AUV Tracking Using a Thruster Communication Link

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Abstract: *The acoustic noise produced by electric thrusters is commonly viewed as undesirable and efforts have been made to minimize this noise. Leveraging this noise, a frequency modulated PWM signal was used to create a uni-directional acoustic data link that does not require a separate acoustic transducer. The motor noise modulation system has demonstrated data transmission speeds of 250 bits/s. Building on this technology, this research investigates the ability to control the motor transmissions allowing other vehicles to localize their position in 3-dimensional space. Initial, calculations indicate that the system can localize the vehicle position to an accuracy of +/- 1% of the targets range. Possible applications of this technology include autonomous docking of underwater vehicles with surface vehicles and for the communication and control of swarms of underwater vehicles.*

Keywords: *Acoustic Communication, Localization, USBL*

Introduction

The use of ultra-short baseline arrays for localization is well established in underwater navigation. Current technologies leverage this technology along with robust bi-directional communication systems to accurately track the position of underwater assets. However, there is a focus as of late to build low cost or compact AUV systems to mitigate issues operating in high-risk or space constrained areas. The target vehicles in this on the size scale of a single sensor vehicle for missions (camera, water quality sensor, etc.) with an inertial measurement unit and compass for basic navigation. Extensions of this technology would enable swarms of these smaller vehicles each with individual motor sources communicating on small frequency bands.

This phase of research focuses on developing an acoustic communication link utilizing the switching frequency of a brushless electric motor, like those found in electric thrusters, as the basis for a frequency modulated data link [1], and a conventional hydrophone array as its receiver. This technology allows for the small vehicle to have a uni-directional data link to a hydrophone array.

Acoustic System

The localization system is based on four Teledyne Reson TC4013 hydrophones. They are arranged in a regular tetrahedron, with 1.8 cm sensor separation. This length was selected as it is less than half a wavelength of the highest frequency (40 kHz) used during testing. Each hydrophone signal is first passed through filtering and amplification hardware removing frequencies outside of the target band while amplifying the signals of interest. This is done in order to better align the incoming data to the expected input of the data acquisition device. The data is then sampled at 500 kSamples/s/channel.

After sampling, the data is filtered digitally removing all but the target frequencies. The signals are then filtered to extract the wavefront of the arriving signal, the portion of the signal free of multipath, which impacts the calculation of signal phase and as such the localization of the source. A phase difference of arrival solution is then implemented to compute the location of the source using a numerical solver based on a 6-phase difference approach [2].

Localization Methodology

Localization of the target is accomplished with a by two separate measuements. The USBL provides bearing and inclination data to the source. Through the data link, the output of a depth sensor is periodically sent. This provides accurate depth data of the vehicle and as such grounds the location on a measurement external to the system. These two measurements can be combined to compute the 3-dimesional location of the vehicle.

Testing Methodology

To facilitate testing without a custom built AUV, a comparable acoustic source (Teledyne Benthos 365 Pinger) was mounted to a surrogate system, the SRS FUSION AUV. This system is outfitted with a host of navigation sensors, including a USBL, DVL, altimeter, and AHRS as well as a software stack allowing for planning missions that are repeatably reliably and repeatably followed [3]. This vehicles localization suite was used to provide a performance reference for localization accuracy. Figure 1 shows the comparison of pulses produced by the motor and pinger. As can be seen, both devices are capable of producing comparable sound pulses, in this case, a 4 ms pulse with multipath reflections trailing off after the arrival.

