Multi-Detect Algorithm for Multibeam Sonar Data

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***Abstract*—When conducting hydrographic surveys the surveyor has to choose between storing just the bottom detections or the entire water column data. The former may result in vital information being lost, while the latter often requires very large storage capability. This paper presents the Multi-Detect Algorithm (MDA), a method for real-time detection of objects in the water column as well as the seafloor beneath. This method is designed to work in conjunction with existing bottom detection algorithms, as a predetection procedure preceding the normal bottom detection. Results from three different scenarios are used to demonstrate that MDA is able to extract more information from the water column than a typical bottom detection algorithm (BDA). Also presented is data from complex underwater objects and a challenging multipath environment. MDA is shown to offer a viable alternative to storage and postprocessing of water column data, and give more details on complex targets and flexibility in challenging environments.**

Keywords*—hydrography; bottom detection; objects; water column; multipath.

I. Introduction

As the interest for detection of objects located in the water column increases [1, 2] collection and storage of multibeam water column data becomes necessary. As a result, the amount of data recorded during a survey becomes increasingly large. Furthermore, extraction of objects in water column data requires time-consuming postprocessing.

Current bottom detection algorithms (BDA) locate the seafloor using well-known principles of magnitude center of gravity and split-array phase difference [3]. When an object is present in the water column, depending on its size relative to the sonar beam footprint, the bottom detection algorithm will detect either the object or the seafloor.

Multipath environments, such as a harbor, pose another challenge for current BDAs. Here, the presence of corners, e.g. constituted by the seafloor and a quay wall, causes multiple acoustic paths, illustrated in Figure 1. The acoustic signal will travel from the transmitter to the wall (a), from the wall to the seafloor (b) and back to the receiver (c). Thus, at certain angles a secondary echo will be received at a distance corresponding to (a+b+c)/2.

The reflections caused by multipath propagation can be predicted by analyzing the geometry of the seafloor and quay wall. It is, however, not enough to consider the specular reflection. The reflection caused by a rough surface is typically a mix between diffuse and specular reflection [4]. Thus, the

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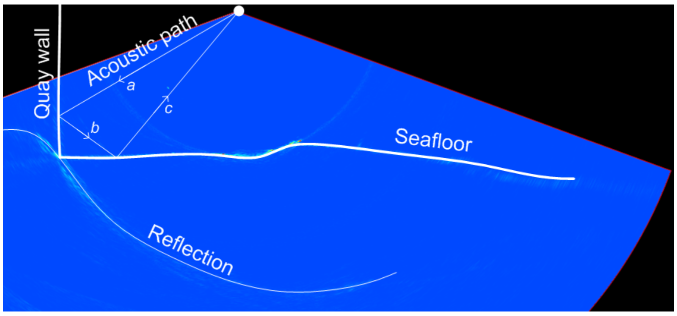

Figure 1: Illustration of the challenging environment posed by the presence of a quay wall.

reflections at a given range and angle may be the result of sound travelling along multiple paths. In these situations, echoes that arrive later in time may have higher intensity than the one originating directly from the target [5].

This paper presents the Multi-Detect Algorithm (MDA), a method for real-time detection of objects in the water column as well as the seafloor beneath. When objects in the water column are of interest, the MDA can significantly reduce the amount of data generated during a survey, because only the detections have to be stored and not the water column data. Also, with the availability of additional detections on targets with weaker signal strength more flexibility is provided when performing hydrographic surveys on complex targets or in challenging environments.

The MDA is described in Chapter II, results from processing water column data recorded at three different locations are presented in Chapter III, and a discussion is provided in Chapter IV.

II. Method

The MDA works on top of an existing BDA by calculating a number of predetections per beam and supplying these detections to the BDA. The predetection procedure uses more aggressive filtering and fitting to locate objects in the water column than a typical BDA. Controls are available for adjusting the sensitivity to small objects and echo strength in real time, allowing the operator to tune the system to detect only certain targets and suppress noise. The accuracy of the predetections is less important as the accurate range to a predetected object is subsequently achieved using proven methods.

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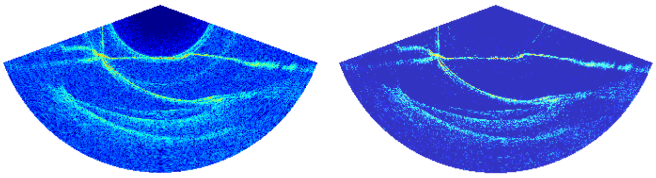

Figure 2: Effect of side-lobe suppression performed prior to peak detection.

Prior to predetection, the specular side lobe is suppressed in order to avoid false detections. An example of the effect of this procedure is shown in Figure 2. Notice the reduced intensity of the specular reflection side lobe.

