THE EVOLUTION OF AN ACOUSTIC HOMING SYSTEM FOR UNDERWATER VEHICLES

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1. INTRODUCTION

Project Cornerstone was a joint Natural Resources Canada and Defence R&D Canada project using deep diving Autonomous Underwater Vehicles (AUV) to assist in the mapping of the Arctic seafloor in support of the Canadian submission to the United Nations Convention on the Law Of the Sea (UNCLOS). The project made use of a pair of modified International Submarine Engineering Explorer AUVs [1]. One of the modifications added to the AUVs was the Long-Range Acoustic Bearing (LRAB) homing system developed at DRDC (patent applied for). This brief paper describes the initial testing of the homing concept, the Explorer version of the LRAB, and a new first-stage of system miniaturization that will allow the homing device to be used in medium-sized AUVs.

2. CONCEPT TESTING

Figure 1 shows the Concept Test Array (CTA) being tested in a tent on the shore-fast ice at CFS Alert during spring 2009. The CTA was built with PVC tubes and plate. Seven hydrophones of an available analogue array, each on a separate cable, were used to provide the CTA receivers.

The CTA was lowered to mid-water depth, while a portable source was moved to a number of different locations around the central location of the CTA. Data were collected for various frequencies, source levels, and source depths.

Following the trial, the data were analyzed and a robust bearing estimation algorithm was developed. Results from the initial tests were good and proved the concept to be viable.

Figure 1. An initial Concept Test Array being readied for testing under the ice at CFS Alert.

3. FIRST GENERATION LRAB

DRDC and Omnitech Electronics have developed a low-cost, low-power, digital array technology that has been used to develop a number of different underwater sensing platforms such as the Northern Watch Underwater Sensing System [2]. This array technology is eminently suitable for the necessarily power conscious application of acoustic homing in the limited energy environment of an AUV.

A contract was established with Omnitech Electronics Inc. who used the DRDC digital array technology to construct a seven-element receiving array and a small, low-power processor, which interacts with the AUV control computer to provide relative bearings to the acoustic signal source. Figure 2 shows the seven-element, first generation, LRAB mounted in the nose cone of an Explorer. Figure 3 shows the processor unit that is mounted within the AUV pressure hull. This processor handles all of the AUV acoustic telemetry and when desired provides bearing and altitude estimates of the acoustic source relative to the vehicle's longitudinal axis.

Figure 4 illustrates the results of acoustic homing under the ice in the Arctic Ocean near the Sever Spur during spring 2010. The AUV activated the homing mode when it was expected to be within 50 km of an ice camp that was drifting freely. The 300-km trek required almost three days of travel time for the AUV during which the ice camp moved a significant distance. The abrupt course change at ‘Homing Start’ is a consequence of the unknown camp drift.

The inset in Figure 4 shows the tight maneuvers of the AUV when it arrived at the camp location. The AUV was forced to

Figure 2. The LRAB array in the ISE Explorer nose cone.

appropriate N_S given the measured data **d**. In Baye's rule, Eq. (1), the conditional probability $P(\mathbf{d}|N_S)$ may be considered the likelihood of N_S, and is referred to as the Bayesian evidence for N_S. Since the evidence serves as a normalizing factor in Bayes' rule it can be written

$$P(\mathbf{d} \mid N_S) = \int P(\mathbf{d} \mid \mathbf{m}, N_S) P(\mathbf{m} \mid N_S) d\mathbf{m}. \tag{7}$$

Unfortunately, numerical solution of this integral is not practical for all models sampled in the localization algorithm. Rather, an asymptotic point estimate, the BIC, is applied here:

$$-2\log_e P(\mathbf{d} \mid N_S) \approx BIC = -2\log_e L(\hat{\mathbf{m}}, N_S) + N_S \log_e N_d \tag{8}$$

where $\hat{\mathbf{m}}$ is the ML source location obtained by minimizing Eq. (6) and N_d is the number of data. As the BIC is based on the negative log likelihood, low BIC values are preferred. The first term on the right of Eq. (8) favours models with low misfits; however, this is balanced by the second term which penalizes unjustified free parameters. Minimizing the BIC provides the smallest number of acoustic sources which fits the data to within uncertainties, or, conversely, the largest number of sources resolved by the data.

