

SIDECAN SONAR IMAGERY PROCESSING SOFTWARE FOR UNDERWATER RESEARCH AND EDUCATION PURPOSES

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ABSTRACT

Detailed submarine digital analysis of side scan sonar images significantly enhances the ability to assess seafloor features and artifacts digital images. These images are usually poor in their resolution if they are compared with optical images. There are commercial solutions that could solve this trouble, such as: the use of high resolution multibeam sidescan sonar, or the use of bathymetric sonar. Present work shows an economical solution to avoid this kind of problem by using digital image processing techniques under MATLAB environment. The application presented here is easy to use and has been developed under user friendly philosophy and could be operated for users at any level. Two types of sonar surveys, seafloor mapping and submerged target searches (buried or not), each require different processing methods for data analysis. This work is the first step and a general purpose tool for future lines of research in submerged objects recognition. Results are comparable in quality with commercial hardware solutions.

Keywords: SSS, single sidescan sonar, underwater, digital image processing, autonomous underwater vehicle, remotely operated vehicle.

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INTRODUCTION

Digital images captured from the echoes of sidescan sonar onboard an unmanned undersea vehicle, are usually characterized for their low resolution. This is so because underwater, sound transmission is limited and this is most notable in useable ranges. The usable range of high frequency sound energy is greatly reduced by seawater, typically to around 50 to 150 m (Blondel, P. 2009). Low frequency sound energy is reduced at a much lesser rate with usable ranges of in excess of 250 m. achievable. Therefore, a tradeoff exists between higher resolution images produced by a high frequency side scan sonar and the longer range provided by a low frequency side scan sonar. In analyzing digital side scan sonar data numerous techniques have been demonstrated to correct and enhance the imagery as well as aid in interpretation (Lurton, X. 2002) (Medwin H. and Clay C.S. 1998)).

The collaboration of two research groups from different departments of the University of Cantabria have been necessary in the development of low cost and flexible software for digital processing of sidescan sonar images under MATLAB environment by using digital filtering and advanced signal processing techniques. Some of these techniques are already used in DVB digital video systems and broadcasting, with excellent results (Hardie, R.C. and Barner, K.E. 1996).

MEASUREMENT TOOLS AND ENVIRONMENT

Advances in the fields of underwater technologies (Bellingham J.G. et al., 1994), robotics (Ishoy A., 2000), acoustical positioning (Marani, G., 2009), (Palomeras N. et al., 2010), remote sensing (Lillesand, Thomas M. and Kiefer, Ralph W. 1994), submarine guidance (Antich J., Ortiz A. and Oliver G., 2005) and digital processing imagery (Padmavathi, G. et al. 2010) have led to the development of Autonomous Underwater Vehicles (AUVs) and reached unimaginable levels only few years ago. Unlike other types of research can be carried out inside a laboratory or in the field, measurement tools used in this work must be adapted to a hostile environment as is the marine environment. These abilities have been enabled better and precise researches in several fields, such as: biological (Dahms, Hans-Uwe and Hwang, Jiang-Shiou, 2010), geological (Drury, Stephen A., 2001), zoological (Cheung, W.W.L. et al., 2009), natural resources (Wang Q. and Wang X., 2010), archeological (Bowens A., 2009) and military (Von Alt C., et al., 2001). These characteristics have led to the design of underwater vehicles with a built-in propulsion system, which has increased the possibilities of movement in the underwater environment. This is the situation of UUVs (Unmanned Underwater Vehicles) which are divided into two different categories:

- ROVs (Remotely Operated Vehicles), can be towed by a boat from the surface at moderate speeds.
- AUVs (Autonomous Underwater Vehicles), which are propelled by electric motors and governed autonomously remotely from the surface, from a ship or from land.