The predetection process follows three steps for locating objects in the water column: 1) Determination of an amplitude threshold, 2) peak detection, and 3) peak width estimation.

1) Determination of an amplitude threshold: The amplitude threshold is calculated dynamically per beam using the following expression [6]:

$$\frac{\max(A) + \frac{1}{N}\sum_{i=1}^{N} A_i}{2} + K \cdot dev \quad (1)$$

where

$$dev = \frac{\sum_{i=1}^{N}\left|A_i - \frac{1}{N}\sum_{i=1}^{N} A_i\right|}{N} \quad (2)$$

The parameter, A is the amplitudes in one beam, N is the number of samples and K is the weight factor of the deviation term. Using $K = 0.5$, the location of the threshold is roughly placed midway between the noise floor and the peak amplitude in each beam. The location of the threshold may be adjusted by using the K-parameter.

2) Peak detection: Peaks are located by detecting the zero-crossing of the derivative of the median- and low-pass filtered beam amplitudes. The slope of the zero-crossing is used to identify the object size. An adjustable threshold is available to suppress detections on small objects. The amplitude of the peak associated with a zero-crossing is compared with the amplitude threshold. If the object size and amplitude are above their thresholds, the peak is classified as a predetection.

Figure 3 shows an example of sonar data presented in wedge format with overlaid indication of one beam and the three largest objects in that beam. Figure 4 illustrates the peak detection procedure for the beam and objects highlighted in Figure 3. The blue curve is the unfiltered beam amplitude, the red curve is the median- and low-pass filtered amplitude, and the green curve is the resulting amplitude threshold calculated for that beam. The peaks designated ***1*** and **2** in Figure 4 are classified as predetections while peak ***3*** is not.

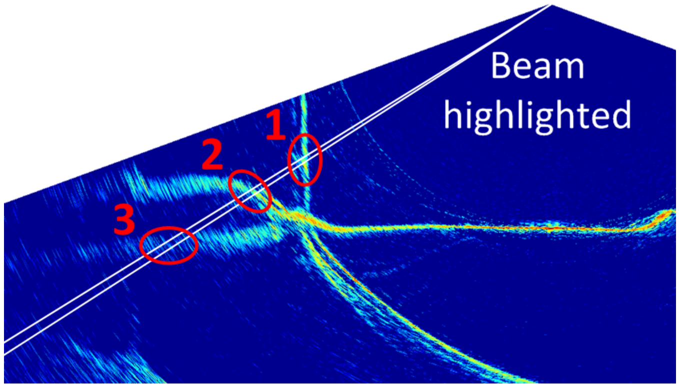

Figure 3: Illustration of the peak detection procedure on real sonar data with highlighted beam and indication of three potential targets overlaid on the wedge data.

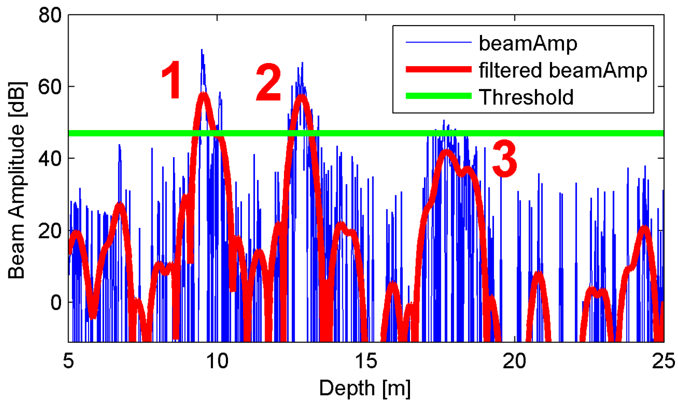

Figure 4: Example of the peak detection procedure in one the beam.

3) Peak width estimation: The peak width is calculated for each predetection and serves as an estimate of the width of an object along a given beam. The peak width is defined as the distance between the points where the low-pass filtered peak amplitude has dropped 6dB relative to maximum.

The calculated predetections are passed to the BDA for final bottom detection. The MDA is not dependent on a specific BDA implementation and may interface a BDA in different ways; a typical interface is using the depths of the predetected peaks as input to the BDA. This allows the BDA to determine the center of gravity and split-array phase difference zero crossing for each predetection. Alternatively, if the BDA uses gates to limit the search area for bottom detection, these may also be used to force the BDA to locate an object within a small window determined by the MDA. This simply requires the MDA to generate a set of gates centered on the predetection.

