Prototype Development of an Underwater Sound Measurement Module Using Four Hydrophones

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***Abstract*—Recently, Korea Institute of Geoscience and Mineral Resources (KIGAM) is developing an ocean surface/bottom multidisciplinary geophysical observatory that integrates hydroacoustic, seismic, and infrasound technologies. In 2014 Korea Research Institute of Ships and Ocean Engineering (KRISO) developed a prototype of a high-frequency underwater sound measurement module of detecting the hydroacoustic signal in the KIGAM system. The module detects incoming acoustic energy from all horizontal directions using four hydrophones. An array configuration of this module is the star-shaped topology, which is isotropic towards all incoming hydroacoustic signal directions and gives better beam resolution than the circular configuration under non-aliasing spacing condition. It is composed of a real-time signal processing device, a memory, a power controller, an Ethernet hub, a thermometer and a pressure sensor. This paper describes its system configuration and its important features. Also the experiment results of the prototype that was tested and verified in a water tank and at a pier are shown.**

Keywords—underwater sound measurement; detecting hydroacoustic signal; conventional beamforming; star-shaped topology; real-time signal processing;

I. INTRODUCTION

For the purpose of measuring vertical seafloor displacement related with submarine volcanic activities and earthquakes, National Institute of Geophysics and Volcanology (INGV, Italy) is operating Cabled Underwater Module for Acquisition of Seismological data (CUMAS) including a hydroacoustic measurement system [1]. Japan Agency for Marine-Earth Science and Technology (JAMSTEC) developed and is operating Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) to monitor crustal activities including earthquakes. A hydroacoustic measurement system has been also installed in the network [2].

Currently, Korea Institute of Geoscience and Mineral Resources (KIGAM) is developing an ocean surface/bottom multidisciplinary geophysical observatory that integrates hydroacoutic, seismic, and infrasound technologies. In 2014 Korea Research Institute of Ships and Ocean Engineering (KRISO) developed a prototype of a high-frequency underwater sound measurement module for detecting hydroacoustic signals which will be installed in the KIGAM system.

The module detects incoming acoustic energy above a certain sound pressure level from all horizontal directions using four hydrophones. The conventional beamforming algorithm is implemented to estimate incident angles. To improve the performance of the beamforming technique, an array of four hydrophones is arranged to a star-shaped topology [3-5]. It is composed of a real-time signal processing device, a memory, a power controller, an Ethernet hub, a thermometer and a pressure sensor. Also it includes fixed frames for installing the module on the seafloor.

In order to verify the performance of the prototype module, we performed two performance tests in a water tank and at a pier. As a results, we verified the detection performance of the prototype module through estimating incident angles from the underwater sound source.

The remainder of this paper is organized as follows. Section Ⅱ describes array configuration and system configuration of the developed prototype module. Section Ⅲ presents experiment results of the performance of the module in a water tank and at a pier. Section Ⅳ presents a conclusion and future plans.

II. DESCRIPTION OF THE MODULE

A. Array Configuration

The developed module detects incoming hydroacoustic signal from all horizontal directions using the conventional beamforming algorithm. To improve the performance of the beamforming technique, we derived a sensor spacing condition to minimize aliasing error in the cases where an array of four hydrophones is arranged to a star-shaped topology and a circular-shaped topology [3-4]. We found that the star-shaped topology could reduce the aliasing error more than the circular-shaped topology. Additional analysis in terms of their

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beamwidth and side-lobe level verified that the star-shaped topology is efficient for the beamwidth while the circular-shaped topology ensures good the side-lobe behavior [5]. Fig. 1 illustrates the array configurations for a numerical simulation. Fig. 2 shows the beamwidth performance of the main-lobe level at a 3dB down point. Fig. 3 shows the result of the peak side-lobe level. As shown in Fig. 4, we selected and designed the star-shaped topology.