With these systems, the researcher can move relatively quickly to a few meters from the sea floor, following the topography of the same and recording video images to find a place or object of interest. The problem presented by these vehicles is that the image quality is degraded in terms of depth, and optical systems that capture images need powerful lighting systems, which in the case of autonomous vehicles (AUVs) without power connection through the umbilical wire to the surface is not feasible and sidescan digital sonar images are used against optical ones. Figure 1 (a) and 1 (b) show the ROV and AUV recently acquired by the University of Cantabria, and used in this work. Figure 1 (a) shows the ROV, model Seaeye Falcon from the Swedish company SAAB, this vehicle is an auxiliary rescue vehicle equipped with an articulated arm. It is possible to use optical image recording underwater since it has powerful illuminators fed from the surface. This vehicle lacks of a sonar device (installation will be considered in the future) and this is the reason that direct comparison of optical images and the acoustic images is not available at this point.

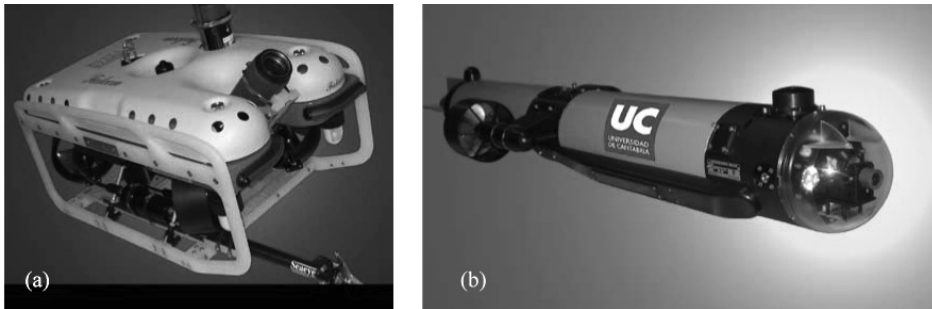


Figure 1: ROV and AUV owned by the University of Cantabria. (a) ROV, model Seaeeye Falcon from SAAB company. (b) AUV, model C'Inspector from Kongsberg company.

Figure 1 (b) shows the AUV, model C'Inspector from the Norwegian company Kongsberg, this is an autonomous vehicle equipped with a high speed optical fiber data connection of 1Km length. The vehicle can be used for inspection tasks in the background and detection of submerged objects and also it has been equipped with a. Tritech SeaKing Sidescan Sonar with 675 kHz of operating frequency and chirp modulation. This device has a narrow beam and shorter range (100m) for more detailed images of closer targets. Technical characteristics of this sonar are shown in Table I. Chirp side scan sonar utilizes pulse compression techniques to produce long transmission pulses and achieve long range without a resultant decrease in across-track resolution. The commercial implementation of Chirp side scan sonar is in a single beam configuration. Underwater, sound transmission is limited and this is most notable in useable ranges. The usable range of high frequency sound energy is greatly reduced by seawater, typically to around 50 to 100m (Blondel, P. 2009). Low frequency sound energy is reduced at a much lesser rate with usable ranges of in excess of 200m achievable.

Table I: Technical Characteristics From Trittech Seaking Sidescan Sonar.

Characteristics	Value
Operating Frequency	675 kHz (chirp modulation)
Horizontal Beam width (-3dB)	1° 0.5°
Vertical Beam width (-3dB)	50°
Weight in air/water	5.3kg/2.7kg
Maximum operating depth	4000 m
Power Requirements	18-36V@12VA
Control Connector	Trittech Sonar Connector
Transmitter Source Level	200 dB re 1μP @ 1 m
Transmitter Pulse Length	50 - 200 μs
Receiver Sensitivity	> 2μV rms
Gain Control Range	80 dB
Display Dynamic Range	40 dB (Software Configurable)
Data Sampling Rates	5 - 200 μs
Data Resolution	4-8 bits (Software Configurable)
Software	Trittech Seanet Display Software or low level language commands
Data file format	Proprietary Trittech "V4Log"
Communication Protocols	Arcnet, RS-232
Communication data rates	RS232 hasta 115.2 kbaud, Arcnet 156 ó 78 kbaud

Therefore, a tradeoff exists between higher resolution images produced by a high frequency side scan sonar and the longer range provided by a low frequency side scan sonar. Unfortunately, the AUV C'Inspector vehicle is not capable of providing quality optical images below 1m in depth because the lack of external illuminators.

