IDENTIFICATION OF RIVERBED STRUCTURES AIDED BY SIDE SCAN SONAR IMAGE PROCESSING

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Abstract

Two-band (100 and 500 kHz) synchronous side-scan-sonar was developed for marine investigations, but this experimental survey carried out in the navigable Guadalquivir river, southern Spain, demonstrated that it is a powerful new tool for river-bottom studies and suggests that it will be most useful for other river surveys. Computer image processing of extracts of synchronous 100 and 500 kHz sonographs to produce independent images differentiated and delineated the different textures and conformations of the underwater sediments and helped us to identify and characterise riverbed morphologies. The surveys were carried out rapidly and precisely. Erosional and depositional morphologies on the river bed were easily visualised on the screen and in the raw images. The Fourier wedge filter attenuated particularly well the confusing noise in the 100 kHz band. The Roberts' edge-enhancement filter and the Laplacean convolution filter enhançed topographical features and revealed geomorphological patterns.

Keywords: Image processing, side-scan-sonar, river-bed structures, Guadalquivir river, Spain.

1. Introduction

The last three decades have seen rapid developments in the use of digital data collected by remote sensing instruments. Side-scan-sonar is an active remote sensing instrument that emits a beam of acoustical waves and differentially analyses the returning waves reflected by underwater structures to produce two-dimensional images, called sonographs [15]. Side scan sonar is now well-established as an important underwater remote sensing tool because it can locate submarine bedforms and depict their positive and negative reliefs; it also differentiates the main types of bottom-sediments. Full details about the operational principles of side-scan-sonar, its image-resolution capacities, and the interpretation of sonographs for different applications are contained in a number of works [1, 2, 5, 6, 10, 13].

As the usefulness of side-scan-sonar in studies of marine, estuarine and lake sites has already been demonstrated (McManus and Duck, 1988), we planned this present work to evaluate its use in studies of river sites and locations.

The study areas are located between some 10-15 km upstream of the Guadalquivir River rivermouth, southern Spain (Fig. 1). The Guadalquivir is navigable for 100 km from the rivermouth to the river port of Seville. Depths vary between 20 and 6 m.

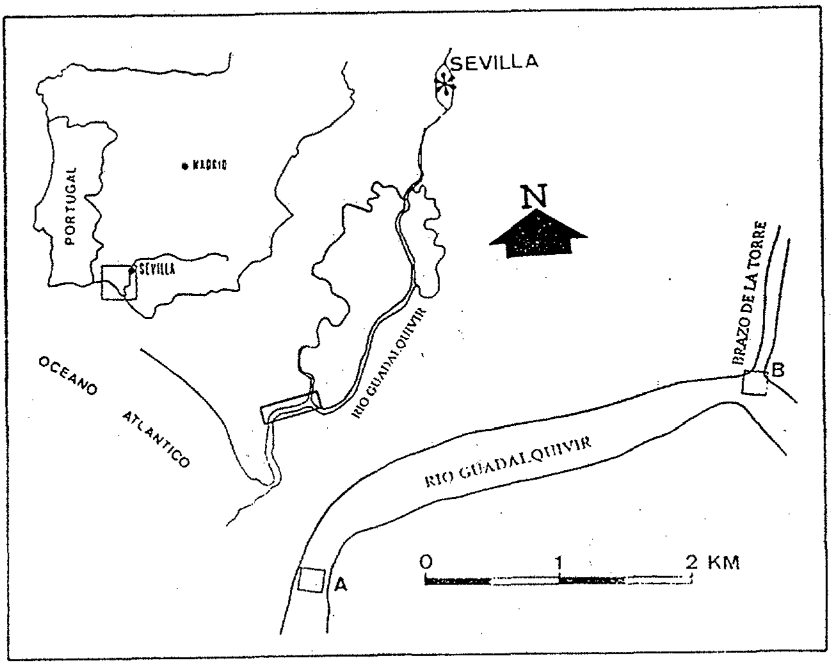

Figure 1 : Guadalquivir River: areas studied. (A) dune.ext (Subaquatic wave structure) and (B) plume.ext (Lobule formation).

2. Data acquisition and processing systems

The work described in this paper was carried out with a Klein Hydroscan two-band side-scan-sonar (Model 595) that emits simultaneously two different-frequency beams (100 and 500 kHz). The side scan range is 100 m per channel (i.e., 100 m to each side of the tow-fish transducer).