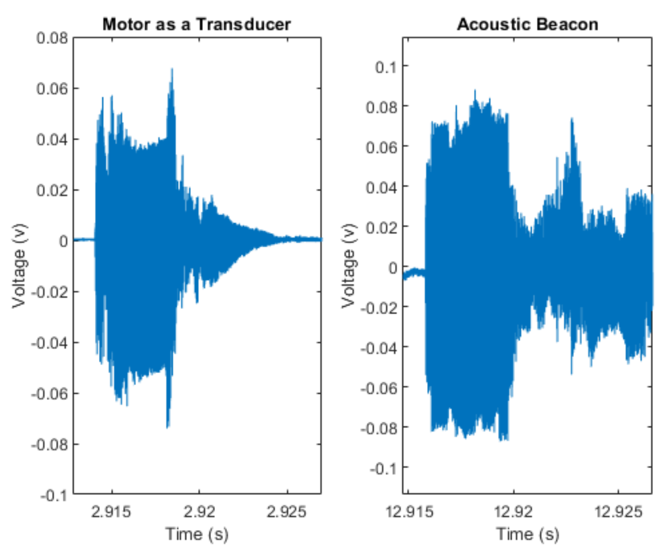

Figure 1: Comparison of Motor and Acoustic Beacon Sound Sources

Testing was conducted at Embry-Riddle Aeronautical University’s pool. This allowed for controlled and repeatable testing free of external disturbances. The presence of solid walls raised concerns regarding the impact of multipath on the received signals. However, the presence of multipath was determined to be an acceptable test condition as it is comparable to operations in littoral areas that small AUV systems are often deployed. To give the array a period of clean signals before the arrival of the multipath, the array was suspended approximately one meter away from the nearest wall and one meter below the surface of the water.

The specific test case run for this test was a static test where the vehicle was positioned at an off angle relative to the hydrophone array. Motion-based test were attempted with some successes, but due to space constraints, it was not feasible to create the desired motion vectors. To simulate the data link, depth data was streamed from the AUV. This data was time aligned to the ground truth data being used for reference and was of comparable accuracy when compared to common solutions for AUV's in the class of vehicles targeted.

Results

The presented test was conducted for a period of at least 60s. With a pinger update rate of once every 0.512s, this resulted in 128 samples. Figure 2 and Figure 3 show the measured bearing and inclination respectively to the ground truth data produced by the navigation suite on the SRS Fusion AUV. As can be seen, both measurements are centered around the ground truth data, with the inclination having slightly more noise than bearing. The characteristics of these measurements are tabulated in Table 1. Of note in this characterization is the zero-mean error. This allows for the application of navigational filters without violating their core assumptions.

