AQS-20 Sonar Processing Enhancement for Bathymetry Estimation

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Abstract - **Bathymetry is used to determine optimal tactics during Mine Warfare operations. Previous work demonstrated that bathymetric data could be acquired from the Volume Search Sonar (VSS) mounted on the AQS-20 system. The VSS transmitter produces a pulse at approximately one-second intervals along the track. The returning pulse from the sea-bottom is received by a group of sensors and beamformed in hardware into two fans (one pitched slightly forward and a second pitched slightly aft). A possible way to increase the accuracy of the bathymetry data is to improve the angle of arrival estimates by processing the adjacent across-track and/or along-track beam pairs. This paper employs narrow-beams monopulse techniques in order to investigate improvements to the bathymetric data over conventional processing. A comparative analysis of the experimental results for both the new and the classical technique is presented.**

I. INTRODUCTION

Due to the vast expanse of the littoral ocean regions and their temporal and spatial variability, real-time information assimilated with historical data is needed to adequately characterize the environmental battle space. Environmental data is used to determine the right tactics and minimize the time required to breech an area while maintaining a true sense of mine detection. During Mine Warfare operations historical environmental data has usually proved to be very useful. However, those data could suffer from some limitations such as incomplete coverage, low data density and perishability that could severely degrade the mission effectiveness by less than optimum environmental conditions. Data perishability could become a serious problem in shallow water littoral regions where environmental parameters often have relatively short temporal and spatial scales and require continuous monitoring [1].

The narrow-beam monopulse technique has been employed in order to improve the data spatial resolution and hence the bathymetry estimation. The narrow-beam monopulse technique used by our procedure was introduced by Brogan and de Moustier in [2] as a potentially promising method for bathymetry and acoustic backscatter imagery computation. Monopulse techniques improve the angle of arrival estimates by processing the adjacent across-track and/or along-track beam pairs. The rest of the paper is organized as follows: Section 2 gives the background on the AQS-20 Sonar, Section 3 describes our implementation, Section 4 shows experimental results and finally Section 5 offers a summary and conclusions.

II. AQS-20 SONAR OVERVIEW

The environmental data are extracted from the AQS-20 mine hunting sonar towed from the MH-53 helicopter. The AQS-20 is an airborne, variable depth, mine hunting sonar designed to detect, classify and identify moored and bottom mines using side-scan, forward-looking, and volume search sonar systems (VSS) from deep water to very shallow [3] as illustrated in Fig. 1. The plan is for the sonar pod to be towed in a reconnaissance mode by the Remote Minehunting System (RMS) miles ahead of the battle group, and in an area search mode by the MH-60 helicopters [4]. RMS is an unmanned diesel powered, semi-submersible vehicle designed for use from surface combatants [5]. A more complete description of these systems and their use within mine warfare is given in complementary papers [6], [7].

Fig. 1. AQS – 20 mine hunting sonar

The AQS-20 data includes a position of the AQS-20 tow body derived from GPS and a cable layback model, the depth of the tow body, acoustic velocity of the water, basebanded time series from the 54 beams of the VSS, and attitude (roll, pitch, yaw) of the tow body. For the analysis, the time series data for each beam are converted to slant-range from the bottom and combined with the corresponding position and tow body attitude data to compute the multibeam bathymetry along the test profile. The transmitter produces a pulse at approximately one-second intervals along the track. The returning pulse from the sea-bottom is received by a group of sensors and beamformed in hardware into two fans (one pitched slightly forward and a second pitched slightly aft) of 27 beams each. An illustration of the forward fan of beams (looking directly at the AQS-20) is shown in Fig. 2. Each beam has a width of approximately 9 degrees and is sampled sufficiently to obtain roughly 0.1 meter range resolution. The two sets of beams are recorded along with other attitude, position, and system data using a special high-speed recorder [8].

