, J. L. Kernec, S. Yang, F. Fioranelli, and O. Romain, "Human activity classification with radar signal processing and machine learning," presented at the 5th International Conference on the UK-China Emerging Technologies (UCET) 2020, Glasgow, UK, 20-21 Aug, 2020.
[178] Z. Li *et al.*, "Multi-domains based Human Activity Classification in Radar," presented at the IET International Radar Conference Chongqing, China, 4-6 Nov, 2020.
[179] X. Zhang, Q. H. Abbasi, F. Fioranelli, O. Romain, and J. Le Kernec, "Elderly Care - Human Activity Recognition Using Radar with an Open Dataset and Hybrid Maps," in *Body Area Networks. Smart IoT and Big Data for Intelligent Health Management*, Cham, M. Ur Rehman and A. Zoha, Eds., 2022// 2021: Springer International Publishing, pp. 39-51.
[180] J. L. Kernec, Z. Li, Q. Abbasi, O. Romain, F. Fioranelli, and S. Yang, "Device for Characterizing the Actimetry of a Subject in Real Time – leveraging adaptive mask, amplitude and phase," Patent Appl. EP21306742, 2021.

[181] A. Napolitano, *Cyclostationary Processes and Time Series*. London, Oxford, UK - Cambridge, San Diego, USA: Elsevier, 2019.
[182] A. Napolitano, *Generalizations of Cyclostationary Signal Processing: Spectral Analysis and Applications*. Wiley-IEEE Press, 2012.
[183] Y. Du *et al.*, "Radar-based Human Activity Classification with Cyclostationarity," presented at the 2021 CIE International Conference on Radar (CIE Radar 2021), Haikou, Hainan, China, 15-19 Dec, 2021.
[184] R. G. Guendel, "Radar Classification of Contiguous Activities of Daily Living," Master, Computer and Electrical Engineering, Villanova University, 2019.
[185] L. Zhang, C. Han, Y. Wang, Y. Li, and T. Long, "Polarimetric HRRP recognition based on feature-guided Transformer model," *Electronics Letters,* vol. 57, no. 18, pp. 705-707, 2021, doi: https://doi.org/10.1049/ell2.12225.
[186] J. A. Tropp and A. C. Gilbert, "Signal Recovery From Random Measurements Via Orthogonal Matching Pursuit," *IEEE Transactions on Information Theory,* vol. 53, no. 12, pp. 4655-4666, 2007, doi: 10.1109/TIT.2007.909108.
[187] D. Needell and J. A. Tropp, "CoSaMP: Iterative signal recovery from incomplete and inaccurate samples," *Applied and Computational Harmonic Analysis,* vol. 26, no. 3, pp. 301-321, 2009/05/01/ 2009, doi: https://doi.org/10.1016/j.acha.2008.07.002.
[188] A. Beck and M. Teboulle, "A fast Iterative Shrinkage-Thresholding Algorithm with application to wavelet-based image deblurring," in *2009 IEEE International Conference on Acoustics, Speech and Signal Processing*, 19-24 April 2009 2009, pp. 693-696, doi: 10.1109/ICASSP.2009.4959678.
[189] H. Mohimani, M. Babaie-Zadeh, and C. Jutten, "A Fast Approach for Overcomplete Sparse Decomposition Based on Smoothed $\ell ^{0}$ Norm," *IEEE Transactions on Signal Processing,* vol. 57, no. 1, pp. 289-301, 2009, doi: 10.1109/TSP.2008.2007606.
[190] M. W. Mahoney, M. Maggioni, and P. Drineas, "Tensor-CUR Decompositions for Tensor-Based Data," *SIAM J. Matrix Anal. Appl.,* vol. 30, no. 3, pp. 957–987, 2008, doi: 10.1137/060665336.
[191] S. Iloga, A. Bordat, J. L. Kernec, and O. Romain, "Human Activity Recognition Based on Acceleration Data From Smartphones Using HMMs," *IEEE Access,* vol. 9, pp. 139336-139351, 2021, doi: 10.1109/ACCESS.2021.3117336.
[192] A. Bordat, P. Dobias, J. L. Kernec, D. Guyard, and O. Romain, "Towards Real-Time Implementation for the Pre-Processing of Radar-Based Human Activity Recognition," presented at the IEEE 31st International Symposium on Industrial Electronics (ISIE), Anchorage, Alaska, USA, 01-03 June, 2022.
[193] M. A. G. von Keyserlingk, J. Rushen, A. M. de Passillé, and D. M. Weary, "Invited review: The welfare of dairy cattle—Key concepts and the role of science," *Journal of Dairy Science,* vol. 92, no. 9, pp. 4101-4111, 2009/09/01/ 2009, doi: https://doi.org/10.3168/jds.2009-2326.
[194] M. R. N. Bruijnis, H. Hogeveen, and E. N. Stassen, "Assessing economic consequences of foot disorders in dairy cattle using a dynamic stochastic simulation model," *Journal of Dairy Science,* vol. 93, no. 6, pp. 2419-2432, 2010/06/01/ 2010, doi: https://doi.org/10.3168/jds.2009-2721.
[195] S. Archer, N. Bell, and J. Huxley, "Lameness in UK dairy cows: a review of the current status," *In Practice,* vol. 32, no. 10, pp. 492-504, 2010, doi: 10.1136/inp.c6672.
[196] J. R. Winter and L. E. Green, "Cost–benefit analysis of management practices for ewes lame with footrot," *The Veterinary Journal,* vol. 220, pp. 1-6, 2017/02/01/ 2017, doi: https://doi.org/10.1016/j.tvjl.2016.11.010.
[197] G. J. Nieuwhof and S. C. Bishop, "Costs of the major endemic diseases of sheep in Great Britain and the potential benefits of reduction in disease impact," *Animal Science,* vol. 81, no. 1, pp. 23-29, 2005, doi: 10.1079/ASC41010023.
[198] J. Slater, "National Equine Health Survey (NEHS) 2016," Blue cross for pets, 13/09 2016.
[199] F. C. Flower and D. M. Weary, "Gait assessment in dairy cattle," *animal,* vol. 3, no. 1, pp. 87-95, 2009, doi: 10.1017/S1751731108003194.
[200] K. Keegan, "OBJECTIVE MEASURES OF LAMENESS EVALUATION," 2012.
[201] H. M. Clayton and H. C. Shamhardt, "Measurement techniques for gait analysis," in *Equine Locomotion*, H. M. Clayton and W. Back Eds., 2nd ed. Edinburgh: Elsevier, 2013.

