Multi-Aspect Feature Extraction and Classification of Buried Underwater Objects

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Objectives:

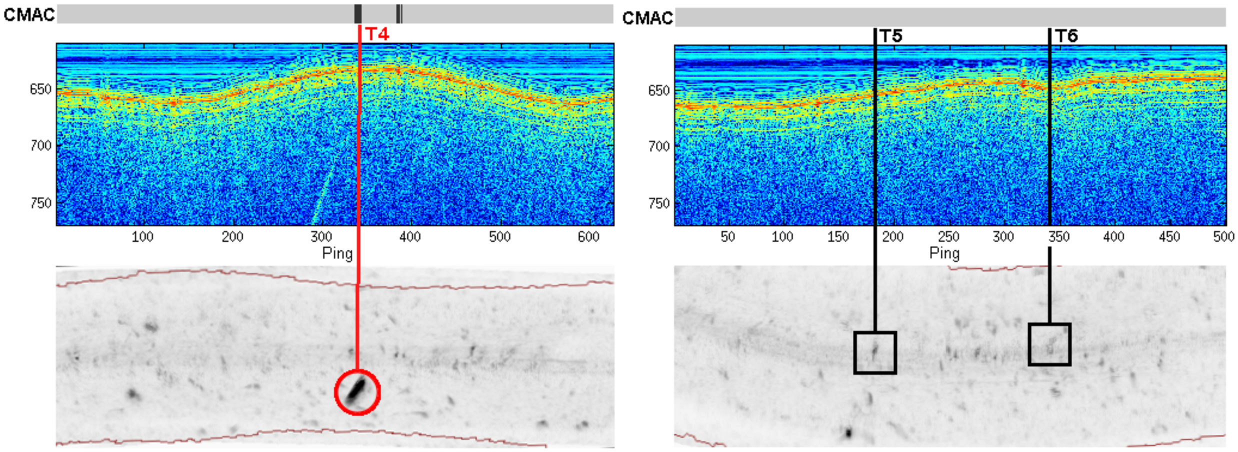
The classification of buried underwater objects is challenging owing to several issues that include: changes in operating and environmental conditions when collecting sonar data, variability of target signatures and features with respect to the aspect angle and range of the sonar, presence of competing natural and/or man-made clutter, bottom reverberation effects, and lack of any *a priori* knowledge about the shape and geometry of abundant non-mine-like objects that can be encountered on the seafloor. Many approaches have been explored to devise a viable solution to the problem or to improve on the previous solutions. These approaches may be broken down into the following three areas: sensor development and data acquisition, feature extraction, and detection and classification. A feasible and efficient solution should include the implementation and seamless integration of these three procedures.

To collect data for this study, the wing buried object scanning sonar (BOSS) system was used to observe a number of target fields that contain a variety of mine-like and non-mine-like objects. This autonomous system, which was designed at the Ocean Engineering Department of Florida Atlantic University (FAU), uses a linear FM pulse over the band of 3-19 kHz to "ping" the seafloor. Sonar backscatter is collected using 40 hydrophone elements mounted on two separate 1 m long wings. Once data on the various mine-like and non-mine-like objects is collected, features are extracted from multiple aspects or sonar pings in order to provide consistent information that exists among consecutive aspects (or sonar pings) regarding the identity of objects. For many orientations, a mine-like object may possess nearly identical backscattering characteristics to those of many types of non-mine-like objects. Hence, incorporating multiple aspects/pings into the feature extraction and classification procedures allows more information to accumulate about the identity of an unknown object, leading to substantial improvements in classification performance, better resolution and sensing of the 3D properties of the object, and better consideration of the changing environment.

The feature extraction method used in this research, referred to as frequency subband coherence analysis, exploits coherence in two sonar returns off an object, where each sonar return is characterized by its specific frequency subbands, which contain valuable discriminatory information to correctly determine the type of object encountered. A subset of subband features that demonstrate the greatest ability to discriminate between mine-like and non-mine-like objects are used to form a feature vector that represents the first ping in the pair. This method offers a more rigorous way of performing acoustic color processing, where ping-to-ping coherence between sonar returns is exploited in extracting acoustic color features. Classifiers can then be trained using these features to discriminate between mine-like and non-mine-like objects.

Several multi-aspect classifiers have been developed and tested in an effort to provide the highest possible correct classification rates. The recently developed collaborative multi-aspect classifier (CMAC) system [1]-[3] has proven to be the best performing classifier of those developed. This system utilizes a group of collaborating decision making agents capable of producing a high-confidence final decision based on features obtained over multiple aspects. Each decision-making agent in the system utilizes a probabilistic neural network to make a local decision regarding the class of a single feature. These local decisions are then evaluated by every other agent in order to produce probability terms necessary to calculate the final decision, which is based on minimizing the overall expected cost of misclassification for each agent.

This research also focuses on the development of new methods for performing blind synthetic aperture sonar (SAS) processing using coherence analysis framework. This SAS-like processing method alleviates many of the major drawbacks of conventional SAS processing, since it does not require elaborate platform motion estimation and compensation techniques. Moreover, unlike the conventional SAS processing that generates images that are typically only useful for object detection and localization, the new coherence-based method produces images that covey information useful for underwater object classification, in addition to detection and localization information.



(b) Run 1 containing mine-like object T4

(a) Run 2 containing non-mine-like objects T5 and T6

Figure 1: Detection and classification results obtained by applying the CMAC system to coherence-based frequency subband features extracted from two different runs through the target field.

