Automatic Mid-Water Target Tracking using Multibeam Water Column

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SUMMARY

A potential new application in multibeam water column imaging is the recognition and precise location of suspended mid-water targets. This has already been utilized manually in the ArcticNet program for searching for lost under-ice mooring hardware, but has never been automated.

The pattern of the scattering field around a point target is directly related to the multibeam imaging geometry, including transmission and reception beam-width, sidelobe spacing and suppression and pulse bandwidth. Knowing this geometry-specific scattering pattern, optimal 3D matched filters can be designed to pick out faint targets from noise. Having picked an object in this manner, its location can be derived with the same positioning uncertainty that we already associate with depth.

Equivalent detection of objects can be achieved by the trained operator when carefully inspecting all the data, but is a very long and tedious task. An automatic algorithm can be used to perform this task, as well as tracking the object's movement. New automated methods are herein being developed to improve the processing speed. These new capabilities can be used in oceanographic research, in search and rescue, also for military purposes, and to track geological activity. A specific case study used as an example is the monitoring of suspended targets over seabed markers that are progressively displaced by landslides.

Key words: watercolumn, multibeam system, detection

1. INTRODUCTION

Hydrographic technological development has always been focused on seafloor detection and accuracy of depth measurements. Although it is still one of the most important features in hydrography, multibeam echosounders (MBES) can now, in addition to measuring bathymetry and sea floor reflectivity, also discriminate the acoustic imaging of the water mass by recording sampled reflectivity measurements along each beam. Water column imaging has been used mostly for fisheries (Gerlotto et al, 1999) (Mayer et al, 1997) but it is now being used for several other applications, such as the detection of gas plumes (Gardner et al, 2009) (Jones, 2003), the determination of least-depth over wrecks (Hughes Clarke et al, 2006) (Van der Werf, 2010), noise detection (Hughes Clarke, 2006), etc…

Most MBES dedicated to seafloor tracking already store the complete acoustic data from each beam, presenting the full trace of the water column for each swath, along the whole survey line (figure 1). This gives the hydrographer a picture of the contents in the mid water range, discriminated in range and angle. Some more work can be done using these tools. While water column is already being widely explored for some other purposes, like fisheries or intruder detection, its use in hydrography is still limited. Several algorithms are being used to track the seafloor, track fish schools or even classify the sea floor type, but the information available with bathymetric MBES allow us to go one more step. With water column data and using MBES high resolution and low uncertainty in positioning it will be possible to accurately position objects in the mid-water range. Several variables have to be taken into account when analysing data in the water column. MBES imaging geometry dictates how the scattering pattern around any single point in the water column appears. Transmission beam width, reception beam width, side lobe pattern, and pulse length are responsible for the characteristic scattering shape of any detection in the water column, creating a 'smile' across track and a 'frown' along track (figure 2). Transmission sectors, minimum slant range, yaw stabilization, and pitch stabilization limit the even sampling and usefulness of the water column data. Vessel speed, swath coverage, sound speed, refraction and, absorption coefficient, all change the way water column data needs to be analysed.

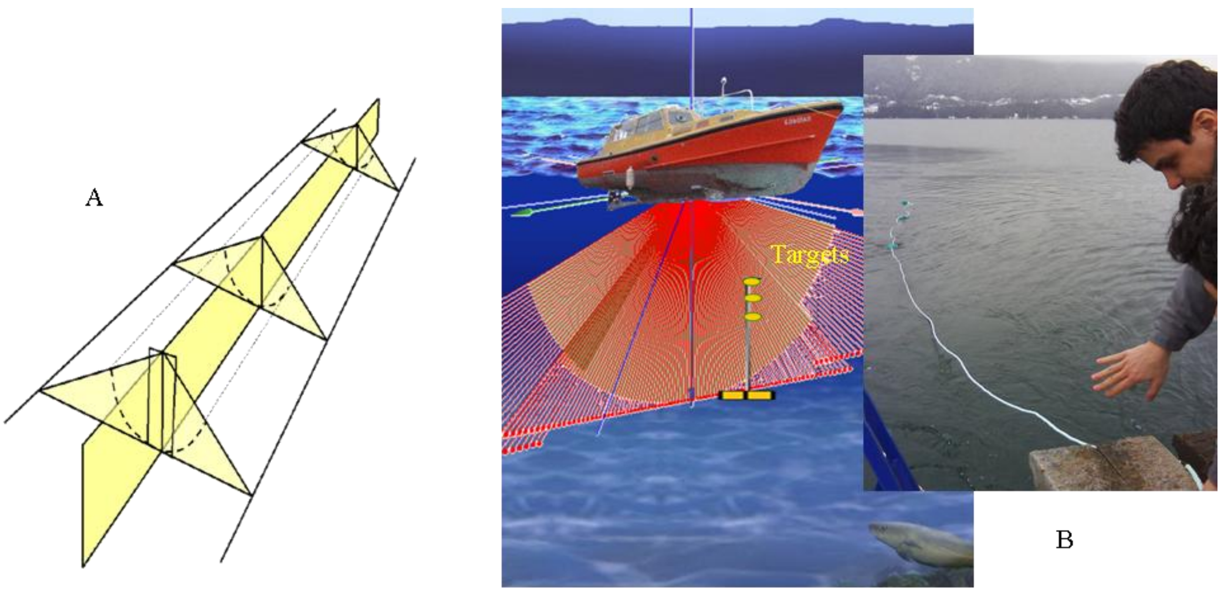

Figure 1 - (A) - A 3D draft of the water column imaging along a survey line,
(B) - Need to locate and accurately position objects in the water column, targets being deployed

A UNB project in Squamish (Hughes Clarke et al., 2011) included a requirement to locate mid water objects and, while that could be done manually, the amount of data to be acquired requested an automatic system that could detect the required objects uniquely and position them. The aim of the project was to track the movement of the targets. So this automation needed to be fast and reliable enough to be used throughout large volumes of recorded data with confidence that no targets would be missed.

