SEDIMENT VOLUME SEARCH SONAR:

AUTOMATED DETECTION AND CLASSIFICATION ALGORITHMS

*David P. Williams, Applied Research Laboratory – Penn State, State College, PA, USA*

*Daniel C. Brown, Applied Research Laboratory – Penn State, State College, PA, USA*

An unfortunate legacy of former military activities is the contamination of aquatic environments with unexploded ordnance (UXO). In shallow water, proud and buried munitions pose a particular threat to both humans and the environment, so remediation is necessary. To address this pressing issue, several low-frequency sonar systems -- importantly, on mobile platforms -- have recently been developed. These downward-looking synthetic aperture sonar (SAS) systems, designed to achieve sediment penetration, provide high-resolution three-dimensional (3-d) volumetric imagery below the seafloor, making large-scale buried object detection newly feasible. With the introduction of this new sensor modality, there is now a need for automated detection and classification algorithms that can efficiently process enormous 3-d images to rapidly flag suspicious objects for closer inspection during remediation efforts. Relying on humans to visually assess these new data products is both inherently challenging and inefficient.

In this work, a fast algorithm for the automated detection of buried and proud objects in 3-d volumetric SAS imagery is presented. The method establishes the positions of underwater targets by finding localized volumes of strong acoustic returns on or within the sediment. The algorithm relies on an important data-normalization step that is grounded in principled physics-based arguments, and it greatly reduces the amount of data that must be passed to a follow-on classification stage.

For the classification stage, 3-d convolutional neural networks (CNNs) for volumetric SAS imagery are developed (the third dimension represents depth into the sediment). A CNN-based classification approach is particularly apropos for this data modality because hand-crafting features is challenging, and CNNs effectively obviate this process. Despite the enormous size of the 3-d data involved, the use of efficient, tiny networks containing relatively few parameters makes training feasible even with modest computational power and limited computer memory. The method is general in the sense that it can be employed for wide classes of objects of interest, but here it is presented in the context of underwater UXO. The proposed CNNs fill a critical capability gap that makes the use of this new class of sensors feasible for real-world UXO remediation operations.

The promise of the detection and classification approach is demonstrated for both buried and proud man-made objects present in real, measured SAS data cubes collected at aquatic sites by an experimental volumetric sonar system, called the Sediment Volume Search Sonar (SVSS). The classification performance of each 3-d CNN exhibits marked improvement over the prescreening detection algorithm alone, and the utility of an ensemble approach is also quantified. An analysis of the effective functionality of the learned networks is provided, with this also accompanied by figures showing example trained filters as well as intermediate representations of a data volume containing UXO. The predictions of the 3-d CNN classifiers can provide valuable guidance for the efficient allocation of resources during real-world UXO remediation operations.