AUGMENTATION OF DOWN-LOOKING 3D SAS DATA WITH A HIGH FREQUENCY MULTIBEAM SONAR

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INTRODUCTION

The Buried Object Scanning Sonar (BOSS) is a low frequency down-looking synthetic aperture sonar (SAS) that creates volumetric imagery by combining an along-track synthetic aperture with an across-track real aperture.[1] The low frequencies transmitted by the BOSS allow for significant acoustic penetration into sediment, enabling imaging of the sediment volume and detection of buried objects. In sediments presenting a small impedance discontinuity with the water, the precise location of the interface may be difficult to discern, especially in off-nadir directions where no specular backscattering contributions from the interface exist. In this case an accurate estimate of the burial depth of a detection – an important parameter for remediation – can be difficult to ascertain from volumetric imagery.

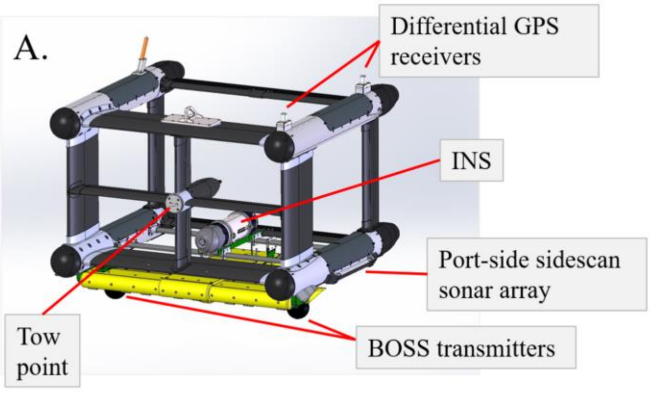
One method for mitigating this issue is to augment the volumetric data with surface detections from a multibeam sonar. Not only does this mitigate the issue of water/sediment interface location ambiguity in the low frequency volumetric BOSS imagery, but it simplifies and enables the automation of near-surface feature extraction from the volumetric imagery.

This paper describes the mechanical integration of a multibeam sonar onto a multi-sensor platform developed at the Applied Physics Laboratory, University of Washington (APL-UW) for detecting and classifying unexploded ordnance (UXO). Subsequently, data-fusion combining the output of the multibeam sonar with data simultaneously captured by a buried object scanning sonar mounted on the same sensor platform will be demonstrated.

MULTIBEAM INTEGRATION ON THE MULTISENSOR TOWBODY

The Multi-Sensor Towbody (MuST) is a sensor platform built around a MacArtney FOCUS 3 Towbody. The platform, developed by APL-UW via funding from the Strategic Environmental Resource and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP), was designed for the detection and classification of proud and buried UXO,[2,3] but has also been used for detailed sub-sediment survey applications and cable tracking. The acoustic UXO detection sensors on the platform include a Edgetech Buried Object Scanning Sonar (eBOSS), a dual-frequency high resolution sidescan sonar also manufactured by EdgeTech and, most recently, a Reson T50 multibeam sonar. Position augmentation sensors, including an IXblue Rovins Nano inertial navigation system (INS) and Teledyne Pathfinder Doppler velocimeter (DVL), are also integrated onboard the system and are used for determining the underwater location of the towbody. A dual GPS antenna is used for positioning when the towbody on the surface.

Figure 1 shows two annotated CAD drawings of the MuST. The main frame, resembling a box-kite, is composed of the FOCUS 3 towbody. The FOCUS 3 has control surfaces for controlling the roll, pitch and heading of the towbody, as well as changing the depth and steering port to starboard. As annotated in the figure, various sensors for UXO detection are mounted onto this towbody.