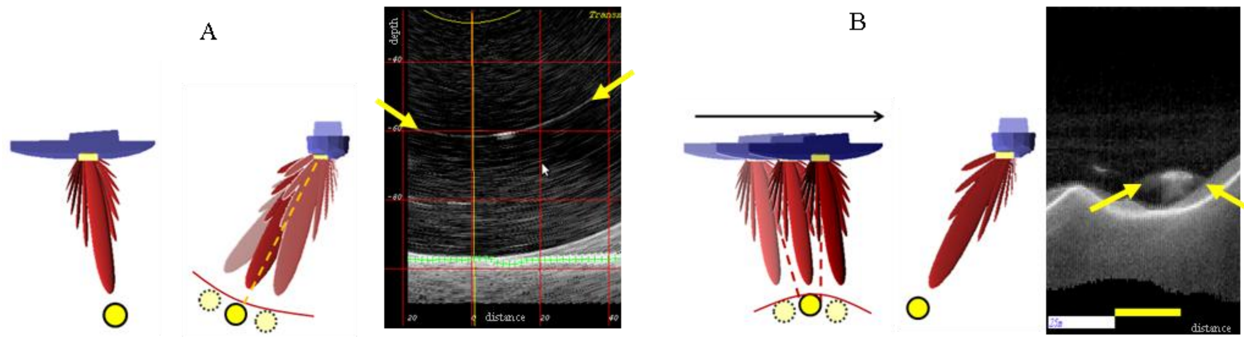

Figure 2 - Specific detection pattern of MBES.
The detection pattern shown in the water column image, receiver side lobes drawing a 'smile' along track (A) and transmiter side lobes creating a frown along track (B)

2. METHOD

2.1 Overview

For the purpose of positioning something in the water column, the first objective will be to detect it and to do that one needs to know its actual dimension and scattering properties and how that compares to the sonar range and angle resolution. It should be an easy task to look for large objects that are big with respect to the beam dimensions. But trying to find small objects, whose target strength differs little from natural scatters is a complex and difficult task. In order to distinguish valuable detections, from regular water column noise one needs to be aware of the water column characteristics, the sonar characteristics, its water column specific imaging geometry, and what a valuable detection is, separating it from the noise. Water column characteristics such as pH, temperature, salinity, pressure, will change the way the sound will attenuate (Francois and Garrison, 1982) and its impedance (Urick, 1983). Sound speed and attenuation define and limit detections, even zooplankton plays its role (Maclennan and Simmonds, 1992).

While water characteristics control the sound reflectivity, MBES aspects determine how that reflectivity will be described in range and angle space. Transmitter beam width, receiver beam width, side lobe characteristics, frequency, pulse length and bandwidth, transmitter and receiver steering angles, sectors and sector boundaries, minimum slant range, slant range itself and vessel speed are all attributes that define a unique water column imaging geometry (fig. 2) and to correctly interpret the water column image they have to be known.

There are 2 main points to notice before even trying to do any detection. First of all is that with the use of yaw stabilization correlating detections across sector boundaries seems impracticable as the sectors simply do not match at the boundaries. Another insuperable task seems to be to detect something after the minimum slant range, as the side lobes contamination from the sea floor seems to mask everything in the water column after it.

The algorithm that was used to track targets in the mid water range, using bathymetric MBES water column imaging, was designed to search detections before the minimum slant range and in sectors separately. First it marks all detections and then within those detections it searches for valid target echoes and finally matching geometry. It can be separated in 7 parts, 5 of which take an important part in the detection and are explained here. The algorithm starts by reading the water column data (step 1), then defines the search area according to the needs and available data (step 2). It then uses an automatic threshold calculation (step 3) after which it starts searching for detections. This search is done using a 3D cubic search (step 4) to isolate credible detections, then a 3D match filter (step 5) using a specific detection pattern, and finally any repeated detections are removed (step 6). Once all valuable detections were found a last filter (step 7) is run through all detections using another 3D optimal filter to uniquely detect user-specified target geometries.

2.2 Calculating the Threshold - step 3

To search for something the search area must be defined. Having the beams, pings and range defined all we are left with is a large set of intensity values for each beam, ranging from -94 to 34 dB (assuming a 30dB affset applied). Figure 3 shows a typical water column image and the corresponding set of intensities for a specific beam.

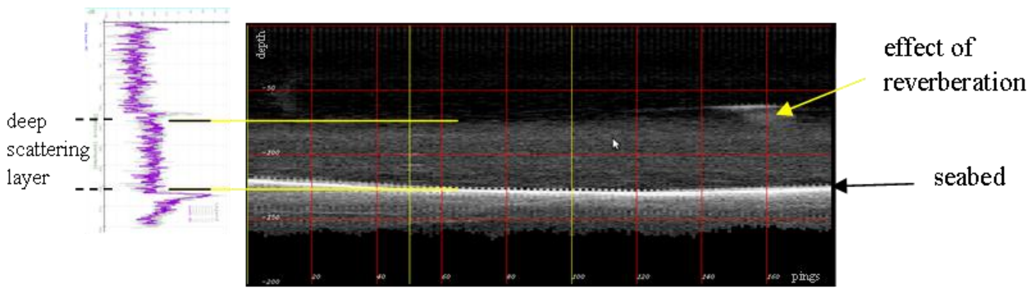

Figure 3 - Typical water column imaging (vertical section along track)

Along the water column some reflections are picked up, either noise or natural features like plankton, air bubbles, small living animals. Usually things we are not interested in seeing when looking for some specific object. When looking for specific objects that have a slightly higher scattering strength than the water column we can safely search above a certain intensity value. As the water column is usually “reasonably” homogeneous, the reflectivity due to water characteristics shows up in values around a specific mean value. Using this as starting point one can figure out several different ways to calculate a threshold value to reduce the search area. This algorithm defines the threshold by simply calculating the mean value of the intensity peaks and intensity troughs on the whole search area inside the swath, then gets the difference between both and adds it to the mean peak intensity. As sometimes depth related differences can be seen in the water column (such as a deep scattering layer – DSL), and homogeneity is mostly guaranteed horizontally, the threshold is actually calculated in depth layers to get better results, the example of a DSL can be seen in figures 3, 4 and 5 (probably due to the existence of zooplankton) showing the vertical variation. The threshold usually gets intensity values for each layer high enough above the water column natural intensities and low enough to detect any features. Figure 4 shows an example of the threshold calculation.

