Development and Modeling of Systems for Source Tracking in Very Shallow Water

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LONG TERM GOALS

Development of passive sonar systems for source tracking in very shallow water as pertains to AUV operations and the development of numerical models for acoustic tracking which can be used for AUV mission planning.

OBJECTIVES

1) Develop a two man deployable autonomous passive sonar to add a bistatic capability to the Ambient Noise Sonar (ANS) array developed in previous years,

2) Develop environmental models for tracking error estimation and reduction,

3) Experimentally calibrate and evaluate the acoustic model, the sonar and acoustic tracking capabilities in very shallow water as pertains to typical AUV operations,

4) Extend the concepts developed for AUV passive sonars to provide a small active system for detecting bubbles under breaking waves from an AUV platform.

APPROACH

Over the last few years a passive sonar array has been developed for deployment either from an Autonomous Underwater Vehicle or statically. This system has been termed the Ambient Noise Sonar (ANS) (sometimes referred to as the Peacock array) and consists of six transducers mounted in a fan shaped arrangement. The array was originally designed to study the ambient noise in the ocean, and a number of interesting studies have been completed [1-4]. Recent results have shown that the array is also well suited for passively tracking boats, scuba divers and AUVs based on their modem signatures. A program of work was started in January 2000 to meet the new objectives 1) -3) described above.

WORK COMPLETED

1) New Passive Sonar Array Design and Development: An illustration of the new ANS sonar design is shown in figure 1. The array will include five transducers, four on folding arms and one on a fixed arm.

Report Documentation Page

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The sensors are ITC 6050C low noise hydrophones and a hydraulic motor operates the folding arms. The system will be positively buoyant and anchored to the sea floor when the arms are deployed. The anchor will be retracted or released on command at the end of the mission so that the system can be retrieved at the surface or, in an AUV configuration, returned to the mothership. The signal processing will be based on a 500MHz Celeron processor mounted on an Advantech 9570/S PCM cards with an A/D board from Innovative Integration, giving 8 channels, 16 bit sampling at 100kHz. Data storage will be on a 12 Gb hard drive, providing a total time available for continuous data storage of 5.5 hours. The mission duration is specified as 6 hours per battery pack.
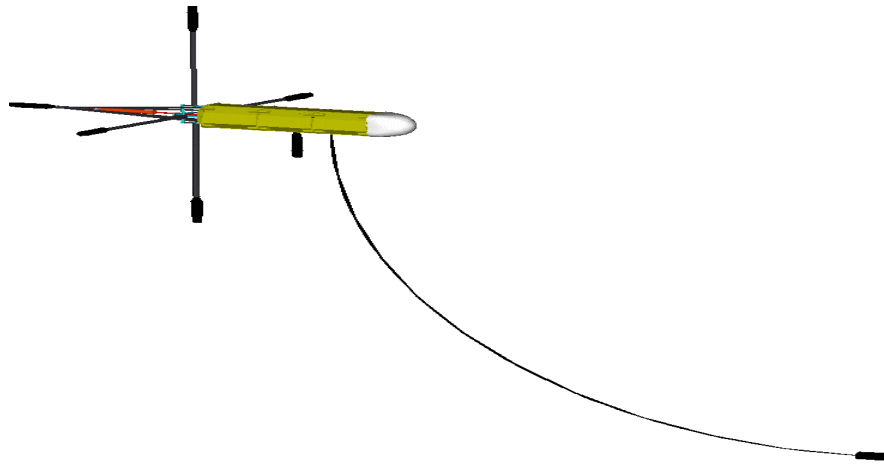
1. The new ANS system (the SQUID sonar).

Since the system is designed to be anchored it will be free to move in the water column, and so corrections for motion and orientation must be included in the design and signal processing package. This will be achieved using an onboard motion and heading sensor. To provide greater accuracy the anchor will be fitted with a low level pinger which can be commanded to emit a signal. This will provide the capability for the array to autonomously assess it's orientation from a source at a fixed position.

At the present time all system components have been designed and are currently being fabricated. The signal processing hardware is in house and software development and testing is underway. It is planned that the complete system will be in the water for testing in December 2000.

2) Numerical Prediction of Tracking Performance: For accurate mission planning and execution over larger and larger areas, AUV navigation and modem performance errors need to be predicted prior to deployment. This requires a data simulation capability based on an acoustic model that accounts for the distortions introduced by the environment. To achieve this we are developing an acoustic module for the AUV simulator[5] based on the parabolic equation model RAM developed by Collins[6]. During the last nine months software interfaces for the code have been developed and the code has been extensively tested against bench mark experimental data[7] and experimental results obtained in May 2000(see below). It is planned to have a full AUV tracking capability based on this software complete by the end of the performance period.

