ANALYSIS AND SIMULATION OF SIDE SCAN SONAR IMAGE TEXTURE

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1. INTRODUCTION

Sea bed remote sensing is of great interest for a large number of human activities. In addition to its use in several scientific fields (hydrography, geophysics, sedimentology, oceanography), whose objectives are to know more and more about the properties and characteristics of the sea bed, sea bed remote sensing also allows operations concerning underwater activities to be optimized by enabling the selection of areas where these activities are more profitable (fishery, dredging...) or by adjusting the means to be used in order to satisfy the objectives of the operation (mine hunting...)

Of course sea bed remote sensing also has to include means of classification in order to extract the relevant characteristics of the sea bed from the measurements.

Side scan sonars are useful tools for sea bed observation; they operate close to the seabed in order to limit the propagation loss and to produce large enough shadows from natural structures of the bottom ; of course, the size of the details on the images depends on the ratio of the wavelength to the length of the antenna.

When a human operator is facing a display, he can recognize different areas on the sea bottom image, which characterize different types of sea bottoms. However, the volume of data produced by side scan sonars is increasing, due to the fact that speed and range are increasing; therefore, automatic tools must be developed in order to make the operator's task easier. This can be done by analyzing the texture of the sonar image.

This paper presents the promising results we have obtained about texture analysis but also about texture simulation, which enables the comparison of real and simulated textures in order to validate the texture model.

2. TEXTURE ANALYSIS OF SIDE SCAN SONAR IMAGES

2.1 Sonar images characteristics

The background of the sonar images of the sea bed is mainly made up of reverberation. Reverberation is produced by the addition of the contributions of the multiple scatterers lying on the sea bed. The intensity of reverberation depends on sonar parameters but also on bottom characteristics (mud, sand, rocks) and is therefore sometimes non stationary.

When using a side scan sonar which generally operates close to the sea bed, shadows appear on the image, due to the masking of the sea bottom produced by the relief, rocks, stones or objects. These shadows give an indication about the relief of the bottom.

2.2 How to classify the sea bed ?

A first way is to measure the bottom scattering strength from the acoustical sonar data. The bottom scattering strength is a function of the operating frequency, the grazing angle and the nature of the sea bottom [1]. Therefore the measured value of the bottom scattering strength gives an indication on the nature of the bottom, but the indication is not quite trustworthy due to the fluctuations of the reverberation.

Another way is to estimate the probability density function of the signals. Statistical analysis of real data from a front looking sonar has shown that different bottom types are characterized by different probability densities [2]. In case of a vertical depth sounder, a Rice density is expected to fit the data, and its parameters are related to the roughness of the sea bottom [3].

However, side scan sonars can produce high resolution images of the sea beds. On these images, local variations of luminance appear, due to the relief (modulation of the backscattered signal, shadows). The spatial arrangement of the pixels on the image creates a texture which is characteristic of the sea bed. A way to analyze the sonar image texture and then to classify the sea bed is to estimate the second order statistics of the image. Indeed, experimentations proved that our visual system cannot discriminate two textures which have the same second order statistics.

2.3 Methods for texture analysis

Second order statistics $P_\Delta(i,j)$ may be estimated by grey level cooccurrence matrices. The general term of the cooccurrence matrix is :

$$C_\Delta(i,j) = \sum_{n=1}^{N} \delta(L_n - i)\,.\,\delta(L_{n+\Delta} - j)$$

Where :

- Δ is a displacement vector between two pixels of the image
- i,j, are grey levels $i \leq K$, $j \leq K$
- L_n, $L_{n+\Delta}$ are grey levels of the image pixels at locations n and n+Δ
- δ is the number of pixels in the image to be analyzed.