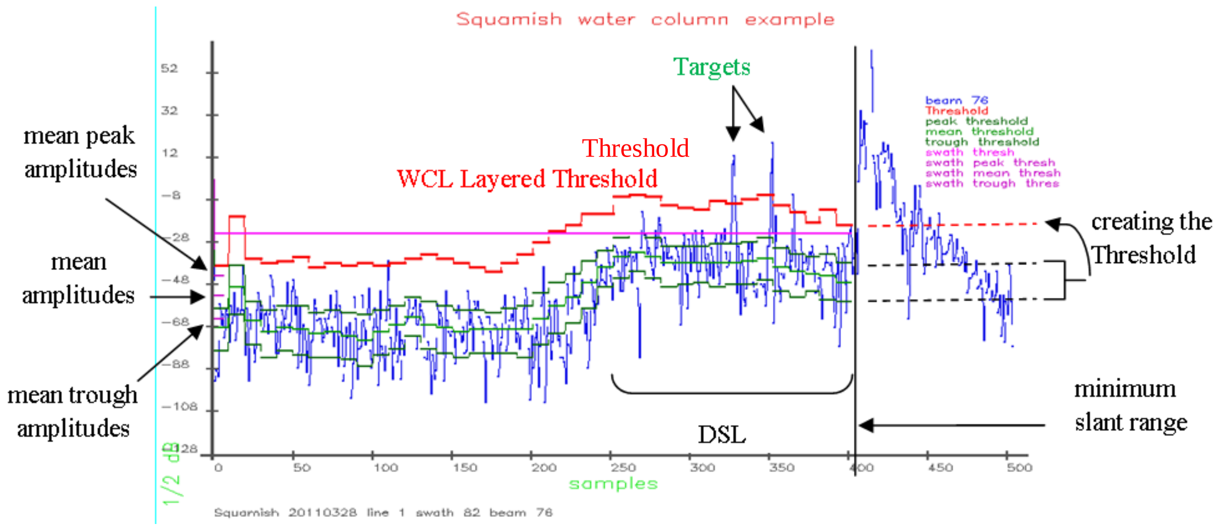

Figure 4 – An intensity/samples plot explaining how the threshold is defined (only values in the search area, and before the minimum slant range are used for calculations).

2.3 3D Cubic Search Box (searching for peaks) - step 4

Once the search area (area where the algorithm will search for targets) is defined (step 2), we can see some examples in figure 5, one can start looking for features of interest. The user defines the size of a 3D search box (area used locally to look for peaks), in beams, pings and samples, meaning that in this cubic area it is guaranteed that only one detection will appear. This feature actually allows the user to have some control on the number of detections and spacing between them, figure 7 shows this effect. As a guide for box dimensions, size in beams should be wider than the receiver main lobe, size in samples wider than range resolution and size in pings wider than transmitter main lobe (see axis, fig. 7).

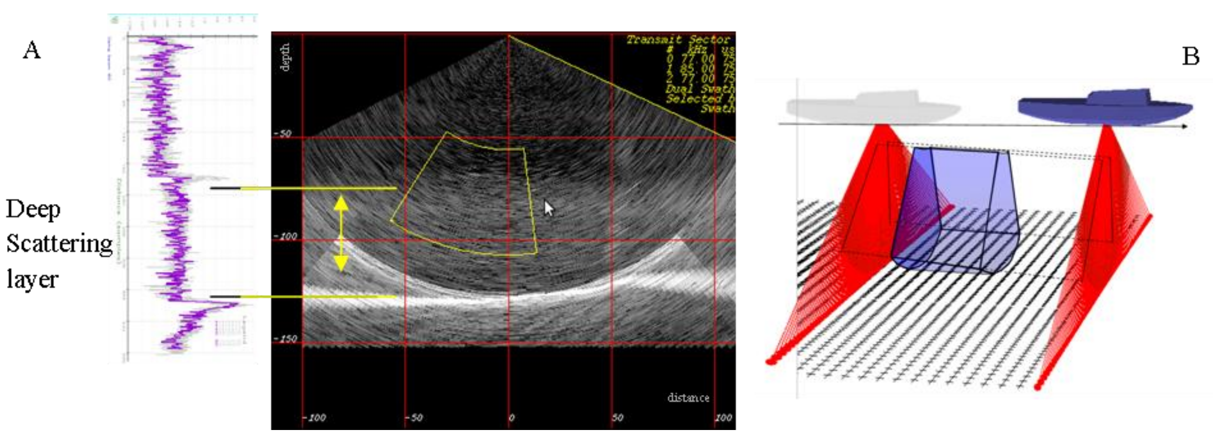

Figure 5 - Search Area limited in samples and beams (A) ,
and also limited in pings or swaths in an along track image (B).