3) Experimental measurements of tracking performance: An experiment was successfully completed to check the accuracy of the modeling capability described above, determine the maximum range of

accurate AUV tracking in a typical operational scenario, and associate the operational limitations with physical effects such as changes in bottom bathymetry, sound velocity profile and background noise levels. Experiments were carried out in the SFTF range on two days in May 2000. The ANS array was deployed from the R/V Stephan in 60 ft of water. The Trackpoint source, which emits pulses at 12 kHz, was mounted over the side of the R/V Oceaneer at a depth of 2.44m. The R/V Oceaneer then steamed away from the ANS array in different directions (NW, W, and S) into a region of shallower water. On the out bound tracks the vessel moved at full speed, but on the in bound tracks the vessel drifted, taking CTD casts at 200m intervals to obtain the details of the sound velocity profile. Acoustic data was collected on both out going and incoming runs. The precise location of the source was obtained using military standard GPS provided by NSWC(CD).

4) Development of a bubble detection sonar for a small AUV : A sonar was developed for a small Autonomous Underwater Vehicle based on the signal processing procedure developed for the ANS array which minimizes the number of receiving elements. The active sonar consisted of a 200kHz source and four receivers. It was found that the most effective way to detect bubbles was to compare the received signal at the source frequency with the noise level at a different near by frequency. Signal returns could be easily detected using this approach. Based on a theoretical study and experimental results conducted with a sheet of bubble wrap and bubbles from a diver, it was concluded that the bubble imager was suitable for detecting bubble clouds but characteristics such as size and shape were not discernable. The sonar has been mounted to the AUV MADDOG and is being tested at sea to identify bubbles in boat wakes.
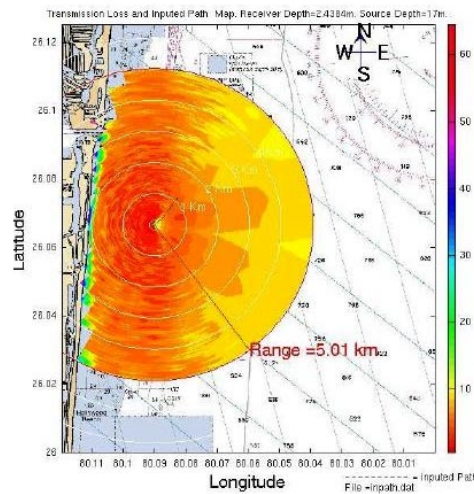
RESULTS

Numerical Prediction of Tracking Performance: One of the limitations of the RAM code is that it does not allow for shear waves in the ocean floor, and this can cause significant under estimates of the transmission loss in some environments. One of the findings of the bench marking exercises undertaken as part of this project is that shear effects could be included into the RAM code by suitably modifying the attenuation coefficient of the sediment so that the bottom impedance matches the impedance of the real case. Details of how this can be done are described by Cichock[7].

The software interface that has been developed for the RAM code provides the transmission loss as a function of range and depth. Figure 2 illustrates a typical output and more details can be found at www.oe.fau.edu/~acoustics. The value of this map is that it shows the locations of high acoustic transmission loss in an operational area. In the case illustrated, the region is quite well insonofied but it is clear that the acoustic signals will be degraded in deeper water. The transmission loss as a function of range and depth at 12 kHz is also available (see www.oe.fau.edu/~acoustics), and gives information on the optimum depth for AUV operations.

The RAM program calculates the range dependent transmission loss at a single frequency, but can also be used to estimate reverberation in the time domain. The approach is to calculate transmission loss maps as discussed above at all frequencies and then use an inverse Fourier transform of the transmission loss and the spectrum of the source signature to obtain the time history at the range of interest. The results demonstrated that the time history is reproduced, but that the model does not give the reverberation at large time delays from the onset of the initial pulse. In contrast the initial transient, or leading edge of the pulse is well defined. If the tracking of vehicles is based on the triggering of an A/D

converter, the errors in estimating position will be caused by distortion of the initial transient. Therefore the reproduction of the initial part of the pulse is all that is required of the numerical model, and this has been achieved. However more sophisticated tracking algorithms will require more detail about the incoming signal, and work continues on improving the reproduction of time histories.