[202] C. J. Rutten, A. G. J. Velthuis, W. Steeneveld, and H. Hogeveen, "Invited review: Sensors to support health management on dairy farms," *Journal of Dairy Science,* vol. 96, no. 4, pp. 1928-1952, 2013, doi: 10.3168/jds.2012-6107.

[203] *Radar for indoor monitoring : detection, classification, and assessment*. Boca Raton: CRC Press, Taylor & Francis Group, 2018, pp. xiii, 390 pages.

[204] F. Fioranelli, M. Ritchie, and H. Griffiths, "Classification of Unarmed/Armed Personnel Using the NetRAD Multistatic Radar for Micro-Doppler and Singular Value Decomposition Features," *IEEE Geoscience and Remote Sensing Letters,* vol. 12, no. 9, pp. 1933-1937, 2015, doi: 10.1109/lgrs.2015.2439393.

[205] D. Tahmoush and J. Silvious, "Remote detection of humans and animals," in *2009 IEEE Applied Imagery Pattern Recognition Workshop (AIPR 2009)*, 14-16 Oct. 2009 2009, pp. 1-8, doi: 10.1109/AIPR.2009.5466303.

[206] Y. Kim, S. Ha, and J. Kwon, "Human Detection Using Doppler Radar Based on Physical Characteristics of Targets," *IEEE Geoscience and Remote Sensing Letters,* vol. 12, no. 2, pp. 289-293, 2015, doi: 10.1109/LGRS.2014.2336231.

[207] A. Shrestha, J. L. Kernec, F. Fioranelli, J. F. Marshall, and L. Voute, "Gait analysis of horses for lameness detection with radar sensors," in *International Conference on Radar Systems (Radar 2017)*, 23-26 Oct. 2017 2017, pp. 1-6, doi: 10.1049/cp.2017.0427.

[208] N. Reamaroon, M. W. Sjoding, K. Lin, T. J. Iwashyna, and K. Najarian, "Accounting for Label Uncertainty in Machine Learning for Detection of Acute Respiratory Distress Syndrome," *IEEE Journal of Biomedical and Health Informatics,* vol. 23, no. 1, pp. 407-415, 2019, doi: 10.1109/JBHI.2018.2810820.