$C_\Delta(i,j)$ measures the occurrence of the levels i and j for two pixels spaced by Δ.
The size of the cooccurrence matrix is equal to the square of the number of grey levels (K^2). It is thus computationally expensive to use all the elements of the matrix to characterize the texture. Therefore Haralick [4] introduced some parameters derived from the elements $C_\Delta(i,j)$, in order to define a textural signature, these parameters are mean, variance, energy, contrast...
Unser [5] proposed another way to estimate the second order statistics by using sum and difference histograms $h_{\Delta,S}(n)$ and $h_{\Delta,D}(v)$ where u = i+j and v = |i−j|.

We then obtain:

$$P_\Delta(i,j) = \alpha\,.\,h_{\Delta,S}(i+j)\,.\,h_{\Delta,D}(|i-j|)$$

Where α is a coefficient.
This method allows an important gain in memory allocation and computing time. Parameters, which are comparable to these given before, are then computed

- mean

$$MEA = \frac{1}{2}\sum_u u\,h_{\Delta,S}(u)$$

- variance

$$VAR = \frac{1}{2}\left[\sum_u (u - MEA)^2\,h_{\Delta,S}(u) + \sum_v (v - MEA)^2\,h_{\Delta,D}(v)\right]$$

- energy

$$ENE = \sum_u h^2_{\Delta,S}(u)\,.\,\sum_v h^2_{\Delta,D}(v)$$

- entropy

$$ENT = \sum_u h_{\Delta,S}(u)\,.\,\log_2(h_{\Delta,S}(u)) - \sum_v h_{\Delta,D}(v)\,.\,\log_2(h_{\Delta,D}(v))$$

- homogeneity

$$HOM = \sum_{v} \frac{1}{1 + v^2} h_{\Delta,D}(v)$$

- contrast

$$CON = \sum_{v} v^2 h_{\Delta,D}(v)$$

- correlation

$$COR = \frac{1}{2} [\sum_{n} (u - MEA)^2 h_{\Delta,S}(u) + \sum_{v} (v - MEA)^2 h_{\Delta,D}(v)]$$

- cluster shade

$$SHA = \sum_{u} (u - 2MEA)^3 h_{\Delta,S}(u)$$

- cluster prominence

$$PRO = \sum_{u} (u - 2MEA)^4 h_{\Delta,S}(u)$$

These parameters were used in order to analyze side scan sonar images for sea bed classification.

2.4 Application of the method to sea bed classification

The principle consists in comparing the images to be analyzed, to reference images which have been previously chosen. Each reference image corresponds to a bottom type and is characterized by some features resulting from image texture analysis. Sea bed classification will be performed by comparing the images features to the reference image features and to perform a best fit.

The different steps are as follows (figure 1):

- partition of the image in different sub-images whose size is larger than the resolution cell of the texture,
- estimation of the second order statistics in each sub-image,
- estimation of the corresponding parameters,
- principal component analysis and selection of the two main parameters P_A and P_B; the textural information is then represented by a point in the space (P_A, P_B),
- clustering of the points into different classes eventually around the reference points. An algorithm is used, which was proposed by Urquhart [6].

This method was used in order to classify sea beds by processing side scan sonar images obtained on different bottom types: flat bottom, sandy bottom with different wavelengths, rocky bottom, flat bottom with stones. The results are presented on figure 2 in the space (P_A, P_B). It can be noticed that the clustering algorithm has exactly separated the different bottom types.

3. TEXTURE SIMULATION

3.1 Simulation of sonar images

Different methods can be used to simulate sonar images [7]. Some methods first simulate the relief of the sea bed and then the sonar image by taking the sonar parameters into account (geometry, processing, ...). These methods naturally allow the introduction of shadowing effects due to the relief. The relief can be simulated by using fractal techniques or by using antoregressive models. Fractal techniques produce reliefs which seem to be fairly different from sea bed reliefs which present particular spatial frequencies or more uneven structures. Such effects can be obtained by modifying the simulated relief, but then the fractal properties of the simulated relief are suppressed. Autoregressive models use different coefficients which have to be adjusted in order to obtain the desired relief. However, these methods have difficulties in simulating transitions between two types of bottom.