III. Results

Water column amplitude and split-array phase data recorded at three different locations have been postprocessed with the MDA in order to demonstrate two applications of the method. The first goal is to extract more details from complex

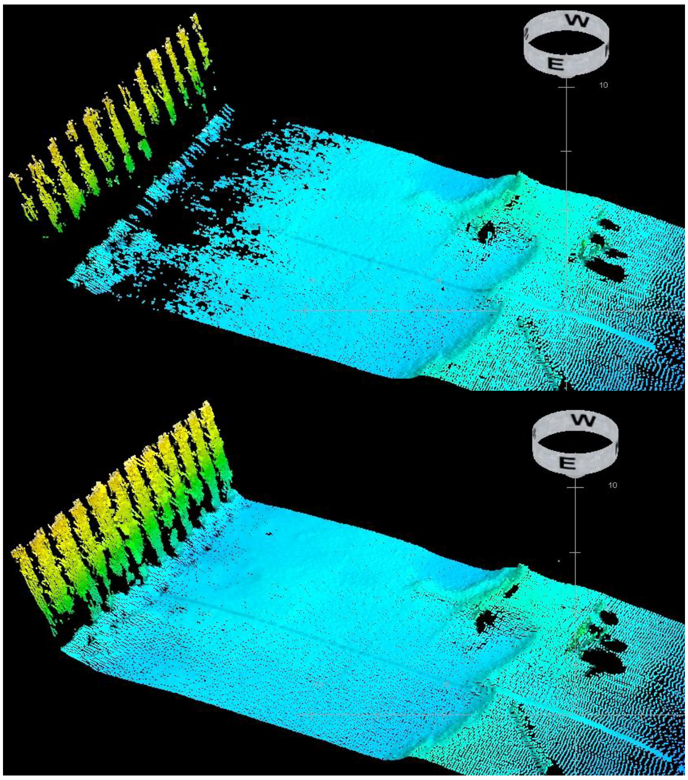

Figure 5: DEM from a survey performed in a harbor next to a quay wall. Top: Standard bottom detections. Bottom: Multi-Detect.

targets when the sonar sees more than one object per beam. The second goal is to improve hydrography in a challenging multipath environment by producing hydrography using only the detections closest to the sonar head.

Data examined includes a harbor survey where the geometry of the quay wall and seafloor creates a multipath environment which, combined with a soft seafloor, causes the traditional BDAs to fail (Figure 5).

Examined data also includes objects suspended in the water column and kelps. Kelps are large seaweeds that grow on the ocean floor and stretch all the way to the water surface (Figure 6). Results from processing this data reveal a wealth of details undetected by the standard BDA.

The results are presented using digital elevation models (DEM) resulting from georeferenced bottom detections generated from a standard multibeam survey acquisition software.

Figure 5 shows the result of applying the MDA to data recorded in a harbor where the quay wall causes a strong multipath echo. The top image shows the detections resulting from a typical split-array phase BDA. The bottom image shows the first detection, closest to the sonar head, made by the MDA. The MDA also detects the multipath echoes, but these are easily filtered by removing all but the first detection in each beam.

Figure 6: Photograph of a kelp forest off California [7].

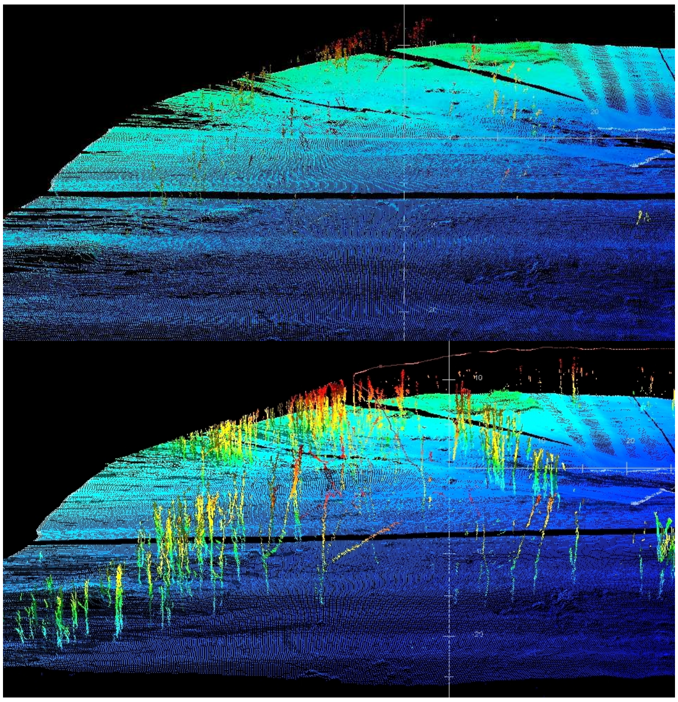

Figure 7: DEM from a survey of kelps located close to the California coastline north of Santa Barbara. Top: Standard bottom detections. Bottom: Multi-Detect.

