CHARACTERIZATION OF SCATTERERS BY THEIR ENERGETIC DISPERSIVE AND ANISOTROPIC BEHAVIORS IN HIGH-RESOLUTION LABORATORY RADAR IMAGERY

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ABSTRACT

This paper deals with the analysis of energetic non-stationary objects in already focused High-Resolution (HR) laboratory Radar imaging. Energetic non-stationary scatterers are some backscattering variations (azimuthal variations and/or frequency variations) which are linked to the target properties, for example the Radar Cross-Section (RCS). A method, based on Multi-dimensional Time-Frequency Transform and using basic statistics, is proposed to analyze the anisotropy and/or dispersive energetic behaviors of scatterers in the Radar image formation. The efficiency of this technique is demonstrated, in terms of laboratory radar imaging where statistics are lain to characteristics target parameters. For example, the orientation of a scatterer in the case of a directive response.

Index Terms— Radar imaging, radar cross-sections, signal analysis, continuous wavelet transforms, statistical analysis

1. INTRODUCTION

In laboratory radar imaging [1]-[4], the energetic signature is characterized by the Radar Cross-Section (RCS) [5]. Consequently, the energetic response of a scatterer is dependent of imaging system parameters (emitted frequency f, wave polarization and imaging configuration : incident directions and scattering directions) and of target parameters (geometrical structure. dielectric properties). Only, Time-Frequency (TF) analysis allows to consider the energetic variations in frequency and the energetic evolution of the aspect angle θ [6]. The problem of the anisotropy and/or dispersive behaviors of scatterers is not new and appears with the High-Resolution (H-R) imaging systems. Indeed, TF method is based on the fact that anisotropy and/or dispersive behaviors are non-stationary signatures. Consequently, the basic tool to study non-stationary phenomena is the TF analysis [6]. First studies propose to use the Multi-dimensional Continuous Wavelet Transform (CWT) to show some scatterers are anisotropic and dispersive in energetic signatures in the case of laboratory radar imaging and in Synthetic Aperture Radar (SAR) imaging [7]-[9]. One application of this method is the classification [13]. Other studies prefer use different TF transforms. For example, the Smoothed-Pseudo Wigner-Ville Transform (SPWVT) is proposed to improve valuable target detection[12]. Another methods porpose to use the multi dimensional Short-Time Fourier Transform (STFT) to describe a scene polarimetric behavior for different azimuth angle of observation and frequencies of illumination [10]-[11]. In the same way, the 2D spectrogramm is used to classify scatterers in energetic signatures [15]. These former studies using TF, [7]-[15], improve either the detection or the classification in HR imaging (SAR imaging and/or laboratory radar imaging). However, none of these methods lies the energetic frequency and/or angle dependent energetic information to target chacteristics

The main aim of this paper is to link energetic non-stationary behaviors to physical properties of the objects under study. Section II describes the principle of multidimensional Time-Frequency Analysis (TF) applied to polarimetric H-R radar imaging and the extraction of marginal densities to study seperatly the dispersive phenomena and the angle responses. Section III defines the first order statistics used to analyze the dispersive and/or the anisotropic signatures extracted in the previous section. Section IV presents results of the first order statistics (defined in section III) applied to the energetic marginal densities in frequency and in angle (analyzed in section II). Application concerns polarimetric laboratory radar imaging to validate the proposed method. Indeed, in laboratory radar imaging the ground truth is well known. So, these results are analyzed to characterise the meaning of statistics in target's properties (orientation, etc.).