This search box is then used in the already defined search area to go through each sample in each beam, in each swath and check if that sample is a peak above the threshold. Having found one peak, the algorithm checks if this peak is a probable detection in the 3D cubic search box and to be considered a detection it has to have the highest value in intensity of all surrounding neighbours (in beams, samples, pings), otherwise it is discarded. The algorithm here compares sample intensity values in three planes, similar sample, similar swath and similar beam angle creating a 3D planar search, simplifying the cube as the changes appear mainly in these directions and not obliquely. If a possible detection is found, the next step is applied using the 3D detection match filter. Then the sweep along all data continues until the end of the search area is reached and all detections are marked and stored for future analysis. Figures 6 and 7 explain the search using this Cubic box.

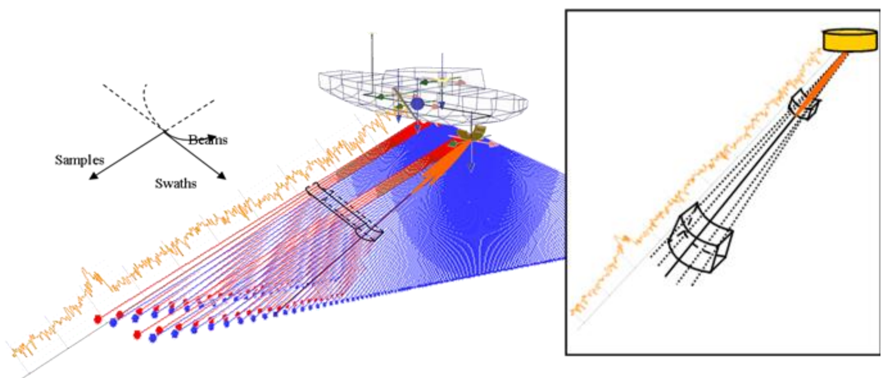

Figure 6 - Understanding the cubic shape through swaths/beams/samples (it grows in size with, distance, inverse ping rate, beam width, bandwidth, etc ...)

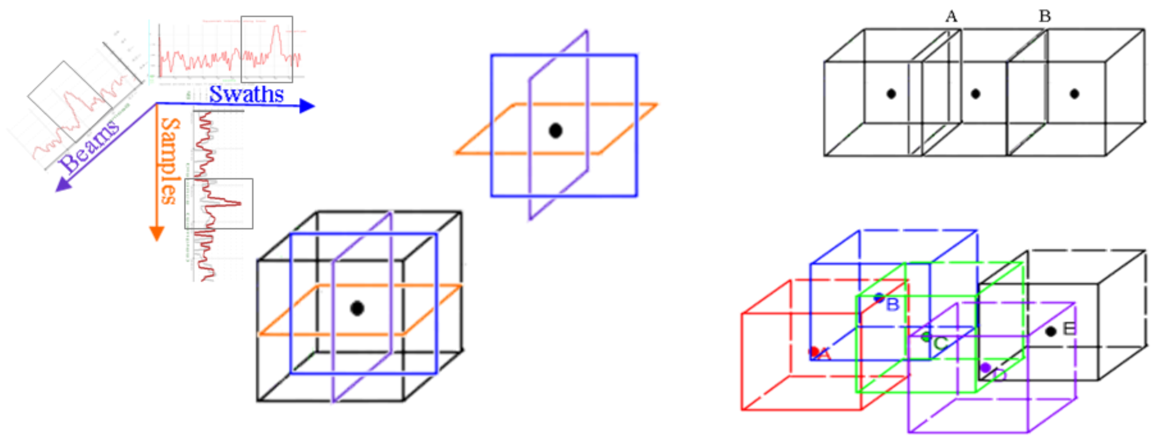

Figure 7 - 3D Cubic Search, at the left the cube is shown next to the axis of its planes. The top right shows that there are no 'A' situations(no detections where cubes overlap), only 'B' is allowed - so the cube defines the minimum detection spacing. Bottom right is the neighbour contamination side effect (if A<B<C<D<E, only E is detected)

This 3D cubic search box has some intended side effects, marking only one detection for large groups of detections, such as in fish schools, or large objects like a large container. As long as the detected object is homogeneous this search will mark as few times as possible. If the target looses homogeneity in a distance large enough (depending on the search box size) a second detection will be picked up. Figure 7 (bottom right) shows the neighbour contamination side-effect that allows this. Notice that it only occurs if the objects keep reflecting similar intensity values. The geometry of an elongate target may cause complications with this approach. A mast, a structure between legs of an oil platform or a vertical train of bubbles may require future modification of the algorithm.

2.4 3D Detection Match Filter - step 5

Having found a probable detection, other tests need to be used to actually certify if it is a detection and not just some random/systematic noise, figure 8 shows both examples. Detections of small targets (with reference to beam-width) have a specific pattern shape in the water column imaging. Depending mostly on the MBES characteristics, the detection will not appear as a single point or as the shape of the object, but it will be shown as something very different in shape. Actually, the scattering field around a single specific point target will reflect the main lobe width and side lobes pattern of the MBES. Figure 9(A) shows a 3D scheme of a single point detection. This imaging geometry changes with each system and even with the changing receiver steering within a single system, and will create a characteristic detection pattern along the water column. A smile like pattern, as in figures 2(A) 9(B), is found across track (neighbour beams) due to the side lobe effect of the receiver and using the receiver beam-width will help to replicate it.

