Underwater Source Localization in a Tank with Two Parallel Moving Hydrophone Arrays

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Abstract—**Presently the synthetic aperture technique is widely used especially for the case where higher resolution images are needed. Synthetic aperture sonar (SAS) in the passive mode is one of the good examples that use this technique. Recently KIRSO performed a tank experiment for high resolution underwater source localization using two horizontally moving linear hydrophone arrays. The frequency interpolation and back projection algorithms are applied for obtaining SAS images. The precise source location can be identified in the horizontal plane whereas the vertical resolution is poor. However, we can conclude that the SAS processing is a more efficient method than the conventional beamforming algorithm. A simulation with the same configuration is also performed in order to verify the SAS algorithms and the results are very similar to the experimental analysis.**

Keywords—underwater source localization; beamforming; synthetic aperture processing; two parallel linear array; tank experiment

I. INTRODUCTION

Synthetic aperture (SA) processing was originally introduced for radar systems and widely used to get high-resolution images for various commercial and military applications [1]. Recently it has been applied to other areas such as sea-floor imaging using a synthetic aperture sonar (SAS) [2-3]. Many researchers believe that it will replace traditional sonars due to its high resolution with relatively high coverage rate. Although most SAS systems are operated in the active mode, the passive technique can be also applied for precise source localization [4]. In order to detect underwater targets towed array systems have been used over several decades [5]. Since the estimation of array shapes was not an easy procedure real applications are generally limited to low frequency ranges. However, as technologies related to autonomous underwater vehicles (AUVs) improve a fixed-shaped array installed on an AUV will take an important role for underwater source localization as well as SAS imaging. Interferometry is another advanced technology which enables us to have depth information [6-7].

In 2013 Korea Research Institute of Ships and Ocean Engineering (KRISO) has performed an experiment in a tank, the goal of which was to develop a signal processing method for high-precision localization [8]. At that time an array of hydrophone was used for source localization. For the three-dimensional source localization with depth information KRISO performed another experiment during which we used two parallel arrays of hydrophones. In this paper preliminary experimental results are described. For the generation of SAS images a couple of synthetic aperture techniques (frequency interpolation and back projection) [1] are used. The analysis algorithms are confirmed by numerical simulations and the both results are compared. The SAS images are also compared with beamforming power obtained by the conventional beamforming method.

II. DESCRIPTION OF THE EXPERIMENT

In July 2015 a tank experiment has been done. Its main purpose is to develop and verify high precision source localization algorithm with moving hydrophone arrays. As a basic step we used two parallel linear arrays moving along the same direction of the arrays with a constant speed. One omni-directional transducer was fixed in a tank as an acoustic source and it was located at a depth of 1.5 m. Two horizontal linear arrays of eight standard hydrophones were used as the receivers and they were fixed to a pole which was installed at the moving carriage over the tank. Horizontal sensor spacing was 30 mm which corresponds to about half wave-length for 20 kHz sound and vertical array spacing was 150 mm. The depth of the array center was set to 1.5 m and 0.8 m. Fig. 1 illustrates the photos of the hydrophone arrays.

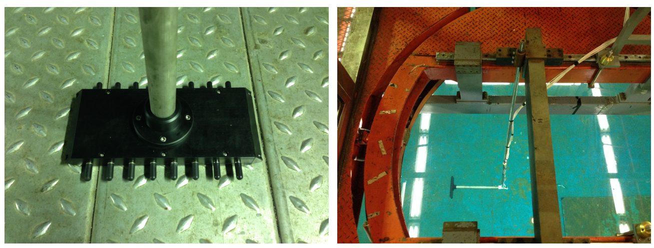

Fig. 1. Photos of the hydrophone arrays (a) out of water (b) in the water tank

This work is a part of the results of the research project (code number PES1940) funded by KRISO.

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The dimension of the tank is about 50 m × 35 m and the water depth is 3.2 m. The used coordinate system is shown in Fig. 2. The source was located at x = 0 m and the position of the array center spanned from x = -10 m to x = 10 m. The moving speed of the carriage varied from 0.05 m/s to 1 m/s in both positive and negative x-axis directions. The default horizontal distance between the source and the array was 5 m. The detail set-up is illustrated in Fig. 3. Each figure shows the configuration at different point of view. As shown in Fig. 3 the channel numbering starts from left to right (-x to +x direction) and top to bottom (-z to +z direction).