In order to increase the realism of the simulation, we used a model which takes the second order statistics into account. Reference images given by the sonar are first analyzed in order to compute the model; then, an interactive method is used to make an initial simulated image converge towards the reference one [8]. This method provides realistic sonar images in which non-homogeneous roughness may be introduced, such as rocks or stones on a sandy bottom as well as transitions.

3.2 Simulation method

The method was developed by the I.N.R.I.A., France. Two models can be used to describe second order statistics: the first one uses second order spatial averages and the second one autocovariance and histogram. The reference image is then characterized by a histogram and a feature vector B_R. The simulation is then performed in two steps (figure 3):

- simulation of a random image I_o which has the same histogram as the reference one,
- modification of the initial image I_o in order to converge towards the reference one. I_o is modified pixel after pixel in such a way that the distance between both feature vectors $\varepsilon = \| B_R - B_S \|^2$ is minimized. A random scanning stragegy is used to modify the pixels of the image. Of course, the procedure has to be iterated in order to obtain satisfying results.

3.3 Application of the method to sonar images simulation

Three reference sonar images were selected from real side scan sonar data and various sea bottoms: sand, sand with ripples, rocks. Second order spatial averages and the resulting features were estimated for displacement vectors in windows of different sizes. The simulated images are presented for the different window sizes (figure 4). The realism of the simulation can be verified by looking at the presented images. This indicates the validity of a texture model which takes second order statistics into account.

4. CONCLUSION

Side scan sonars provide images of the sea bed which are of great interest for sea bed classification. A method has been described which takes advantage of the relation between the characteristics of the sea bed and the characteristics of the texture. This method is based on texture analysis and uses an estimation of the second order statistics of the image; the validity of the method has been proven by processing images obtained on different sea bottoms and by simulating images according to the chosen model.

Nevertheless, in order to increase the robustness of texture analysis, the presented method could be combined with other methods such as edges density analysis and shadows density analysis.

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1 – a
Partition of the image

