Hydrographic Survey Data Without a Motion Reference Unit

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Abstract - *Traditionally, the data collected with bathymetry sensors contains an artifact based on the motion to which the sensor was subjected during data collection. Integrated survey systems must also collect motion data, which is useful for applying a correction to the bathymetry data in order to correct for the motion artifact. Often, a high-resolution motion sensor forms a significant percentage of the overall cost of any bathymetry sensing system. If it is possible to extract the motion signature from the uncorrected bathymetry data, then the bathymetry sensor could not only produce a motion-corrected bathymetry solution, but also generate a motion parameter estimation.*

In an attempt to quantify the nature of this issue, one may intuitively note that in towed and AUV systems, one can expect a tight coupling between pitch and heave, and heading roll and sway. If we can bound these relationships, we can expect to reduce the number of uncertainties in the motion estimation solution. Further, we can reasonably expect that the hydrodynamics of the towbody or AUV in combination with a notion of the sea state could also limit the motion estimation solution. Finally, combining these bounding functions with the detailed artifacts that appear in the bathymetry data as a result of motion applied to the sensor presents an opportunity for the bathymetry data to be useful in determining a motion parameter estimation.

1.0 INTRODUCTION

The Benthos C3D is a novel, off-the-shelf acoustic technology available for hydrographic survey applications. C3D utilizes a single acoustic source and an array of 6 receive elements stacked vertically to generate both bathymetry and sonar imagery. Although C3D data does have a nadir gap, it provides co-located bathymetry and imagery data in a single towed sensor at sidescan swath widths, that is, C3D provides bathymetry and imagery data swaths at 10X the sensor height above bottom per side. C3D utilizes a technique called Computed Angle of Arrival Transient Imaging (CAATI), and an array of N = 6 receive elements[1] to resolve N-1 = 5 simultaneous angles of arrival, providing results that have advantages over both interferometric sidescan sonar and multibeam echosounders [Kraeutner, et. al. 2002].

For traditional survey applications, an acoustic sensor such as C3D is integrated into a data collection system along with GPS and a motion sensor. Offsets between the sensors are precisely measured in order to minimize the errors associated with the measurements. A patch test is conducted with the integrated system in order to eliminate any angular offsets between the acoustic sensor and the motion sensor. This final step is crucial for C3D because the wide data swath makes data acquisition very sensitive to roll errors. That is, the width of the swath is effectively a lever arm which magnifies roll errors in the final data set.

Clearly, the motion to which the acoustic sensor is subjected manifests itself in the collected data. Given that each ping provides a large number of samples, the seafloor in general is nominally flat, and the air-sea interface provides a motion input with a general character with a well-understood frequency domain component, potential exists to generate a motion estimation directly from the bathymetry data. Considering that a high-end motion sensor accounts for a significant portion of the cost of a seafloor survey system, some real cost benefits may arise from success in this investigation.

Intuitively, with pole-mounted or Autonomous Underwater Vehicle (AUV) based system, we can expect a tight coupling between pitch and heave, as well as roll and sway. This coupling of these potentially independent variables is essential to reduce the order of the solution.

2.0 BODY

Preliminary analysis is intended to evaluate the potential for this method and application. As such, the coupling of the paired rotation and translation components is unnecessary. We utilized a Teledyne Benthos, Inc. C3D in a towed configuration. Clearly, with sufficient scope on the tow cable this choice substantially reduces pitch and heave related effects. We use a TSS DMS-05 motion sensor as a reference, collecting 10 replicate lines over the same area with known extremely small variability in the topography. The multiple data streams are time tagged for correlation during post-processing. C3D data is logged in Teledyne Benthos .k8e format independent of any 3rd party data acquisition software.

Because the seafloor is flat in the test area, the slope of the seafloor translates directly to the towfish roll. Variations in the seafloor will confound this process, however, when we evaluate the process in the frequency domain, a fully realized solution should be effective in all cases except where the seafloor varies within the frequency band of the air-sea interface induced motion. Although it is not robust, we utilize the least squares estimator to determine the slope of the seafloor data. For C3D, it is reasonable to expect independent, identically distributed errors, thus, the least squares estimator is the optimal choice.

The plot below shows a representative comparison between the roll data collected with the DMS-05 and the slope of the seafloor calculated from the C3D raw data. The constant bias in the two data sets could be the result of an offset in the mounting of the DMS-05 within the towfish, so, evaluation of the two data sets should only include the general character of the data. Excellent correlation exists between these two data sets, clearly suggesting that the approach has merit.

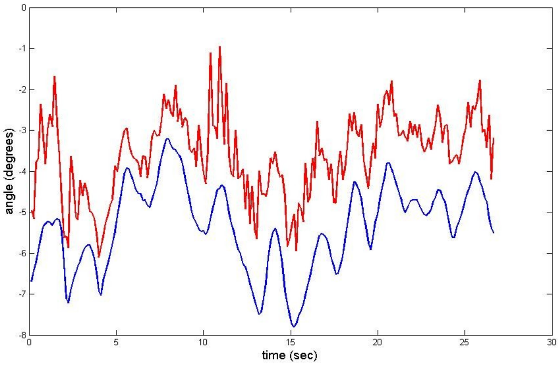

Illustration 1: Measured Roll with DMS-05 vs. Seafloor Slope

There exists a high frequency component to the seafloor slope data that does not exist in the DMS-05 data. As such, it is valuable to evaluate the frequency component of these similar but distinctly different data sets to investigate the source of the difference. If this artifact is fundamentally tied to the air-sea interface motion, the frequency domain representation of this data will be distinctly different based on the direction the survey vessel travels.