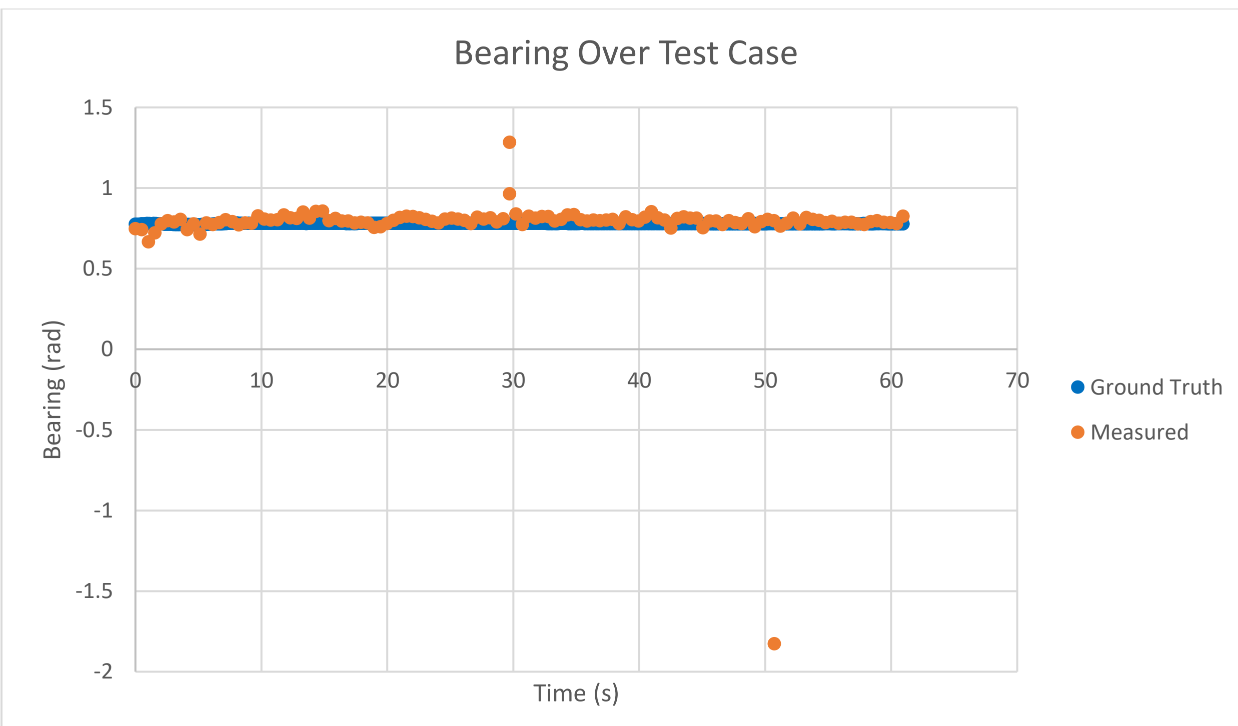

Figure 2: Bearing Measurement Comparison

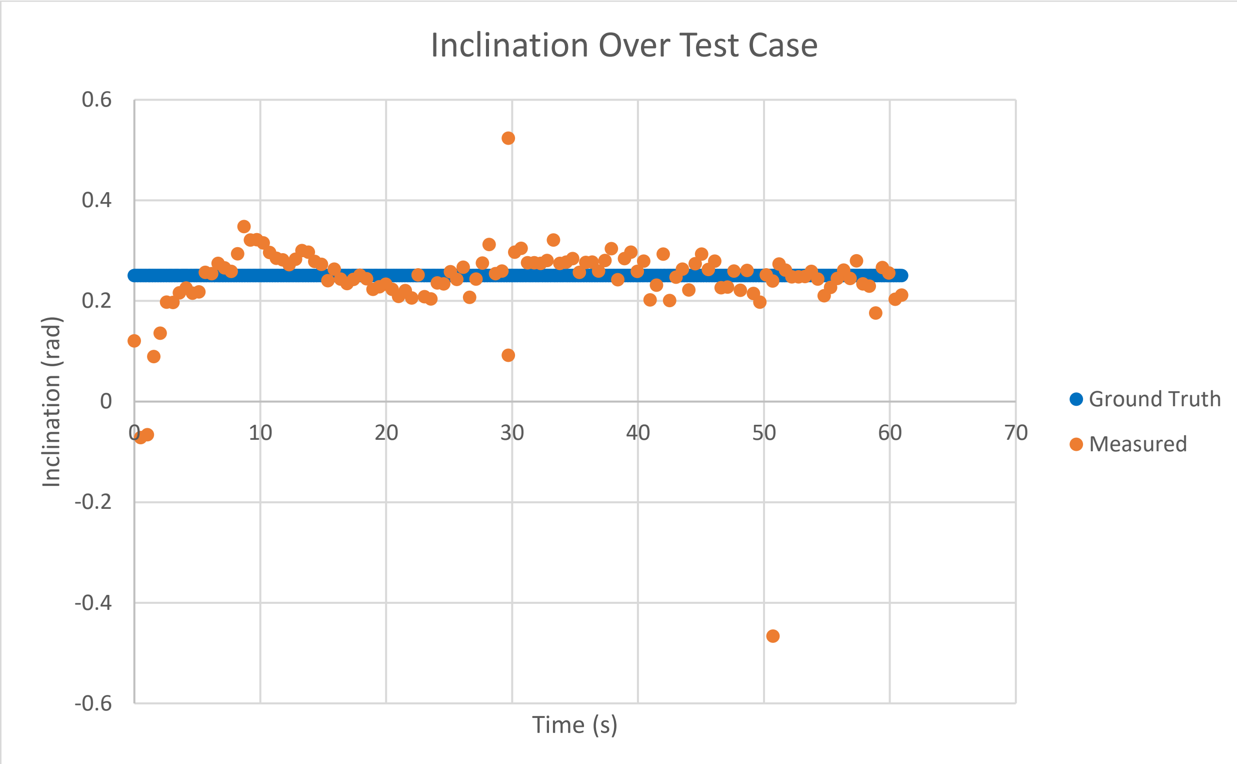

Figure 3: Inclination Measurement Comparison

Measurement	Mean Error (rad)	Variance (rad)	Std. Deviation (rad)
Bearing	~0	0.05284	0.2298
Inclination	~0	0.009247	0.09614

Table 1: Measurement Characteristics

An area of interest when analyzing this data is the presence of "pops" in the measurements. These "pops" are evident in their dramatic deviation from the correct value. When evaluating the overall accuracy of the localization of the source, it is useful to filter this data to better understand the underlying behavior. A moving average filter was applied to the measurement results. If a subsequent sample was beyond 0.4 radians of the average, it was removed from the set. In this case, 6 samples were removed, accounting for 4.68% of the data. In practice on a moving system, this boundary may need to be adjusted based on the update rate of the source or the speed of travel.