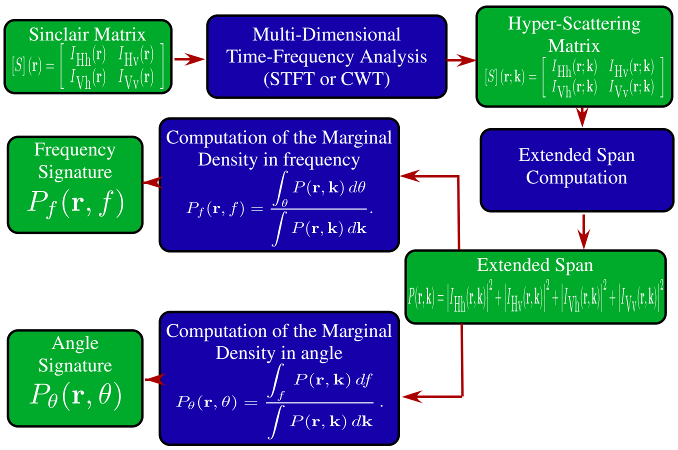


Fig. 1. Computaion of the frequential and aspect angle energetic signatures

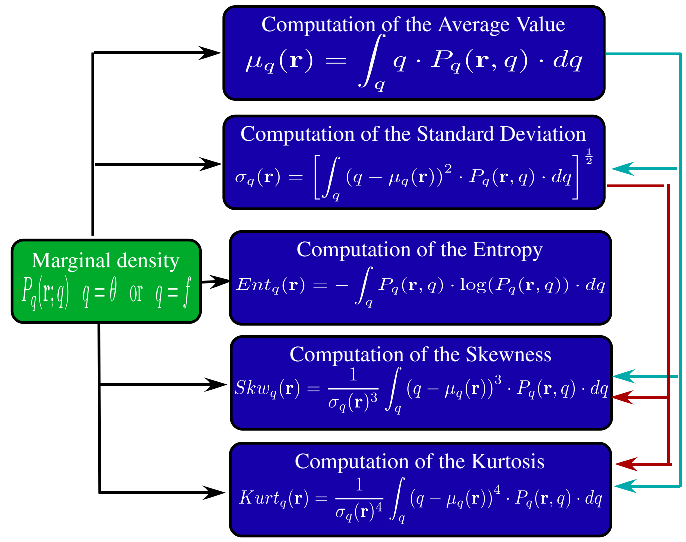


Fig. 2. Definition of statistical parameters applied on the energetic signatures

2. COMPUTATION OF THE ENERGETIC SIGNATURES

TF techniques dealing with polarimetric data need preserve the relative phase information between the polarimetric channels. This coherent constraint is only verified by atomic decompositions, like the short time Fourier transform (STFT) and the continuous wavelet transform (CWT). The TF techniques is applied in a similar way to each of the four polarimetric channels of the Sinclair matrix $S(\mathbf{r})$ where $\mathbf{r}$ is the cartesian coordinates of scatterers. The resulting scattering matrix is a multivariate function of the wave vector $\mathbf{k}$, where the wave vector is characterized by the frequency f and the illumination angle θ. Consequently, the resulting scattering matrix is called hyper-scattering matrix. From the hyper-scattering matrix, the extended span $P(\mathbf{r},\mathbf{k})$ can be defined as the sum of the squared modulus of each element of the hyper-scattering matrix. The extended span permits one to highlight scatterers with an anisotropic or dispersive polarimetric energetic response and may be used to investigate local scattering phenomena, in terms of scattering mechanisms and orientation with respect to the radar beam. In order to characterize the degree of anisotropy and dispersion of the extended span, one can compute the marginal densities in the frequency $P_f(\mathbf{r},f)$ and angular domains $P_\theta(\mathbf{r},\theta)$ defined in Fig.1

3. STATISTICAL ANALYSIS EXTRACTED FROM THE ENERGETIC SIGNATURES

To analyze the marginal densities in frequency and in angle defined in the former part, the basic tool is the statistics. Consequently, the statistics definitions extracted from the marginal densities in the frequency $P_f(\mathbf{r},f)$ and angular domains $P_\theta(\mathbf{r},\theta)$ are recalled in Fig. 2. The first one, the average value, is the measure of the central tendency. The second, the standard deviation shows how much variation or "dispersion" exists from the average. The third parameter is the entropy. The entropy is defined from the Von Neuman approach. This entropy, determines the degree of randomness of the frequential and/or angular energetic signatures, which can be also interpreted as the degree of statistical disorder. This parameter varies between 0 and 1. The fourth parameter, the kurtosis is any measure of the "peakedness" of the distribution (signatures). The last one parameter is the Skewness. Skewness is a measure of the asymmetry of the marginal energetic distribution. The Skewness value can be positive or negative, or even undefined.

The meaning of statistical parameters is summarized on the Tab. 1.

The next section consists in applying this method described in section two and three on full-polarimetric anechoc chamber data, to analyze the efficiency of statistics.

4. RESULTS IN LABORATORY RADAR IMAGERY

4.1. Configuration of the application

The proposed approach is applied to fully polarimetric measurements acquired in an anechoic chamber. The observed target is a "Cyrano" weapon scaled model, made out of steel (length 1.2 m - width 0.60 m). Backscattering coefficients are measured over a frequency band ranging from 12 up to 18 GHz, with a sampling rate of 0.75 MHz, and for an azimuthal orientation varying from -25 to 25 degrees with 0.5 degrees increments. Then, the spatial image is computed. From these data, the marginal densities (angular and frequential), defined previously, are processed. The time-frequency transform for this application is the Multi-dimensional Con-

Table 1. Physical interpretation of statistics

	Angular Domain		Frequential Domain	
Target & Scatterer	Directive Response Energy focused in one direction	Isotropic Response Energy spreads in all direction	Resonant Response Energy centered in one frequency	Non-Dispersive Response Energy spreads in all the frequency range
Mean	Average Value is focusing on the direction		Average Value is the resonant frequency	
Standard Deviation	Low Value	High Value	Low Value	High Value
Entropy	Tends to 0	Tends to 1	Tends to 0	Tends to 1
Kurtosis	Kurt ≥ 0	Kurt ≤ 0	Kurt ≥ 0	Kurt ≤ 0

