Results of a Multi-static Synthetic Aperture Sonar Experiment

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***Abstract*-It has long been recognized that point targets in synthetic aperture sonar (or radar) imagery could be used to calculate the beamformer coefficients and the motion compensation functions for the system. One difficulty with this approach arises when no point targets are available. Another problem exists in the initial recognition of true point targets, or rather, the automatic separation of point targets from complex targets in the raw data. A multi-static synthetic aperture sonar (MSSAS) laboratory experiment, instructive to practical field applications, was conducted at Naval Surface Warfare Center, Dahlgren Division, Coastal Systems Station (CSS) Acoustic Test Facility (ATF) in December 2000. The experimental method and three dimensional imagery results are described. Practical field system designs suggested by this experiment are explored. Hyperbolic Frequency Modulation (HFM) transmissions in the 5-17 KHz band were sent to a vertical array that was four wavelengths high at 10 KHz. A horizontal aperture of 40 wavelengths (at 10 KHz) was synthesized. A bullet shaped shell, approximately 32 inches long, was used as the target. A simplified self-calibration technique is harnessed to simultaneously form the basic multi-static beamformer kernel, remove motion effects, and resolve the unknown distances among transmitter, receivers, and target.**

I. INTRODUCTION

A simple technique for establishing a reliable point target in three dimensional multi-static synthetic aperture sonar data is described herein. Liberal rules for acquiring the data permit convenient separation of the point function from the target bearing data and are discussed. An experiment is explained, raw data are shown, the beamformer, its adaptive qualities, and the aperture synthesis strategy are described, and the beamformer output data are exhibited.

II. TECHNIQUE

In order to obtain a point target at the range, azimuth, and height of the complex target, that contains the motion information, a repeater with negligible delay was sought. The intent was to place it near enough to the complex target to approximate the data collection parameters, including those resulting from geometric bi-static delays and vehicle motion. The separated 3 dimensional point target response would then be used to calculate the beamformer coefficients that would, hopefully, be close enough to the analytically correct coefficients to produce an intuitively correct three dimensional image of the target at the beamformer output. Such a repeater could not be found, within the cost constraints of the experiment. Use of an omni-directional transmitter, placed directly above the complex target, and at half the water depth, with the receive array arranged vertically, such that it was bisected at the depth that stood halfway between transmitter and complex target, provided the zero delay repeater point target needed. This method depends on a reasonably symmetric sound velocity profile (SVP) in the depths between transmitter and complex target. It is assumed, since the horizontal range between receiver and the transmitter or complex target was short, that the SVP was stratified. The vertical order of the receive element data is reversed in beamformer kernel production. This technique is an extension of Dr. W. K. Pratt's Image Process[1] to a third dimension.

III. EXPERIMENT DESCRIPTION

Figure 1 illustrates the experiment. The vertical array was placed at 80 locations along a horizontal line. The spacing between horizontal locations was 3 inches, about half a wavelength at ten kilohertz. The vertical array had eight ITC-1089 elements, also spaced at 3 inch intervals. The transmitter and target remained static for the

duration of the experiment. A hyperbolic frequency modulated pulse was transmitted in a band from 5 KHz to 17 KHz for each of the 80 receiver array positions. The 8 channels of received data were captured with simultaneous sample and hold. The transmitter was driven by a digital to analog converter (DAC) that shared a common trigger with the receiver analog to digital converter (ADC). Since the direct path was about five feet, and the path to target and then to receiver was about 15 feet, the nearly ideal point target, in the middle of the complex target, arrived about 2 milliseconds before the complex target echoes at closest point of approach (CPA).

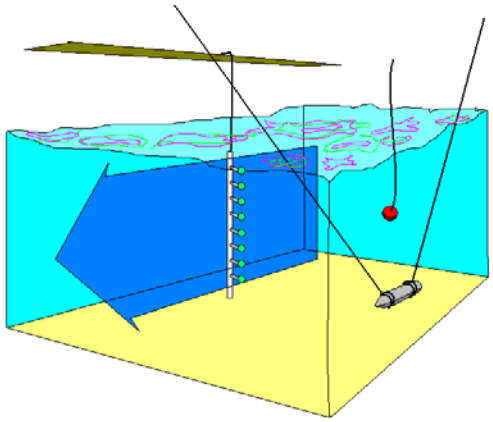


Figure 1. MSSAS experiment set-up.

Actual distances are shown in figure 2. A one meter stick lies between the transmit element and the target for scale.

Figure 2. MSSAS experiment scale and construction.

There was no smooth motion during data acquisition. The vertical receive array was moved from one location to the next, transmission was made, and the eight channels were recorded, then the receive array was moved and so forth.