The instrument system applies anamorphic and slant-range corrections to the raw data by using data about position and depth supplied by the vessel's computer log system. This quantitative geometric processing removes the lateral and longitudinal distortions caused by the slope of the beam and fluctuations in the speed of the vessel and sensor over the river bed. In this way the system generates accurate analog isometric images (on thermal paper) and, simultaneously stores the digital data on tape. We do not discuss the pre-processing algorithms because they were specifically written to conform to the unique data-acquisition characteristics of the Klein system and its specific geometric and radiometric distortions).

The information extraction techniques that were carried-out on-shore were those applied to data collected by any imaging system: spatial filtering, colour-coding, classification of type of bottom cover, etc. [12]. This mathematical image-intensifying process not only added spatial definition and textural richness by filtering-out confusing "noise" from the relatively small amount of information contained in only two bands of poor-quality input-image signals, it also provides a better visual interpretation of the scanned area. In this way image analysis and intensification improved considerably the information quality of the original image. After processing blurred or indistinct objects or patterns became sharper and more informative, visual interpretation was easier and better, and digital classification was more effective. [3, 7, 14].

3. Sonographic information extraction and geomorphological interpretation.

The two images of the Guadalquivir River bed were specially selected for the geomorphological features they contain: dune.ext and plume.ext (Fig. 2 A and B and Fig. 3 A and B, respectively). Both images are independent and produced by two scans each at a different frequency (100 and 500 kHz). Therefore, four original images had to be processed. Initially, we had dune1.ext: and dune5.ext and plume1.ext: plume5.ext:. The processing started by using an interactive, image-to-image process of common reference points to superimpose exactly the common elements in the sub-image frames of each frequency band of the same scene so that they could be compared. This process includes the construction of a first-order map model that merges each scene with another to form a composite image. The re-sampling involved is based upon nearest-neighbour interpolation.

To improve visual interpretation, contrast enhancement was applied to each subscene independently. This process stretches or potentiates, either lineally or by histogram equalization, the digital signal values of the monochrome image.

A major problem with the sonograph images is the continuous interference (noise) pattern that overlies and partially obscures the image. The sonar echo-sensor receives unwanted underwater acoustic or electromagnetic waves, extraneous to the wave systems of the transducer-signal echoes that the sonar instrument is designed to detect and analyse [9]. Elimination of this confusing noise instrument is very difficult, so it is done during image-processing and needs carefully-designed image-processing filters for each band-width and even then the filters must be changed or adjusted for each image to cope with different circumstances .

3.1. The search for characteristic morphological patterns: dune.ext

The duna1.ext and duna5.ext images (1097 x 1277 pixels) also depict a curved and narrow part of the river, near the rivermouth. The image shows part of the eastern bank of the principal channel. At this point the river-bottom shows little slope towards the main channel. This riverbed displays an interesting phenomena, it has two types of sand-waves: long-wavelength, small-amplitude ones that extend linearly and obliquely across the main axis of the river: and many smaller, short-wavelength, symmetric ones whose parallel crests transverse the river around 90° to its axis.

The winding and narrowing of the river favours faster water flows at this point and, consequently, the structures associated with current flows are very well defined. Both types of sand waves are sedimentary structures generated by bottom-transport in water flows of different speeds and different directions, they can also indicate changes in sediment texture and particle composition. It is evident that tidal flows greatly influence bottom currents at this point.