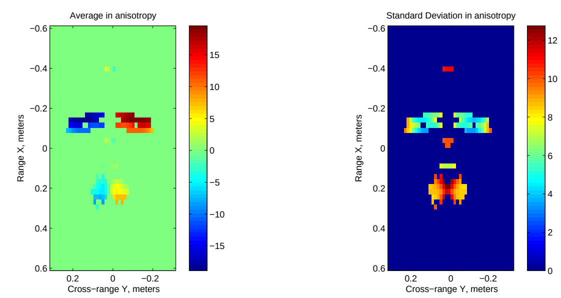
tinuous Wavelet Transform (CWT). The choice of the mother wavelet is a gaussian shape to minimize the Heisenberg principle and the spread of the wavelet is manual chosen to $\frac{1}{9}$ of the emitted bandwidth, (in frequency) and $\frac{1}{9}$ of the total angular excursion (in azimuth). The spread of the wavelet can be discussed [7], however our selection is based to find a good compromise between the spatial resolution and the meaning of time-frequency signatures. From these choices, the different statistics parameters are calculated from the energetic marginal densities.

4.2. Results on the angular signatures

The results of the mean value in azimuthal is presented in the following figure Fig. 3. Concerning the azimuthal signatures, the edges of the wing backscatters the energy when the radar beam is perpendicular to the edges. Consequently, the response of the edges of the wing are directive. All in all, the mean value corresponds to the orientation of the edges in the horizontal plan. However, the ”Cyrano” weapon is symmetric, the value of the mean is the opposite between the left edges and the right edges. Consequently, the main drawback of this parameter is that two identical objects but with a different azimuthal orientation, have two different angular average values So, the same object has two angular mean values, for two different orientations.

The results of standard deviation are presented in the following figure Fig. 3. As suggested in the average value, the response of the edges (leading and trailing) of the wing is directive. Consequently, the standard deviation of the edges is low. Moreover, the nature between the edges of the wings is identical. Concerning the stabilizers, the response is nor directive nor isotropic, that's why the standard deviation of stabilizers is important. All in all, the head of the weapon, is a semi-sphere, so the response of this scatterer is isotropic. Then, the standard deviation of the ”Cyrano”'s head is the maximum.

The results of azimuthal entropy, Fig. 4, of the edges of wings in angle is low. These results check the energetic directive behavior of these scatterers. Concerning, the closed air



(a) (b)

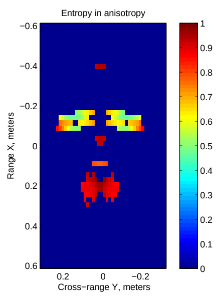
Fig. 3. Results of the angle signature, (a) average value and (b) standard deviation.

exit, the entropy in angle is superior to the edges but is less important than the other scatterers. The closed air exit signature is halfway between directive and isotropic scatterers. All in all, all other scatterers of the target have a high entropy translating isotropic behaviour (as the head of the weapon) or spreading azimuthal signatures (as stabilizers).

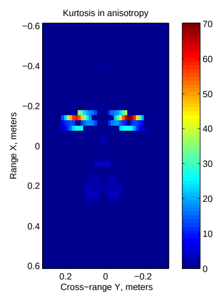
This interpretation of the Kurtosis parameter is checked on the results of the Kurtosis in angle, Fig. 4. For example, the edges of wings present a high value of Kurtosis because the energetic signature of edges is directive (”peak” distribution). For all other scatterers the value of Kurtosis can be neglected (”flat” distribution).

4.3. Results on the frequential signatures

The Skewness in frequency is the best valuable dispersive statistic parameter to distinguish the different scatterers of the target under study. The other results in frequency, average value, standard deviation, entropy and Kurtosis are not efficient.



(a)



(b)

Fig. 4. Results of the angle signature, (a) Entropy and (b) Kurtosis.

5. CONCLUSION

In this paper, a method based on statistics applied to energetic multi-dimensional time-frequency is proposed. The aim is to analyze the energetic non-stationary behaviors of scatterers in High-Resolution (HR) laboratory radar imaging. This application allowed to show the relevant and/or the limitations of the statistics parameters. For example, the Skewness in frequency seems to be the alone valuable statistic parameter in frequency. Concerning the azimuthal signatures, the average value and the Skewness value in angle present the same drawback. Indeed, two identical scatterers but with a different orientation present two different signatures in mean value and in Skewness in angle. Concerning the standard deviation in angle, this parameter can allow distinguish the scatterers. However, to be valuable, this parameter needs a strong angular excursion. All in all, the two most valuable parameters to differenciate directive responses and isotropic signatures seem to be the entropy and the kurtosis value. Future works concern the application of this method to Synthetic Aperture Radar (SAR) imaging or circular radar imaging.

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