

BOTTOM-MOUNTED ARRAY SHAPE ESTIMATION USING SHIP RADIATED NOISE

Yanqun Wu, Zhuang Cheng, Dezhi Wang, Zemin Zhou, Yongxian Wang and Wen Zhang

yqwu_nudt@163.com, zcheng96@163.com, wang_dezhi@hotmail.com,
zzm@nudt.edu.cn, yxwang@nudt.edu.cn, zhangwen06@nudt.edu.cn

Contact author: Yanqun Wu, Academy of Marine Science and Engineering, National University of Defense Technology, Changsha, China, 410073

Abstract: *Bottom-mounted array shapes are often uncertain during the deployment, which greatly degrades the estimation performance of the target directional-of-arrival and localization algorithms. Recent research interests in solving inversion problems with ship noise are increasing due to its several advantages, including reduced environmental impact, low cost and easy implementation of trials. By utilizing the broadband nature of ship noise, the auto/cross correlations between sensors reveal the multipath structures in ocean waveguide. The paper presented an array shape estimation method by matching multipath cross-correlation peaks between the candidate sensors and the reference sensor from a cooperative ship. The validation was performed using two sets of horizontal array data collected during event S5 of SWellEx-96 Experiment. It is shown that the results are in good agreement with those by the matched field inversion method (W. S. Hodgkiss, et al. Array Shape Estimation from Sources of Opportunity. Oceans 2003 Proceedings, vol. 1, 582-585). The applicability of the proposed method was analysed using 50-min data when the ship-to-array range spanned from around 600m to 4000m. It's found that when the ship passes the array at the Closest Point of Approach (CPA), peaks in multipath cross-correlations between further spaced receivers are smeared at a given integration time. Consequently, the method in the paper is effective to estimate the bottom array shapes using radiated noise of ships at a distance of tens of water depth.*

Keywords: *Bottom-mounted array, array shape estimation, ship noise, multipath cross-correlation.*

1. INTRODUCTION

The accurate knowledge of the locations of each receiver in an array is often a prerequisite for the target directional-of-arrival (DOA) estimation and localization algorithms [1]-[3]. However, for a bottom-mounted array, there are several uncontrolled and uncertain factors during its deployment, which results in a different array shape from the expected one. Most of array shape estimation techniques demand one or more known active sources, which are costly and complex in the sea trials.

Recent research interests in solving this problem with passive sources, especially ship noise, are increasing due to its several advantages, including reduced environmental impact, low cost and easy implementation in sea trials [2]-[4]. Morley et al. applied the relative arrival times of a passing-by ship noise between pairs of hydrophones to invert both the hydrophone and ship locations based on iterated linearization of the acoustic ray equations [2]. Sabra et al. extracted the travel times between the elements of a bottom hydrophone array from the time-averaged ambient noise cross-correlation function (NCF), and conducted the array element self-localization (AESL) and array element self-synchronization (AESS) [3]. Both methods utilize the coherent part of the broadband passive sources at any two receivers of the array.

The paper introduces a practical array shape estimation method by matching multipath cross-correlation peak and a passing-by ship of known GPS. Section 2 presents the theory of the array shape estimation method. To validate the algorithm, Section 3 provides the analyses of the data in SWelLEX-96 during which two horizontal linear array (HLA) collected the radiated noise of the R/V Sproul [5]. Section 4 concludes the study.

2. THEORIES OF THE ARRAY SHAPE ESTIMATION

Assume all the receivers of the bottom mounted array are the same depth as the water depth, and the number of the receivers is N . Without loss of generality, let the first receiver be the reference sensor with the position \mathbf{r}_1 , and the range between the n th receiver and the first one be $R_{n1} = \|\mathbf{r}_n - \mathbf{r}_1\|$, where $\mathbf{r}_n = [x_n, y_n, H]^T$ and H is the water depth.

The ship radiated signal is characterized as broadband noise, and the cross correlation is helpful to extract the coherent ship noise between the n th receiver and the first one, that is [4]

$$c_{n1}(\tau) = E\{p(t, \mathbf{r}_1) p(t + \tau, \mathbf{r}_n)\} \quad (1)$$

Where $p(t, \mathbf{r}_1)$ and $p(t + \tau, \mathbf{r}_n)$ are the pressure signals for the first and n th receivers, respectively; $E\{\cdot\}$ is the expectation operator.

