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Various digital filters, edge detectors, histogram modification, and three-dimensional display experiments are performed on mosaicked Geologic Long-Range Inclined Asdic (GLORIA) acoustic imagery. These experiments have the motivation of establishing Navy capability for viewing the seafloor--especially in deep water and in three dimensions detecting objects on the seafloor, and enhancing existing monochrome GLORIA imagery. It was found that a Gaussian filter with a kernel size of 5 x 5 provided subjective enhancement to the lower intensity areas while some of the other filtering techniques, e.g., difference and gradient destroyed the dynamic range of the image. Kernel sizes were found to be extremely crucial in the experiments with this imagery, especially the median filter which did provide excellent smoothing of the imagery without sacrificing the edges. The digital mosaicking performed on this particular data set of acoustic imagery was determined to introduce multiple artificial artifacts. Image analysis showed the intensities (8 bit, 0-255) to follow the classic Gaussian distribution. Histogram equalization yielded exceptional results for adding contrast (which allows the determination of geological boundaries and detection of various seafloor objects. The vector intensity profile of the intensity offered an interesting future research objective, the correlation of acoustic imagery to bathymetry, the measurement of the depth of large bodies of water.

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Digital filtering/enhancement/analysis of Geologic LOng-Range Inclined Asdic (GLORIA) acoustic imagery

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ABSTRACT

Various digital filters, edge detectors, histogram modification, and three-dimensional display experiments are performed on mosaicked Geologic LOng-Range Inclined Asdic (GLORIA) acoustic imagery. These experiments have the motivation of establishing Navy capability for viewing the seafloor—especially in deep water and in three dimensions, detecting objects on the seafloor, and enhancing existing monochrome GLORIA imagery. It was found that a Gaussian filter with a kernel size of 5 × 5 provided subjective enhancement to the lower intensity areas while some of the other filtering techniques, e.g., difference and gradient destroyed the dynamic range of the image. Kernel sizes were found to be extremely crucial in the experiments with this imagery, especially the median filter which did provide excellent smoothing of the imagery without sacrificing the edges. The digital mosaicking performed on this particular data set of acoustic imagery was determined to introduce multiple artificial artifacts. Image analysis showed the intensities (8 bit, 0-255) to follow the classic Gaussian distribution. Histogram equalization yielded exceptional results for adding contrast (which allows the determination of geological boundaries and detection of various seafloor objects. The vector intensity profile of the intensity offered an interesting future research objective, the correlation of acoustic imagery to bathymetry, the measurement of the depth of large bodies of water.

2. GLORIA ACOUSTIC IMAGING SENSOR

The United States Navy is very interested in improving/modernizing current underwater mapping technologies. Prior to the 1970's there was virtually no automated manner in which the Navy could generate bathymetric contours of the ocean bottom, not to mention acoustic imagery of the ocean bottom. However, in the 1970's multi-beam echo sounding systems began to be developed, namely one called Sea Beam (developed by General Instrument). This new technology provided for the real-time generation of bathymetric contours of the ocean bottom as the survey ship moved along a given track. The next key development was that of side-scan sonar which is basically an echo sounding system that looks sideways at the ocean floor, e.g. GLORIA. This paper will focus on the application of this side-scan sonar technology to the mapping of the ocean bottom. The resultant images from side-scan sonars will be referred to as "acoustic imagery" throughout this paper.

A state-of-the-art side-scan sonar for this type application is being developed by Texas A&M, Naval Oceanographic and Atmospheric Research Laboratory (NOARL) and John Chance. This paper discusses various experiments carried out on mosaicked GLORIA acoustic imagery, which is a good zeroth order model for the upcoming state-of-the-art sensor output.

2.1 United States Geological Survey experiment

Significant work has been done by the United States Geological Survey (USGS) related to the exploitation of GLORIA imagery. Software has been designed, written, and expanded to process digital images from the GLORIA system. The USGS software is separated into two broad categories: preprocessing/analysis and information extraction. The various products being generated show, often for the first time, detailed information that will be used to map the ocean floor. These maps will give the large overview "picture" of the region, similar to regional views of land areas provided by Landsat MSS images, and will help identify areas of interest for further detailed studies for exploration and/or potential hazard areas. The software to process the GLORIA data is part of the USGS Mini Image Processing System (MIPS) and was developed in Flagstaff Arizona.[1]

The GLORIA data discussed in this paper has arisen from a USGS survey in the Gulf of Mexico for the Exclusive Economic Zone (EEZ) program and has been passed through the USGS MIPS preprocessing routines. The GLORIA sensor provided approximately 50 meter pixels, approximate mainly because the along track distance is not equal to the cross track distance per pixel, with the port operating frequency at 6.8 kHz and the starboard operating frequency at 6.2 kHz.[2] Note, GLORIA is somewhat a low frequency side-scan sonar, as compared to TAMU[2] which operates at 12 kHz or 72 kHz, which points to the collection of sub-bottom information. Sub-bottom information has not been decoded or verified from this data at the writing of this paper.