[209] A. Shrestha *et al.*, "Animal Lameness Detection With Radar Sensing," *IEEE Geoscience and Remote Sensing Letters,* vol. 15, no. 8, pp. 1189-1193, 2018, doi: 10.1109/lgrs.2018.2832650.

[210] F. Fioranelli *et al.*, "Radar-based Evaluation of Lameness Detection in Ruminants: Preliminary Results," presented at the IEEE MTT-S 2019 International Microwave Biomedical Conference (IMBioC2019), Nanjing, China, 6-8 May, 2019.

[211] V. Busin *et al.*, "Evaluation of lameness detection using radar sensing in ruminants," *Veterinary Record,* vol. 185, no. 18, p. 572, 2019, doi: 10.1136/vr.105407.

[212] V. Busin *et al.*, "Radar Sensing as a Novel Tool to Detect Lameness in Sheep," presented at the Ontario Small Ruminant Veterinary Conference, Ontario, Canada, 17-19 June, 2019.

[213] K. Linardopoulou, L. Viora, Q. H. Abbasi, F. Fioranelli, J. Le Kernec, and N. Jonsson, "Lameness Detection in Dairy Cows: Evaluation of the Agreement and Repeatability of Mobility Scoring," in *74th Annual AVTRW Conference*, online, 14-15 Sep 2020.

[214] K. Linardopoulou *et al.*, "Time-series Observations of Cattle Mobility: Accurate Label Assignment from Multiple Assessors, and Association with Lesions Detected in the Feet," presented at the 31st World Buiatrics Congress, Madrid, Spain, 04-08 Sep, 2022.

[215] A. Shrestha, H. Li, F. Fioranelli, and J. Le Kernec, "Multimodal sensing for assisted living using radar," in *Micro-Doppler Radar and its Applications*, F. Fioranelli, H. Griffiths, M. Ritchie, and A. Balleri Eds.: IET, 2020.

[216] V. C. Chen, D. Tahmoush, T. R. M.-D. S. P. William J. Miceli, and Applications. Institution of Engineering and Technology, 2014.

[217] K. Ishak, N. Appenrodt, J. Dickmann, and C. Waldschmidt, "Advanced Radar Micro-Doppler Simulation Environment for Human Motion Applications," in *2019 IEEE Radar Conference (RadarConf)*, 22-26 April 2019 2019, pp. 1-6.

[218] B. Erol, S. Z. Gurbuz, and M. G. Amin, "GAN-based Synthetic Radar Micro-Doppler Augmentations for Improved Human Activity Recognition," in *2019 IEEE Radar Conference (RadarConf)*, 22-26 April 2019 2019, pp. 1-5, doi: 10.1109/RADAR.2019.8835589.

[219] Q. Zheng, C. Guo, J. Ding, M. O. Akinsolu, B. Liu, and G. A. E. Vandenbosch, "A Wideband Low-RCS Metasurface-Inspired Circularly Polarized Slot Array Based on AI-Driven Antenna Design Optimization Algorithm," *IEEE Transactions on Antennas and Propagation,* pp. 1-1, 2022, doi: 10.1109/TAP.2022.3161389.

[220] H. Li, J. Le Kernec, A. Mehul, and F. Fioranelli, "Distributed Radar Information Fusion for Gait Recognition and Fall Detection," presented at the IEEE Radar Conference (RadarConf2020), Florence, Italy, 21-25 Sep, 2020.

[221] M. Arsalan, A. Santra, and C. Will, "Improved Contactless Heartbeat Estimation in FMCW Radar via Kalman Filter Tracking," *IEEE Sensors Letters,* pp. 1-1, 2020, doi: 10.1109/LSENS.2020.2983706.

[222] H. Rohling and M. Kronauge, "New radar waveform based on a chirp sequence," in *2014 International Radar Conference*, 13-17 Oct. 2014 2014, pp. 1-4, doi: 10.1109/RADAR.2014.7060246.

[223] L. Kai-ming, Z. Qun, L. Bi-shuai, W. Hui, and L. Hong-jing, "A novel method for occlusion modeling and micro-doppler analysis of truck target," in *IET International Radar Conference 2013*, 14-16 April 2013 2013, pp. 1-5, doi: 10.1049/cp.2013.0470.

[224] D. Filonov, B. Z. Steinberg, and P. Ginzburg, "Asymmetric micro-Doppler frequency comb generation via magnetoelectric coupling," *Physical Review B,* vol. 95, no. 23, p. 235139, 06/22/ 2017, doi: 10.1103/PhysRevB.95.235139.