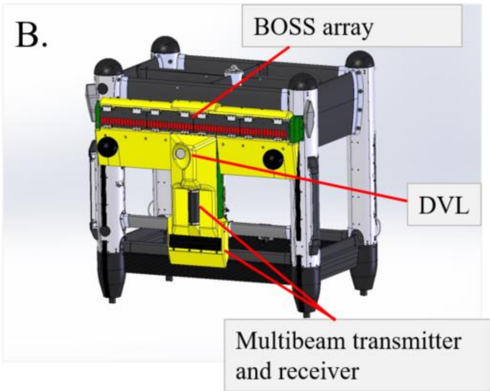


Figure 1: A CAD model of the MuST towbody viewed from the front (A) and from beneath (B). Navigation systems, including an INS, DVL and GPS (for when the system is on the surface) are annotated. The location of the sidescan arrays on the nacelles are indicated, and the eBOSS and multibeam sonars are visible in the figure on the right. For scale reference the eBOSS array is 1.6 meters wide.

The acoustic sensors integrated on the MuST are all mounted on the lower side of the towbody, with the sidescan sonar arrays being mounted on the outside of the lower port and starboard nacelles and the eBOSS, DVL and Multibeam being combined on the underside in a mechanical fairing.

Along with the other sensors, the multibeam has a dedicated gigabit Ethernet channel used to stream data and communicate top-side with the ship. The data streams from the various sensors on the towbody are received by a data hub in the ship main lab where they are simultaneously recorded and redistributed for the purpose of real-time processing and display for towbody control and monitoring. Timing for the multibeam, INS and onboard sensors is performed via a Network Time Protocol (NTP) server, with the Multibeam having an additional 1PPS trigger to lock in the timestamps.

LAKE WASHINGTON DATA FUSION TRIALS

Lake Washington, located near APL-UW, is a large body of freshwater that has been used as a testing and performance verification site for the MuST. The lake, formed from a glacial trough, has an approximate surface area of 89 km^2, a maximum depth of 65 meters,[4] and a large number of natural and man-made targets of interest including many shipwrecks, plane wrecks and man-made debris. Strong currents are not present in the lake, and the average water residence time is approximately 2.3 years.[5] The lake has undergone significant limnological changes over the last ~70 years, primarily as a result of fluctuations from phosphorous loading.[5] Fine particles deposited from the Cedar and Sammamish rivers and local tributaries have formed a silty layer over much of the lakebed.[6] Acoustically, this silty layer has a very similar acoustic impedance to water and, in the operational band of the MuST, appears very nearly acoustically transparent. Though a weak specular scattering contribution is often detectable, very little scattering from the surface or volume is present off nadir. Figure 2 illustrates this, showing along track vertical slices captured at nadir and at +4 meters to starboard.

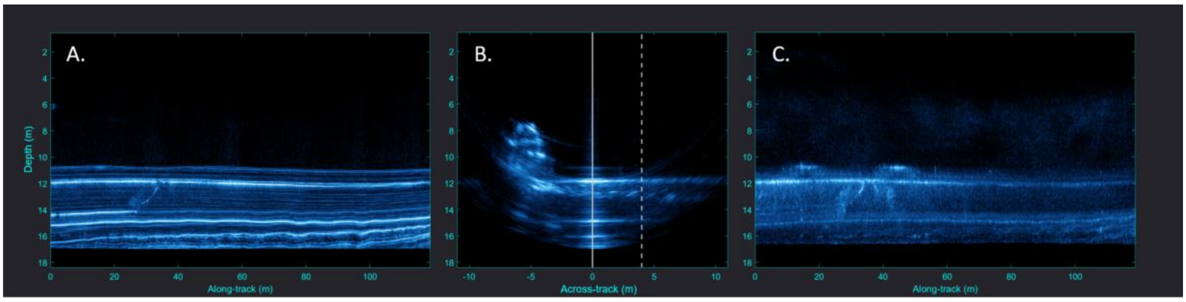


Figure 2. Slices through a SAS volume illustrating nadir and off-nadir specular reflections from sediment layering. Plot A) shows an along-track, vertical slice through the SAS volume directly at nadir. Plot C) shows a parallel slice at +4 meters to starboard. Plot B) is an across-track slice showing the relative locations of the nadir slice (solid vertical line) and offset slice (dashed vertical line). Depth values are relative to the sonar.