Preparation of the data for analysis consists of several steps to produce a range estimate from the sea-bottom return on each beam. The VSS multibeam data is decoded / demultiplexed from the original files and converted from the basebanded data back to the original time series. The data are deconvolved with the transmitter source pulse to produce a zero phase response, and the envelope magnitude is computed from the deconvolved data. The initial bottom return of the incident nadir beam (directly downward looking beam) is determined from the envelope time series using a peak amplitude detection technique. This nadir bottom return time is used to construct a window over which to compute the bottom returns for the non-normally incident beams. The bottom return time for each beam is determined by computing the weighted-mean-time within a time window determined from the nadir bottom return. The weighted-mean-time (WMT) is computed using (2.1).

$$WMT = \frac{\sum_{i=1}^{N} A_i^2 t_i}{\sum_{i=1}^{N} A_i^2} \qquad (2.1)$$

In equation (2.1), A is the amplitude of the returned acoustic pulse, t is the time of the acoustic return, and N is the total number of samples in the window of the returning pulse. Limits of the window are defined by computing a beginning and ending travel-time curve from a horizontal bottom for each beam. The travel-time curves are defined by the angle of the beam, the range of the tow body from the bottom for the nadir beam, and by the velocity of the water. The WMT is adjusted for the start time of the transmitted pulse, and used to compute a bottom detection range for the beam. The beam angles are adjusted for the roll, pitch, and heading of the tow body, and the position of the beams on the bottom are corrected for the ray bending due to the velocity structure of the water. The position of the tow body at the time of measurement is used to compute the location of the beam on the bottom. Tow body position is generated from the GPS position of the helicopter, tow body attitude and depth, and a cable layback model for the system. Depth of the tow body is determined from a pressure sensor and is used in the computations to determine the location and water depth of each sounding. Due to the large 9 degree beamwidth, only beams with an angle of less than 45 degrees from the nadir beam are used in the analysis. The results are written to a standardized bathymetry file format for analysis [8].

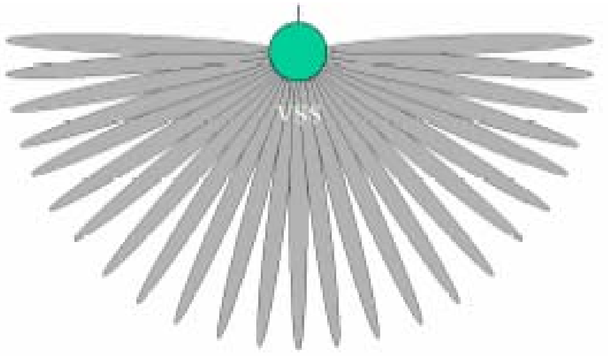

Fig. 2. Forward fan of beams as looking directly at the AQS-20. Two fans of 27 beams each are formed from the receiver units. One fan pitched slightly forward and a second pitched slightly aft.

III. IMPLEMENTATION

It is known from the literature that monopulse techniques improve the angle of arrival estimates by processing the adjacent along-track and/or across-track beam pairs [9]. We used the narrow beam method since our goal is to increase the spatial resolution of the bathymetric data. Given two adjacent beams denoted A and B, the narrow beam (NB) is represented in Fig. 3 (across-track) or Fig. 4 (along-track) and its magnitude is computed as in equation (3.1).

$$NB = |A + B| \, (|A + B| - 0.5\, |A - B|) \qquad (3.1)$$

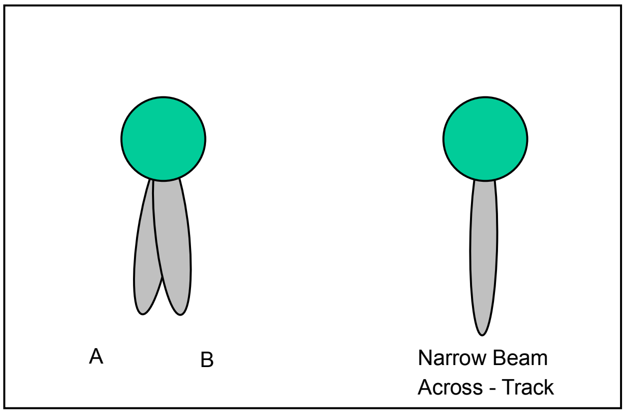

Fig. 3. Narrow Beam Monopulse Technique applied to an across-track pair of beams (front view)

