Optimal Target Detection Using One Channel SAR Complex Imagery : Application to Ship Detection

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INTRODUCTION

Target detection is a delicate process in SAR imagery. Single-point targets are often supposed to have a reflectivity level higher than the clutter mean power and one could think that a simple thresholding operation would permit to detect them. Because of the speckle, however the signal has a very high variability (especially in the one-look case) which may cause confusion between high speckle peaks and target points.

In this paper, we present optimal target detection based on radiometric criteria. Complex images permit to use optimal radiometric estimation by means of the Spatial Whitening Filter (SWF), which takes spatial correlation into account.

The application to ship detection on a complex fine mode Radarsat image will be presented.

PRINCIPLE OF DETECTION

Theoretical description

We suppose in this study that the targets are spread over a few pixels, mainly due to the impulse response. It can be considered as a very difficult task to describe for all types of targets and all configurations of illumination the backscattering coefficient.

The simplest approach consists in testing one hypothesis : the likelihood of the clutter with regard to a given model. Here, we suppose that the clutter is modeled as a stationary circular gaussian random process. This description of the clutter lead us to use a radiometric criterion which consists in comparing the radiometry of a test sample to the clutter mean power.

Actually, several approaches can be used. Larson *et al.* [1] have used the generalized likelihood ratio test (GLRT) which is not based on any optimality criteria. Nevertheless, this test is widely used because it can be used even for complicated problems [2].

The likelihood ratio test (LRT), which permits to choose between two hypothesis, can also be used. However, it is very difficult to model target responses in general conditions. We suppose here that the circular gaussian model applies to the target too. The null hypothesis H_0 supposes that the mean radiometry in area 1 is equal to the mean radiometry of area 2, as shown in Fig. 1 (target is not present). Hypothesis H_1 supposes that the mean radiometry of area 1 differs from the mean radiometry of area 2 (target is present). The LRT, which considers the measure $p(X|H_1)/p(X|H_0)$, where X is the measured vector, leads to optimal results and radiometric criteria.

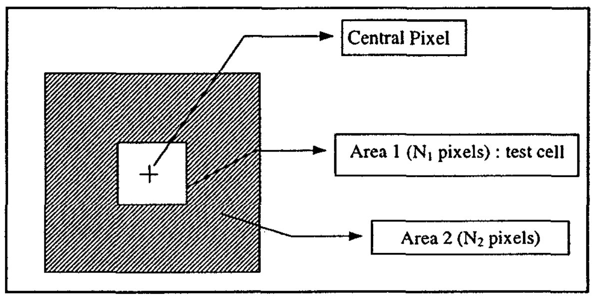

Figure 1 – Area 1 is the test cell where a gaussian target may be present and Area 2 represents the gaussian clutter

Radiometric criteria

The clutter homogeneity assumption can be rather restrictive in particular cases (target near borderlines, ...) which are not considered here. The probability density function (pdf) of the intensity of a gaussian clutter pixel is a negative exponential function given by

$$p(I|\sigma_2)=\frac{1}{\sigma_2^2}\exp\left(-\frac{I}{\sigma_2^2}\right) \quad (1)$$

where σ_2^2 is the mean power of the clutter (area 2, see fig. 1). It is well known that the speckle diversity is extremely strong since the standard deviation of the signal equals its mean radiometry $\left(\sqrt{\mathrm{var}(I)}=E[I]\right)$. In order to reduce the dispersion, averaging is done by means of the arithmetic mean over N_2 pixels. Under the hypothesis that the N_2 pixels are uncorrelated, we have

$$p(\bar{I}_1|\sigma_2)=\frac{1}{\Gamma(N_1)}\left(\frac{N_1}{\sigma_2^2}\right)^{N_1}\exp\left(-\frac{N_1\bar{I}_1}{\sigma_2^2}\right)\bar{I}_1^{N_1-1} \quad (2)$$

where $\bar{I}_1 = \frac{1}{N_1}\sum_{k=1}^{N_2} I_k$, and $\Gamma(x)$ is the gamma function. We will use the following normalised random variable (rv)

$$r = \bar{I}_1 / \sigma_2^2 \quad (3)$$

and equation (2), with the assumption that σ_2 is known, becomes

$$p(r|\sigma_2) = \frac{N_1^{N_1}}{\Gamma(N_1)} e^{-N_1 r} r^{N_1 - 1} \quad (4)$$