[225] J. C. Lin, "Noninvasive microwave measurement of respiration," *Proceedings of the IEEE,* vol. 63, no. 10, pp. 1530-1530, 1975, doi: 10.1109/PROC.1975.9992.

[226] D. L. Gorgas, "Vital signs and patient monitoring techniques," in *Clinical Procedures in Emergency Medicine*, E. J. R. Roberts and J. R. Hedges Ed., 4th ed. hiladelphia, 2004, pp. pp 3-28.

[227] C. Li, Y. Xiao, and J. Lin, "Experiment and Spectral Analysis of a Low-Power Ka-Band Heartbeat Detector Measuring From Four Sides of a Human Body," *IEEE Transactions on Microwave Theory and Techniques,* vol. 54, no. 12, pp. 4464-4471, 2006, doi: 10.1109/TMTT.2006.884652.

[228] C. Li, V. M. Lubecke, O. Boric-Lubecke, and J. Lin, "A Review on Recent Advances in Doppler Radar Sensors for Noncontact Healthcare Monitoring," *IEEE Transactions on Microwave Theory and Techniques,* vol. 61, no. 5, pp. 2046-2060, 2013, doi: 10.1109/TMTT.2013.2256924.

[229] Y. Xiong, S. Chen, X. Dong, Z. Peng, and W. Zhang, "Accurate Measurement in Doppler Radar Vital Sign Detection Based on Parameterized Demodulation," *IEEE Transactions on Microwave Theory and Techniques,* vol. 65, no. 11, pp. 4483-4492, 2017.

[230] M. S. Raheel *et al.*, "Breathing and Heartrate Monitoring System using IR-UWB Radar," in *2019 13th International Conference on Signal Processing and Communication Systems (ICSPCS)*, 16-18 Dec. 2019 2019, pp. 1-5, doi: 10.1109/ICSPCS47537.2019.9008755.

[231] C. Gu, Z. Peng, and C. Li, "High-Precision Motion Detection Using Low-Complexity Doppler Radar With Digital Post-Distortion Technique," *IEEE Transactions on Microwave Theory and Techniques,* vol. 64, no. 3, pp. 961-971, 2016, doi: 10.1109/TMTT.2016.2519881.

[232] I. Mostafanezhad and O. Boric-Lubecke, "An RF Based Analog Linear Demodulator," *IEEE Microwave and Wireless Components Letters,* vol. 21, no. 7, pp. 392-394, 2011, doi: 10.1109/LMWC.2011.2154318.

[233] W. Pan, J. Wang, J. Huangfu, C. Li, and L. Ran, "Null point elimination using RF phase shifter in continuous-wave Doppler radar system," *Electronics Letters,* vol. 47, no. 21, pp. 1196-1198, 2011.

[234] M. Alizadeh, G. Shaker, J. C. M. D. Almeida, P. P. Morita, and S. Safavi-Naeini, "Remote Monitoring of Human Vital Signs Using mm-Wave FMCW Radar," *IEEE Access,* vol. 7, pp. 54958-54968, 2019.

[235] Y. She, J. Wang, H. Li, and D. Wu, "Group Iterative Spectrum Thresholding for Super-Resolution Sparse Spectral Selection," *IEEE Trans. Signal Process.,* vol. 61, no. 24, pp. 6371-6386, 2013, doi: 10.1109/TSP.2013.2281303.

[236] C. Li, J. Ling, J. Li, and J. Lin, "Accurate Doppler Radar Noncontact Vital Sign Detection Using the RELAX Algorithm," *IEEE Trans. Instrum. Meas.,* vol. 59, no. 3, pp. 687-695, 2010, doi: 10.1109/TIM.2009.2025986.

[237] P. Bechet, R. Mitran, and M. Munteanu, "A non-contact method based on multiple signal classification algorithm to reduce the measurement time for accurately heart rate detection," *Review of Scientific Instruments,* vol. 84, no. 8, pp. 84707-84709, 2013, doi: 10.1063/1.4818974.

[238] L. Sun, Y. Li, H. Hong, F. Xi, W. Cai, and X. Zhu, "Super-resolution spectral estimation in short-time non-contact vital sign measurement," *Review of Scientific Instruments,* vol. 86, no. 4, 2015, doi: 10.1063/1.4916954.