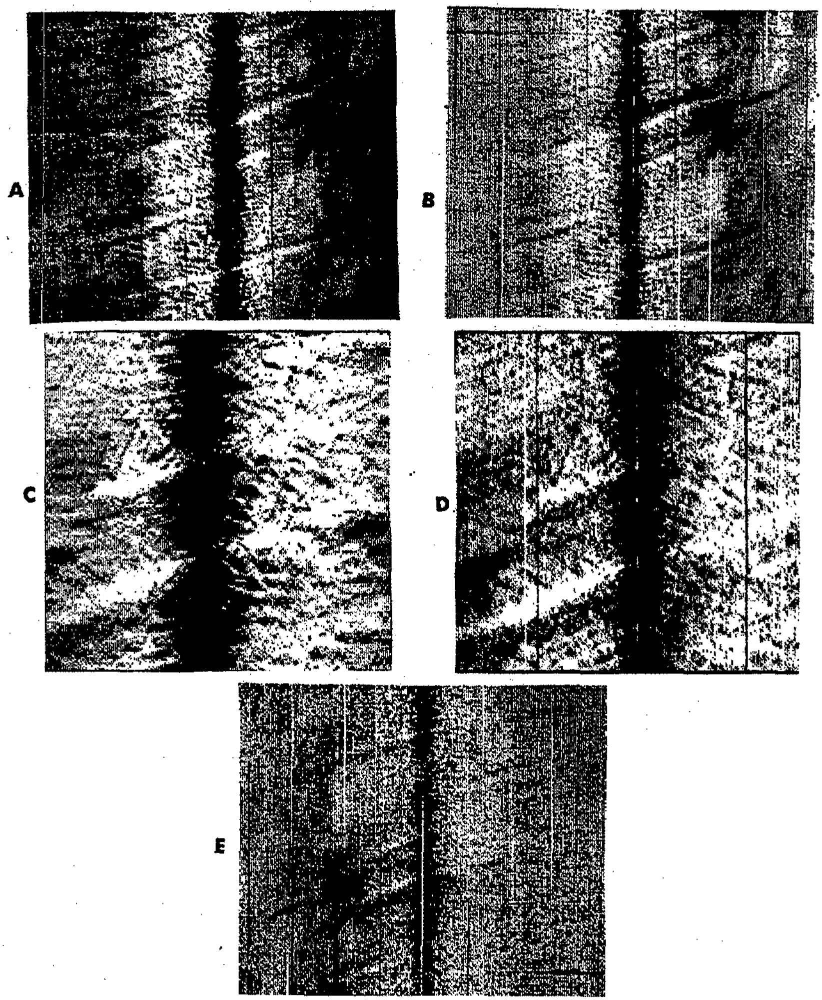

Figure 2 : Raw images corresponding to the two frequencies to the dune.ext site, (A) dune1.ext (100 kHz) and (B) dune5.ext (500 kHz); (C) shows the resulting image, after applying an horizontal wedge filter in the Fourier space to dune1.ext; (D) presents the resulting image after applying a vertical wedge Fourier filter dune5.ext. Note the attenuation of the noise present in the former images; (E) corresponds to the dune5.ext with a Laplacean filter.

The long-wavelength sand waves advance to to the south because the ebb-current potentiates the river flow and increases the speed of the water over the bottom.

In the Guadalquivir, seawater tidal inflow is usually much slower than the river outflow, especially in the rainy season. The parameters that could give rise to these phenomena are being studied at present [11, 4]. Future surveys with side-scan-sonar equipment and image processing may help us understand better the interactions between tidal flows and riverflows that produce the sandwave patterns and certain erosion structures.

The extracted component images of the sub-images were contrast enhanced by a histogram stretching method, but because of the small size sand-waves and their irregular pattern, the final images were poor.

To improve image quality, we had to carry out a more detailed analysis. For this, .smaller scenes (500 x 500 pixel) were extracted from the previously registered and superimposed images. These smaller-size images allowed us to work within the Fourier frequency domain, in which we applied a vertical-wedge filter to the 500 kHz image extract, and a horizontal-wedge filter to the 100 kHz one. The filters were different in each case because the orientation of the noise waves to be attenuated in the images of each band was different. The new images permitted us to interpret satisfactorily each band independently (Fig. 2, D and C).

The best visual enhancement of the sand-waves of the several different filters applied experimentally to the raw images was given by the Laplacean convolution filter when applied to the 500 kHz extract (Fig. 2, E).

3.2. Textural pattern-recognition experiments: plume.ext

The (plume1.ext, Fig.3. A) and (plume 5.ext, Fig. 3, B) images (both 2012 x 1815 pixels) are of river site A (Fig. 1). They reveal two interesting river-bottom features: firstly, a "lobule" formed of sediment of different textures, and, secondly, the steep walls that form the sides of the navigable canal of the river.

At this point, the river curves and narrows and receives a tributary (Brazo de la Torre) that in the wet season contributes a large amount of surface run-off water. The confluence of the two flows is very well shown by the abrupt, cliff-like erosional structures displayed in dark tones. In addition, coarser sediments are deposited here and are later remodelled by the flow in the principal channel. The coarser fractions of the sediments (silts, and even sands) show here a "lobule" shape because the tributary flow lessens after the rainy period.

To help textural enhancement, we extracted another, even smaller, (easier to work with) subscene (1215 x 1129 pixels) from the images of both frequencies The 100 kHz scene is darker and more blurred than the 500 kHz one, consequently, we applied density-slice color coding to it (Fig. 3, C). We obtained the best results when we employed unsupervised classifications with an isodata algorithm and minimum-distance classifier on both frequency bands. The resultant thematic map has four classes (in grey-scale), that reveal the different textures of the riverbed (Fig. 3, D).