Note that in Figure 2.A the specular contribution from the silt layer at ~10.8 meters below the towbody is present but, as shown in both 3.B and 3.C, the interface is almost undetectable off nadir. From 2.B in particular it can be seen that the water/sediment interface is only detectable in the near vicinity of nadir. In contrast, a bright but persistent layer exists at 12 meters below the towbody. As can be observed in Figure 2.B, this layer is visible across almost the entire real-aperture field-of-view of the sonar. A layer with similar persistence is visible at 15 meters below the towbody. The reason for the persistence is unclear, but perhaps may be a result of roughness or the accumulation of debris along the interface boundary.

Water/sediment interface detection is important for several reasons, such as ascertaining the burial depth of off-nadir sub-surface scatterers and segmenting near-surface scatterers from deeply buried scatterers. The latter is particularly important for data-driven mosaic alignment, which is performed during post-processing to enable multi-look imaging and multi-look target strength synthesis.[7] Refraction through sediment layers has, in the Lake Washington environment, been observed to scramble the relative location of subsediment features acquired from different viewpoints, causing failure in feature-based navigation and mosaic alignment algorithms. Accurate knowledge of the location of the interface has the potential to enable stable features to be isolated for mosaic alignment in the absence of accurate sound velocity corrections for sub-sediment imaging. Off nadir, however, the exact location of the interface is difficult to determine, as Fig.'s 2.B and 2.C indicate. A potential solution would be to combine interface detection at nadir with a flat bottom assumption, however this omits the possibility of performing surficial feature isolation in sloped or bathymetrically varied regions, or for separation of surficial and interior features in complex objects such as a wrecks.

In September 2022 the MuST system with the newly integrated T50 multibeam was deployed in Lake Washington to perform simultaneous capture of high frequency multibeam data and low-frequency volumetric synthetic aperture sonar data. The purpose of the test was to determine if data captured by the multibeam can effectively address the difficulty of interface detection and provide the information necessary perform near-surface feature extraction in BOSS data. Figure 3 shows an example of a sediment profile captured by the BOSS and T50 at the same aperture location.