[239] L. Sun *et al.*, "Noncontact Vital Sign Detection based on Stepwise Atomic Norm Minimization," *IEEE Signal Process. Lett.,* vol. 22, no. 12, pp. 2479-2483, 2015, doi: 10.1109/LSP.2015.2494604.

[240] H. Zhao, H. Hong, L. Sun, Y. Li, C. Li, and X. Zhu, "Noncontact Physiological Dynamics Detection Using Low-power Digital-IF Doppler Radar," *IEEE Trans. Instrum. Meas.,* vol. 66, no. 7, pp. 1780-1788, 2017, doi: 10.1109/TIM.2017.2669699.

[241] F. Auger *et al.*, "Time-frequency reassignment and synchrosqueezing: An overview," *IEEE Signal Process. Mag.,* vol. 30, no. 6, pp. 32-41, 2013, doi: 10.1109/MSP.2013.2265316.

[242] K. Seoktae and N. Cam, "On the development of a multifunction millimeter-wave sensor for displacement sensing and low-velocity measurement," *IEEE Transactions on Microwave Theory and Techniques,* vol. 52, no. 11, pp. 2503-2512, 2004, doi: 10.1109/TMTT.2004.837153.

[243] B. Park, O. Boric-Lubecke, and V. M. Lubecke, "Arctangent Demodulation With DC Offset Compensation in Quadrature Doppler Radar Receiver Systems," *IEEE Transactions on Microwave Theory and Techniques,* vol. 55, no. 5, pp. 1073-1079, 2007, doi: 10.1109/TMTT.2007.895653.

[244] A. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, J. Lin, and G. T. A. Kovacs, "Range correlation and I/Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring," *IEEE Transactions on Microwave Theory and Techniques,* vol. 52, no. 3, pp. 838-848, 2004, doi: 10.1109/TMTT.2004.823552.

[245] Y. Yan, C. Li, J. A. Rice, and J. Lin, "Wavelength division sensing RF vibrometer," in *2011 IEEE MTT-S International Microwave Symposium*, 5-10 June 2011 2011, pp. 1-4, doi: 10.1109/MWSYM.2011.5972827.

[246] J. Wang, X. Wang, L. Chen, J. Huangfu, C. Li, and L. Ran, "Noncontact Distance and Amplitude-Independent Vibration Measurement Based on an Extended DACM Algorithm," *IEEE Transactions on Instrumentation and Measurement,* vol. 63, no. 1, pp. 145-153, 2014, doi: 10.1109/TIM.2013.2277530.

[247] R. Moraes and D. H. Evans, "Compensation for phase and amplitude imbalance in quadrature Doppler signals," *Ultrasound in Medicine & Biology,* vol. 22, no. 1, pp. 129-137, 1996/01/01/ 1996, doi: https://doi.org/10.1016/0301-5629(95)02027-6.

[248] M. J. Connelly, "Digital synthetic-heterodyne interferometric demodulation," *Journal of Optics A: Pure and Applied Optics,* vol. 4, no. 6, pp. S400-S405, 2002/11/01 2002, doi: 10.1088/1464-4258/4/6/387.

[249] F. Schadt, F. Mohr, and M. Holzer, "Application of kalman filters as a tool for phase and frequency demodulation of IQ signals," in *2008 IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering*, 21-25 July 2008 2008, pp. 421-424, doi: 10.1109/SIBIRCON.2008.4602570.

[250] M. Holzer and F. Mohr, "Aspects of Signal Processing in Laser Vibrometry and their Embedded-Realisation on FPGA with NI-LabVIEW," in *2007 17th International Conference Radioelektronika*, 24-25 April 2007 2007, pp. 1-5.

[251] G. Welch and G. Bishop, "An Introduction to Kalman Filter," Department of Computer Science, University of North Carolina at Chapel Hill, 2006.

[252] M. S. Rahman, M. M. Haque, B. Jang, and K. Kim, "Extended Kalman Filter for Doppler radar cardiopulmonary monitoring system," in *2012 7th International Conference on Electrical and Computer Engineering*, 20-22 Dec. 2012 2012, pp. 264-267, doi: 10.1109/ICECE.2012.6471536.

[253] G. Vinci *et al.*, "Six-Port Radar Sensor for Remote Respiration Rate and Heartbeat Vital-Sign Monitoring," *IEEE Transactions on Microwave Theory and Techniques,* vol. 61, no. 5, pp. 2093-2100, 2013, doi: 10.1109/TMTT.2013.2247055.