1 – b
Estimation of second order statistics

1 – c
Estimation of N_P texture parameters

1 – d
Principal component analysis

1 – e
Clustering

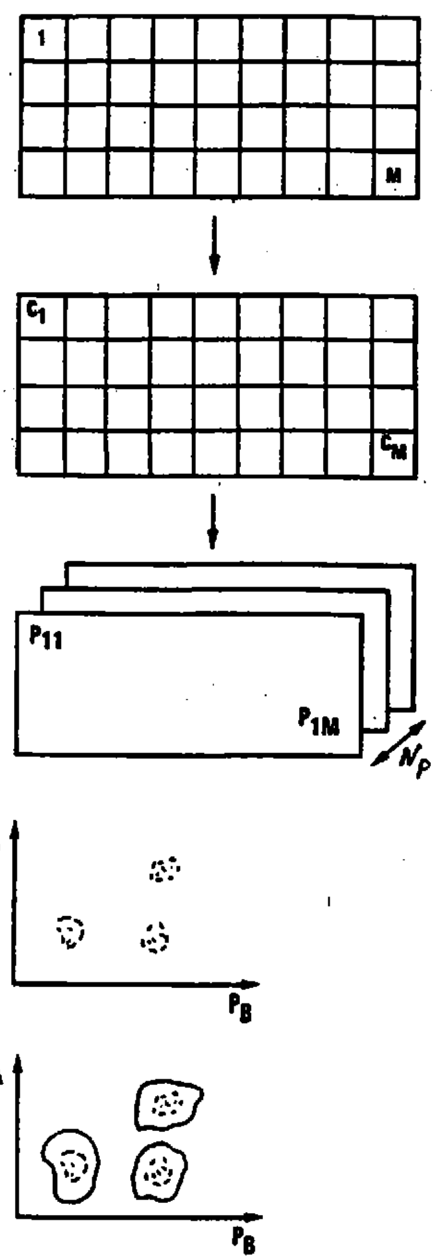
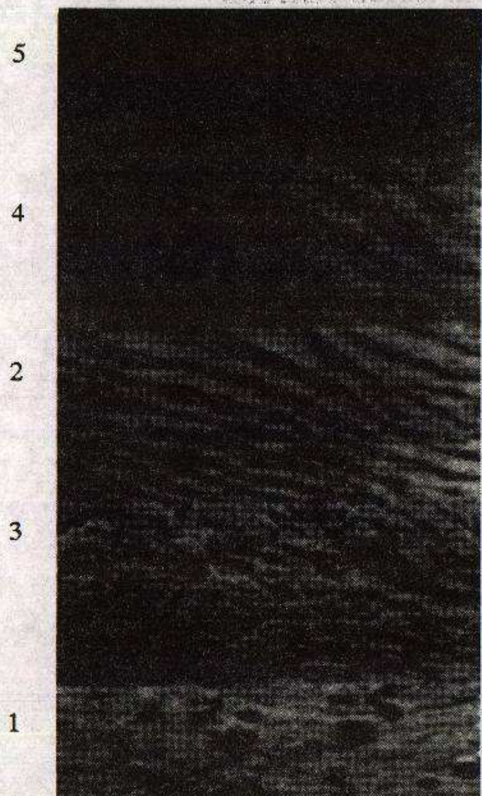
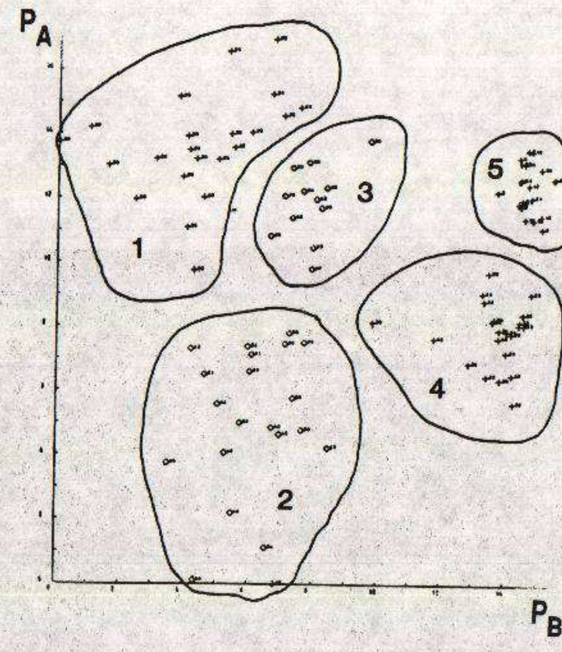