3. APPLICATION OF HISTOGRAMMING TECHNIQUES

Image Analysis is normally thought of as involving the study of feature extraction, segmentation, and classification techniques. In this section three fundamental standard image processing techniques will be applied to the GLORIA imagery which will provide the necessary initial information such that further future image analysis techniques can be applied/developed. This paper will only address these initial steps. First a standard but very powerful histogram will be performed which will provide the first quantitative analysis of this imagery. Next, this histogram will be equalized using a standard histogram equalization technique (note acoustic imagery is monochrome). Finally, a 3-D Mesh Analysis will be performed on the imagery yielding a supplemental perspective of the imagery.

Primarily the Gould DeAnza Image Processor in concert with a Vax 11/780 and the Gould Library of Image Processing Software (LIPS) will be used for the following image processing functions.

3.1 Conventional histogram

Figure 1, Acoustic Imagery Histogram, shows a sample of GLORIA acoustic imagery taken from a USGS survey in the Gulf of Mexico. It is apparent from the image histogram that this type imagery has basically a Gaussian distribution of intensity values. Note these intensity values are 8 bit values, i.e., they vary from 0 to 255 numerically. Exceptions to the standard Gaussian distribution are seen at approximately the 120 and 255 intensity values, which arise from the filling of areas without data and the white strip on the left of the image. Note also in Figure 1 directly below the digits 255, two linear features are easily detected. These linear features will be enhanced in the following figure. Also, the ship's track is visible and shown by the two "wide" diagonal lines on the image. This clutter around the ship's track is caused by the rapid returning nadir or near-nadir values. GLORIA data is recorded immediately as soon as it transmits an acoustical wave, therefore the pixels to both sides of nadir contain invalid information.

3.2 Histogram equalization

Next, this Gaussian distribution histogram was transformed to a uniform (approximate uniform) histogram or histogram equalized, shown in Figure 2. Noting the equalized histogram plot, shown in Figure 2, the intensities are spread out to yield more contrast in the image. Figure 2 notably accents the relief, shown by the lower intensity values, much more so than given by the raw imagery. Also, the linear features mentioned above relating to Figure 1 have been highlighted even more in Figure 2. These linear features are probably artifacts from the digital mosaicking procedures used by USGS. The relief that is barely detectable in Figure 1 is very apparent in Figure 2.

3.3 Wireframe "mesh" vector plot projection

Finally, a wireframe mesh of the GLORIA imagery was generated in order to better interpret its intensity values and their spatial orientation, shown in Figure 3. Figure 3 utilized a 16×16 sampling window.

The mesh procedure used in this figure utilized a hidden line technique to produce a "wireframe" vector plot projection of the intensity surface of the image. The size and orientation of the wireframe mesh can be controlled by adjusting the viewing position coordinates. The size, however, will also vary with the size of the memory region on the output channel, as the mesh is scaled to fit in the output region. This wireframe mesh was by far the most computationally intensive task performed in the initial analysis of the acoustic imagery. Figure 3 also suggest the future production of a 3-D "sun-angle" shaded relief view of this type imagery would likely contribute to the interpretation of acoustic imagery.

Figure 1. Histogram of GLORIA Imagery.

