Characterization of scatterers by their anisotropic and dispersive behavior

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I. INTRODUCTION

Synthetic Aperture Radar (SAR) images built from received signals are high-resolution maps of the spatial distribution of the reflectivity function of targets. Conventional radar imaging assumes that all the scatterers are considered as bright points (isotropic for all observation angles and white in the frequency band) [1]. Recent studies based on multidimensional Time-Frequency Analysis describe the angular and frequency behavior of scatterers and show that they are anisotropic and dispersive [2]. Another useful information source in radar imaging is the polarimetry. Studies based on multidimensional wavelet and coherent decompositions allow to represent the angular and frequency polarimetric behavior and show the non-stationarity of this behavior. The aim is to characterize scatterers by time-frequency analysis and polarimetry.

II. HIGHLIGHTING THE ANISOTROPIC AND DISPERSIVE BEHAVIOR OF SCATTERERS BY TWO-DIMENSIONAL TIME-FREQUENCY ANALYSIS

When a target is illuminated by a broad-band signal and/or for a large angular domain, it is realistic to consider that the amplitude spatial repartition $I(\vec{r})$ of the reflectors depends on frequency $f$ and on the aspect angle $\theta$. This repartition depending on the wave vector $\vec{k}$ will be noted in the following by $I(\vec{r}, \vec{k})$. Such images can be built using the multidimensional continuous wavelet transform extended to two dimensions of the backscattering coefficient $H$ and are called hyperimages [3]:

$$I(\vec{r}_0, \vec{k}_0) = \int H(\vec{k}) \Psi^*_{\vec{r}_0, \vec{k}_0}(\vec{k}) d\vec{k}.$$  (1)

where $\Psi_{\vec{r}_0, \vec{k}_0}(\vec{k})$ is a family of wavelet bases generated from the mother wavelet $\phi(k, \theta)$ localized around $(k, \theta) = (1, 0)$ and located spatially at $\vec{r} = 0$ according to:

$$\Psi_{\vec{r}_0, \vec{k}_0}(\vec{k}) = \frac{1}{k_0} e^{-2\pi \vec{k}.\vec{r}_0} \phi \left( \frac{k}{k_0}, \theta - \theta_0 \right).$$  (2)

In polarimetry, the scattering matrix or Sinclair matrix, will now depend on frequency and on the angle of presentation and is called hyper-scattering matrix :

$$[S](\vec{r}, \vec{k}) = \begin{bmatrix} S_{hh}(\vec{r}, \vec{k}) & S_{hv}(\vec{r}, \vec{k}) \\ S_{vh}(\vec{r}, \vec{k}) & S_{vv}(\vec{r}, \vec{k}) \end{bmatrix}$$  (3)

The span is generally defined as the sum of the squared modulus of each element of the matrix. The extended span is now defined as the sum of the squared modulus of each element of the hyper-scattering matrix [5].

$$Span(\vec{r}, \vec{k}) = |S_{hh}(\vec{r}, \vec{k})|^2 + |S_{hv}(\vec{r}, \vec{k})|^2 + |S_{vh}(\vec{r}, \vec{k})|^2 + |S_{vv}(\vec{r}, \vec{k})|^2.$$  (4)

![Fig. 1. Span of the image SAR.](image-url)
The extended span is an energetic description of the anisotropic and dispersive behavior of scatterers. Let us rewritten $\text{Span}(\vec{r}, \vec{k})$, $\text{Span}(x; y; f; \theta)$: for each frequency $f_o$ and each angle of radar illumination $\theta_o$, $\text{Span}(x; y; f_o; \theta_o)$ represents a spatial repartition of reflectors which respond at this frequency and this angle. Inversely, for each reflector located at $r_0 = (x_0; y_0)$, we can extract its feature $\text{Span}(x_0; y_0; f; \theta)$ in frequency $f$ and in angular $\theta$. This is this aspect that we decided to point out in order to see if this quantity is anisotropic or/and dispersive.

By application of the coherent decompositions to the hyper-scattering matrix we obtain representations of the polarimetric nature versus the emitted frequency and the observation angle. For example, the Cameron decomposition represents the Sinclair matrix $[S]$ as a combination of a maximum symmetric component, a minimum symmetric component and a non-reciprocal component. Indeed, it decomposes the scattering matrix according to:

$$\bar{S} = A \left[ \cos(\theta_{rec}) \ \left( \cos(\tau) \ \bar{S}_{\text{sym}}^{\max} + \sin(\tau) \ \bar{S}_{\text{sym}}^{\min} \right) + \sin(\theta_{rec}) \ \bar{S}_{\text{nr}} \right]$$ \hspace{1cm} (6)