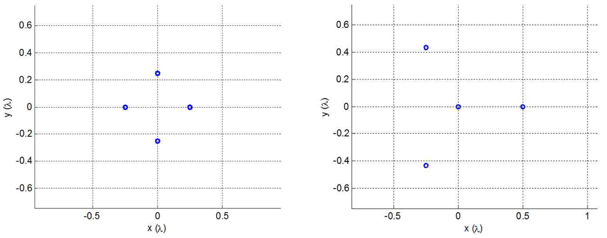

Fig. 1. Array configuration using four hydrophones; circular-shpaed and star-shaped

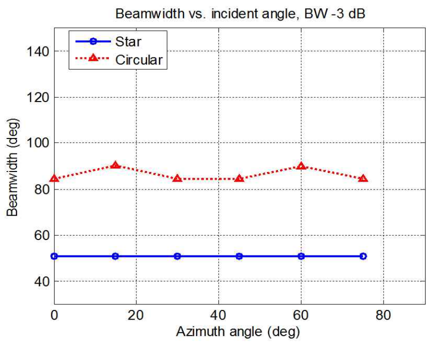

Fig. 2. Performance comaparison by beamwith

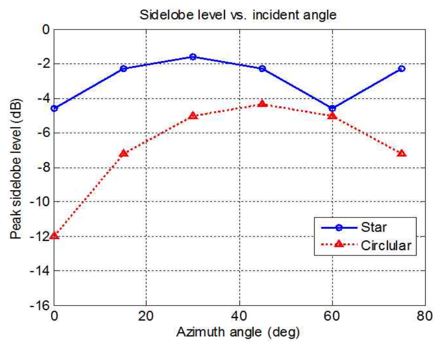

Fig. 3. Performance comaparison by peak side-lobe level

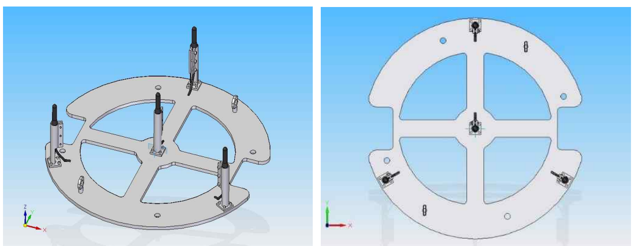

Fig. 4. Design of star-shaped array

B. System Configuration

Fig. 5 illustrates the schematic diagram of the developed module. It is composed of a real-time signal processing device, a memory, a power controller, an Ethernet hub, a thermometer and a pressure sensor. The real-time signal processing device includes an amplifier with filter, an A/D converter, a digital I/O, a digital signal processor and a chassis assembled with FPGA. A small-sized four channel amplifier with band-pass-filter has been developed to fit in the processing device. The other devices except the amplifier in the processing device used commercial products [6]. The digital data are stored into the memory and transmitted through the Ethernet hub. The thermometer and the pressure sensor are used for calculating the underwater sound velocity. The total power consumption of the module is about 12 W and the function of remote power control was also implemented in order to reach the average power consumption less than 10 W. Fig. 6 shows the real-time signal processing apparatus and other devices used for the development. Fig. 7 shows the prototype module with fixed frames. TABLE 1 is the specifications of this module.

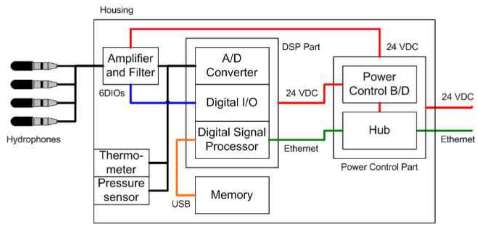

Fig. 5. Schematic digram of the module

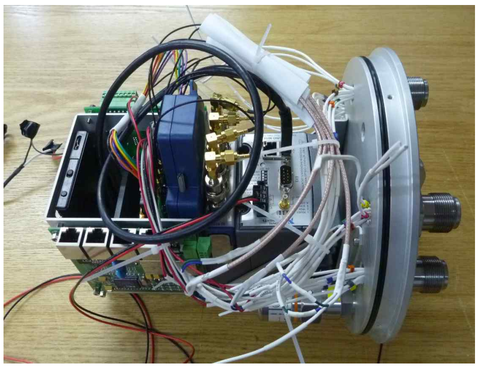

Fig. 6. The devices for real-time signal processing

Fig. 7. The prototype module

TABLE 1. SPECIFICATIONS OF THE MODULE

Parameter		Value
Signal Processing Properties	real-time processing results	spectrum and beamforming power
	sampling rate	50 kHz
	A/D resolution	24 bit
	update rate	1 sec
Acoustic Properties	number of hydrophones	4
	receiving sensitivity	-170 dB
	horizontal directivity	omni-directional
	vertical directivity	270 deg
	measureable frequency range	100 Hz to 10 kHz
Electrical Properties	input power voltage	16 to 30 VDC
	power consumption	less than 12 W