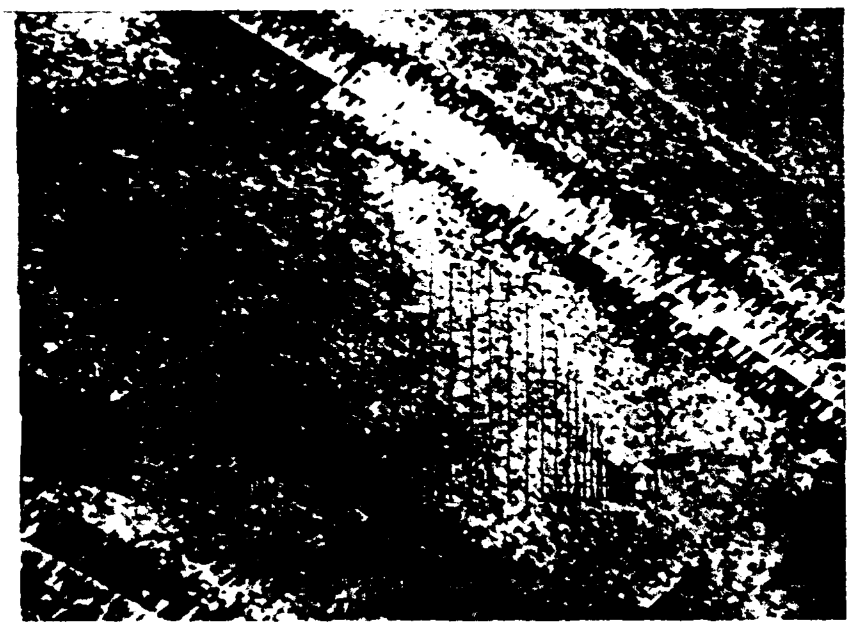

Figure 2. Histogram equalized GLORIA Imagery.

4. APPLICATION OF IMAGE ENHANCEMENT TECHNIQUES

In this section several digital image enhancement techniques are applied to the acoustic imagery shown in Figure 1. It is demonstrated that existing Gaussian, median, and difference techniques can provide significant acoustic image degradation given the improper kernel size selection. This kernel size or filter size, usually square, is crucial to the computational speed of some of these techniques (especially the median filtering routine) as well as the final image quality. These enhancements can make the difference between detecting a feature, say an underwater mine, or not.

4.1 Various sized Gaussian filters

It is very apparent from running various Gaussian filters that the kernel size for the Gaussian filter is of paramount importance. A 29×29 kernel size blurred significantly the image while the 5×5 kernel did provide some enhancement of the darker "relief" areas.

4.2 Various sized median filters

In the process of smoothing imagery, usually the edges or the high frequency components suffer. However, with median filtering these edges can be preserved through the process, given the proper kernel size. The 5×5 kernel size offered the most promise for enhancing this GLORIA imagery without sacrificing the image fidelity.

4.3 Various sized difference filters

One way of defining difference operators for edge detection purposes is to fit a polynomial surface to the gray levels in the neighborhood of the given pixel and take the gradient (magnitude and direction) of this polynomial as an estimate of the image gradient. The x and y partial derivatives of the polynomial can be expressed directly in terms of the gray levels in the neighborhood, so that actual surface fitting is not necessary. For example if we fit a plane by least squares to a 2×2 neighborhood, the magnitude of the gradient of that plane turns out to be the same as the rms magnitude of the Roberts operator, and if we fit a quadric surface to a 3×3 neighborhood, the x and y partial derivatives are proportional to the results of convolving the image with:

$$\begin{matrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{matrix} \quad \text{and} \quad \begin{matrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{matrix}$$

the Prewitt operator.

Another local feature detection technique (enhancement in the sense that it provides "enhanced detection") is the Sobel operator, defined by convolving the image with:

$$\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix} \quad \text{and} \quad \begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$$

This responds to an edge in two positions, but is less sensitive to the noise, because it combines differencing across the edge with averaging along the edge.[3]

Experiments with these difference filters seem to also point to possible bottom texture. This is an exciting area for future pursuit.

4.4 Vector intensity plots

The Gould LIPS package offers a powerful tool, called vector intensity profiling, which allows one to interactively draw (with trackball) a vector where an intensity plot or profile is desired. This technique was used in Figure 4 with varying vector placements, shown in red, as to obtain a graphic intensity profile of varying regions. One use of the technique is to search for edges or rapid transitions in the intensity profile. This technique also seems promising for the exploitation of acoustic imagery.

5. FUTURE NOARL RESEARCH THRUST AREA

The Texas A&M University Topography and Mapping Undersea System (TAMU^2) sensor offers a tremendous breakthrough in the acoustic imagery arena due to the fact that it is one of the first sensors that has combined the collection of high resolution acoustic imagery with quality bathymetry where these two data sets are registered. In the above research performed with GLORIA imagery, the bathymetry was not an integral part of the survey, therefore this link between the imagery and the bathymetry did not exist. Also, the TAMU^2 sensor promises higher resolution than the GLORIA sensor.

NOARL has proposals pending to develop techniques and algorithms necessary to create a new mapping, charting and geodesy acoustic imagery product out of the TAMU^2-like imagery/bathymetry. This information would provide the submarine or ship captain with a confidence check on the existing contour charts as well as three-dimensional perspective views of the region. Hence, because a 3-D perspective can be generated, the ocean bottom can be interpreted more quickly than simply by using a bathymetric contour chart.

NOARL is also focusing attention on the three-dimensional characterization of the sub-bottom with related technology.