It is necessary to remark to refine and debug the software presented in this paper authors have been used some images from the sidescan sonar of C'Inspector taken in several measurement campaigns carried out in the Bay of Santander. But, most of the sonar images have been used to test and refine the algorithms of digital processing implemented in the software proceeds from free image libraries without copyrights from different Internet sites.

SIDESCAN SONAR OPERATION AND ACOUSTIC SCATTERING THEORY

Single sidescan sonar devices transmit two beams, one on each side as it is shown in Fig.2. These beams are narrow along-track to get a high resolution, and wide across-track to cover as much range as possible. The distance from the sonar to a

point on the seabed or target is called the slant range. It should not be confused with the ground range, between this point the point immediately below the sonar. The angle of incidence of the incoming acoustic wave is a key factor in understanding how it will scatter. Most of the energy is reflected in the specular direction. Some will be reflected along other angles (scattering angles, distributed along the main refec-tion angle). Depending on the seafloor or the submerged target, some energy will be lost in the seabed. A very small portion, several orders of magnitude lower, might be reflected back toward the imaging sonar also known as backscatter (Blondel and Murton, 1997). The seabed reverberation area is mainly constituted by background noises (Zhang Xiao-wei, Zheng Xiong-bo and Shen Yang, 2010).

Figure 2: Definitions of basic geometric parameters used in sidescan sonar imagery.

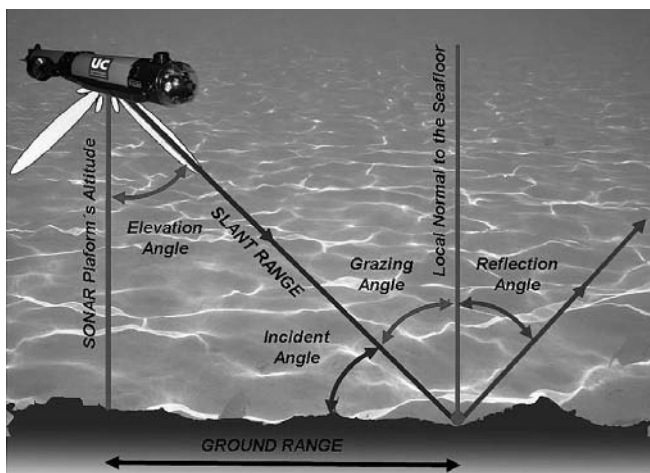
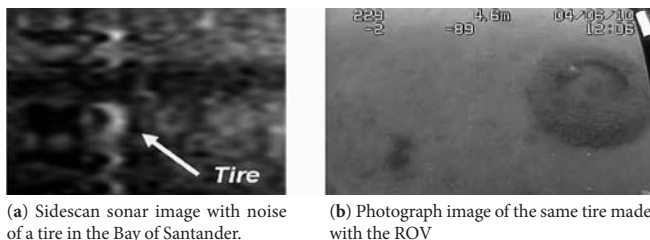


Figure 3: Comparison between a sidescan sonar image and the photograph of a tire in the Bay of Santander.



influences of the noise, it is very important to remove noises of sonar images, as it is shown in Fig. 3 (a) for a grayscale sidescan image. Fig 3 (b) shows a photograph of the same tire on a sandy seafloor.

