ARRAY ELEMENT LOCALIZATION OF A BOTTOM-MOUNTED HYDROPHONE ARRAY USING SHIP NOISE

Gordon R. Ebbeson[1], I2ETA Laetitia Thierion[2] and Garry J. Heard[1]
[1]DRDC Atlantic, PO Box 1012, 9 Grove St., Dartmouth, NS, Canada, B2Y 3Z7, gordon.ebbeson@drdc-rddc.gc.ca
[2]ENSIETA, 2, rue François Verny 29806 Brest Cedex 9 – France

1. INTRODUCTION

The DRDC Atlantic Rapidly Deployable Systems (RDS) project was a major research effort whose purpose was to develop an array system that could be deployed in a few minutes and was capable of detecting and localizing sources of acoustic and electromagnetic energy traveling on or underneath the sea surface. For this system to be functional, the locations of the deployed sensors must be known with considerable accuracy. The three-dimensional sensor positions are obtained using a technique referred to as Array Element Localization (AEL). The AEL process is based on the linearized inversion of the measured arrival time data from a series of controlled impulse sources activated in a pattern around the array [1]. Traditionally, imploding light bulbs are used as the sources. Recently, researchers at the University of Victoria in BC [2] have been investigating the use of ship noise as a source of broadband energy for AEL. Encouraged by these results, ship noise was used to carry out AEL on two RDS bottom-mounted horizontal arrays that were previously localized using light-bulb pops. This paper describes the ship AEL method and presents the results for those two arrays.

2. ARRAY ELEMENT LOCALIZATION

AEL acoustic surveys conducted after the array has been deployed involve measuring the arrival times of the signals transmitted from a series of impulsive sources to the hydrophones that are to be localized. Given the sound speed profile in the ocean and the positions of the sources, these arrival times can be inverted to produce estimates of the array hydrophone locations. Ideally, the AEL inversion should address all sources of error in the environment and use all physical *a priori* information about the solution. For a bottom-mounted array, the exact positions and depths of both the sources and the hydrophones are unknown. However, *a priori* information about these parameters, that is, their nominal deployment locations, are often available. In addition, it is quite likely that the array was laid in a smooth curve. This constraint adds further information to the AEL process. Finally, any uncertainties in the sound speed profile can also be included in the inversion. If all of this information is taken into consideration and the corresponding uncertainties are kept as small as possible, the AEL technique will yield an accurate result.

3. Light-Bulb AEL

The AEL process with light bulbs utilizes the arrival that travels directly from the imploding light bulb to the hydrophone as the source of timing. The direct arrival time at each hydrophone is measured relative to some arbitrary start time. This measurement is easy to carry out as the direct arrival is always the first to arrive at the hydrophone [3].

Figure 1 shows the AEL results for a 22-sensor horizontal RDS array. The black triangles show the locations of the 14 light bulbs that were used for the localization. The light-bulb depths, which were measured with a depth recorder that was attached to the bulb breaker, were all very close to 42 m. The black squares of the figure show the sensor locations used to start the AEL process, which are based on the GPS positions of the start and finish of the array deployment. The hydrophone depths were taken from the measured bathymetry around the array and were all estimated to be 67.7 m. The uncertainties in the source positions in Easting, Northing and depth were set to 5, 5 and 2 m, respectively. Those for the hydrophones were set to 150, 150 and 2 m, respectively. In addition, the uncertainty in the sound speed profile was assumed to be 1 m/s. To ensure convergence, an uncertainty of 0.1 ms in the direct arrival times was required. After 20 iterations of the AEL inversion, the hydrophones were localized to the locations shown by the grey triangles of the figure. The AEL result shows the curved shape that was the goal of the array deployment.

A longer, 34-sensor RDS array was localized in a similar manner and the results are shown in Fig. 2. In this case there were 16 light bulbs (black triangles) that were imploded at depths near 40 m. Once again, the black squares show the starting array locations and the hydrophones were all assumed to have a depth of 67.7 m. The uncertainties in the source and hydrophone locations and depths, and the sound speed profile were the same as for the shorter array. An uncertainty in the direct arrival times of 0.1 ms was required to ensure convergence. After 11 iterations, the AEL inversion localized the hydrophones to the slight "S" shape shown by the grey triangles of the figure. This was the shape that was intended at the time of the deployment.