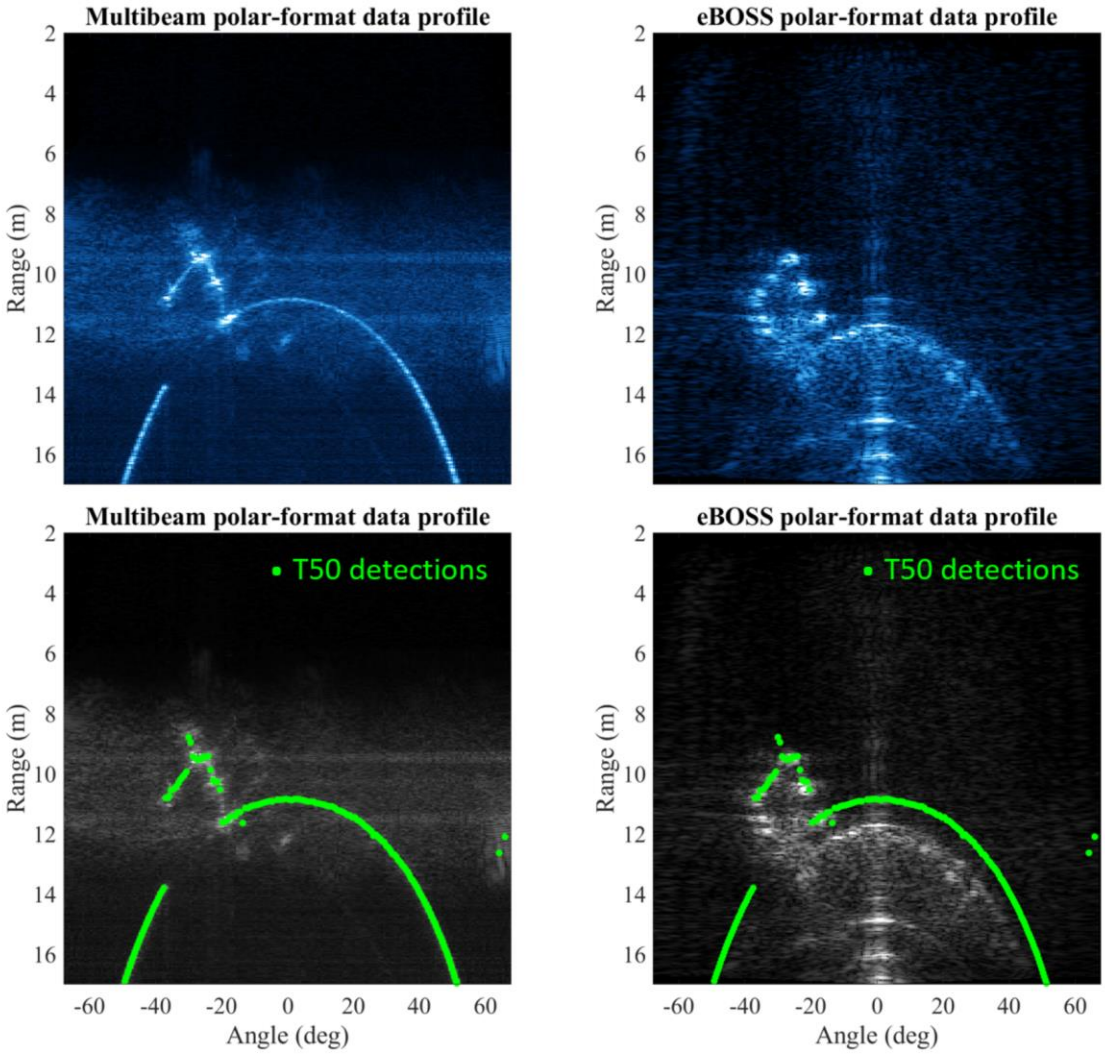


Figure 3. An across-track polar-format data slice captured by the T50 (left) and eBOSS (right) at the same towbody location. The lower row superimposes the T50 detections over the full, beamformed T50 data slice (left) and eBOSS data slice (right). The cross-section of a fishing-boat at approximately 10 meters range, -30 degrees angle is also visible in both images.

In Figure 3, the T50 multibeam sonar shows strong backscattering from the water/sediment interface. The center frequency of the T50 is variable and for this and subsequent images the center frequency was 400 kHz with a pulse bandwidth of 35 kHz. The same interface is weakly visible in the low frequency (5 – 23 kHz) eBOSS imagery, but only near nadir. In contrast, several more deeply buried sediment layers are clearly visible. Note also that only the close-range edge of the fishing boat is visible in the T50 image, whereas corner scattering from the interior is visible on the far side of the ship in the eBOSS imagery. This is likely due to acoustic penetration into the hull of the vessel. The detections plotted in green dots on the bottom row of Figure 3 are those output by the T50's detection software that has been developed by Reson.

Data from the T50 multibeam and low frequency eBOSS volume data were combined in a simple data fusion algorithm that leverages the multibeam detections provided by the multibeam sonar software to carve near-surface features from eBOSS data. Following detection and removal of outliers from the detection data, the algorithm applies a +/-20cm window in range to the low frequency SAS volume data based on the angles and ranges of the detections associated with each slice of SAS volume data. Outlier rejection is performed by applying a 5 x 5 pixel adaptive median filter to the multibeam detections. Points in which the median varies from the original value by greater than 50 centimeters were replaced with the median value. The size of the window and threshold for rejection were empirically determined; optimization of these parameters for different environments and tasks is a potential topic for future study.