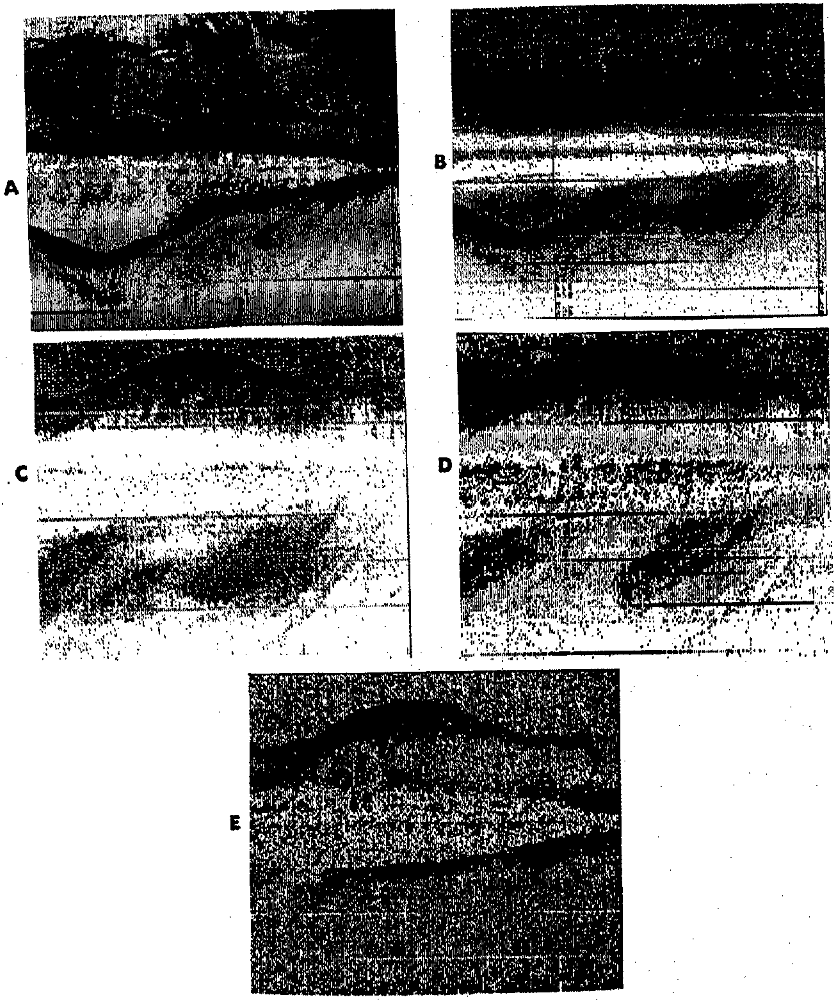

Figure 3: Raw images corresponding to the (B) site in Figure 1. (A) corresponds to plume1.ext (100 kHz), and (B) to plume5.ext (500 kHz); (C) presents a density slice in grey tones applied to plume5.ext.; (D) corresponds to an unsupervised classification performed on both extracts, obtaining a thematic map with four classes represented in grey scale; (E) shows the resulting image after applying a Roberts edge detector filter on the plume1.ext. Note the disappearance of textural changes, and enhancement of topographic features.

None of the filters that we applied to the original images gave sufficient textural enhancement because, even when the different sediment textures were visible in the original images, they became indistinct and almost invisible after the filtering process. On the other hand, edge detector filters like the Roberts model displayed the topography very well when applied to the *100 kHz* images (plume1.rbr, Fig. 3, *E*). The near-vertical sides of the steep slopes, typical indicators of erosion, that mark the channel where the river flows fastest, gave such strong returns that they were easily recognizable in the raw images.

4 . Conclusions

As expected, digital processing of sonographs enhanced the visual interpretation and information extraction. The quality of the scenes of each frequency (100 and 500 kHz) that form the composite image, were improved by using the appropriate filter. The Fourier wedge was outstanding; it attenuated the particularly disturbing noise in the 100 kHz band. The Roberts edge enhancement filter, or the Laplacean convolution filter, were useful to to enhance topographical relief and to detect geomorphological patterns.

Unsupervised classification gave satisfactory results only in the search for changes of texture because the sand-wave patterns it produced became too confusing and the processed image was not very informative.

This work demonstrated that sonograph-image processing supplemented and complemented very well conventional geomorphological riverbed studies and suggests that side-scan-sonar survey will be a faster safer, and more cost-effective method for underwater geomorphological studies of large rivers than diver inspections; especially when river currents are fast and the waters turbid.

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