6. SUMMARY/CONCLUSIONS

Acoustic Imagery from the GLORIA sensor was investigated in this paper. Various digital image analysis techniques as well as digital image enhancements were applied to a GLORIA acoustic imagery data set. Finally, future NOARL research was outlined with respect to acoustic imagery and the TAMU^2 sensor.

It was shown in Figure 2 that the histogram equalization technique is very effective on acoustic imagery where the original distribution of intensity values are somewhat Gaussian. Also, it was concluded from the mesh analysis that three dimensional perspectives will be very effective given the appropriate bathymetry (as with TAMU^2). Problems with the USGS digital mosaicking were obvious as well as some registration difficulties. Also, two linear (seemingly processing) artifacts were identified in Figure 2 running parallel to the ship's track. The various sized difference filters seem to enhance the bottom texture. These are all areas that NOARL will continue to research within the coming year.

Finally, no correlation between bathymetry and the acoustic imagery intensity profile, shown in Figure 3, can currently be verified due to the severe mismatches in resolution of the acoustic imagery and the existing National Ocean Service bathymetry.

7. ACKNOWLEDGMENTS

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2. Bonnie McGregor, et al., "USGS EEZ Acoustic Imagery Atlas," Ver 1.0, 1986.
3. Michael Ekstrom, *Digital Image Processing Techniques*, Academic Press, 1984.

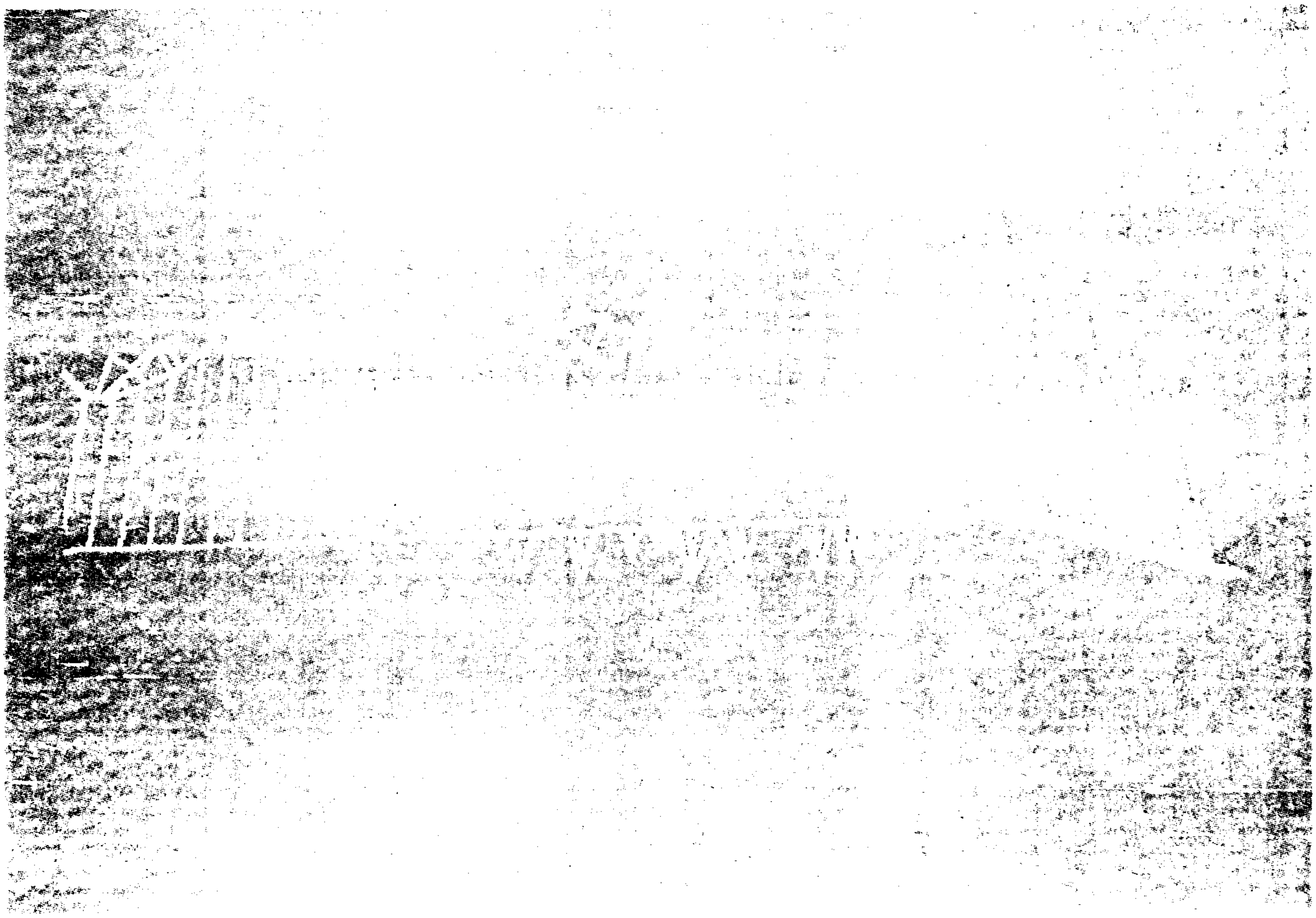

Figure 3. Wireframe mesh.