2. Transmission Loss maps in the SFTF range at 12 Khz for fixed source and receiver depth.

Experimental measurements of tracking performance: Typical results from a source track are shown in Figure 3. In this example the source is drifting towards the array and so the range is decreasing as a function of time. Figure 3(a) shows the bearing angle estimated by the ANS array for all signals received. In general these results are widely scattered with the exception of the period from 69 minutes to 75 minutes. During this period a boat was passing through the area and the tracking has logged onto this source. Figure 3(d) shows the signal level at 12 kHz and at 9 kHz(typical of the noise level). Each spike on the plot indicates a source ping has been received. Note that during the period from 69 to 75 minutes a different type of source dominates indicating the presence of a boat in the area. By selectively choosing only those signals for which the ping level at 12 kHz exceeds the "noise" level at 9 kHz by 15dB, the tracking capability is dramatically improved as shown in Figure 3(b), and is even better if a 20 dB SNR is used. Tracking accuracy is still good at a range of 2km, but the results are more intermittent due to a lower signal level. These results show that tracking is accurate at quite large ranges if the signal level is high enough, but the transmission loss at ~2km causes the main restriction on tracking consistency. The algorithm used in this analysis was not necessarily optimized for noise rejection, but the results clearly indicate that signal fading is the main issue that has to be addressed at larger ranges.

The signal level predicted by RAM has also been compared with the measured data. This indicates that the model accurately predicts the acoustic field out to a range of ~1.2 km, but at larger ranges the model over estimates the measured level significantly. These calculations were carried out using the sound velocity profile as measured and the correct bathymetry. In light of the results of this experiment the prediction error at large ranges is clearly an issue for mission planing and more work is required to improve the acoustic predictive capability. One of the features which is not included in the model is

surface wave scattering. During these tests the surface wave height was 2-3 ft and the wind speed was 15-25 knts from the east. This could cause significant surface scattering to the high frequency pulse used by the Trackpoint source.

IMPACT/APPLICATION

The tracking of AUVs out to the maximum possible range is of direct relevance to MCM operations. The results of experiments to date have accurately characterized the limitations of current systems at ranges in excess of 1 km. It has also been shown that current numerical models overestimate signal levels at larger ranges and this implies better tracking performance than could be achieved in practice. For accurate mission planning better performance prediction is required.
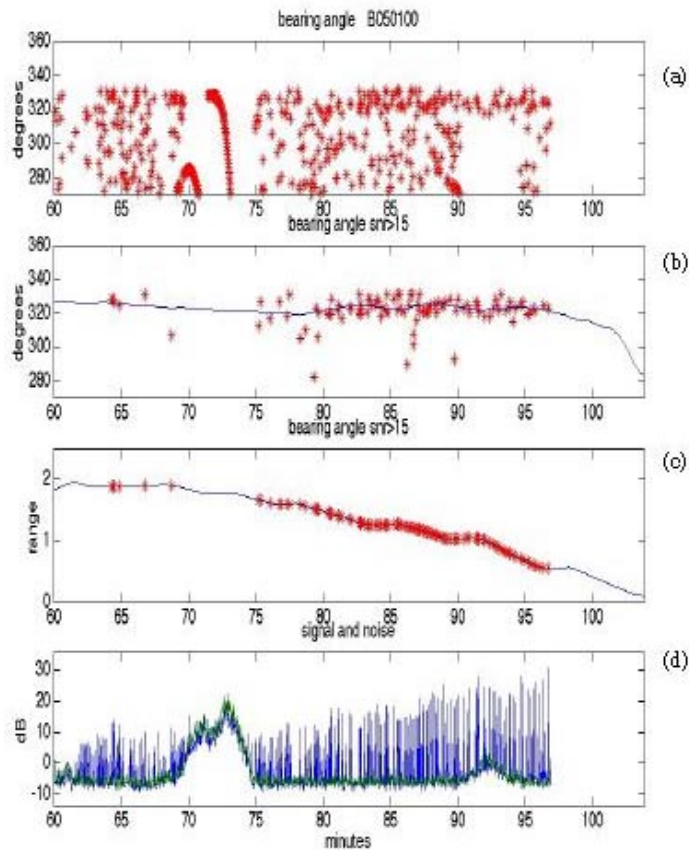
3. Results of tracking experiment. Figure (a) shows bearing angle estimated from all received signals, figure (b) shows bearing angle when signal to noise exceeds 15dB (*) compared with calculated bearing from the GPS, figure (c) shows range calculated from the GPS (each point in figure (b) is marked), figure(d) shows signal and noise levels.

RELATED PROJECTS

1. Edgar An at FAU is developing an AUV simulator which will incorporate a module for tracking performance.

2. Lester LeBlanc at FAU is developing acoustic modems which also require acoustic propagation modeling for performance evaluation.

3. Ken Hollappa at FAU is developing a small AUV for investigation bubbles below breaking waves.

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