Classification of Buried Underwater Objects using Coherence-based Synthetic Aperture Sonar Processing Methods

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Introduction and Problem Statement:

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 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. Synthetic aperture sonar (SAS) processing is a method that can be used to generate high-resolution images of the seafloor from which targets can be detected, localized, and possibly classified. Compared to conventional side scan sonar, SAS offers much better azimuth resolution by coherently combining the sonar data from successive pings. The increased resolution, however, comes at the cost of increased processing and susceptibility to various sources of errors that impair the coherency that is central to SAS such as medium instability and time variations of the acoustic propagation paths. Coherency is also severely impaired by deviations from a perfectly linear track caused by motion of the sonar platform, hence giving rise to the need for accurate motion compensation. Motion estimation and subsequent compensation can be achieved by either employing rather expensive but accurate inertial navigation systems on the sonar vehicle to monitor the platform path or by using rather inaccurate autofocusing methods that originate from synthetic aperture radar (SAR). Therefore, there is a need for new SAS processing methods that avoid the shortcomings of traditional approaches, are robust to environmental variations, and can generate high resolution and accurate beamforming to prevent range and azimuth ambiguities. This research focuses on the development of SAS processing methods that use a coherence analysis framework to extract features from sonar data that can be used to generate images of the seafloor.

Approach:

In the proposed coherence-based SAS-like processing, coherence analysis is carried out in the frequency domain between two subarrays (sonar array partitioned into two subarrays) over a sequence of sonar pings and the first canonical correlation is used as a pixel in the SAS-processed image. In this case, averaging in the canonical correlation analysis (CCA) [1] takes place over a sequence of pings similar to the conventional SAS. However, comparing to the conventional SAS processing methods, our proposed approach is computationally less laborious.
and does not require motion estimation and compensation, which are critical to the success of any SAS processing and image generation system. More importantly, in contrast to SAS images that fail to carry acoustic color information, the generated images can be considered as SAS-acoustic color image. That is, the SAS-like images generated using our approach carry not only high resolution target information for detection and localization but also those critical coherent acoustic color features to allow better classification and possible identification. This is due to the use of the first canonical correlation as a feature to calculate the value of a pixel in the ping-frequency plane of an image. This research has shown that applying the proposed framework to sonar data that captures an object results in larger dominant canonical correlations than when the signatures of the object are absent from the sonar returns.

Current Results:

Figures 1(a) and (b) show the results of applying the coherence-based SAS-like processing to simulated near-field sonar data. For these simulations a ping rate of 25 pings/sec was used and averaging in the CCA process took place over a window of 71 pings. In each of these figures the dominant canonical correlation $k_1$ is plotted against frequency for four different cases, including three cases where a simulated target is present with different signal to clutter ratios (SCR), and the case where no target is present. Figure 1(a) shows the results when five sensors per subarray are used, while Figure 1(b) shows the results for ten sensors per subarray. As can be seen, when a target is present the dominant canonical correlation is larger for all frequencies, with higher SCR scenarios yielding larger values of $k_1$. Larger values of $k_1$ are also witnessed when more sensors are used; a direct result of increased data poverty owing to the use of more channels in the CCA process. Overall, these simulation results demonstrate the utility of using canonical correlations for detecting targets in sonar data.

Figure 1: Results showing the value of the dominant canonical correlation extracted from simulated sonar data using the proposed SAS-like processing method for different SCR and (a) five sensors per subarray (b) ten sensors per subarray.
The results of applying the proposed coherence-based SAS-like processing to real sonar data are shown in various runs in Figure 2. To collect data for this study, the wing buried object scanning sonar (BOSS) system was mounted on the Bluefin 12 unmanned underwater vehicle and used to observe a target field that contains a variety of mine-like and non-mine-like objects. This sonar 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. To generate a pixel for each ping and frequency, the canonical correlations are estimated based on a window of $N = 71$ pings.

Figure 2 shows four separate runs where the images generated using conventional delay-and-sum SAS processing are at the bottom and the new coherence-based SAS-like images are at the top for each run. As can be seen, the conventionally generated SAS images display information useful for object detection as well as along track and across track localization. The coherence-based SAS-like images display information useful for object classification in addition to along track (ping) localization, since they display information using a ping-frequency plane. These SAS-like images show that if an object is present, the canonical correlations become large compared to areas where there are no objects. This phenomenon appears prominently in the frequency band of 7-19 kHz for mine-like objects T1, T4, and T10 (circled in red). The signatures of non-mine-like objects (outlined in black squares) are weaker as can be seen by the fact that T5 and T6 are not very prominent, and M4 has large $k_1$ values only in the frequency band of 3-8 kHz. Overall, these results demonstrate the ability of the new SAS-like processing method to produce images useful for object detection, classification, and localization without the use of elaborate motion estimation and compensation techniques. Additionally, from the acoustic color pattern one may be able to determine the target types as well.

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**Recent Publications:**


Figure 2: Comparison of conventional SAS (bottom) and coherence-based SAS-like (top) images generated using data from four separate runs through the target field.