[254] G. F. Engen and C. A. Hoer, "Application of an Arbitrary 6-Port Junction to Power-Measurement Problems," *IEEE Transactions on Instrumentation and Measurement,* vol. 21, no. 4, pp. 470-474, 1972.

[255] L. Chioukh, H. Boutayeb, K. Wu, and D. Deslandes, "f/nf harmonic radar system with optimal detection of vital signs," in *2012 42nd European Microwave Conference*, 29 Oct.-1 Nov. 2012 2012, pp. 25-28, doi: 10.23919/EuMC.2012.6459334.

[256] L. Chioukh, H. Boutayeb, D. Deslandes, and K. Wu, "Noise and Sensitivity of Harmonic Radar Architecture for Remote Sensing and Detection of Vital Signs," *IEEE Transactions on Microwave Theory and Techniques,* vol. 62, no. 9, pp. 1847-1855, 2014.

[257] L. Chioukh, T. Djerafi, D. Deslandes, and K. Wu, "Concurrent cardiopulmonary detection using 12/24 GHz harmonic multiport interferometer radar architecture," *IET Microwaves, Antennas & Propagation,* vol. 13, no. 13, pp. 2396-2404, 2019, doi: 10.1049/iet-map.2018.5665.

[258] F. Wang *et al.*, "An injection-locked detector for concurrent spectrum and vital sign sensing," in *2010 IEEE MTT-S International Microwave Symposium*, 23-28 May 2010 2010, pp. 768-771, doi: 10.1109/MWSYM.2010.5517103.

[259] F. Wang *et al.*, "A Novel Vital-Sign Sensor Based on a Self-Injection-Locked Oscillator," *IEEE Transactions on Microwave Theory and Techniques,* vol. 58, no. 12, pp. 4112-4120, 2010, doi: 10.1109/TMTT.2010.2087349.

[260] L. Changzhi and L. Jenshan, "Random Body Movement Cancellation in Doppler Radar Vital Sign Detection," *IEEE Transactions on Microwave Theory and Techniques,* vol. 56, no. 12, pp. 3143-3152, 2008, doi: 10.1109/tmtt.2008.2007139.

[261] F. Wang, T. Horng, K. Peng, J. Jau, J. Li, and C. Chen, "Single-Antenna Doppler Radars Using Self and Mutual Injection Locking for Vital Sign Detection With Random Body Movement Cancellation," *IEEE Transactions on Microwave Theory and Techniques,* vol. 59, no. 12, pp. 3577-3587, 2011, doi: 10.1109/TMTT.2011.2171712.

[262] J. Piou, "A state identification method for 1-D measurements with gaps," presented at the Proc. Amer. Inst. Aeronautics Astronautics Guid. Navigat. Control Conf. Exhibit, San Francisco, USA, 2005.

[263] K. Naishadham and J. E. Piou, "A Robust State Space Model for the Characterization of Extended Returns in Radar Target Signatures," *IEEE Transactions on Antennas and Propagation,* vol. 56, no. 6, pp. 1742-1751, 2008, doi: 10.1109/TAP.2008.916932.

[264] R. Lingyun, W. Haofei, K. Naishadham, Q. Liu, and A. E. Fathy, "Non-invasive detection of cardiac and respiratory rates from stepped frequency continuous wave radar measurements using the state space method," in *2015 IEEE MTT-S International Microwave Symposium*, 17-22 May 2015 2015, pp. 1-4, doi: 10.1109/MWSYM.2015.7166886.

[265] S. Nahar, T. Phan, F. Quaiyum, L. Ren, A. E. Fathy, and O. Kilic, "An Electromagnetic Model of Human Vital Signs Detection and Its Experimental Validation," *IEEE Journal on Emerging and Selected Topics in Circuits and Systems,* vol. 8, no. 2, pp. 338-349, 2018, doi: 10.1109/JETCAS.2018.2811339.

[266] W. Yin, X. Yang, L. Li, L. Zhang, N. Kitsuwan, and E. Oki, "HEAR: Approach for Heartbeat Monitoring with Body Movement Compensation by IR-UWB Radar," *Sensors,* vol. 18, no. 9, p. 3077, 2018, doi: 10.3390/s18093077.

[267] L. Changzhi and L. Jenshan, "Complex signal demodulation and random body movement cancellation techniques for non-contact vital sign detection," in *2008 IEEE MTT-S International Microwave Symposium Digest*, 15-20 June 2008 2008, pp. 567-570, doi: 10.1109/MWSYM.2008.4633229.