Our algorithm computes a total narrow beam over all beams in two steps. Thus the total narrow beam will provide unique bathymetry information for each ping. First we compute the Narrow Beam Across-Track for the fore beams and aft beams, respectively, as indicated in (3.2) and (3.3).

$$NB_{fore}(i)=|Beam_{fore}(i)+Beam_{fore}(i+1)|(|Beam_{fore}(i)+ +Beam_{fore}(i+1)|-0.5|Beam_{fore}(i)-Beam_{fore}(i+1)|) \quad (3.2)$$

$$NB_{aft}(i)=|Beam_{aft}(i)+Beam_{aft}(i+1)|(|Beam_{aft}(i)+ +Beam_{aft}(i+1)|-0.5|Beam_{aft}(i)-Beam_{aft}(i+1)|) \quad (3.3)$$

where i = 1,…,27.

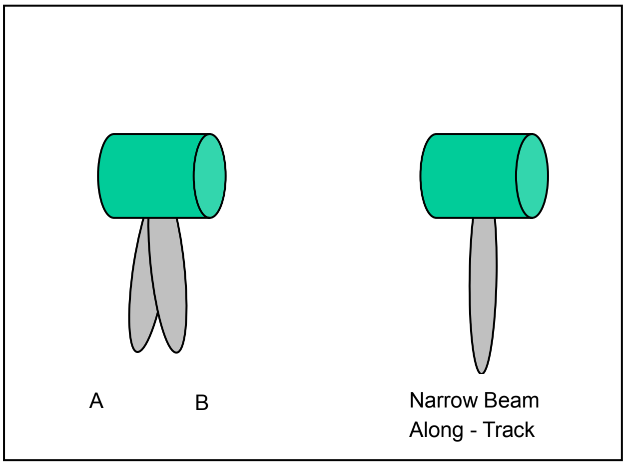

Fig. 4. Narrow Beam Monopulse Technique applied to an along-track pair of beams (side view)

The total narrow beam is computed along track in the final step between the across-track narrow beam fore and aft pairs computed with the results from (3.2) and (3.3):

$$NB_{total}(i) = |NB_{fore}(i) + NB_{aft}(i)| \, (|NB_{fore}(i) + NB_{aft}(i)| - - 0.5 \, |NB_{fore}(i) - NB_{aft}(i)|) \quad (3.4)$$

where i = 1,…,27.

IV. EXPERIMENTAL RESULTS

Empirical studies of our technique vs. the classical approach have been performed on backscatter data collected from the AQS-20 mine hunting sensor during a mission in the Gulf of Mexico. A set of 200 pings has been used as a test case. Due to space limitations, the experimental results will be reported for one ping only.

The envelope time series of the fore beams (beams 7 thru 19) for the classical and the new narrow beam approach are shown in Fig. 5 and 6, respectively.

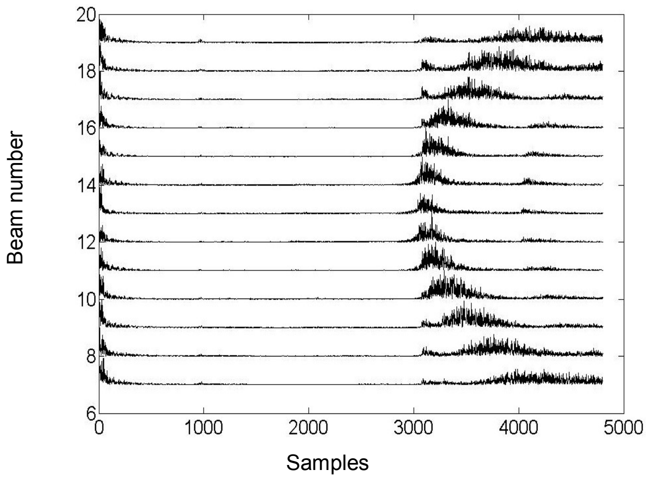

Fig. 5. Return signal time series (normalized) - fore beams 7 thru 19 (Classical Technique)

This algorithm provides strong returns not only for central beams but also for outer beams. One can observe that the return signal is much narrower using this technique compared to the classical one, as shown in the Fig. 7 thru 12. The former return signal has been shifted for a better visualization.