This process was applied to a complex scene containing a ~1 meter thick layer of soft sediment and a derelict fishing boat. Figure 4 shows renderings of the original and depth-carved (segmented) SAS volumes, using maximum intensity projections through the range and angular axes of the polar format data slices.

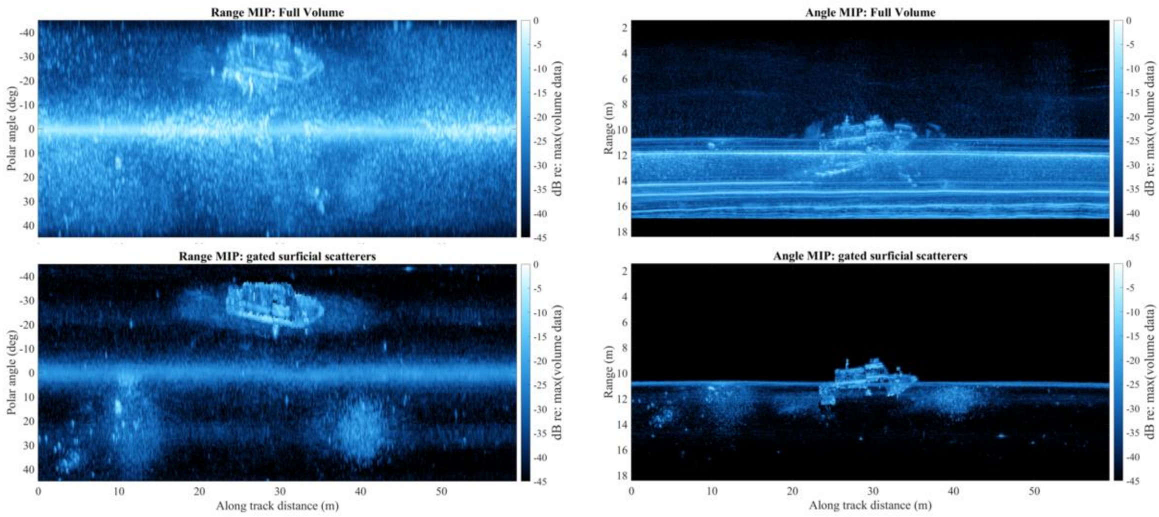


Figure 4. Maximum intensity projections through the full volume (top row) and segmented volume (bottom row). The left column shows projections through the range axis of the polar format data slices, and the right column shows projections through the angle axis. Dynamic range is 45dB relative to the brightest point in the full volume for both images.

Of significance in Figure 4 are the discrete scatterers distributed near the surface throughout the image, two regions of debris located on the starboard side of the scan at along-track locations of ~12 and 40 meters, and surface details of the shipwreck. Of these features, only those corresponding to the shipwreck are readily visible in the original volume rendering. A large pile of debris on the starboard side of the stern of the shipwreck is also visible in the rendering of the full volume, but the pile is absent in the image of surficial features, indicating burial. It is also worth noting that the approach leveraging multibeam detections handled the complex geometry of the shipwreck very well. The only visibly prominent feature of the ship surface missing from the depth carved result is the railing on the bow, which is clearly visible in the full-volume rendering but is missing, for the most part, from the depth-carved rendering. This is possibly due to being filtered out during the automatic outlier rejection process, but may also be due to the multibeam detection data not detecting the railing.

Figure 5 shows a Cartesian-coordinate rendering of the combined T50 multibeam and eBOSS data volumes. The low frequency eBOSS data is colorized with a red hue, and near-surface features in close proximity to surface features captured by the multibeam have been gated out of the eBOSS data. Volume scattering captured by the T50 is colorized with a gray hue.