[268] X. Yu, C. Li, and J. Lin, "Two-dimensional noncontact vital sign detection using Doppler radar array approach," in *2011 IEEE MTT-S International Microwave Symposium*, 5-10 June 2011 2011, pp. 1-4, doi: 10.1109/MWSYM.2011.5972723.

[269] K. Han and S. Hong, "Differential Phase Doppler Radar With Collocated Multiple Receivers for Noncontact Vital Signal Detection," *IEEE Transactions on Microwave Theory and Techniques,* vol. 67, no. 3, pp. 1233-1243, 2019, doi: 10.1109/TMTT.2018.2884406.

[270] I. Mostafanezhad, E. Yavari, O. Boric-Lubecke, V. M. Lubecke, and D. P. Mandic, "Cancellation of Unwanted Doppler Radar Sensor Motion Using Empirical Mode Decomposition," *IEEE Sensors Journal,* vol. 13, no. 5, pp. 1897-1904, 2013, doi: 10.1109/JSEN.2013.2238376.

[271] S. Tomii and T. Ohtsuki, "Heartbeat detection by using Doppler radar with wavelet transform based on scale factor learning," in *2015 IEEE International Conference on Communications (ICC)*, 8-12 June 2015 2015, pp. 483-488, doi: 10.1109/ICC.2015.7248368.
[272] W. Junfeng and D. Kasilingam, "Global range alignment for ISAR," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 39, no. 1, pp. 351-357, 2003, doi: 10.1109/TAES.2003.1188917.
[273] J. M. Muñoz-Ferreras and F. Pérez-Martínez, "Subinteger Range-Bin Alignment Method for ISAR Imaging of Noncooperative Targets," *EURASIP Journal on Advances in Signal Processing,* vol. 2010, no. 1, p. 438615, 2010/05/31 2010, doi: 10.1155/2010/438615.
[274] Y. Lee *et al.*, "A Novel Non-contact Heart Rate Monitor Using Impulse-Radio Ultra-Wideband (IR-UWB) Radar Technology," *Scientific reports*, vol. 8, no. 1, p. 13053doi: 10.1038/s41598-018-31411-8.
[275] S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Physics in Medicine and Biology,* vol. 41, no. 11, pp. 2251-2269, 1996/11/01 1996, doi: 10.1088/0031-9155/41/11/002.
[276] D. Andreuccetti, R. Fossi, and C. Petrucci. *An Internet resource for the calculation of the Dielectric Properties of Body Tissues in the frequency range 10 Hz - 100 GHz*. [Online]. Available: http://niremf.ifac.cnr.it/tissprop/
[277] A. D. Leo *et al.*, "An EM Modeling for Rescue System Design of Buried People," *International Journal of Antennas and Propagation,* vol. 2015, no. Wideband, Multiband, Tunable, and Smart Antenna Systems for Mobile and UWB Wireless Applications 2014, 465651, 2015, doi: https://doi.org/10.1155/2015/465651.
[278] R. Neely, K. Naishadham, A. Sharma, and K. Bing, "Electromagnetic human body modeling with physiological motion for radar applications," in *2012 IEEE Radar Conference*, 7-11 May 2012 2012, pp. 0818-0823.
[279] S. Yang, J. L. Kernec, F. Fioranelli, and O. Romain, "Human Activities Classification in a Complex Space using Raw Radar Data," presented at the International Radar Conference, Toulon, France, 23-27 Sept, 2019.
[280] L. Vignaud, A. Ghaleb, J. L. Kernec, and J. M. Nicolas, "Radar high resolution range & micro-Doppler analysis of human motions," in *2009 International Radar Conference "Surveillance for a Safer World" (RADAR 2009)*, 12-16 Oct. 2009 2009, pp. 1-6.
[281] Y. He, P. Molchanov, T. Sakamoto, P. Aubry, F. L. Chevalier, and A. Yarovoy, "Range-Doppler surface: a tool to analyse human target in ultra-wideband radar," *IET Radar, Sonar & Navigation,* vol. 9, no. 9, pp. 1240-1250, 2015, doi: 10.1049/iet-rsn.2015.0065.
[282] S. Julier and J. Uhlmann, *New extension of the Kalman filter to nonlinear systems* (AeroSense '97). SPIE, 1997.
[283] A. Doucet, N. d. Freitas, and N. Gordon, *Sequential Monte Carlo Methods in Practice*. New York, NY: Springer, 2001.
[284] F. Fioranelli, M. Ritchie, S. Z. Gurbuz, and H. Griffiths, "Feature Diversity for Optimized Human Micro-Doppler Classification Using Multistatic Radar," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 53, no. 2, pp. 640-654, 2017, doi: 10.1109/taes.2017.2651678.
[285] J. S. Patel, F. Fioranelli, M. Ritchie, and H. Griffiths, "Multistatic radar classification of armed vs unarmed personnel using neural networks," *Evolving Systems,* vol. 9, no. 2, pp. 135-144, 2017/11/10 2017, doi: 10.1007/s12530-017-9208-6.
[286] F. Fioranelli, M. Ritchie, and H. Griffiths, "Performance Analysis of Centroid and SVD Features for Personnel Recognition Using Multistatic Micro-Doppler," *IEEE Geoscience and Remote Sensing Letters,* vol. 13, no. 5, pp. 725-729, 2016, doi: 10.1109/lgrs.2016.2539386.
[287] R. Zhang and G. Li, "Multistatic micro-Doppler signatures for rotation radius estimation," in *2016 CIE International Conference on Radar (RADAR)*, 10-13 Oct. 2016 2016, pp. 1-4, doi: 10.1109/RADAR.2016.8059197.
[288] F. Fioranelli, M. Ritchie, and H. Griffiths, "Multistatic human micro-Doppler classification of armed/unarmed personnel," *IET Radar, Sonar & Navigation,* vol. 9, no. 7, pp. 857-865, 2015, doi: 10.1049/iet-rsn.2014.0360.