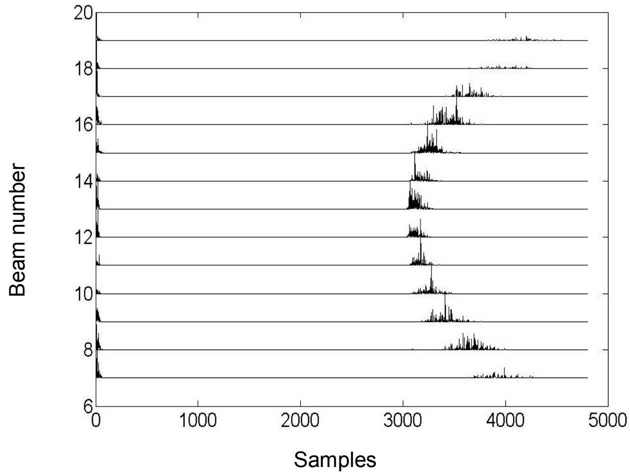

Fig. 6. Return signal time series (normalized) - fore beams 7 thru 19 (Narrow Beam Technique)

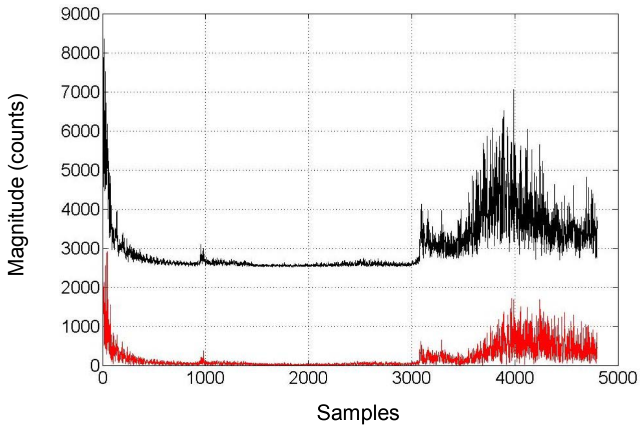

Fig. 7. Return signal time series of beam 7 Narrow Beam (above) vs Classical Technique (below)

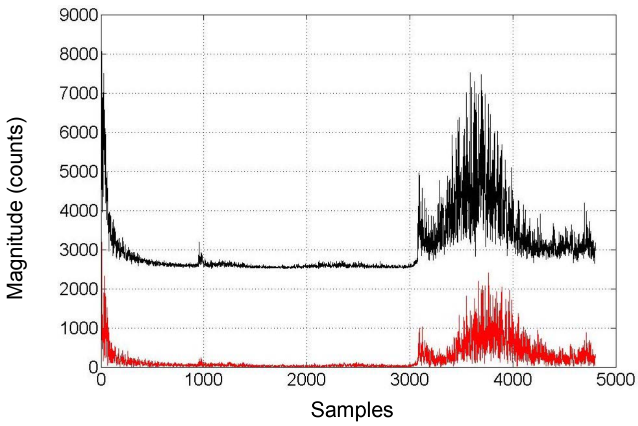

Fig. 8. Return signal time series of beam 8 Narrow Beam (above) vs Classical Technique (below)