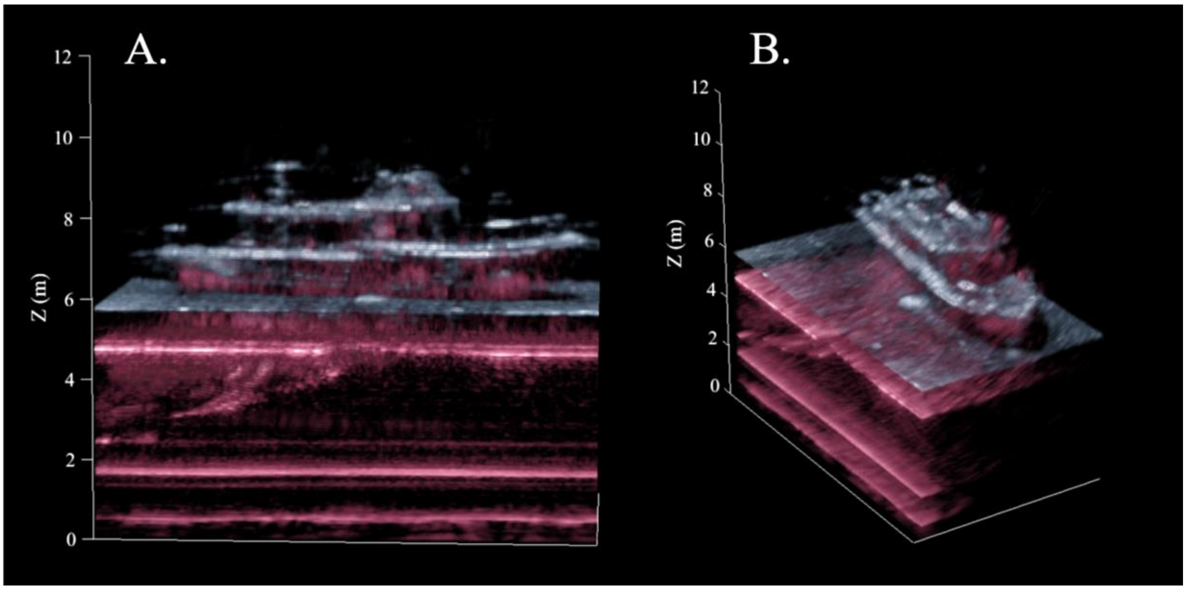


Figure 5. Two views of volume data combining multibeam data from the T50 (gray) and eBOSS (red). The volume data has been converted to Cartesian coordinates. Heights along the Z-axis are relative to the bottom of the volume snippet.

In contrast to Figure 4, Figure 5 contains backscattering information from both the multibeam and eBOSS. High resolution surface features of the shipwreck are contributed by the multibeam, and deeper layer interfaces and a significant volume scatterer at Z = 4 are contributed by the eBOSS.

CONCLUSIONS AND FUTURE WORK

Initial lake trials using the Multi-sensor Towbody indicate that data captured by a high frequency multibeam system can be complementary to low frequency volumetric synthetic aperture sonar data by providing information about the location of interfaces exposed to the water column. The demonstrated sensor fusion process in which surficial features are extracted from low-frequency SAS volume data using multibeam detections is most applicable in environments where the upper layer of sediment presents a small acoustic impedance discontinuity with the water and in scenarios involving complex structures like the shipwreck shown in the examples. In both of these cases, the correct surfaces around which surficial structures are to be extracted can to be ambiguous in low frequency volume data, and the multibeam sonar is able to reduce or remove the ambiguities. Applications include automatic detection of near-surface scatterers in low frequency SAS volume data captured in soft sediments, segmentation of exterior and interior features in complex structures, and feature extraction for data-driven navigation. Future work will involve improving outlier rejection for multibeam data pre-processing, or leveraging the full backscattering data captured by the multibeam to perform gating of surficial features instead of using the discrete detections provided by the T50 software.

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