IV. RAW DATA

Figure 3 illustrates four of the eight channels of received data over the 80 transmissions. The progress from longer range at the start, through CPA, to longer ranges at the end is apparent. Each panel in this series represents the reception history for one receive element in the stave.

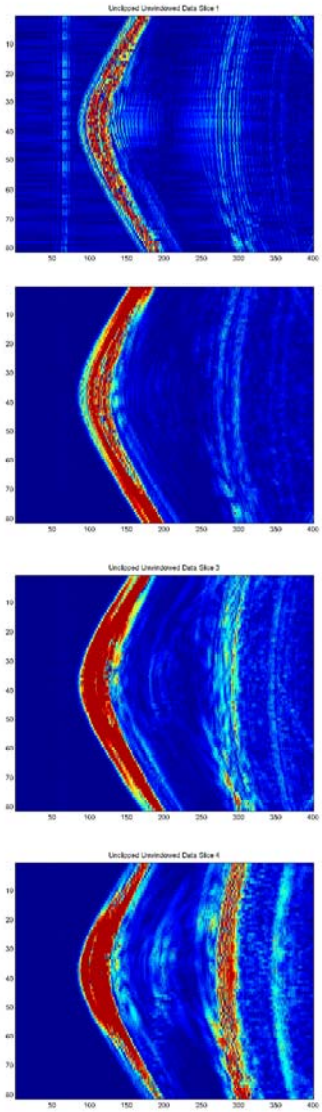


Figure 3. Four of the eight panels of raw data.

The bright arc to the left of center in each panel shown in figure 3 is the direct path arrival and is the point target sought for use in calculating the

beamformer kernel. The arc of less curvature to the right of center in the panels of figure 3, brightest in the fourth panel, is a combination of surface and bottom reflections. The target echo lies between these arcs, near the center of each panel.

V. SEPARATION OF BEAMFORMER KERNEL AND TARGET ECHO

A windowed target echo for one channel appears in figure 4.

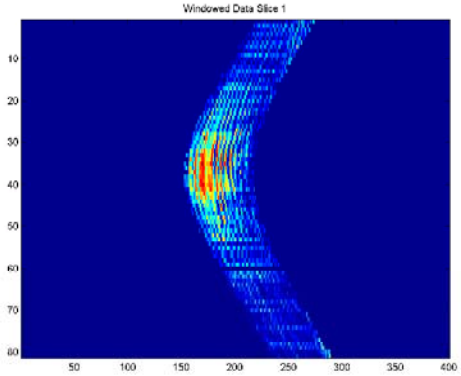


Figure 4. Windowed target echo from channel 1.

Using the same technique, the direct path reception data were windowed for all channels. The resultant three dimensional data field was then transformed, the negative frequency components zeroed in the transformed time dimension, and the conjugate taken for production of the beamformer coefficients. The target echoes were then transformed in three dimensions. The two transform domain functions were then multiplied, point for point, the result was inverse transformed, and the magnitude of the output was divided into eight time-space domain panels for display.

VI. POINT SPREAD FUNCTION

In order to get an idea of the three dimensional resolution of this system, the beamformer was convolved with the windowed direct path data. Figure 5 shows the eight resulting panels. The eight panels correspond to eight different heights or values of z. Each panel is 80 elements along the ordinate by 400 range (actually delay) elements on the abscissa.

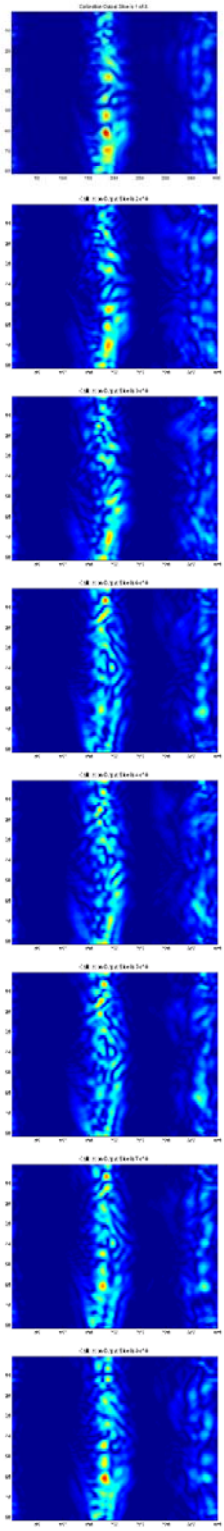
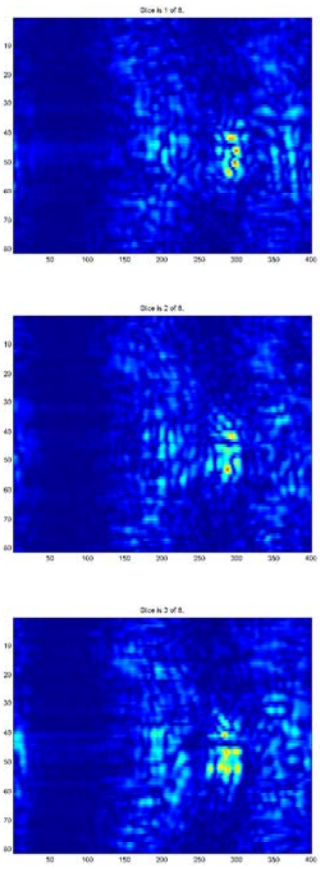