From the source-receiver geometry shown in Fig. 1, the source and every receiver are a vertical plane. The waveguide is assumed to be isotropic so that the environment for each slice of the vertical plane is the same. Due to the multipath effect in the shallow water, each receiver measures the multipath arrivals from the source. If the ship noise is broadband enough, the cross-correlation between a pair of receivers in a limited aperture

array will show several peaks due to coherent arrivals from the source to two receivers, which are called multipath cross-correlations in the paper.

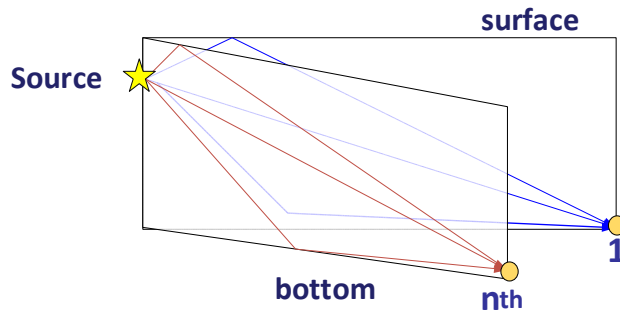


Fig.1: Reflection coefficient at the water-sediment interface for the sediment types listed in table 1.

The process of the array shape estimation is provided in Fig. 2. Firstly, the time delays extracted from the multipath cross-correlations are used as a template. Secondly, to match these correlation time delays, an acoustic propagation model Bellhop is used here to simulate them under the known environment and potential candidate receiver positions [6]. If the relative position of the ship and the reference receiver is a prior, a brute-force search is applied for estimation of positions of all the other receivers. Note that the array length between the neighbour sensors is always known once the array is fabricated. This information is used as a constraint for the sensor positions in order to reduce the computation load. Finally, the simulated correlation peaks are selected and matched with the template.

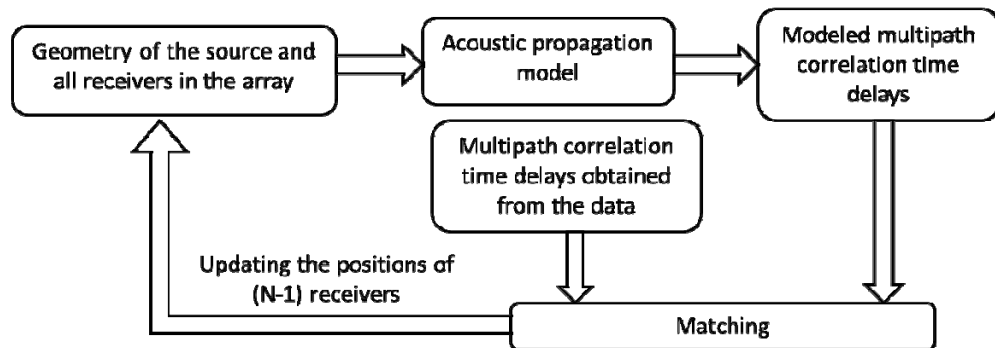


Fig.2: Diagram of the process of the array shape estimation.

3. ANALYSIS OF EXPERIMENTAL DATA

The SWellEx-96 Experiment was conducted between May 10 and 18, 1996 near San Diego, California and the data during Event S5 and Event S59 is available on the Internet [5]. Two horizontal line arrays (HLAs) were deployed on the seafloor and distinguished as northern and southern HLA's. Acoustic sources, towed from the R/V Sproul, transmitted various broadband and multitone signals at frequencies between 50 and 400 Hz. It's found during Event S5, the radiated noise of the ship R/V Sproul was collected by both HLA arrays.

To keep away from the transmitted signals, the noise in the frequency band between 400Hz and 700Hz was used for cross-correlation. Using the data at 35min of S5 track, the cross correlations between the 1st and the other receivers are shown in Fig. 3(a). By extracting the multipath time delays and matching them, the estimated sensor spacing R_{n1} between the n th and 1st receivers is given in Fig. 3(b), and compared with the result using the MFP method by Hodgkiss et al. [1]. Here the MCC represents the multipath cross-correlation method in the paper. It can be seen that both results are consistent with each other.