By application of the Cameron decomposition to the hyper-scattering matrix, the following decomposition is obtained:

$$[S(\vec{r}, \vec{k})] = A(\vec{r}, \vec{k}) \left\{ \cos(\phi_{rec}(\vec{r}, \vec{k})) \ \left( \cos(\tau(\vec{r}, \vec{k})) [S(\vec{r}, \vec{k})]_{\text{sym}}^{\max} + \sin(\tau(\vec{r}, \vec{k})) [S(\vec{r}, \vec{k})]_{\text{sym}}^{\min} \right) + \sin(\phi_{rec}(\vec{r}, \vec{k})) [S(\vec{r}, \vec{k})]_{\text{nr}} \right\}$$ \hspace{1cm} (7)

From the Cameron decomposition, a classification can be processed, see figure 3. This work leads to a new classification hyperimage $C(\vec{r}, \vec{k})$ and allows to extract the Huynen orientation $\psi(\vec{r}, \vec{k})$. For each $k_0$, the classification hyperimage and the Huynen orientation, represent the classification and the orientation of the target around the line of sight for an aspect angle and for an emitted frequency.

For each $r_0$, the classification hyperimage and the Huynen orientation represent the polarimetric behavior evolution and the angle in the vertical plane of the scatterer located at $r_0$.

![Fig. 2. Extended span of the weapon target Cyrano in anechoic chamber.](image)

**III. STUDY OF THE POLARIMETRIC STATIONNARY BEHAVIOR BY POLARIMETRIC HYPERIMAGES**

The polarimetric behavior can be stationary (ie. the polarimetric behavior is independent of the emitted frequency and the angular aspect) or non-stationnary (ie. the polarimetric behavior is dependent of the emitted frequency and the observation angle). The aim is to build a polarimetric representation versus the emitted frequency and the observation angle to characterize this behavior. In our case we are interested by man-made targets because they present a dispersive and anisotropic behavior. The basic tool to study the deterministic targets is the coherent decompositions [4], [5]. The objective of the coherent decompositions is to express the Sinclair matrix $[S]$ (ie. the measured scattering matrix by the radar) as a combination of the scattering responses of simpler objects:

$$[S] = \sum_{i=1}^{k} C_i [S]_i$$ \hspace{1cm} (5)

![Fig. 3. Classification process of the Cameron decomposition.](image)
These representations are called polarimetric hyperimages. Polarimetric hyperimages allow to describe the backscattering mechanisms by the orientations of scatterers and their nature. Studies based on polarimetric hyperimages showed the polarimetric behavior could be stationary or non-stationary [6]. In these cases the non-stationary behavior is due to the fact that the radar does not see the same geometry at different observation angles.

IV. CHARACTERISTICS PARAMETERS OF THE POLARIMETRIC DISPERSIVE AND ANISOTROPIC BEHAVIOR

A scatterer can be isotropic or anisotropic, dispersive or non-dispersive, polarimetric behavior stationary or non-stationary. The goal is to extract characteristics parameters which highlight these three behaviors. The anisotropy and dispersivity can be expressed from the extended span. So, the marginal densities in the frequency and angular fields can be calculated.

\[ \text{Marginal}_f(\varphi, f) = \frac{\int_0^\varphi \text{Span}(\varphi, k) \, d\theta}{\int_0^\varphi \int_f \text{Span}(\varphi, k) \, d\theta \, df} \]  \hspace{1cm} (8)

\[ \text{Marginal}_\theta(\varphi, \theta) = \frac{\int_0^\theta \text{Span}(\varphi, k) \, df}{\int_0^\varphi \int_0^\theta \text{Span}(\varphi, k) \, d\theta \, df} \] \hspace{1cm} (9)

From these densities the standard deviations are extracted. The standard deviation in frequency means the dispersivity, the standard deviation in angle means the anisotropy. Standards deviations have been tested on the SAR image of the figure 1. This image is composed of four calibrating trihedrals, three buildings and one parking. The standard deviation in frequency, figure 6, shows the buildings, trihedrals and parking have a strong value of the standard deviation. So, deterministic scatterers are non-dispersive, although natural media and vegetation have a low value of standard deviation and they can be considered as dispersive. The standard deviation in angle, figure 7, is not very meaning. These results can be explained by the fact that the angular excursion of the image is only two degrees. So we can not consider the angle information. Former
works show the anisotropy is important, for example on targets in anechoic chamber [7], however these former results are obtained for a angular excursion of fifty degrees.

and dispersive scatterers can be separated by thresholding the standard deviation in frequency, the anisotropic and isotropic scatterers can be highlighted by thresholding the standard deviation in angle, and the stationary or non-stationnary polarimetric behavior can be pointed out by thresholding the density. So, a classification into eight classes can be obtained.

V. CLASSIFICATION BY THE ANISOTROPIC AND DISPERSE BEHAVIOR OF SCATTERERS

From the standard deviations and the polarimetric density a classification can be processed. Indeed, the non-dispersive and dispersive behavior is proposed. It highlights the fact that time-frequency analysis and polarimetry are well adapted to characterize scatterers. Future work will consist in finding parameters more pertinent and in developing other classification algorithm.

REFERENCES