Figure 5. Eight panels of the Point Spread Function.

The point spread function displays a disappointing resolution for the system. In azimuth (that is, along track) and height, the energy is spread liberally, though the delay resolution was better. This range resolution is attributed to the large time bandwidth product of the transmission. The azimuth and height resolution are more closely related to the dimensions of the aperture which is 40 lambda wide by 4 lambda high. Azimuth and height point spread would have been improved by addition of zero padding to the data field to prevent circular convolution effects.

VII. COMPARISON OF BEAMFORMED DATA AND PHYSICAL TARGET

The beamformer output is illustrated in figure 6. Since the stave spacing was 3 inches and the target was 32 inches in length, the image could be expected to measure 10 or 11 resolution cells in the along track direction. The red area in the seventh (brightest) panel is 10 cells along track.



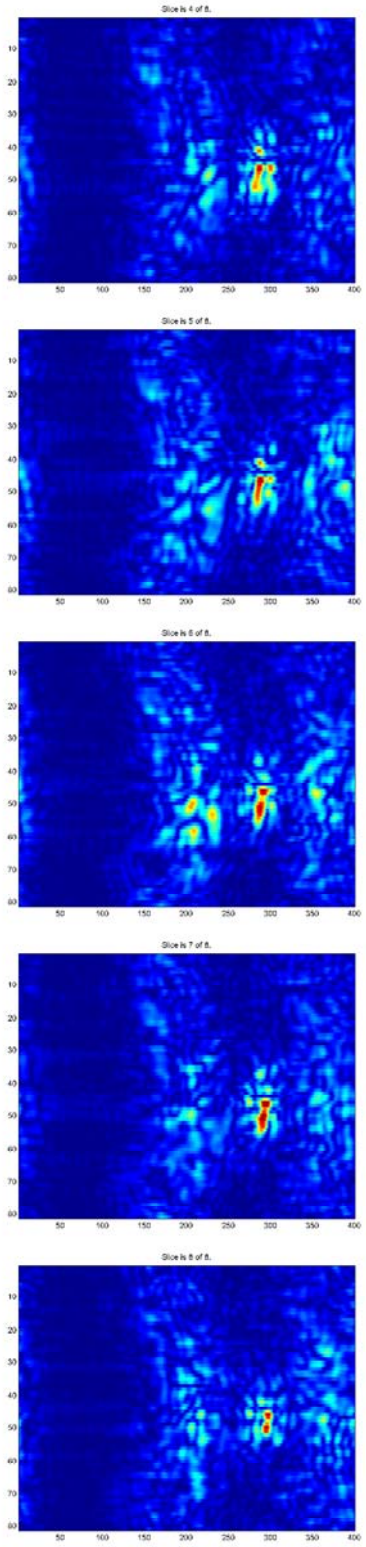


Figure 7. Eight panels of the MSSAS beamformer output.

CONCLUSION

The real aperture (stave) was moved along a straight path and kept at constant depth for the data acquisition. Consequently there was little motion to compensate. The delays due to the geometry were predictable, but the prediction was not undertaken. Rather, the delays were found by means of the point target offered by the direct path reception of the transmissions. The motion can be found in the inexact location of the elements as they were placed according to a marked tether that was placed at 80 locations along a planked walkway, outdoors, in light breezes. These small motion effects are compensated, along with the geometric location delays, by use of the direct path receptions for the beamformer kernel. It is recognized that this technique does not adhere to an exact convolution. It is interesting that, over a small region near the vertical reflection point below the transmitter, the convolution appears to work well. This suggests that the focal volume for this system is larger than the physical target, and encloses it.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Pratt, William K., *Digital Image Processing*, (Wiley-Interscience, New York, 1978)