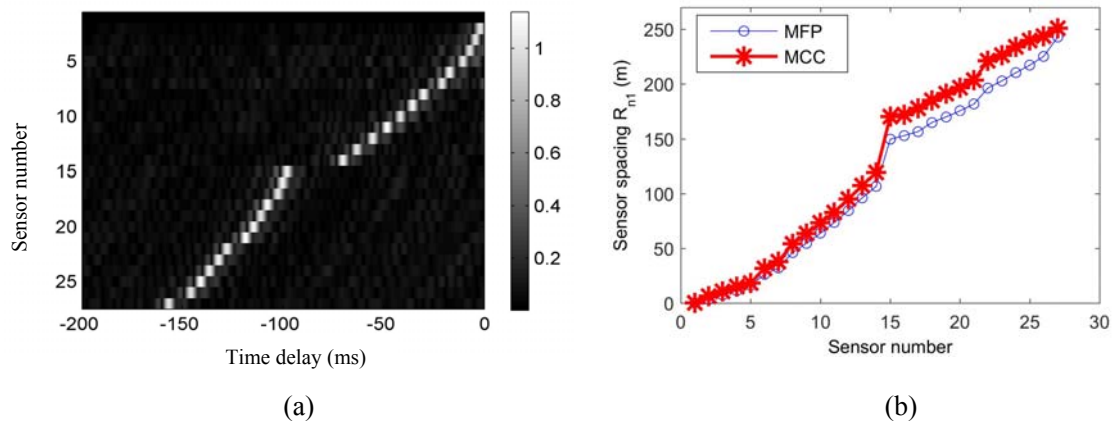


Fig. 3 (a) Cross correlations between the sensors and the reference sensor using the data at 35min of S5 track; (b) Comparison of the estimated sensor spacing R_{n1} between the n th and 1st receivers between the MCC method (the method in the paper) and the MFP method.

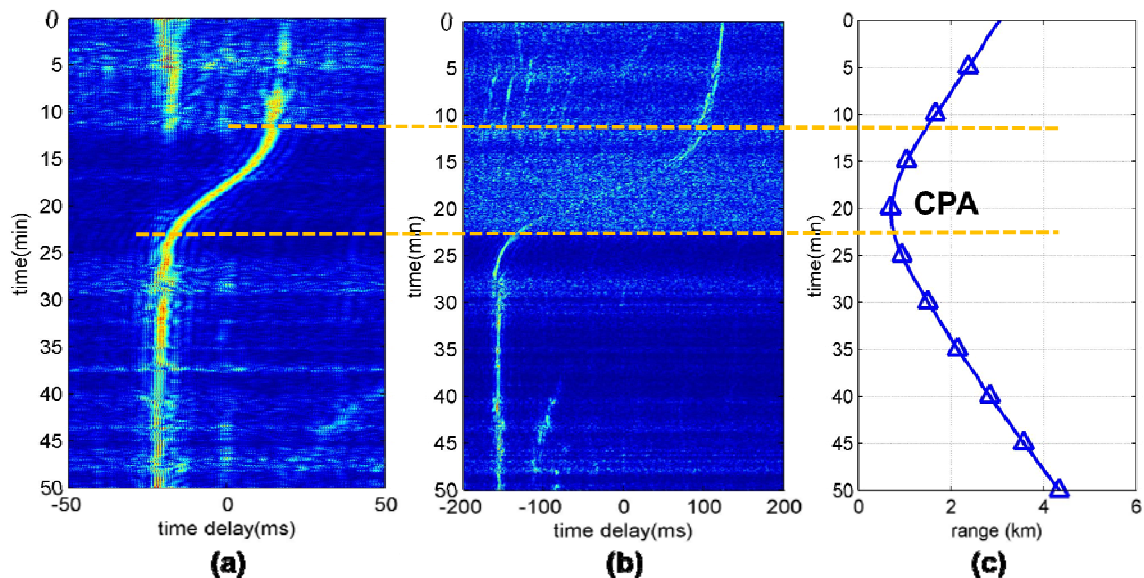


Fig.4: Event S5: (a) Cross-correlation between the 7th and 1st receivers; (b) Cross-correlation between the 27th and 1st receivers; (c) Range R_s from the ship Sproul to the center of the HLA North.