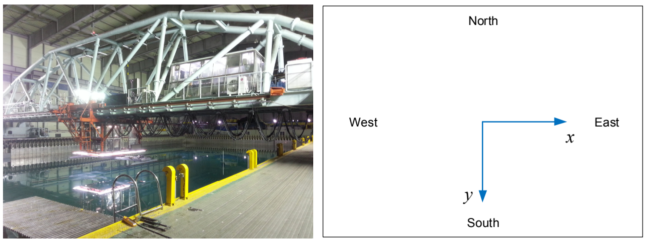
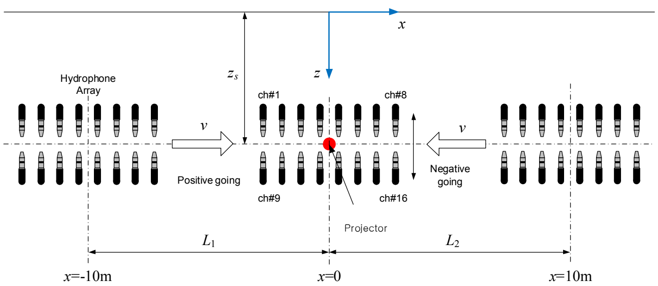
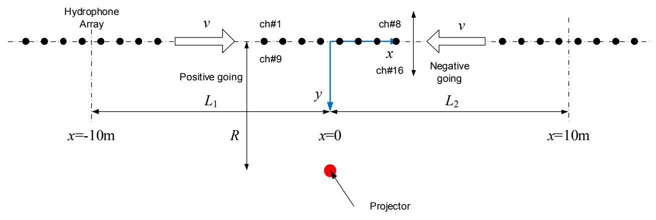


Fig. 2. Water tank (a) photo of the tank with a moving carriage (b) the coordinate system used



(a) Front view



(b) Top view

Fig. 3. Experimental configuration

Fig. 4 shows the equipment set-up. The hydrophone signals were simultaneously sampled by using five four-channel DA converters. The source signal and carriage position data were also recorded for a reference. All data were sampled at 200 kHz.

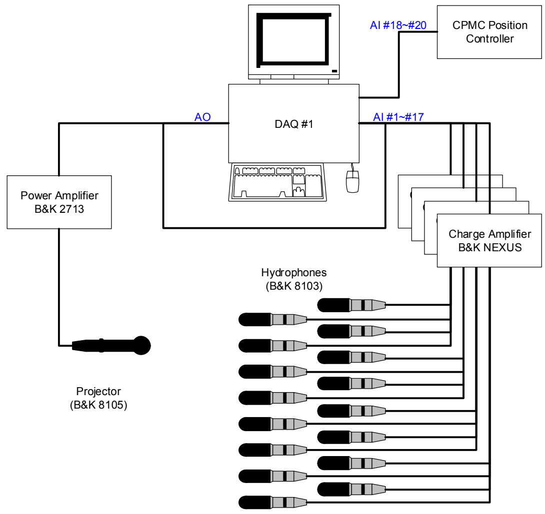


Fig. 4. Transducers and data acquisition equipment set-up

We used five kinds of source signals. They were continuous wave (CW) of a single tone, burst tone, linear frequency modulation (LFM), continuous binary phase-shift-keying (CW BPSK), and burst BPSK. Two signals had narrow-band spectrum and the others did broad-band ones. The center frequencies of all signals were 20 kHz. The pulse lengths of all burst signals were either 1 ms or 6.2 ms. The detail parameters are shown in Table I.

We also measured sound velocity profiles several times using an SVP. All measured data indicate that the average speed of sound is around 1465 m/s and the variation is limited by ±2 m/s.

TABLE I. PARAMETERS OF THE SOURCE SIGNALS

Signal Type	Parameters	Remark
CW Tone	20 kHz	
Tone Burst	20 kHz, 1 ms	Kaiser-Bessel Window
Chirp (LFM)	15-25 kHz, 1 ms	Kaiser-Bessel Window
CW BPSK	20 kHz, Rsym=5 kHz, 511 symbols	
BPSK Burst	20 kHz, Rsym=5 kHz, 31 symbols, 6.2 ms	Kaiser-Bessel Window

III. NUMERICAL SIMULATION

In order to verify the analysis procedure for the experiment we performed numerical simulation. For the generation of the received signals we used sonar channel modeling program developed by KRISO [9]. The configuration of the simulation was the same as the experiment except reflected waves. In the simulation only three paths (direct, surface-reflected, and bottom-reflected paths) were considered and perfect reflection was assumed at the top and bottom boundaries. Fig. 5 shows SAS images for the case where the array moving speed is 0.2 m/s in the positive direction. The frequency interpolation algorithm was used for the SAS processing. The left figure is obtained by using the upper array and the right one is by the lower array. From the results we can point out the image sources by reflection as well as we can identify the exact source position (x,y) = (0,5) m. Fig. 6 illustrates a vertical image obtained by using the back projection algorithm. The z-directional resolution is very poor because the vertical aperture size is only about 5λ long whereas the horizontal synthetic aperture is more than 200λ wide.

