AN END-TO-END ERROR MODEL FOR CLASSIFICATION METHODS BASED ON A SAR INTENSITY RATIO

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1. INTRODUCTION

Many usual and easy-to-implement classification methods using SAR data are based on the ratio of two intensity (backscattering coefficient) images. For example, the temporal change between two dates is frequently assessed by the ratio of the backscattering coefficient images at two dates with the same polarisation (e.g. VV_2/VV_1). This has been widely used since satellite SAR systems have been available in the early 90's (ERS-1, RADARSAT-1), which provided data periodically. In the more recent years, multi-polarization systems such as ASAR onboard ENVISAT (dual-polarization), PALSAR onboard ALOS (dual- and quad-polarization), RADARSAT-2 (dual- and quad-polarization), and TerraSAR-X (dual- and quad-polarization) have become available, making it possible to use the polarization ratio at one date -i.e. the ratio of two backscattering images at the same date at two different polarizations-, which can be very relevant for some applications (e.g. HH/VV for rice classification [1]).
The accuracy of such classification methods has been assessed in [2] for the two-class problem, taking into account the target characteristics. However, no study has been published so far to assess the effect of satellite system parameters on this accuracy (e.g. spatial resolution, ambiguity, orbit repeat cycle, channel gain imbalance, radiometric stability).
This paper extends the expression of the probability of error (PE) given in [2] to take into account some of these satellite system parameters. This will provide a useful tool for the design of future SAR missions such as Sentinel-1.

2. EXPRESSION OF THE PROBABILITY OF ERROR AS A FUNCTION OF INTERMEDIARY PARAMETERS

Rignot and van Zyl [2] developed a theoretical framework for a classification method using a threshold on the ratio of backscatter intensities at two dates $r = \left(\sigma_p^0\right)_{d2} \big/ \left(\sigma_p^0\right)_{d1}$, dates where p is the polarization and d1 and d2 the dates. The approach is valid for any other backscatter intensity ratio, including polarization ratios $r = \left(\sigma_{p2}^0\right)_d \big/ \left(\sigma_{p1}^0\right)_d$, where p1 and p2 are the polarizations and d the date. This study builds on this previous work to give an alternative formulation of the Probability of Error of the method, involving a supplementary parameter.

When the backscattering intensity I of an homogeneous area in a SAR image with a number of looks equal to L is modelled as a gamma distribution, and when I1 and I2 are the intensities of two independent channels, the pdf of the intensity ratio r=I1/I2 is found to depend only on the ratio of average intensities $\bar{r}$ =< I1>/< I2>, and not directly on the average intensities < I1> and < I2> [3]:

$$p(r \mid \langle I_1 \rangle, \langle I_2 \rangle) = \frac{\Gamma(2L)}{\Gamma(L)^2} \frac{\bar{r}^L r^{L-1}}{(\bar{r}+r)^{2L}} .$$

In this method, a threshold r_t is used to decide on whether to classify a pixel having a given intensity ratio r into class A, characterized by an intensity ratio $r_A = \langle I_{1,A} \rangle / \langle I_{2,A} \rangle$, or class B, characterized by a polarization ratio $r_B = \langle I_{1,B} \rangle / \langle I_{2,B} \rangle$. Assuming $r_B > r_A$, a pixel with a ratio $r \geq r_t$ is classified as class B and with $r < r_t$ as class A.

The probability of error for class A and class B are then given by $PE_A = \int_{r_t}^{\infty} p(r \mid r_A) dr$ and $PE_B = \int_0^{r_t} p(r \mid r_B) dr$. The total probability of error is thus $PE = p(A).PE_A + p(B).PE_B$ where p(A) and p(B) are the *a priori* probabilities of class A and class B in the scene.

The optimal threshold r_{opt} is found to be:

$$r_{opt} = \sqrt{r_A r_B} \cdot \left(\sqrt{\frac{r_B}{r_A}} \left(\frac{p(A)}{p(B)} \right)^{\frac{1}{2L}} - 1 \right) \cdot \left(\sqrt{\frac{r_B}{r_A}} - \left(\frac{p(A)}{p(B)} \right)^{\frac{1}{2L}} \right)^{-1}$$

reducing, for equal a priori probabilities (p(A)=p(B)) or a very high number of looks, to $r_0 = \sqrt{r_A r_B}$.
In the general case of unknown a priori probabilities, we find that the probability of error in the classification with a threshold $r_t = d.r_0$ is

$$PE = (1 - p(B)) \cdot h_L(d \cdot X) + p(B) \cdot h_L\left(\frac{X}{d}\right)$$

where $h_L(X) = \frac{\Gamma(2L)}{\Gamma(L)^2} \sum_{j=0}^{L-1} \frac{\Gamma(L)}{\Gamma(j+1)\Gamma(L-j)} \frac{(-1)^j}{L+j} \frac{1}{(1+X)^{L+j}}$ and $X = \sqrt{r_B / r_A}$.

The probability of error therefore depends on 4 parameters:

- **L**, the number of looks of the intensity images,
- **X**, a measurement of the distance between the ratios of the two classes,
- **p(B)**, the *a priori* probability of class B,
- **d**, a measurement of the distance between the retained classification threshold r_t and the threshold r_0 when the two classes are equiprobable.

3. RESULTS ON THE IMPACT OF SAR SYSTEM PARAMETERS

The effects of the SAR system parameters on these 4 parameters -namely L, X, p(B) and d- and consequently on the Probability of Error, is assessed in the general case of unknown *a priori* probabilities (r_t=r_0).
An illustration of the calculations will be provided for the case of the application on rice monitoring using C-band SAR data, with modelled temporal backscattering profiles.

In the general case, it is found that:

- **Channel gain imbalance** in the polarisation ratio method and **radiometric stability** in the temporal change method both affect the d parameter. Early results indicate that the additional error due to these 2 parameters is inferior to 3% in usual cases.

In the specific case of rice monitoring:

- The **orbit repeat cycle** (temporal sampling) affects the X parameter. It is found to be a critical parameter for the temporal change method. Its impact is much reduced in the polarisation ratio method.
- The **ambiguity level** also affects the X parameter. It is not critical for the method based on the polarisation ratio, but needs to be lower than -20 dB to guarantee an additional error lower than 4% for the method based on the temporal change**.**

4. REFERENCES

[1] A. Bouvet, T. Le Toan, and N. Lam Dao, "Monitoring of the Rice Cropping System in the Mekong Delta Using ENVISAT/ASAR Dual Polarisation Data," *IEEE Transactions on Geoscience and Remote Sensing,* accepted, 2009.

[2] E. Rignot and J. van Zyl, "Change detection techniques for ERS-1 SAR data," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 31, pp. 896-906, July 1993.

[3] R. Touzi, A. Lopes, and P. Bousquet, "A statistical and geometrical edge detector for SAR images," *IEEE Transactions on Geoscience and Remote Sensing,* vol. 26, pp. 764-773, 1988.