SAR COMPLEX IMAGE ANALYSIS: A GAUSS MARKOV VERSUS A MULTIPLE SUB-APERTURE BASED TARGET CHARACTERIZATION

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ABSTRACT

In this paper we compare Gauss-Markov Random Field (GMRF) and 4-D Representation based Time Frequency Analysis (TFA) methods for the analysis of targets in complex valued high-resolution SAR data. This work is based on the work carried out in [1], [2] & [3], [4] and it is an extension of the work presented by authors in [5]. In [1], [2] a parametric Gauss-Markov Random Field (GMRF) model has been proposed for texture analysis and in [3], [4] a time-frequency analysis (TFA) method has been proposed as a nonparametric approach for classification scheme of different targets with different backscattering behaviors. In [6], the authors consider the source of the anisotropy, i.e. the geometric and volumetric scatterers, and present a general characterization of azimuthal anisotropy based on a sub-aperture pyramid which is a set of sub-apertures arranged in a pyramidal fashion: the collection of sub-apertures provides a multi resolution representation of SAR data.

Since the task in SAR is to detect and recognize objects and structures, we can redefine the texture as a local descriptor of the scatterers and structured scatterers. The contextual information is the spatial descriptor in the vicinity of each pixel. Thus, texture information is a descriptor of the scene structures and objects, to be extracted as texture parameters, which are a fingerprint of the local structure and a feature for classification of different textures and for object recognition. We consider an extension of the Gauss-Markov Random Field (GMRF) model in the complex domain for complex-valued data, and we investigate into a GMRF model for complex-valued SAR data. Models may have different orders, thus capturing different degrees of the data complexity. We want to exploit the full information contained in the scene signal, i.e. amplitude and phase in terms of its textural parameters. Considering the SAR signal as the complex envelope of a zero-mean band-limited Gaussian process, the GMRF model for complex valued pixels has the following form [7]:

$$\boldsymbol{p}(\boldsymbol{z}_s \mid \boldsymbol{z}_{s+r}, \boldsymbol{r} \in \mathrm{N}) = \frac{1}{2\pi\sigma^2}\left\{-\frac{\left(\begin{bmatrix}\boldsymbol{x}_s\\ \boldsymbol{y}_s\end{bmatrix} - \mu\right)^2}{2\sigma^2}\right\}, \text{ with } \mu = \sum_{r\in \mathrm{N}} \begin{bmatrix}\xi_r & -\tau_r\\ \tau_r & \xi_r\end{bmatrix}\begin{bmatrix}x_{r+s}\\ y_{r+s}\end{bmatrix}.$$

Where $z = x + jy$ is the complex valued pixel, $\theta = \xi + j\tau$ is the complex-valued parameter vector, σ^2 is the model variance and the sum is over the entire pixel r belonging to the vicinity neighbor N. The model order r decides the number of textural parameters used for analysis purpose. For model order 2 we obtain 8 GMRF parameters, 4 for real and 4 for complex part of complex valued SAR data. We also compute the evidence of the model which is a quantitative measure of how well the model is fitting the data. It is computed as: $p(z_s \mid H_i) = \int_{\Theta} p(z_s \mid \boldsymbol{\theta}) p(\boldsymbol{\theta} \mid H_i) d\boldsymbol{\theta}$, where the integration is all over the parameter space Ω and the integral can be computed analytically.

Sub-aperture decomposition or azimuth splitting is one of the methods used mainly for relevant scatterer detection in high-resolution SAR images. Azimuth splitting gives information about the directivity of the scattering on different objects, depending on the orientation, the material, and the surrounding surface. As there exists a coupling between range chirp and azimuth chirp, it should be possible to extend azimuth splitting in both range and azimuth direction. This analysis falls under the category of joint time frequency analysis (TFA). Realization of TFA proposed in [1] & [2] involves simple band pass filtering of spectrum with continuous displacement of the analyzing window to obtain a 4-D function. For a target centered at pixel $(\boldsymbol{x}, \boldsymbol{y})$, this 4-D function can be written as follows:

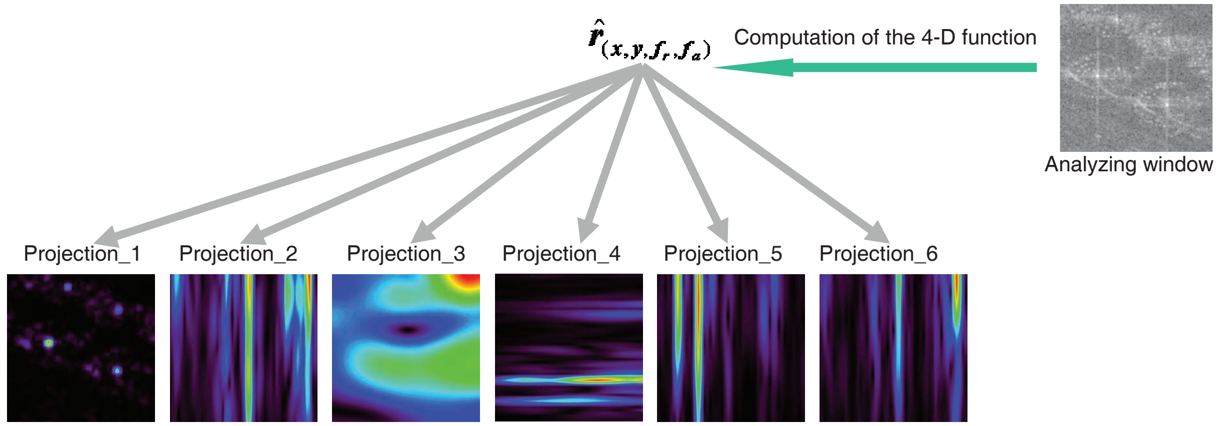
$$\boldsymbol{r}_{(x,y,f_r,f_a)} = \mathrm{FFT}^{-1}\left[\boldsymbol{w}_{(f_r,f_a)} \times \mathrm{FFT}(\boldsymbol{s})\right](\boldsymbol{x}, \boldsymbol{y}),$$

with, $\boldsymbol{w}_{(f_r,f_a)}$ is a band pass filter centered at (f_r, f_a), range and azimuth frequencies which correspond to chirp bandwidth and antenna sub-aperture centers respectively. $\boldsymbol{s}$ is the image containing the target centered at pixel $(\boldsymbol{x}, \boldsymbol{y})$. Visualization of this 4-D function in 2-D array form corresponding to a center frequency is called Radar Spectogram. The 2-D representation of $\boldsymbol{r}_{(x,y,f_r,f_a)}$ results in loss of information to a great extent and corresponds to the signature of the target centered at $(\boldsymbol{x}, \boldsymbol{y})$ only. Thus for a broader understanding of targets, in the extension of previous work, we tried to exploit the whole information available in this 4-D function to enhance the interpretability of various targets. Here, instead of using a small window containing only the target of interest, a larger analyzing window with contextual information is used. Now we obtain a new 4-D function as follows:

$$\hat{\boldsymbol{r}}_{(x,y,f_r,f_a)} = \mathrm{FFT}^{-1}\left[\boldsymbol{w}_{(f_r,f_a)} \times \mathrm{FFT}(\boldsymbol{S})\right](\boldsymbol{k}, \boldsymbol{l}),$$

with, $\boldsymbol{w}_{(f_r,f_a)}$ is a band pass filter with size $\boldsymbol{n}$ centered at $(\boldsymbol{f}_r, \boldsymbol{f}_a)$ same as before. $\boldsymbol{S}$ is the image of size $(\boldsymbol{N} \times \boldsymbol{N})$ containing target of interest and contextual information. Here $\boldsymbol{k}$ & $\boldsymbol{l}$ run from $\boldsymbol{n}/2$ to $\boldsymbol{N} - \boldsymbol{n}/2$. Thus, instead of obtaining one radar spectogram, we obtain a series of images corresponding to different sub-apertures in range and azimuth, visualized in form of an animation. This information can be stored in a 4-D array.

Projections of this 4-D array in different 2-D planes keeping remaining two dimensions fixed gives the insight of targets in analyzing window as shown below:



In each projection we obtain an animation showing the variation of target behavior for analysis along with contextual information in different range and azimuth sub-apertures.

In [5], we presented comparison of GMRF and non-linear short time Fourier transform (STFT) methods mainly for classification of complex-valued SAR data. Non-linear STFT analysis is also a form of TFA, where the cut of spectrum allows the study of the phase responses of scatterers, based on the principle of stationarity of signal in short time. The purpose of present paper is to discuss a more advanced version of TFA for understanding targets behaviors and comparing it with GMRF model. The TFA is a linear model exploiting signal non-stationarity in the time-frequency domain, whereas the GMRF model with a quadratic energy function parameterizes the spectrogram of the signal. We have focused our attention mainly on High-resolution Spot Light (HS) mode data from TerraSAR-X.

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