The brightness of sonar image is related to the ratio between the echoes to the noise, if a comparison with ordinary optical images is made, sonar images are low frequency images and they have less detail, and the background noises of sonar images are high-frequency impulse noises with larger amplitudes relative to the multiple echoes from the target area. Because of the complexity of the underwater environment, the gray level or monochrome color of sonar image from the target area is usually smaller than that of background noise. To improve the visual effects and reduce the

SIDESCAN SONAR ACQUISITION SOFTWARE

In present communication authors have been taking into account the geometrical requirements shown in the prior section with the aim to get the best quality sonar digital images. But, the sidescan sonar acquisition software has been provided by the sonar manufacturer of the device and it has several limitations as shown below. The standard file format use by the applications is the Trittech's proprietary format V4LOG which is not compatible with usual image processing tools that generally use standard types of video and static image formats, to load the file such as: AVI (Audio Video Interleave) or TIFF (Tagged Image File) formats for motion images and static ones. Although, the application add the calibration grid, to the image file, which is a serious limitation when the image is post-processed using digital techniques. This is because the export filter makes a screen capture or rasterization (this actuates like a flat bed scanner) of the image presented in the screen. To avoid this kind of problems now we are working a new in-house control software using the low level commands of the sidescan sonar.

During the first step of the research, our main effort has been focused on maximizing the quality of the original image provided by the commercial control software, so we used a, uncompressed TIFF storage format. We do not use any other most popular and compact graphic formats with uses compression such as JPG (Joint Experts Group) to avoid the introduction of additional errors or compression artifacts prior processing the image.

IMAGE EASY SONAR SOFTWARE

The interpretation of sonar images has traditionally been performed visually by trained interpreters (Blondel, P. 2009); this feature presents the distinct advantage of using the skill of the human interface to limits which are often unattainable by computers. But there are also many disadvantages to a purely visual interpretation. First of all, it is a subjective procedure: two interpreters with different experience, or different skills, are likely to get different interpretations for some features and details, depending on their experience of the sonar used or of the environment studied. Visual interpretation is also time-consuming, and a longer amount of time spent on analysis does not ensure higher objectivity. As a result of this, present work has been focused in the use of existing techniques applied in other areas of image digital processing to the problem of sidescan sonar image processing. As a result of our research, a simple and powerful software tool called *ImageEasySonar*, has been developed. The application has been programmed under the friendly user philosophy and could be operated by users at any level and would be used in educational and training purposes. Although, the software could be running in different hardware platforms such as: PC, Apple Macintosh, UNIX and, Linux machines because it has been write under MATLAB environment. Another advantage consists in source code

can easily modified by the programmer. In addition, through integrated MATLAB tool guide is possible to develop professional applications with elements such as: pull-down menus, pop-up menus, dialog boxes, alerts, etc. without the person responsible for coding should make further efforts to create such objects. All these features, combined with mathematical optimization routines and processing accompa-

nying the MATLAB software package has enabled that the first version of software *ImageEasySonar* presented here has been operative in a relatively short time.

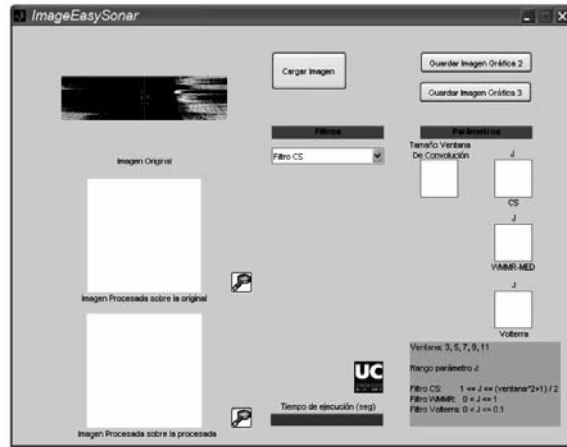


Figure 4: Aspect of the main interface of ImageEasySonar software.