Using this measured data along with the transmitted depth data, the position of the vehicle can be mapped, and the accuracy of the localization evaluated. Figure 4 shows the XY plot of the computed locations, with Z data omitted from being shown as it was a measured value. The mean value of the location is shown with the green and orange marker for the measured and ground truth data respectively. From this data, the accuracy of the localization can be characterized using the average range error. In this case, the value was computed to be 1.18%, at the proposed performance goal set to be achieved in this work.

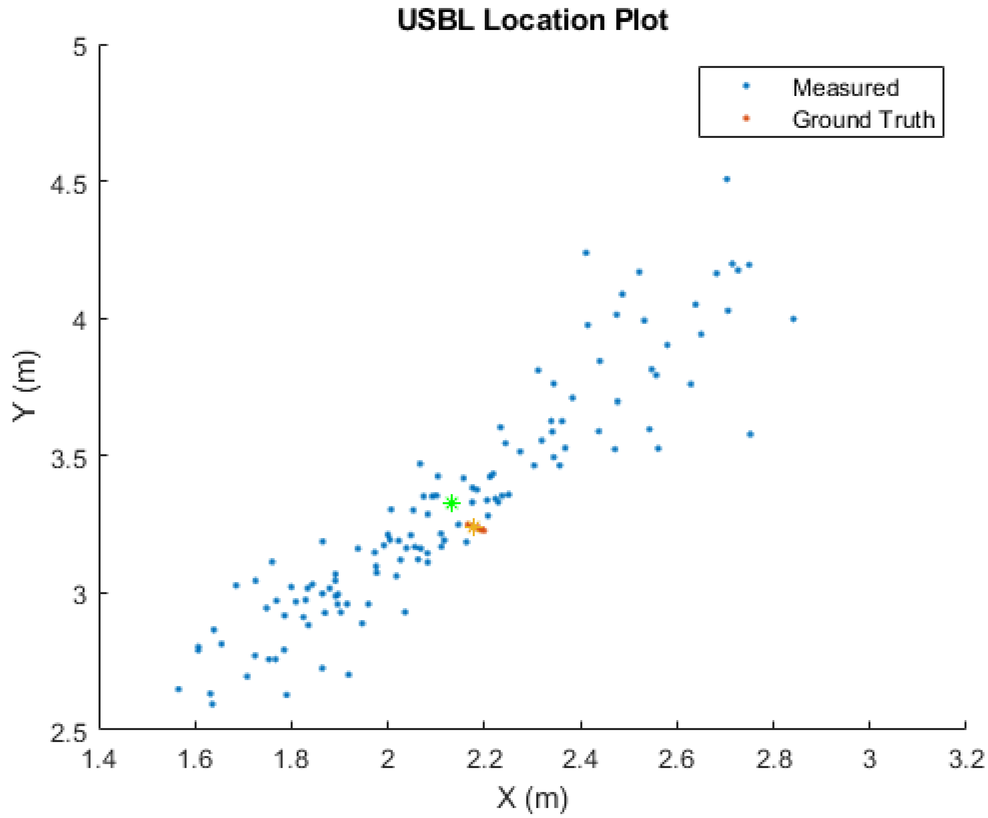

Figure 4: XY Plot of Position Data

Conclusions

The intended application of this technology is to enable tracking capabilities on simple low-cost AUV systems, which cannot support a discrete higher-fidelity navigation system due to cost or size. Building on the results of prior research, it was demonstrated that the system can accurately track the bearing to the vehicle while providing depth data through the data link. This work establishes foundational technologies to provide localization through a low-cost motor based communication system.

Future Work

The primary focus of future endeavors involves implementing this system on a small AUV to test a complete end-to-end implementation of the technology. Intermediate testing will involve a similar approach to the one outlined here, by mounting the communication system to a more instrumented platform or by conducting the testing with a motor mounted on a more capable system. In terms of the localization itself, considerations to further mitigate the impact of multipath should be taken to improve the accuracy of the source localization.

Acknowledgments
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