The multiple-source localization algorithm developed here optimizes over the number and locations of acoustic sources, as well as complex sources strengths and noise variance at each frequency, by minimizing the BIC. This minimization is carried out by applying heat-bath (Gibbs sampling) simulated annealing with fast cooling. Source locations are treated as explicit parameters, and source strengths and variances as implicit parameters. Each iteration of the simulated annealing process consists of Gibbs sampling each location parameter as well and an attempt to either add or remove a source. Sources are added by Gibbs sampling from the conditional probability distribution defined by the existing sources, and when sources are removed the remaining sources are Gibbs sampled to compensate for the change in acoustic fields. Implementation of the implicit formulation, Eq. (6), requires a large number of complex matrix inversions which are handled efficiently using a parallel implementation of Gauss-Jordan elimination that is stable without pivoting since the matrices are diagonally dominant.

3. EXAMPLE

This section presents a (simulated) example of the multiple-source localization algorithm involving 2 submerged sources and 3 louder near-surface interfering sources, with acoustic fields recorded at $N_F = 3$ frequencies of 200, 300, and 400 Hz at a 24-hydrophone vertical array spanning a 100-m water column. The ranges, depths, and signal-to-noise ratios (SNR, taken to be constant over frequency) of the sources are as follows: source 1 (8 km, 4 m, 10 dB), source 2 (3 km, 2 m, 8 dB), source 3 (5.5 km, 2 m, 6 dB), source 4 (4 km, 30 m, 4 dB), and source 5 (6 km, 60 m, 0 dB). The source search region is 0-10 km in range and 0-100 m in depth, with from 1 to a maximum of 7 sources allowed in the search. This formulation includes a total of $2N_S\ (1+N_F)+N_F$ (real) unknowns (e.g., up to 51 for 6 sources), of which $2N_S$ are treated as explicit parameters and the remaining as implicit parameters.

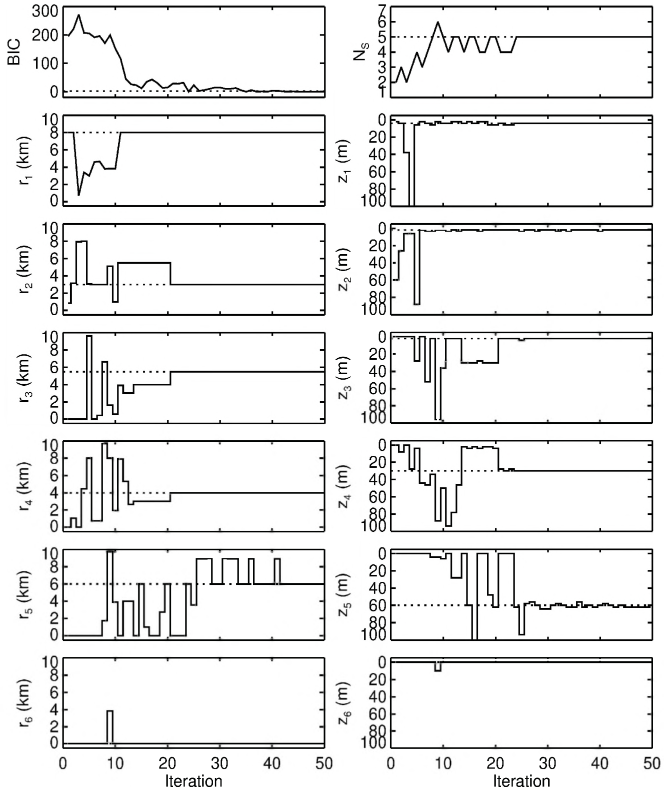

Figure 1. Inversion results as a function of simulated annealing iteration for BIC, number of sources, and ranges and depths of up to 6 sources (a maximum of 7 sources was allowed, but never accepted in the inversion). An absent source is assigned zero range and depth. The BIC is arbitrarily shifted so the minimum value corresponds to zero. Sources are ordered according to SNR. Dotted lines indicate true values.

The results of the localization are shown in Fig. 1. The BIC drops quickly (although not monotonically) and the number of sources settles into the correct value of $N_S = 5$ by about iteration 30 of the simulated annealing process. All source ranges and depths are correctly determined by about iteration 40, with the order in which the sources converge approximately following that of decreasing source SNR (i.e., the highest SNR source converges first, followed by the second highest, etc.).

REFERENCES

[1] S.E. Dosso, 2012. Acoustic localization of an unknown number of sources in an unknown environment. Canadian Acoustics, **40**, 3-12.