In practice, σ_2 is also a random variable, which is gamma distributed and estimated over N_2 samples. This leads to the following pdf for r

$$p(r|N_1, N_2) = \frac{\Gamma(N_1 + N_2)}{\Gamma(N_1)\Gamma(N_2)} \left(\frac{N_2}{N_1}\right)^{N_2} \frac{r^{N_1 - 1}}{(r + N_2/N_1)^{N_1 + N_2}} \quad (5)$$

Very high values of r are unlikely (this corresponds to high reflectivity targets) and a threshold T can be applied, the corresponding probability of false alarm (pfa) being given by

$$pfa = 1 - \frac{1}{B(N_1, N_2)} \frac{t^{N_1}}{N_1} {}_2F_1(N_1, 1 - N_2; 1 + N_1; t) \quad (6)$$

where ${}_2F_1$ is the hypergeometric function, B(x,y) the Beta function and $t = N_1 T / (N_2 + N_1 T)$.

It must be noted that lower values of r are also unlikely (in that case, we are in presence of very low reflectivity targets), which must be disregarded. The lower threshold may be choosen equal to $1/T$ when the LRT is used.

Figure 2 shows the pdf of r and the corresponding pfa (given by (5) and (6) respectively).

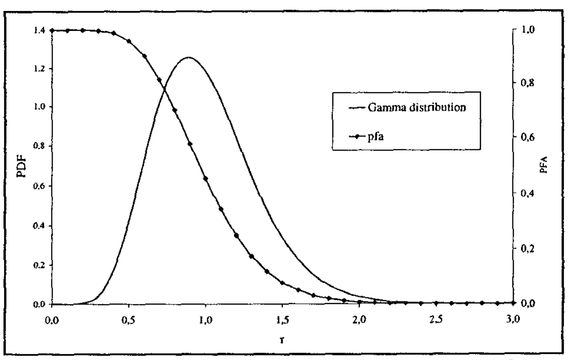

Figure 2 – pdf of the ratio and the corresponding pfa

Use of the Whitening Filter

The ratio r defined in the above section has to be estimated. Generally, the arithmetic mean of intensity (AMI) is used but with a drawback if the samples are correlated. In that case, the AMI is not a minimum-variance estimator. The Whitening Filter (WF) applied in the spatial domain permits to take into account spatial correlations [1], leading to optimal estimation of the radiometry. The SWF requires that complex data is available. Given a complex correlation matrix Σ_ρ for the samples $X = \{x_i\}$, the mean power ML estimator $\hat{R}$ ($\hat{R} = \hat{\sigma^2}$), by means of the SWF, is given by

$$\hat{R} = \frac{1}{N} {}^t X^* \Sigma_\rho^{-1} X \quad (7)$$

where N is the number of samples.

The SWF is shown to improve the results significantly when the samples are correlated [3].

RESULTS

This study has been applied to ship detection. One Radarsat® image is available, acquired on September 2nd 1997 in fine mode over the coastal town Toulon, south-eastern France. The sea state was favourable for ship detections as it was very calm and the wind very light. We should have the localization of all ships at the time of acquisition. Unfortunately, the ship localization database is not yet available.

Nevertheless, the algorithm was applied and some results produced. Fig. 3 shows the 1-look image in amplitude. Some targets are easily recognizable, some others are difficult to see. Fig. 4 shows the normalised radiometry r (texture) as expressed by (3), which permits to increase the contrast between targets and clutter. Detection can then easily be done by thresholding. Complete results will be presented during the oral presentation.