The illustrations below shows the same data as above in the frequency domain, utilizing the standard Matlab tool for Fast Fourier Transform (FFT). The first plot shows the frequency domain content of the DMS-05 data.

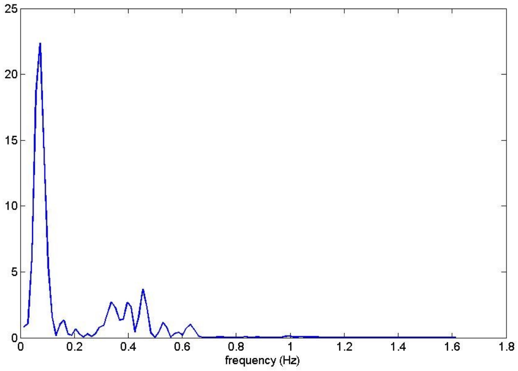

Illustration 2: Frequency Component of DMS-05 Motion

Clearly, the seafloor slope data shows a nearly flat response in the upper portion of the frequency band that does not exist in the DMS-05 data. The magnitude of this white noise data is small, whether it is negligible remains to be seen.

As the scales are relevant across the plots, clearly, the fundamental frequency is a more significant portion of the time varying data with the DMS-05 motion than it is with the interpreted motion from the bottom data. Also, although small, a non-zero component exists in the interpreted data from about 1.6 Hz out to 3.75 Hz that does not exist in the DMS-05 data. Further investigation is required in order to determine whether this artifact is the result of the small scale variations in the seafloor as nowhere in the real world is the seafloor actually flat, or the result of some other currently unexplained phenomenon.

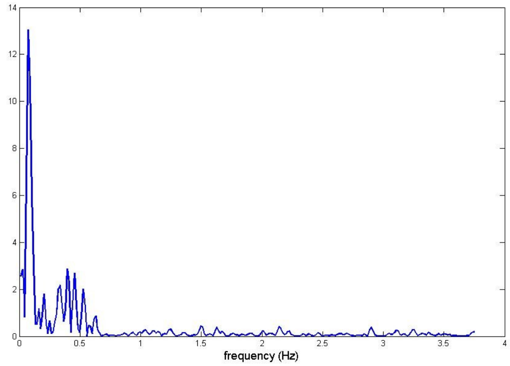

Illustration 3: Frequency Component of Seafloor Slope Data

Since the location of the peaks in both plots are the same, one might reasonably conclude that these plots represent very similar wave forms in the time domain. The disparate data exists in the upper frequency range, say between approximately 0.8 Hz and 3.75 Hz. Because this potentially problematic data doesn't appear to be in the same frequency range as the actual motion data, applying a low-pass filter to the reconstructed motion could provide a solution very similar to the data coming from the DMS-05.

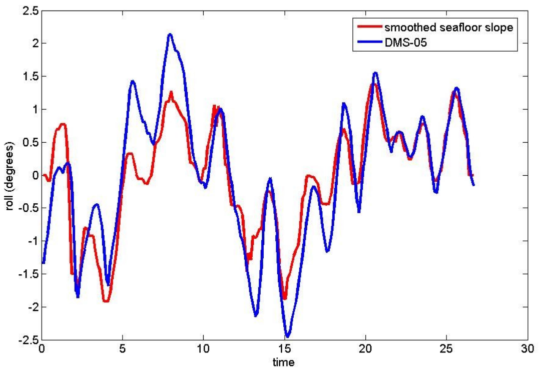

Illustration 4: Smoothed Slope of the Seafloor vs. DMS-05 Roll Data

The plot above is the result of applying a 5 element median filter to the seafloor slope data, and removing any constant bias from the data. Although this technique can pass for a rudimentary low-pass filter, it does tend to reduce the amplitude of the greatest excursions from the mean. Clearly, we can see this result in the plot as the DMS-05 data consistently achieves higher excursions from the mean in both directions. A more effective low-pass filter should provide improved results. Still, the results here are extremely promising. Toward the right side of the graph (later in time), the two solutions agree to a high degree of accuracy.

3.0 CONCLUSION

This analysis clearly demonstrates that by utilizing appropriate existing line fitting algorithms to determine the slope of the data resulting from each ping, one can effectively approximate the roll output from a DMS-05. The raw results suggest that the technique imparts some low amplitude nearly white noise. It is currently unclear what the source of this noise might be, however further investigation should fill the knowledge gap. Filtering this noise also shows promise in terms of the ability of the technique to accurately represent the output of the motion sensor.

More highly variable seafloor topography may prove a significant challenge for this technique, and further investigation will be required in order to determine the operational limitations on effectiveness.

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[1] The number of array elements can be larger, but at this time we use six.