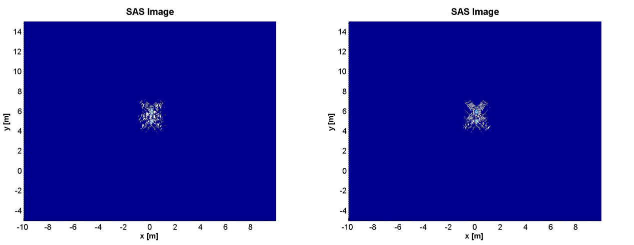


Fig. 5. Simulation result: SAS images obtained by using the frequency interpolation algorithm (array moving speed = +0.2 m/s) (a) upper array data (b) lower array data

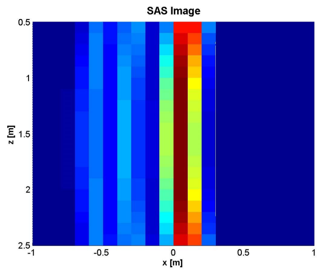


Fig. 6. Simulation result: SAS image obtained by using the back projection algorithm (array moving speed = +0.2 m/s)

IV. EXPERIMETNAL RESULTS

A. Conventional Beamfomring

Beamforming power is estimated by using the conventional beamforming technique assuming spherical wave source model. All channel data acquired at a fixed position are used for the process. Fig. 7 illustrates the results for the case where source signal is continuous tone. The two upper figures show beamforming power on the xy-plane at z = 0 and the lower ones xz-plane at y = 5. When the array position is at x = 0 the horizontal image seems to indicate the exact source position. However the resolution is very poor especially along y-axis direction. Moreover the vertical image (Fig. 7(c)) cannot identify the source location which is caused by poor vertical resolution and reflected waves in the tank. In the case where array position is at x = 5 m the conventional beamforming algorithm is not useful anymore. Fig. 8 is the results when the source signal is LFM. We can observe the same conclusion with that we have in Fig. 7. That means beamforming with broadband signal cannot be much help in localization of the source in a reverberant sound field such as in a water tank.

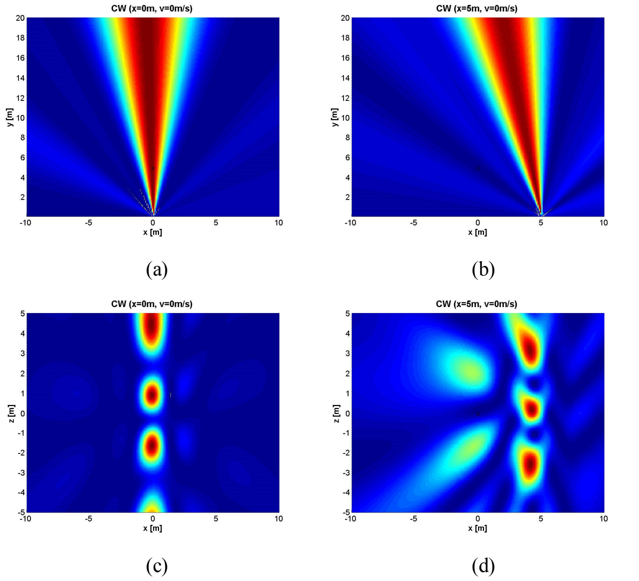


Fig. 7. Experimental result: beamforming power for the case where source signal is continuous tone (a) estimation plane: z = 0 m, array position: x = 0 m (b) estimation plane: z = 0 m, array position: x = 5 m (c) estimation plane: y = 5 m, array position: x = 0 m (d) estimation plane: y = 5 m, array position: x = 5 m