Figure 6 shows a picture of kelps stretching from the seafloor to the water surface using gas filled bladders. These bladders provide good targets for sonar due to the fact that the large difference in density of water and gas causes strong reflection of sound. However, as the bladders are small in size, the sound emitted by the sonar is allowed to travel past the kelps and hit the seafloor, which in most cases provide an even stronger reflector.

The result of surveying kelps is shown in Figure 7. Notice how most of the kelps remain undetected by the conventional BDA and when detected leave ‘holes’ in the DEM. The MDA

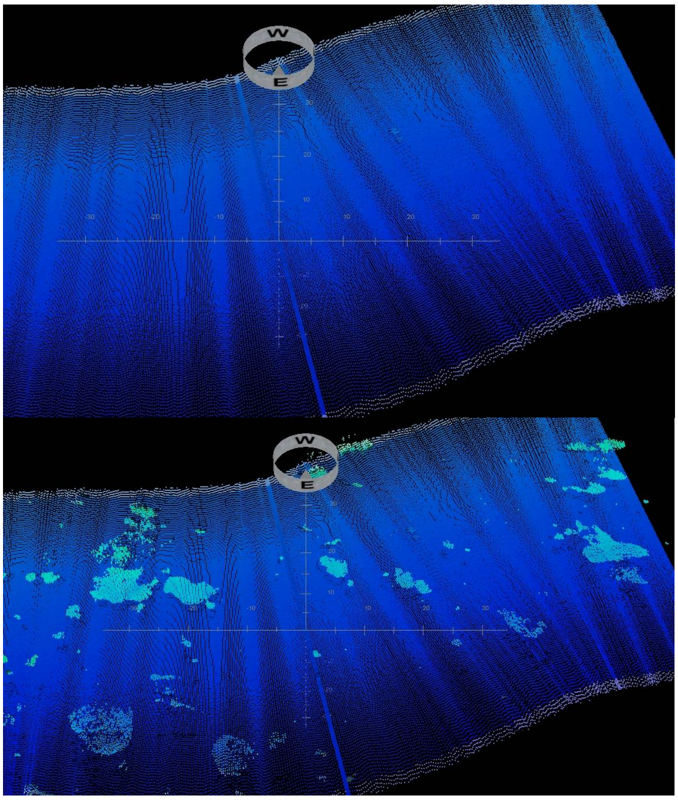

Figure 8: DEM from surveying an area with multiple targets located in the water column. Top: Standard bottom detections. Bottom: Multi-Detect.

detects kelps, often all the way from the seafloor to the sea surface when not limited by the sonar's field of view.

Figure 8 shows the result of applying MDA to data recorded in an area with multiple objects suspended in the water column. These objects are approximately 1m thick and acoustically transparent, allowing MDA to detect both the objects and the seafloor beneath. Due to the fact that the backscatter from the objects is weak compared to that from the seafloor the objects remain undetected by the BDA.

IV. Discussion

MDA is able to detect multiple targets located in the same beam and estimate their widths. Using an algorithm that is sensitive to objects located in the water column requires an increased awareness from the sonar operator on the applied sonar settings. While MDA is robust to varying scenarios and environments, successful detection requires use of sensible sonar settings. Compared with hydrography, optimum utilization of the MDA is achieved when not only the seafloor but also the water column is illuminated satisfactorily.

MDA may result in multiple detections on the same object. This may happen for different reasons, e.g. 1) if the sonar uses a large number of overlapping beams, an object smaller than one beam is detected in several beams or 2) if one coherent object is distributed along one or more beams.

Logging more than one detection per beam implies that the acquisition software used for georeferencing is able to handle the increased amount of information. While detection of multiple objects per beam is the strength of MDA it may also be its weakness in some cases: If unwanted objects, such as fish or reflections, are detected by the MDA more data cleaning may be required when comparing with standard hydrography.

The MDA logs the estimated widths of all detected objects; this information may be used to perform volume estimation of clouds of detected objects such as oil pollution or fish.

The increased amount of data resulting from the MDA, compared to traditional BDAs, is insignificant; rarely more than five detections are made per beam and each detection, including supplemental information, takes up only a few bytes. Storage of water column data, on the other hand, produces large amounts of data. Using the maximum possible ping rate, limited only by range (*2 x Range / Speed of Sound*), the amount of magnitude and phase data in bits per second becomes

$$Beams \ x \ F_s \ x \ Bit \ resolution \ x \ 2 \quad (3)$$

where F_s is the sampling frequency. Using a sample rate of 34kHz, water column data produces roughly 120GB per hour of continuous recording.

The benefit of recording full water column data is that all information is retained. Furthermore, future postprocessing methods may become available allowing for extraction of further information in previously recorded data. The MDA, on the other hand, allows for immediate improvement of bottom detections on complex targets and in challenging environments.

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