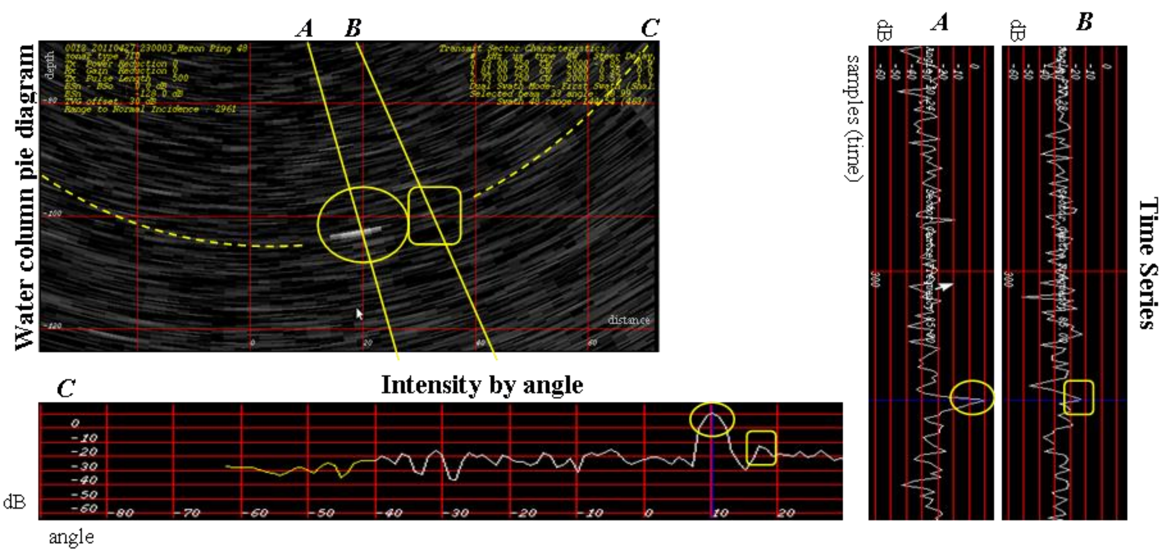

Figure 8 –Detection pattern, the circle shows a detection, its shape can be seen along the same distance and it is not a single spike along the same beam. The square shows noise, a spike in amplitude values. Water column displaying 2 possible detections. Intensity plot by angle (C) 2 intensity plots along beam (A & B).

Along track (neighbouring swaths), a frown shape (fig. 2B) pattern is found due to the transmitter side lobes, and using the transmitter beam width will assist us on recreating this effect. This is analogous to the hyperbolic echoes well known to single beam trace interpretation. Along the beam axis the shape seems to depend mostly on the bandwidth but also on the attenuation and size of the detection.

Unfortunately, as these patterns are examined in beam/swath units, they will also change with some user defined variables such as vessel speed, or swath coverage. Those also need to be considered, as can be understood by figure 10. One complication is internal multiples. Some targets appear to reverberate on a time scale much longer than the physical pulse length (figures 3, 2B).

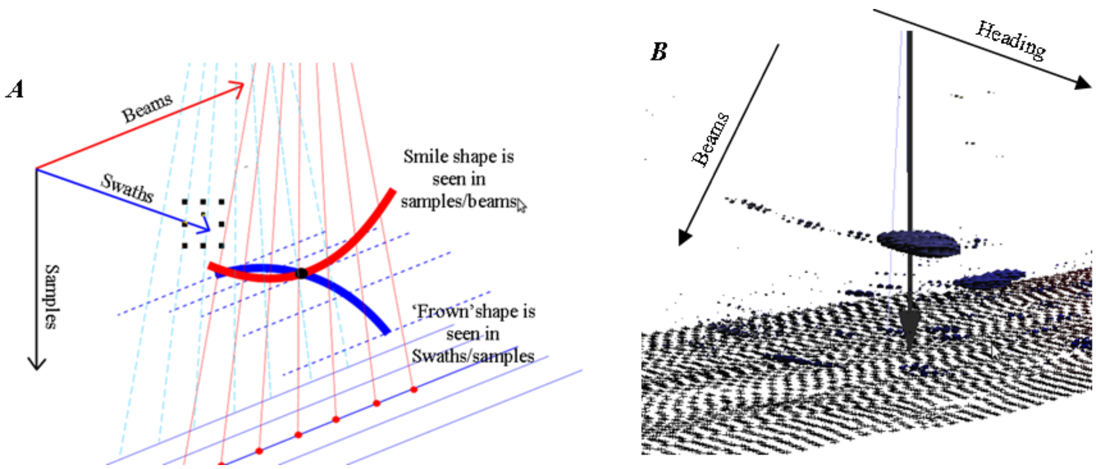

Figure 9 - 3D detection pattern of a single point in multibeam imaging geometry, a smile is detected across track, along the same distance, while a frown is detected along track, increasing the distance before and after the point. Figure at the right shows the smile in 3D image.

The first step of this algorithm is to create the expected detection pattern. Primarily it needs to have a physical detection size defined so that it knows what to look for and create the detection pattern shape. Then it uses the sample rate as a bandwidth approximation, together with sound speed, beam width and pointing angle, also ping rate and speed for along track, to calculate the expected size of the detection in ping spacing. Using receiver beam width and beam angle will support the calculation of the across track detection shape, the 'smile' like shape. Finally the 'frown' like shape along track is computed using transmitter beam width, transmit steering angles, ping rate and vessel speed.

Once the scattering pattern match filter is created, the probable detection and its surrounding samples are compared with it and any probable detection that does not match the filter is discarded. We must notice this scattering pattern is unique for every beam, and every sample of a single swath.

2.5 Excluding possible repeated detections (coping with dual swath) – step 6

Several systems now use dual swath, using different frequencies on consecutive swaths. Knowing that different frequencies have different source levels, different attenuations, different reflectivity values, and even different side lobes for similar objects, all previous tests were run only for similar frequencies, avoiding the comparisons with different scales. This last step on automatic detection brings back the concept of one survey line and one system only by actually comparing detections in different frequencies and choosing between them. The algorithm will now check through all detections found and searches around the 3D search box area, including all frequencies, for neighbour detections. If any detection is found it uses the frequency characteristics and the intensity value of both detections to exclude the weakest one, leaving only one detection per search box as desired (figure 10).

