AUV Localization in an Underwater Acoustic Positioning System

Dugald Thomson and Stan E. Dosso
School of Earth & Ocean Science, University of Victoria, Victoria, BC, Canada
dugalthomson@gmail.com

1. INTRODUCTION

Precise positioning of autonomous underwater vehicles (AUVs) is an important problem for the ocean science community as it attempts to extend its reach to ever-greater depths. Terrestrial Global Positioning Systems are of little use for an underwater target as the high-frequency/low-power signals they employ are unable to penetrate beyond the surface layers of the ocean due to reflection and absorption by seawater. The Integrated Acoustic System (IAS) being designed at the University of Victoria aims to overcome this obstacle by developing a high-precision underwater acoustic positioning system, similar in operation to a commercial long baseline positioning unit, that receives power and transmits data via the Victoria Experimental Network Under the Sea (VENUS) infrastructure, a cutting-edge underwater cabled observatory. The IAS will be capable of localizing a target within the IAS range to a sufficient accuracy for use as ground truth for testing onboard navigation systems.

The IAS, located in a range which covers an area of approximately 1.5 km by 1.5 km, is comprised of five 3-m high hydrophone towers mounted on the seabed at depths of 60 m to 130 m, located in the four corners of the range plus one in the centre, as depicted in Fig 3. AUVs operating in the range are outfitted with a transducer that periodically emits an acoustic pulse. Pulse time difference of arrivals (TDOA) are used to localize the AUV using a method known as multilateration, and the IAS employs the IEEE 1588 precision timing protocol (PTP), allowing a precision of +/- 10 μs in clock timing (Lentz & Lecroart, 2009), a substantial improvement over the milliseconds-order accuracy offered by less precise network timing protocols typically employed in a data communication network.

2. METHOD

The analysis summarized here consists of two distinct studies, involving a ray-based Bayesian inversion algorithm developed to estimate AUV position and uncertainties. The first study estimates the non-linear localization accuracy for a target located within the range, based on a Monte Carlo method of estimating uncertainties of the source-location in x, y, and z. The second study maps the target positional uncertainty as a function of position within the range by estimating the linearized posterior uncertainties of the source-location in x, y, and z, as well as the lateral uncertainty in $r = [x^2+y^2]^{1/2}$.

2.1 Linearized Uncertainty Model

Each simulation is executed for three distinct test cases which were developed to simulate target positions representing a favourable source-receiver geometry (test case 1), a poor source-receiver geometry (test case 2), and an average over geometries in terms of a series of random source positions drawn from within the range (test case 3). The simulation scenarios were developed to investigate: (1) modelling transmission paths accounting for refraction due to a depth-varying SSP instead of using straight rays through a constant sound-speed approximation, (2) inverting for a potential sound-speed bias in the measured profile, (3) accounting for errors in hydrophone position by including these positions as unknowns in the inversion, and (4) applying path correction factors to account for lateral variability in the sound-speed profile. Each scenario is studied using a Monte Carlo method in which a large number of noisy data sets are inverted to derive statistical measures to quantify the various effects. In addition, inversions for scenarios 2–4 are carried out for a single source transmission, as well as for 20 source transmissions, to determine the degree to which the over-determined inverse problem improves localization accuracy. Linearization error is computed by comparing the results of the non-linear Monte Carlo analysis to the linear uncertainty estimates of the model covariance matrix.

2.2 Linearized Uncertainty Model

Once linearization errors are verified as described above, the posterior uncertainties of the source-location in x, y, z and r are calculated. Since the source-location uncertainty varies with source location, uncertainties are calculated for the source at each point within a grid of positions over the area of the test bed. At each grid point, the source-location uncertainties are estimated using a linearized Bayesian approach that includes the effects of arrival-time errors as well as uncertainties in hydrophone locations and sound speed. A complete description of these methods can be found in Dosso & Ebbeson (2006).

3. RESULTS

Monte Carlo analysis of the scenarios described in Sec. 2.1 were carried out, and the results from scenario 1 are shown in Fig. 1, while the results from a test that combines the factors described in scenarios 2–4 into a single inversion are shown in Fig. 2.

Comparing results when inversions are based on straight rays versus refracted (curving) rays, Fig. 1 shows systematic

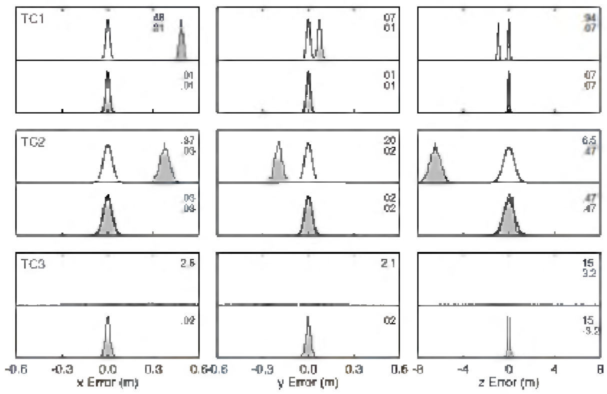

Figure 1. Histogram of errors for x, y, and z (left, centre, and right panels, respectively) for test cases 1, 2, and 3 when inversions are based on straight rays (top distribution in each panel) and refracted rays (bottom distribution). RMS errors and standard deviations (except for TC3) in metres are given in each panel.

error in the straight-ray model that biases the target position away from the true position. With the curving-ray model, however, results show excellent agreement with the true locations, and linearization error, shown in the difference between histogram results and the linearized uncertainty estimate from the continuous line in TCs 1 and 2, is seen to be small.