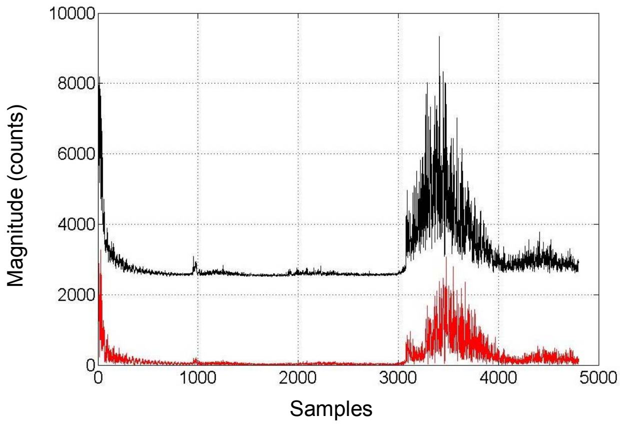

Fig. 9. Return signal time series of beam 9 Narrow Beam (above) vs Classical Technique (below)

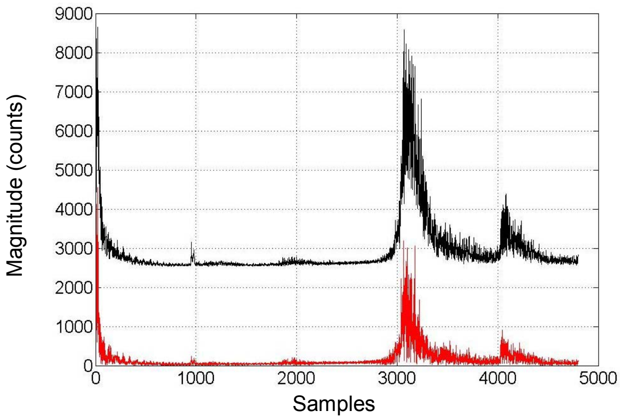

Fig. 10. Return signal time series of beam 13 (nadir) Narrow Beam (above) vs Classical Technique (below)

The return signals have been approximated with Gaussian distribution in order to statistically analyze their compression. The standard deviation of the outer and central beams is much smaller for those obtained with the technique introduced in this paper comparing to the classical one, as illustrated in Figure 11. As expected the standard deviation decays smoother for the former return signal as we approach the nadir.

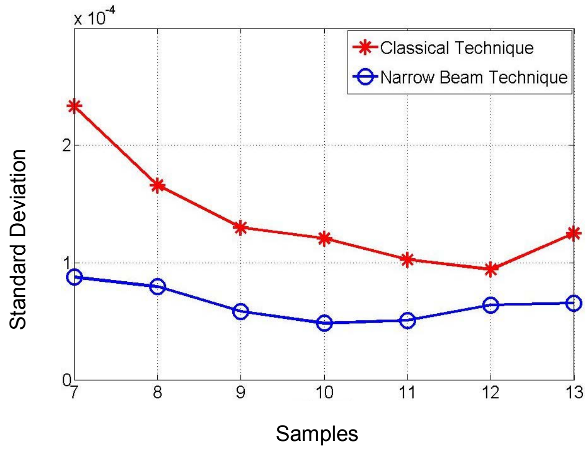

Fig. 11. Standard Deviation of the return signal vs. beam numbers for classical (above) and narrow beam (below) techniques

The standard deviation for the nadir (beam 13) return signal turned out to be slightly larger than that of the neighbored beams (9 thru 12). This situation can be explained due to the approximation of the return signals' time series with Gaussian distributions. The narrow-beams obtained improve the data spatial resolution and hence the bathymetry estimation as resulted from the ground truth cross-check.

IV. SUMMARY AND CONCLUSIONS

The narrow-beam monopulse technique has been used to demonstrate AQS-20 sonar signal processing enhancement. Our procedure is based on the improvement of the angle of arrival estimates by processing the adjacent across-track and along-track beam pairs. Better positioning of the bathymetry points has been achieved using the new technique due to the higher data spatial resolution on the outer (higher grazing angle) beams. The approach presented here is suggested to be a useful tool for improving bathymetry using these type sonars.

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