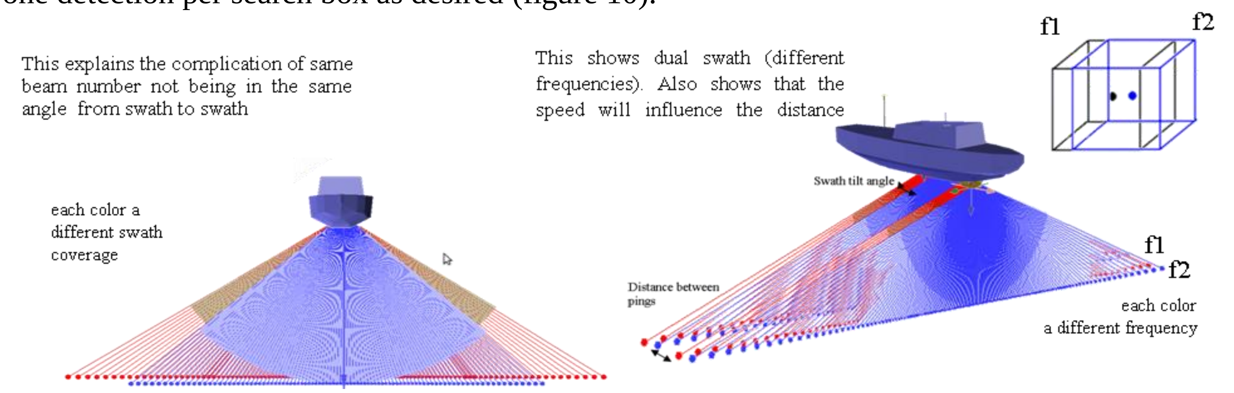

Figure 10 - Swath coverage (right) and vessel speed both change the detection pattern of a single point in the water column. Also different frequencies have different reflections and need to be tested separately, the 3D search cube is used to decide on only one detection between frequencies if more exist.

2.6 Final 3D Target Geometric Filter – step 7

Finally, having all the detections marked as one, a search for the specific target geometry is executed. The user defines one or more specific targets that are intended to be found in a separate format file. The target shape is defined by using the concept of pieces, meaning the user must describe the known spatial relationship between each piece. Each target is then considered to be composed of a group of pieces, each one separated from each other from a certain distance and angle. The last piece will give the distance to the sea floor. Figure 11 depicts the target shape definition.

A final 3D geometric match filter is created using the target shape and size, then a run through all detections is done using this filter on each one marking each target found (marks all pieces), as is shown in figures 11 and 14. The algorithm identifies each specific target from the list given in the targets format file and names it accordingly for future use (fig. 14).

The final results, will allow the computer to use the bathymetric MBES characteristics, using beam depression and azimuth angles, detection range and, sound speed to calculate the position of the object (each piece) and subsequently by using several survey lines separated in time (usually several days), calculate its movement if required.

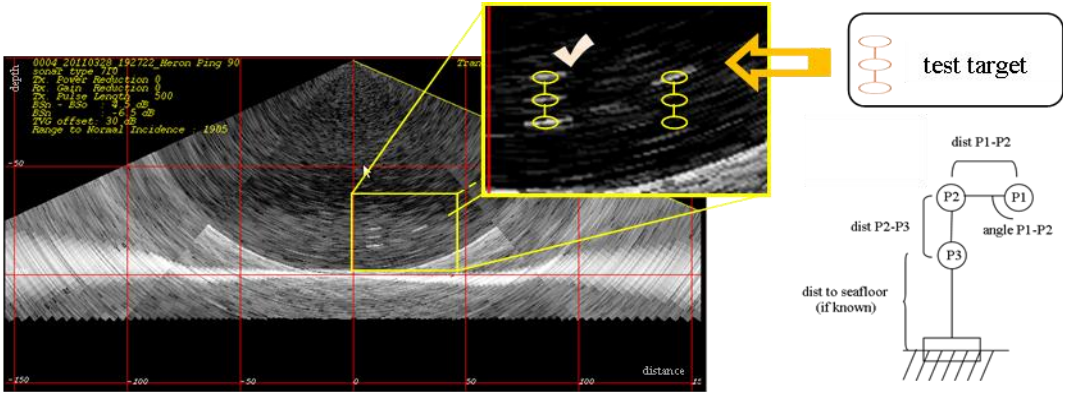

Figure 11 - Target shape detection, bottom right shows a target design example

3. EXAMPLES

3.1 Overview

This project started with the necessity to track targets in the Squamish Project (Howe Sound, British Columbia) (Hughes Clarke et al, 2011), using a Konsgberg EM 710 system, so this was the main case study used. However the algorithm was tested for other purposes in the ArcticNet Project (mooring detection) data and even in some OMG older data (wrecks and sunken lattice structures).

3.2 Squamish targets

The Squamish project aim is to monitor underwater landslides and several strategies were applied to achieve that purpose. These strategies included placing some specifically designed targets in the believable path of the landslide and monitor their displacement over time. As small targets could not just be put on the sea floor or they would be buried and mixed up with the landslide, and big targets were unlikely to move, a mooring system was used to place heavy targets on the sea floor and monitor their displacement by tracking the buoys suspended above them (and marking them).