DIGITAL ALGORITHMS AND FILTERS USED IN IMAGE EASY SONAR SOFTWARE

The spatial filtering operation techniques are applied to a digital image and highlight or reduce details in order to simplify visual interpretation or provide further processing. These techniques included in the image enhancement toolbox of MATLAB, improve edge detail images and thus refocus digitally the scene digitally to reduce or eliminate noise patterns in digital video before making a DVB transmission and they are considered as local operations in digital image processing, in the sense of changing the value of each pixel in accordance with the values of the pixels that surround it, transforming it comes to original levels so that they resemble or differ more than those for neighboring pixels (Parker, J.R., 1996). The image enhancement algorithms are applied to remotely sensed images in order to improve the appearance of an image for the human visual analysis or occasionally for further computer analysis (Lee Y. and Fam A., 1987). A possible classification of spatial filters based on its linearity, being able to distinguish between linear and nonlinear filters. Within the first section we can distinguish the spatial filters according to their spatial frequency. CS filters (Comparison and Selection), (Lee Y. and Fam A., 1987), WMMR-MED (Weighted Majority of M values with Minimum Range), (Longbotham, H. and Eberly, D., 1993), Volterra (Taiho Koh and Powers, E., 1985) and EDGE (Canny, J. 1986), (Hardie, R.C, Barner, K.E. 1996) , among others discussed in this paper correspond to the group of non-linear enhancement filters. In addition to the aforementioned filtering tech-

niques, it has been implemented in the program 14 additional filters from the image processing MATLAB toolbox. The user of ImageEasySonar can select among 17 different image process techniques, which are widely detailed in the literature (Canny, J. 1986), (Corinthios, M., 1999), (Longbotham, H. and Eberly, D., 1993), (Mitra, S.K., et al., 1991), (Jensen, John R. 1996), (Zhuo, S. Guo D. and Sim, T., 2010).

The Comparison and Selection (CS) filter is one of the simpler enhancement filters (Lee Y. and Fam A, 1987). As an example, we give a brief explanation about this filters works. The first step is to choose the color space to apply the transformation, if grayscale is chosen the mathematical transformation is apply to one layer. If RGB space is chosen it is necessary to apply separately the technique layer by layer (Red layer, Green layer and Blue layer) as it is shown in figure 5(a) and Fig 5 (b). Values are in the integer range from 0 up to 255. This feature expands by other tree the computation time.

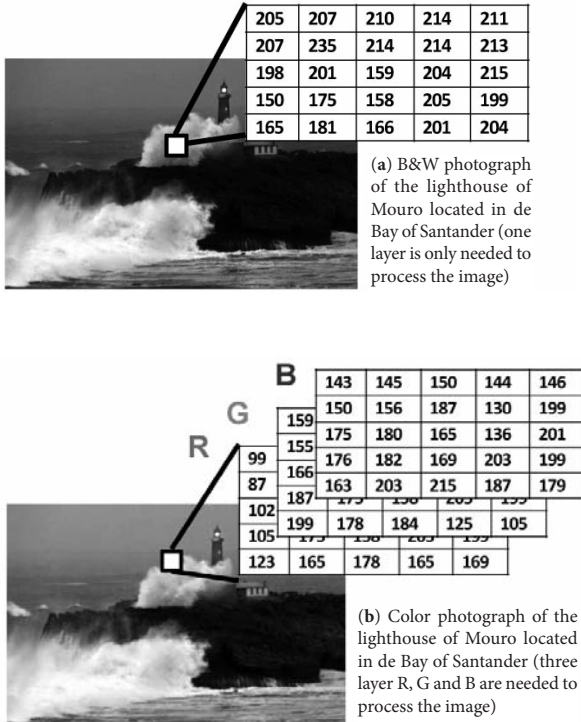


Figure 5: The color space is an important election to apply spatial digital filtering.

The second step consist in properly choose the geometry (linear, square, circular, etc) and size (3x3 pixels, 5x5 pixel, 9x9 pixels or 11x11 pixels), of the movable exploring window or kernel, which size makes more visible the edges as shown in Fig. 6 (c), or soften as it is shown in figure 6 (b). Third step consist to properly fix the J parameter of the algorithm, this parameters fixed the distance (in pixels) from the mean of all numerical values of the kernel renumbered from reordered from the minimum to the maximum according with the following.