Figure 2 shows that localization results are substantially improved when the sources of error described in scenarios 2–4 are inverted for as parameters in the model, and linearization errors are much reduced. Over-determined

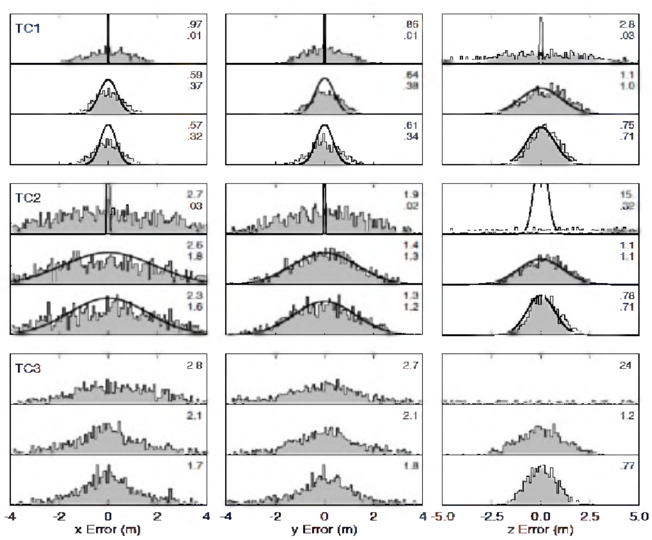

Figure 2. Histogram of errors for x, y, and z for test cases 1, 2, and 3 when sound speed bias, hydrophone positions, and path correction factors are not included as inversion parameters (top distributions), when these factors are included as inversion parameters for 1 source transmission (middle distributions), and for 20 source transmissions (bottom distributions). RMS errors and standard deviations (except for TC3) are given in metres.

inverse problems, where data from 20 source transmissions are inverted rather than from a single transmission, show improved positional accuracy, particularly in z.

Since linearization errors are shown to be small for the test cases investigated above, linearized uncertainty estimates can now be used to estimate target positional uncertainty for locations throughout the range (Fig. 3) with a high level of confidence. Figure 3 shows that the lateral component of uncertainty is lowest for target locations towards the centre of the range, while the vertical uncertainty is lowest when the target is located above a hydrophone.

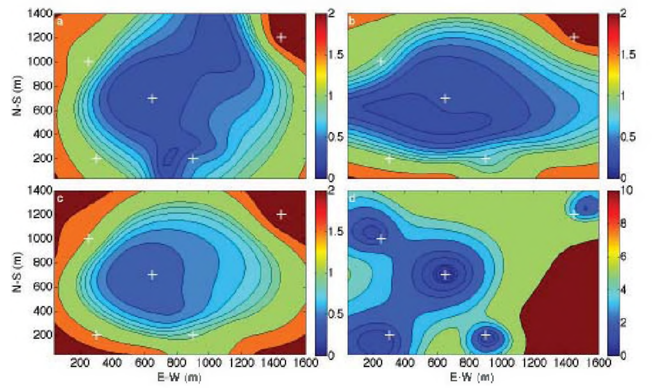

Figure 3: Linearized localization u over the range. Panels (a)-(d) show absolute errors in x, y, r, and z, respectively, for a source at 10-m depth. Contours represent uncertainty in metres. Hydrophone locations are depicted as white crosses.

4. DISCUSSION

The modeling studies described in this paper served as simulation tests for a ray-based Bayesian inversion algorithm developed for an acoustic positioning system for AUV localization in the IAS test range, which should become operational some time in 2012-13 within the VENUS infrastructure, and will serve as an functional ‘ground truth’ test bed for AUV operations.

REFERENCES

Lentz, S. & Lecroart, A. (2009). Precision timing in the NEPTUNE Canada network. *OCEANS 2009-EUROPE*, 1-5.

Dosso, S.E. & Ebbeson, G. (2006). Array element localization accuracy and survey design. *Canadian Acoustics*, 34(4), 1-11.

Thomson, D., Dosso, S. E., Gamroth, E., & Bradley, C. (2012). Modelling Uncertainty in an Underwater Acoustic Positioning System. *Canadian Acoustics*, *40*(1), 30–37.

AUTHOR NOTE

This work was conducted while Thomson was a student at the University of Victoria (2012).