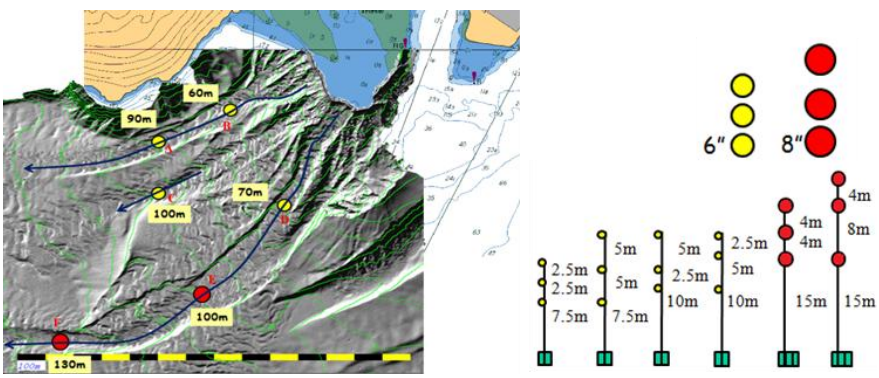

Figure 12 - Squamish survey map, and target locations

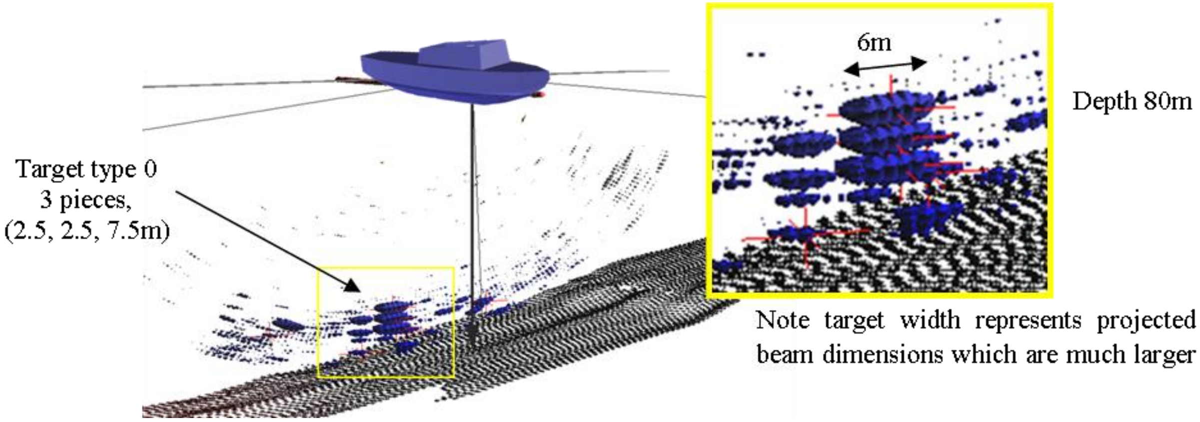

Figure 13 - 3D image of target detection (targets marked in red crosses)

Several sets of moorings were used, with specific unique multiple target spacing geometries as shown in figure 12. Each set was later uniquely detected using this target detection algorithm and the targets positions used to confirm the landslide movements occurred during the period of study. Figure 13 shows a 3D image of the targets in the water column. Figure 14 shows the target detection among all other detections.

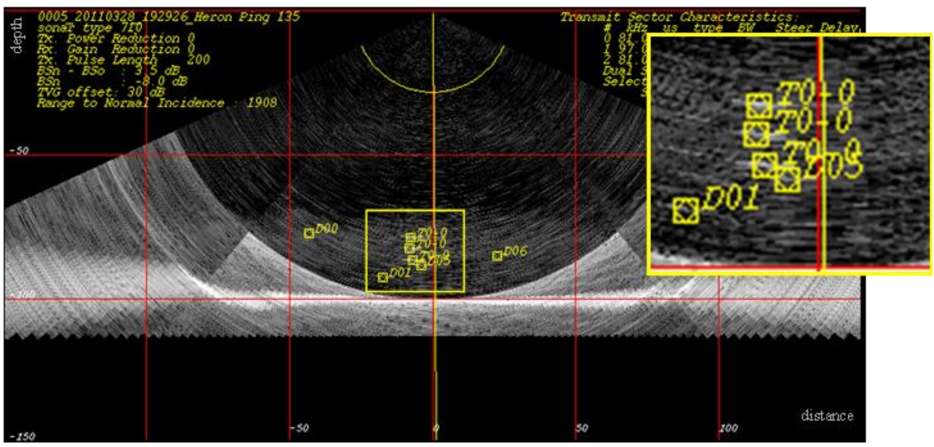

Figure 14 - Squamish target detection, notice the targets marked near the nadir. (T0-0) target number 0, type 0 (from format file).

3.3 Squamish gas plumes

While searching for the targets, other applications of the algorithm were tested including the capacity to detect gas plumes. Some sets of gas plumes are visible in the water column data of the Squamish survey, this algorithm detects the gas plumes and as they are not an homogeneous object it actually marks them as several detections along the gas plume, this same results can be seen in figure 15.

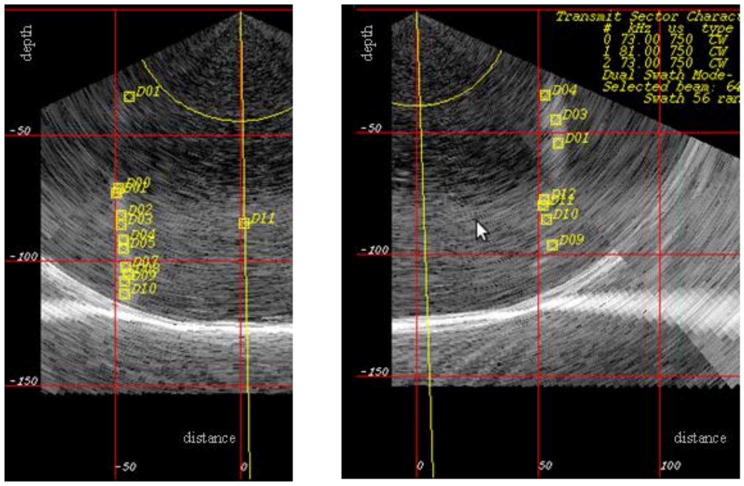

Figure 15 – Gas plumes in Squamish. Note the gas plumes clearly detected, even across sectors.

3.4 ArcticNet Moorings

Another data set where the algorithm was tested was in the ArcticNet project, using a Kongsberg EM302 System. During 2011 data acquisition period, the need to recover oceanographic moorings in the Beaufort Sea allowed the acquisition of some survey lines over mooring sites. As shown in figure 16 and 17, using this algorithm on those survey lines produced also the expected results, marking the mooring systems as unique targets and positioning them accurately as requested. Also some noise can be seen in the data that was acquired while operating other acoustic systems.