The output Y_k of the CS filter with parameter J at time k is defined through the input values X_k-N, \dots, X_k+N , in a window of length $2N+1$, for a positive integer N by:

$$Y_k = \begin{cases} X_k^{(N+1-J)}, & \text{if } \mu_k \geq M_k \\ X_k^{(N+1+J)}, & \text{otherwise} \end{cases} \quad (1)$$

where $X_k^{(i)}$ is the i th smallest sample inside the window, μ_k and M_k are the sample mean and median, respectively, and J is an integer satisfying $1 \leq J \leq N$.

When $J = N$, the CS filter selects either the minimum or the maximum value in the window depending on the data. For the case of $J = 0$, this filter reduces to the well investigated median filter. Since CS filters are nonlinear, the superposition property does not hold in its general form. (Lee Y. and Fam A., 1987). The CS filter ranks the values in the filter window or kernel in numerical order, and calculates the mean value. Parameter J identifies a pair of rank numbers (measured inward from the top and bottom of the rank list) whose corresponding raster values provide the two possible filter output values. If the center cell value is less than the window mean, the lower output value is assigned, and if it is greater than the mean, the higher output value is used. The CS filter sharpens blurred edges while smoothing non-edge areas. The sharpening effect increases with lower values of Parameter J (which move the filter output values farther from the mean).

Some of the results obtained when applying digital filtering techniques just been discussed and depicted in Figure 6. For brevity the mathematical expressions used in each filtering technique are not shown here and we have ignored many of the results obtained for other images. Another interesting feature of the application is that user can apply several different digital filters on the same image and visualize graphically, original image and up to two different transformations before save them into the hard disk. An important parameter the execution time of each digital filtering process, which is dependent on the selected parameters in the application as shown in Figure 6 (b) and Figure 6 (c) obtained as the digital processing from the image shown in Figure 6 (a).

Figure 6 (d) shows the result of applying the algorithm edge (it is noticeable that the calibration grid is visible) to the image, while filtering when combined CS plus edge filtering, result not only removes the grid also shows in detail the edges of the processed image. The edge detection class is designed to detect and highlight boundaries between image areas that have distinctly different brightness. The output raster is a grayscale image of the edges, with the cell brightness proportional to the difference in neighboring cell brightness in the original image. The resulting image can be used as the basis for additional image interpretation and analysis, such as image segmentation.

Filtering techniques based on the Prewitt filters and/or Sobel shown in Figure 6 (f) and Figure 6 (g) require a lower computational cost than the above-mentioned CS, and EDGE WWMED. In our case, the result not only gives different color to the original image but it gives an appearance of high-relief, or false 3D. Results are similar results to those obtained with more expensive hardware. As for future work, authors wish to apply these techniques in real-time time or at least “quasi-real” time in this part of the research the main goal has been the computational speed versus quality processing.