The effectiveness of the MCC method depends on whether the peaks in the cross-correlations are smeared in the noise or not. The multipath cross-correlations between

sensors are examined by 50 min data collected by the HLAN in S5 track, as shown in Fig.4 (a) and (b). It is found that cross-correlations between the 7th and 1st receivers have clear multipath peaks from 7min to 38min, which correspond to R_s of less than 2km, where R_s is the range from the ship Sproul to the centre of the HLA North. By contrast, multipath peaks of cross-correlations between the 27th and 1st receivers are ambiguous during 10 min to 25 min. According to the source-receiver range in Fig. 4(c), the source passed the range at the Closest Point of Approach (CPA) at that time. Moreover, as shown in Fig. 5, when the source passes the CPA, the range differences between the 27th and 1st receivers change faster than that between the 7th and 1st receivers. Consequently, with a given integration time, the signal-to-noise ratio (SNR) in the cross-correlation between the 27th and 1st receivers is too low to show the correlation peaks.

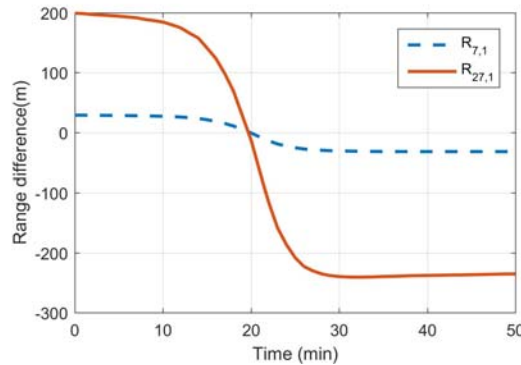


Fig.5: The range differences versus time (min), where $R_{7,1}$ is the range difference between the 7th and 1st receivers, and $R_{27,1}$ is that between the 27th and 1st receivers.

4. CONCLUSIONS

The paper inverts the bottom-mounted array shape by extracting the multipath time delays from the cross-correlations between two receivers in the array. The data in SWelLEX-96 validated the method and the results are consistent with the MFP result by Hodgkiss et al. Furthermore, it's found that the coherent part from a passing-by ship noise is emerged to show clear multipath peaks, and the peaks are clear even when the source-receiver range is more than 4km. Besides, when the ship passes the CPA, the cross correlation peaks between receivers of further spacing are smeared at a given integration time, which may result in the performance degradation of the method in the paper.

5. ACKNOWLEDGEMENTS

This work is supported by the National Key R&D Program of China (No.2016YFC1401800), and the Scientific Research Project of National University of Defense Technology under Grants No. ZK16-03-31, No. JC15-11-01, and No. JC14-07-03.

REFERENCES

- [1] **W. S. Hodgkiss, P. Gerstoft, and J. J. Murray**, Array shape estimation from sources of opportunity [C], *Oceans 2003 Proceedings*, vol. 1, pp. 582-585, 2003.
- [2] **M. G. Morley, S. E. Dosso, and N. R. Chapman**. Array element localization using ship noise [J], *J. Acoust. Soc. Am.*, vol.125 (3), pp. 1403-1409, 2009.
- [3] **K. G. Sabra, P. Roux, A. M. Thode, G. L. D'Spain, W. S. Hodgkiss, and W. A. Kuperman**. Using ocean ambient noise for array self-localization and self-synchronization [J], *IEEE Journal of Oceanic Engineering*, 30(2), 338-347, 2005.
- [4] **Yanqun Wu, Ana Bela Santos, P. Felisberto, and S. M. Jesus**. Close range ship noise cross correlations with a vector sensor in view of geoacoustic inversion [C], *IEEE/OES COA 2016*, pp. 1-5, 2016.
- [5] **N. O. Booth, W.S. Hodgkiss, D.E. Ensberg**. SWellEx-96 Experiment Acoustic Data. UC San Diego Library Digital Collections. <http://dx.doi.org/10.6075/J0MW2F21>, 2015.
- [6] **Porter M B**. The Kraken normal mode program, user's manual. SACLANT Undersea Research Centre, La Spezia, Italy, 1991.