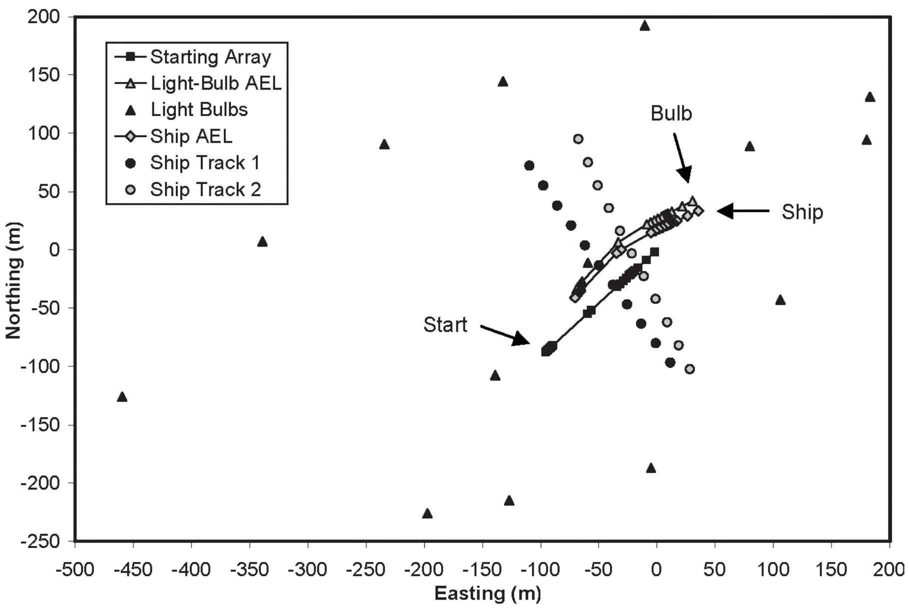

Fig. 1. AEL results for the 22-sensor array.

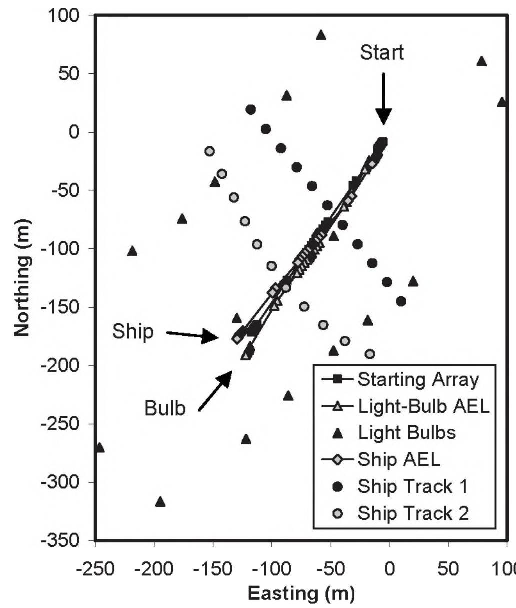

Fig. 2. AEL results for the 34-sensor array.

4. Ship AEL

The AEL process with broadband ship noise also uses the direct arrivals that reach the hydrophones. However, since the ship noise is continuous in time, the ship-AEL method relies on measuring the time delays between the first hydrophone in the array and the remaining hydrophones. This is done by taking the cross-correlation between these hydrophones. Unfortunately, determining a time delay for the direct arrival is not easy as it is often bracketed in time by the delays for the other arrivals. Tracking the delays with ship movement helps in the arrival identification. To increase the measurement accuracy of the time delays, the time series of the ship noise were interpolated in time before carrying out the cross-correlation. In addition, a frequency domain cross-correlation technique was used in order to suppress the narrow band lines in the ship noise [4].

Figure 1 shows the results of the ship AELT for the 22-hydrophone array. The black and grey circles mark the 22 segments of the ship tracks that were used for the localization. Each segment contained 4.1 s of broadband noise. The depth of the ship's propeller, which was 1.2 m, was taken as the source depth. The array starting locations and depths were the same as for the light-bulb AEL (black squares) as were the uncertainties in the source and hydrophone locations and depths, and the sound speed profile. For the AEL process to converge, an uncertainty of 0.13 ms in the direct arrival times was required. After 15 iterations of the AEL inversion, the hydrophones were localized to the locations shown by the grey diamonds in the figure. These AEL results compare extremely well with the light-bulb AEL results (grey triangles).

The ship AEL results for the 34-hydrophone array are shown in Fig. 2. Once again, 22 segments of ship noise, each 4.1 s long, were chosen for the noise sources (black and grey circles). Also, the array starting locations and depths were the same as for the light-bulb AEL (black squares) as were the uncertainties in the source and hydrophone locations and depths, and the sound speed profile. With an uncertainty of 0.37 ms in the arrival times, the inversion converged after 9 iterations and localized the hydrophones to the locations given by grey diamonds of the figure. Once again, these ship-AEL results are very close to the light-bulb AEL results (grey triangles).

5. Summary

Initial efforts using broadband ship noise for AEL have provided encouraging and fast localization results. Proper identification of the direct arrival time differences is the most difficult aspect of the ship noise technique.

REFERENCES

[1] Dosso, S.E. and Ebbeson, G.R. (2006) "Array Element Localization Accuracy and Survey Design", Can. Acoust., Vol. 34, No. 4, 3-13.

[2] Morley, M.G., Dosso, S.E. and Chapman, N.R (2007) "Array element localization using ship noise", http://pruac.apl.washington.edu/abstracts/Morley.pdf.

[3] Ebbeson, G.R., Heard, G.J., Desharnais, F., Matthews, M.N.R. and Dosso, S.E. (2007) "Array Element Localization of a Rapidly Deployable System of Sensors", DRDC Atlantic TM 2007-009.

[4] Knapp, C.H. and Carter, G.C. (1976) "The Generalized Correlation Method for Estimation of Time Delay," IEEE Trans. Acoust., Speech and Signal Processing, Vol. ASSP-24, No. 4.