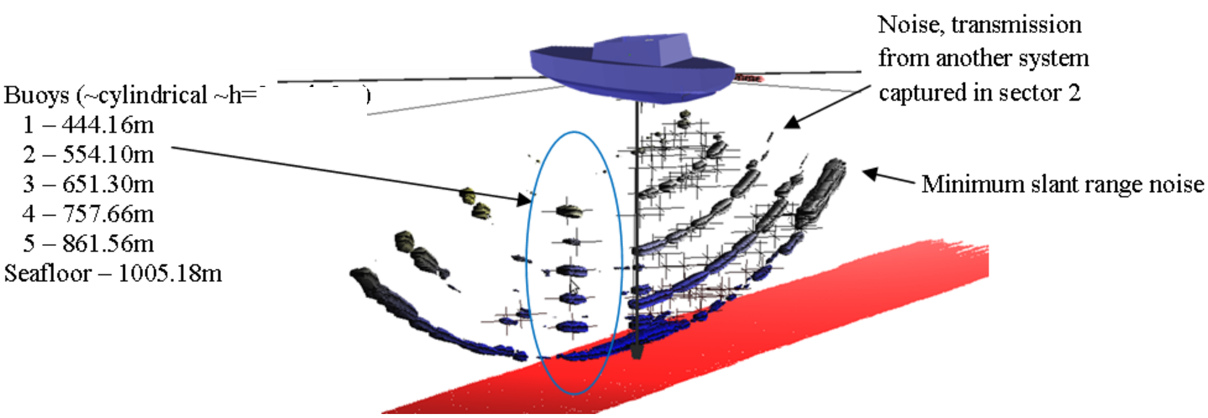

Figure 16 - 3D image of oceanographic hardware moorings, the whole set of 5 buoys (sector 1) Notice also the noise (interference from another system – sector 2). Data acquired with KM EM302, detection done separately for sectors 1 and 2 only.

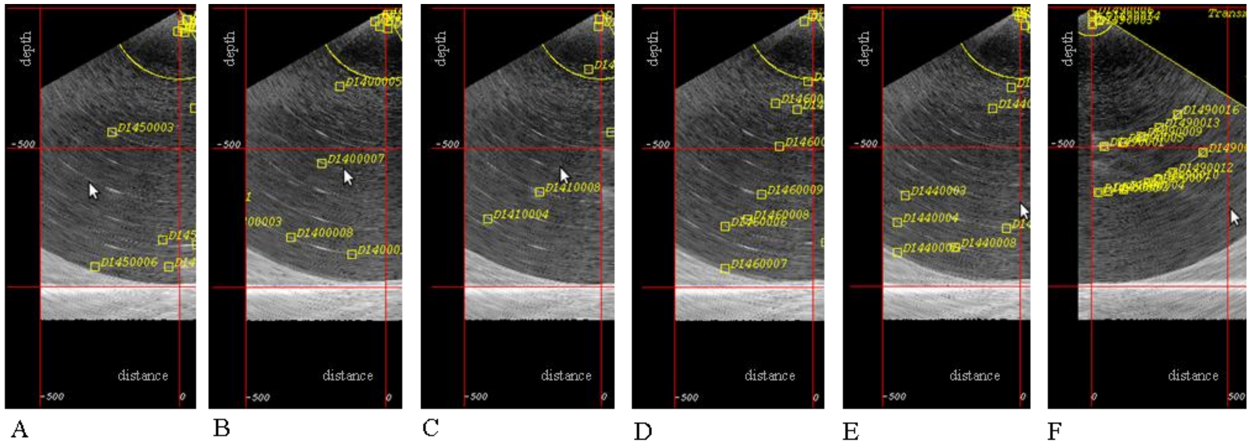

Figure 17- ArcticNet data moorings detected along contiguous swaths A,B,C,D,E (sector 1) and also detections along a noise pattern F (sector 2).

4. CONCLUSION

Manual detection of objects in the water column usually implies a tiresome and error susceptible task performed by a trained operator that has to run through all survey lines searching for a specific known pattern until the object is found and then it can be positioned. When tracking for object movement or searching for objects in unknown positions the amount of work needed grows to large proportions. Using this detection algorithm, specific objects can effectively be detected and accurately positioned in a 3D reference frame just by running the algorithm in the whole survey.

5. FUTURE WORK

Although initially the development of a method to track targets in the mid water range was solely aimed for the Squamish Project, new capabilities arose as the results from the tests were being analyzed. Using the same approach to water column detection, new strategies can be studied to automatically position gas plumes as well as possibly characterizing their density and direction. Also the new method can be used to accomplish man made structure detection, like ships and ship masts that usually are mistracked by traditional bottom detection algorithms. Finally automatic systematic noise detection and characterization methods could be designed starting from the same assumptions used in this algorithm.

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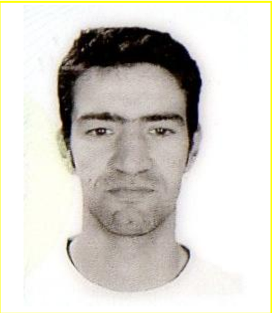
BIOGRAPHICAL NOTES



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Mainly interested in water column detection, he is a M.Sc.E. student in Geodesy and Geomatics Engineering at University of New Brunswick, supervised by Dr. John E. Hughes Clarke.

John E. Hughes Clarke is the Chair in Ocean Mapping and a Professor in the Dept. Geodesy and Geomatic Engineering at UNB. His prime interest lies in submarine sediment transport processes. As part of this, maximizing the information content available from integrated swath sonar systems is a major component of his research.

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