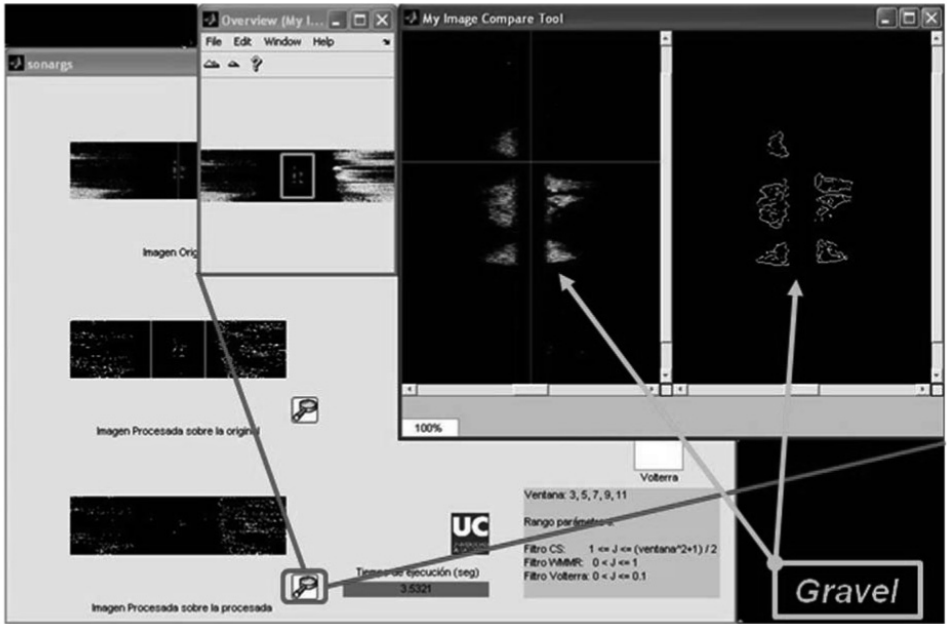
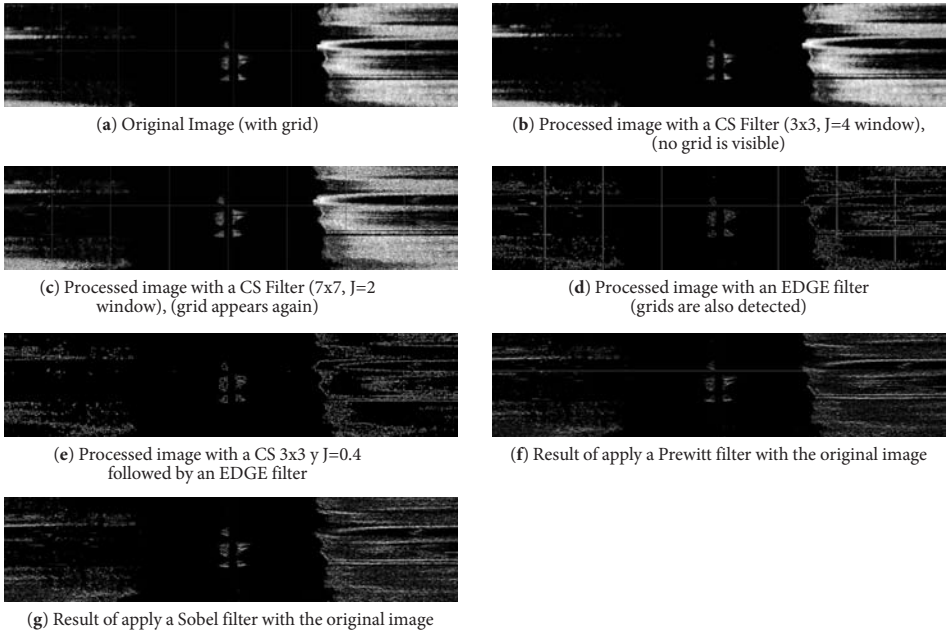


Figure 6: Aspect of the interface and results of digital processing sidescan sonar images using ImageEasySonar software.

The hardware and software characteristics used in this study, are presented here:

- PC compatible with μ P AMD Athlon64 X2 Dual Core @ 3.01 GHz y 2 GB RAM DDR memory.
- Operative System Windows XP Professional v2002 with Service Pack2.
- MATLAB R2009b 7.9.0.

CPU computation time is less than 5% with about 40 processes running at that time and increasing from 50 to 55% during the processing of the filter applied. The memory usage during the process of computing including loading the program itself in any case not exceeds 90 MBytes. Figure 6 (h) shows the zoom tool included in the application that allows seeing the details more clearly, even compared to the initial image. The novelty of the work presented here is the use of these techniques designed for static and DVB video optical captured images to “acoustically” ones from low resolution single sidescan sonar.

CONCLUSIONS

It has developed an application software that allows processing images from a sidescan sonar by using techniques of post-digital signal processing, some of them already used in DVB digital video systems. The intuitive interface to use has been programmed under user-friendly, and WYSIWYG (What you see is what you get) philosophies and could be operated for users at any level for research or educational purposes. Furthermore, the application allows the overlapping of different filtering techniques and improving the image quality on the same box or frame. By applying the Prewitt and Sobel filters is possible to get an approximate high relief profile of the seafloor without the need of acquires expensive hardware like: multibeam side-scan sonar or a slow scan by bathymetric sonar.

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