CONCLUSION

Optimal stationnary target process has been presented in this paper, with only one complex image. Since it is very difficult to model target SAR responses for a wide range of target types and configurations, it has been shown that the LRT can be applied, provided that the target can be modelled by a gaussian circular signal, leading to a radiometric-criterion algorithm. The use of the SWF permits to optimize the estimation of radiometry.

Future work will assess these preliminary results, by means of a precise knowledge of the localization of ships, and will define methods to extract all the information from the target SAR signal.

REFERENCES

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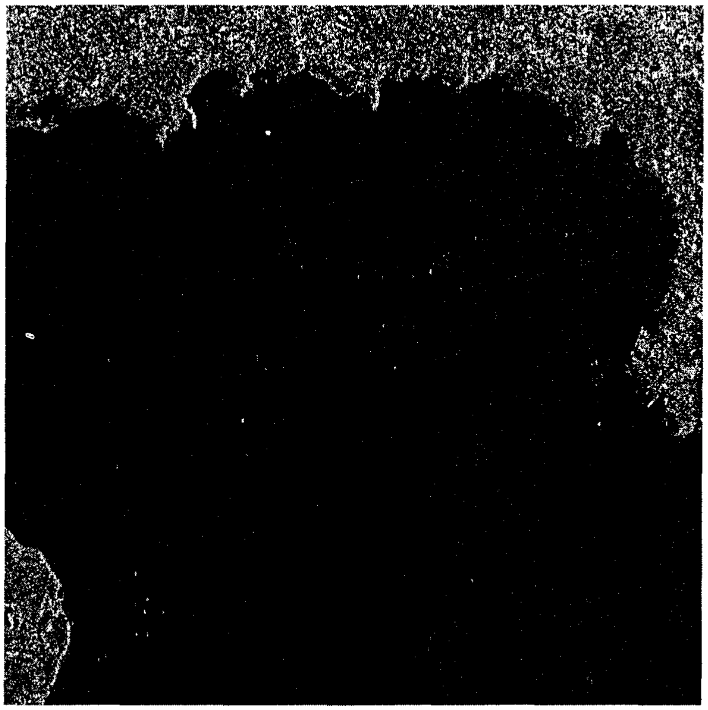

Figure 3 – One-look amplitude image of the test site

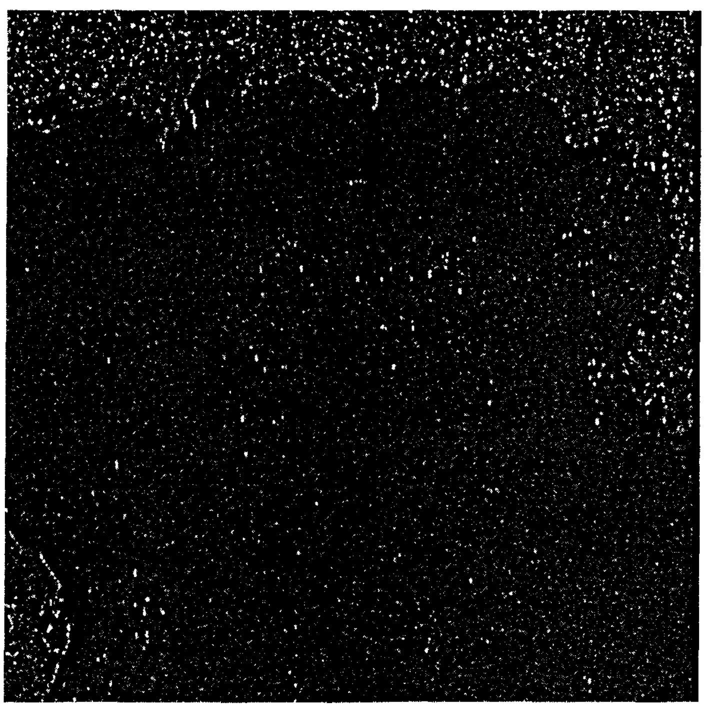

Figure 4 – Texture image of the test site