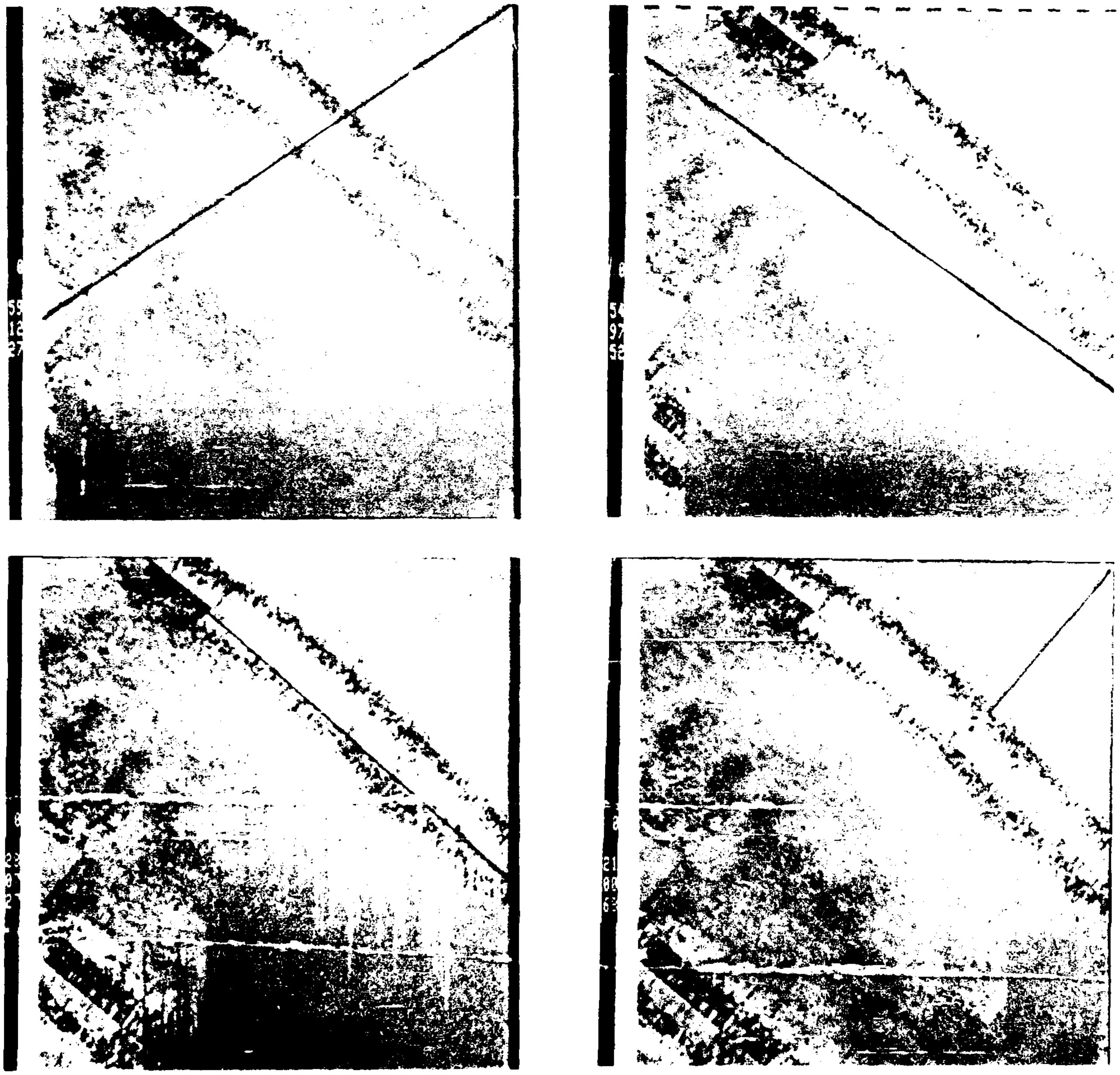

Figure 4. Vector intensity profiles.