Figure 1 – Texture Analysis – Different steps



2a – Sonar images



2b – Results

Figure 2 – Texture analysis – Some results

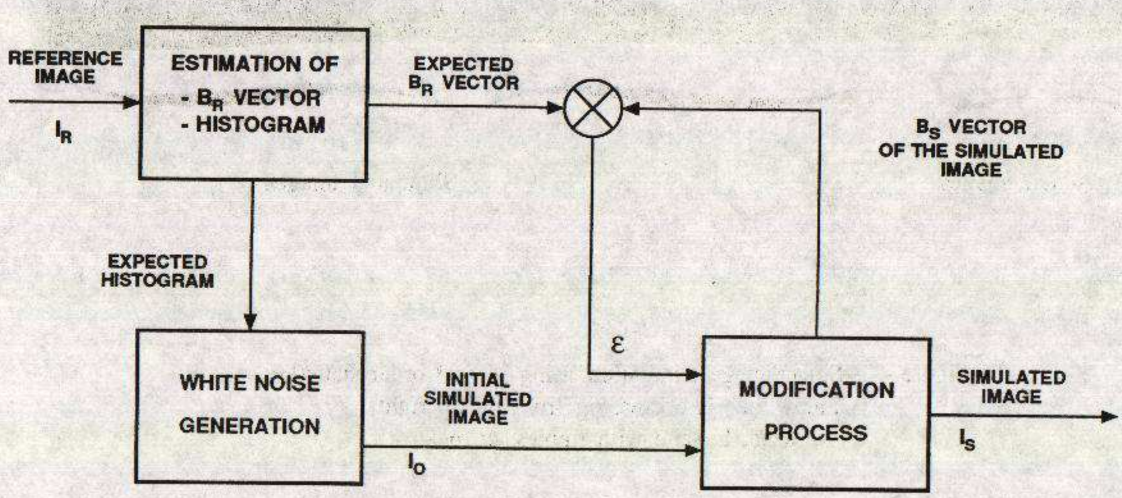


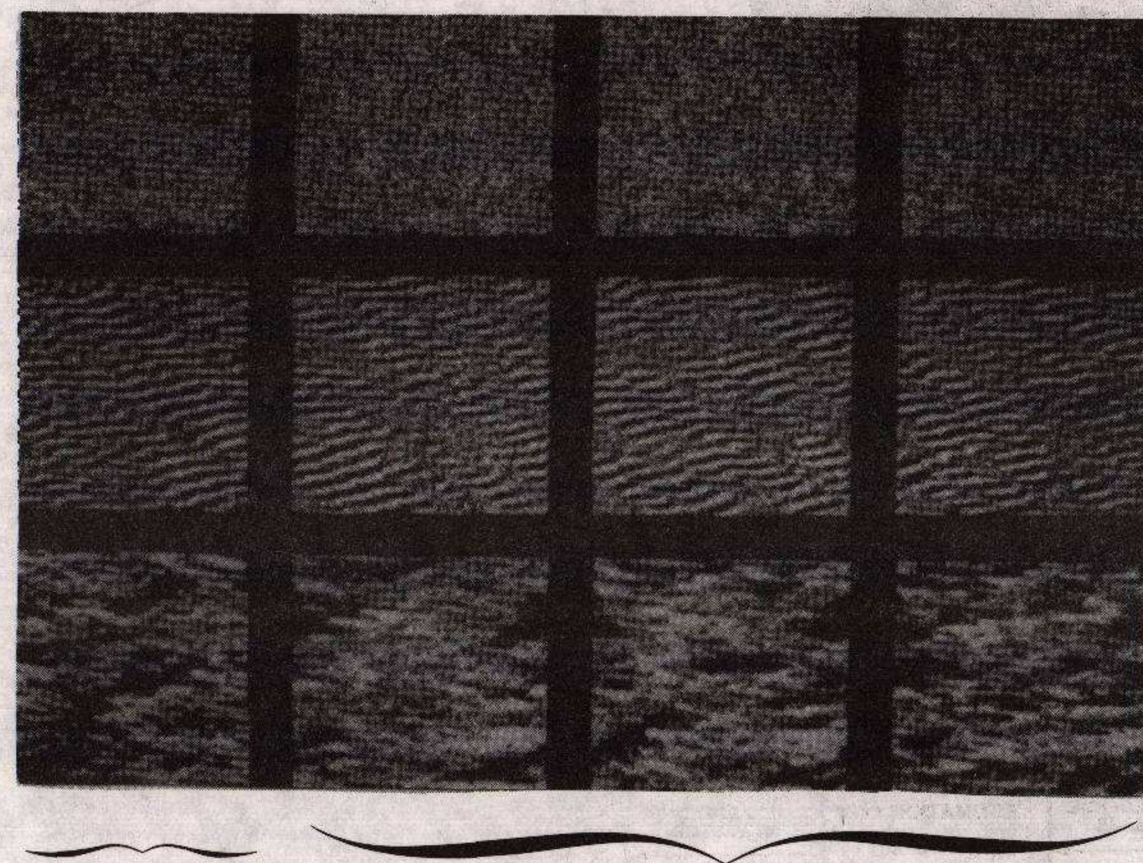
Figure 3 – Simulation method – Adaptive algorithm

ANALYSIS AND SIMULATION OF SIDE SCAN SONAR IMAGE TEXTURE

a

b

c



Actual images

Simulated images

Figure 4 – Sonar image simulation using second order statistics
(window size is decreasing from left to right)
a: sand, b: sand with ripples, c: rocks