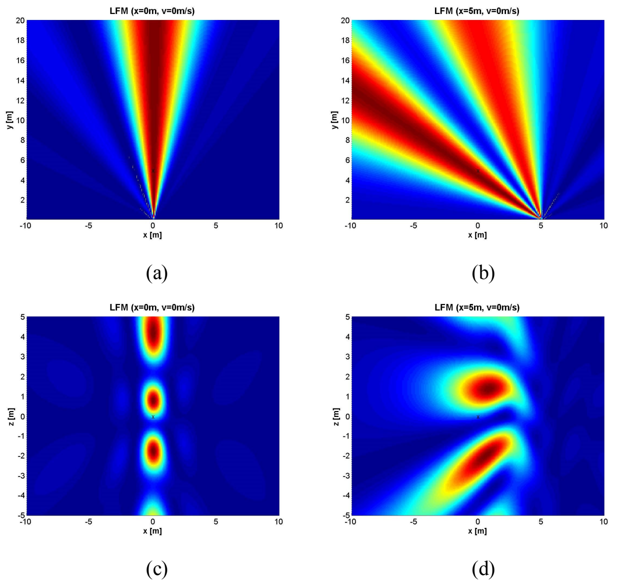


Fig. 8. Experimental result: beamforming power for the case where source signal is LFM (a) estimation plane: z = 0 m, array position: x = 0 m (b) estimation plane: z = 0 m, array position: x = 5 m (c) estimation plane: y = 5 m, array position: x = 0 m (d) estimation plane: y = 5 m, array position: x = 5 m

B. Synthetic Aperture Processing

1) Localization in the Horizontal Plane

In order to obtain horizontal SAS images the frequency interpolation algorithm is applied. Fig. 9 shows SAS data after matched filtering of received signal with the source signal. The left figure is the image obtained from upper array data and the right one is from lower array data. Since there are many reflections at surface and bottom boundaries many curved lines are observed and their locations in the images are slightly different.

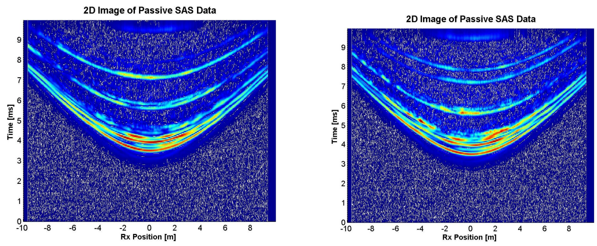


Fig. 9. Experimental result: 2D images of SAS data after matched filtering (source signal: LFM, array moving speed = +0.2 m/s) (a) from upper array data (b) from lower array data

Fig. 10 shows the final SAS images. As expected several sources are observed which is caused by surface reflection. However, the source location is exactly estimated with high resolution. The images are similar to the ones we observe in the simulation.

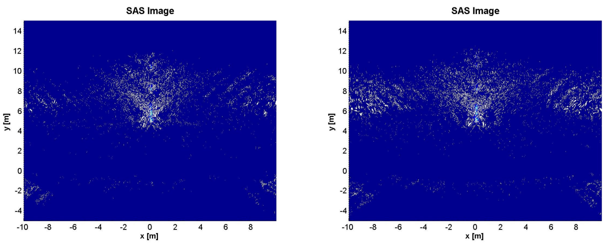


Fig. 10. Experimental result: SAS images obtained by using the frequency interpolation algorithm (source signal: LFM, array moving speed = +0.2 m/s) (a) upper array data (b) lower array data

For the cases where array moving speed is higher similar results are obtained except that SAS images become blurred.

2) Localization in the Vertical Plane

In order to find the source depth vertical SAS images are obtained by back projection algorithm using both upper and lower array signals. Fig. 11 depicts the results when array moving speed is +0.2 m/s. It is observe that z-directional resolution is much poorer than the horizontal one similar to Fig. 6. However we can find that the maximum value is located at the real depth of the source.

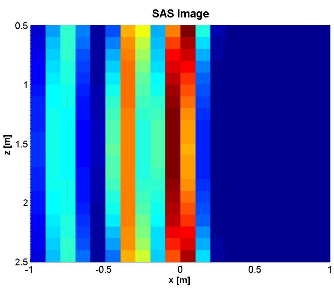


Fig. 11. Experimental result: SAS image obtained by using the back projection algorithm (source signal: LFM, array moving speed = +0.2 m/s)

V. Conclusion

A tank experiment has been performed for high resolution underwater source localization using a fixed source and two horizontally moving linear hydrophone arrays. Various kinds of source signals are transmitted and synthetic aperture techniques are applied for the localization. The horizontal resolution is much higher than the vertical one. Due to the surface and bottom reflections a few image sources are observed in the SAS images. A simulation with the same configuration is also performed in order to verify the SAS algorithms and the results are very similar to the experimental analysis. By comparing with the conventional beamforming algorithm we can conclude that SAS processing is more efficient in source localization.

Acknowledgment

The authors would like to thank Gunyoung Lee, who helped gather measurement data during the tank experiment.

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