[289] F. Fioranelli, H. Griffiths, and M. Ritchie, "Personnel recognition based on multistatic micro-Doppler and singular value decomposition features," *Electronics Letters,* vol. 51, no. 25, pp. 2143-2145, 2015, doi: 10.1049/el.2015.3513.

[290] Y. He, F. L. Chevalier, and A. G. Yarovoy, "Range-Doppler processing for indoor human tracking by multistatic ultra-wideband radar," in *2012 13th International Radar Symposium*, 23-25 May 2012 2012, pp. 250-253, doi: 10.1109/IRS.2012.6233325.

[291] E. Klinefelter and J. A. Nanzer, "Interferometric Radar For Spatially-Persistent Gesture Recognition in Human-Computer Interaction," in *2019 IEEE Radar Conference (RadarConf)*, 22-26 April 2019 2019, pp. 1-5, doi: 10.1109/radar.2019.8835739. [Online]. Available: https://ieeexplore.ieee.org/document/8835739/https://ieeexplore.ieee.org/ielx7/8819608/8835488/08835739.pdf?tp=&arnumber=8835739&isnumber=8835488&ref=

[292] J. A. Nanzer, "Micro-motion signatures in radar angular velocity measurements," in *2016 IEEE Radar Conference (RadarConf)*, 2-6 May 2016 2016, pp. 1-4, doi: 10.1109/RADAR.2016.7485234.

[293] J. A. Nanzer and K. S. Zilevu, "Dual Interferometric-Doppler Measurements of the Radial and Angular Velocity of Humans," *IEEE Transactions on Antennas and Propagation,* vol. 62, no. 3, pp. 1513-1517, 2014, doi: 10.1109/tap.2013.2296325.

[294] J. A. Nanzer, K. Kammerman, and K. S. Zilevu, "A 29.5 GHz radar interferometer for measuring the angular velocity of moving objects," in *2013 IEEE MTT-S International Microwave Symposium Digest (MTT)*, 2-7 June 2013 2013, pp. 1-3, doi: 10.1109/MWSYM.2013.6697333.

[295] J. A. Nanzer, *Interferometric measurement of the angular velocity of moving humans* (SPIE Defense, Security, and Sensing). SPIE, 2012.

[296] Y. Wang *et al.* "Neural Network Accelerator Inference." NICS Lab of Tsinghua University. https://nicsefc.ee.tsinghua.edu.cn/projects/neural-network-accelerator/ (accessed 13 Dec, 2018).

[297] J. Starzyk and Y. Guo, "Dynamically Self-Reconfigurable Machine Learning Structure for FPGA Implementation," in *Proc. Int. Conf. Eng. Reconfig. Syst. & Algo.*, Las Vegas, 2003, pp. 296-299.