Current Results:

Figures 1 (a) and (b) show the results of applying the CMAC classifier to coherence-based frequency subband features [4] extracted from pings in two different runs through the Davis Point target field. The top of each figure shows the detection/classification strip for the associated run. The portions of a strip that are black indicate the where the CMAC system has classified pings as mine-like. Each figure also displays the matched filtered image of channel 1 (out of 40) as well as the SAS image for the associated run. As can be seen from Figure 1(a), mine-like object T4 has been correctly classified for all its pings, while Figure 1(b) shows that non-mine-like objects T5 and T6 were also correctly classified, since there are no portions of classification strip that are black in this run. Applying the CMAC system to the coherence-based frequency subband features yields an average correct classification rate of 94% on this particular data set.

Figure 2 shows images generated using conventional delay-and-sum SAS processing (bottom) and the new coherence-based SAS-like processing (top) for a single run through the target field. As can be seen, the conventionally generated SAS image displays information useful for object detection as well as along track and across track localization. The coherence-based SAS-like image displays information useful for object classification in addition to along track (ping) localization, since it displays information using a ping-frequency plane. In these SAS-like images, higher pixel intensities are seen typically in the mid-frequency range of approximately 9-12 kHz for every mine-like object, whereas non-mine-like objects often exhibit more erratic frequency behavior, with higher pixel intensities in a very broad spectrum extending either from the low-frequency range through the mid-frequency range, or from the mid-frequency range through the high-frequency range.

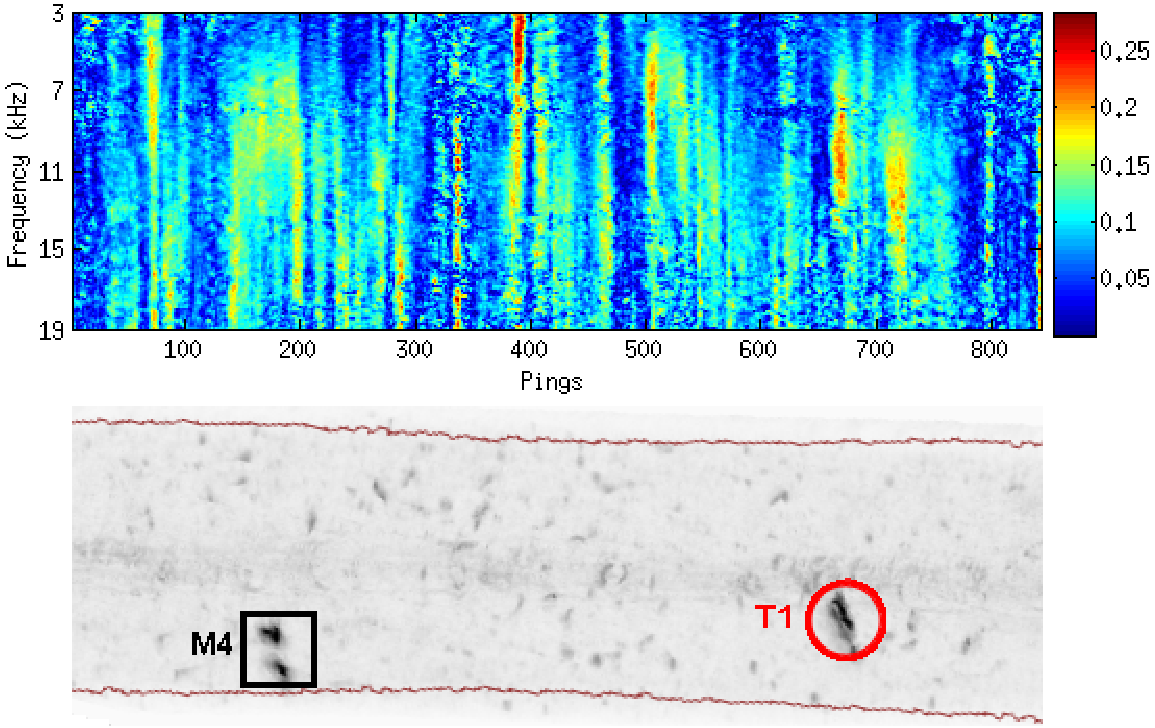


Figure 2: Comparison of conventional SAS (bottom) and coherence-based SAS-like (top) images generated for a single run through the target field.

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Recent Publications:

[1] J. Cartmill, N. Wachowski, and M. R. Azimi-Sadjadi, “Buried underwater object classification using a collaborative multi-aspect classifier,” *Proc. of the Inter. Joint Conf. on Neural Networks (IJCNN’07),* pp. 1807-1812, August 2007.

[2] N. Wachowski, J. Cartmill, and M. R. Azimi-Sadjadi, “Underwater target classification using the wing BOSS and multi-channel decision fusion,” *Proc. of SPIE Defense and Security 2007,* Vol. 6553, April 2007.

[3] J. Cartmill, N. Wachowski, and M. R. Azimi-Sadjadi, “Buried Underwater Object Classification Using a Collaborative Multi-Aspect Classifier”, To appear *IEEE Journal of Oceanic Engr*.

[4] N. Wachowski, and M. R. Azimi-Sadjadi, “Buried Underwater Object Classification using Frequency Subband Coherence Analysis”, To appear *Proc. of MTS/IEEE Oceans 2008.*