III. EXPERIMETNAL RESULTS

A. Experiment in a water tank

The first performance test of the prototype module has been performed in a water tank from November 5 to November 7 in 2014 (Fig. 8). The purpose of the experiment is to verify the detection performance of the module. An acoustic transducer is used as a sound source and a bridge over the tank is used for setting a location of the source. Fig. 9 shows the location of the source and the module (hydrophone array) in the tank. Operating frequency of the sound source is 800 Hz and a tone signal is used. Fig. 10 illustrates the beamforming results from the horizontal directions of north (Position #3), east (Position #8), south (Position #13) and west (Position #18) among a total of 20 positions. As a results, the beamforming power from other directions except south is similar to the real value. The reason for the deterioration from the southern direction is assumed that the received signal is distorted due to the influence of the reflected wave in a water tank.

Fig. 8. Exprimental scene for the test and verification in a water tank

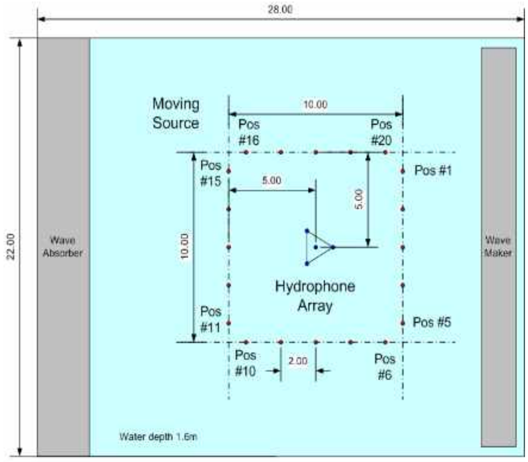

Fig. 9. Expriment configuration for the water tank test

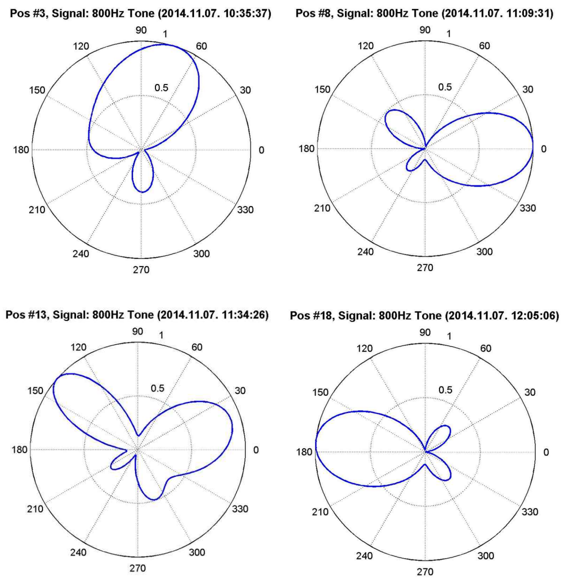

Fig. 10. Estimated beamforming power for the water tank test at various source positions (a) north (position #3) (b) east (position #8) (c) south (position #13) (d) west (position #18)

B. Experiment at a pier

The second performance test of the prototype module has been performed at a pier from November 10 to November 12 in 2014 (Fig. 11). The purpose of the experiment is to verify the detection performance of the module. A fishing boat is used for moving noise source. Fig. 12 shows the location of the source and the module (hydrophone array) at a pier. Fig. 13 illustrates the beamforming results from the horizontal directions of northwest (Position #1), west (Position #2), south (Position #3) and east (Position #4). As a results, we verified the performance of the prototype module through estimating the incident angles from the direction of the fishing boat.

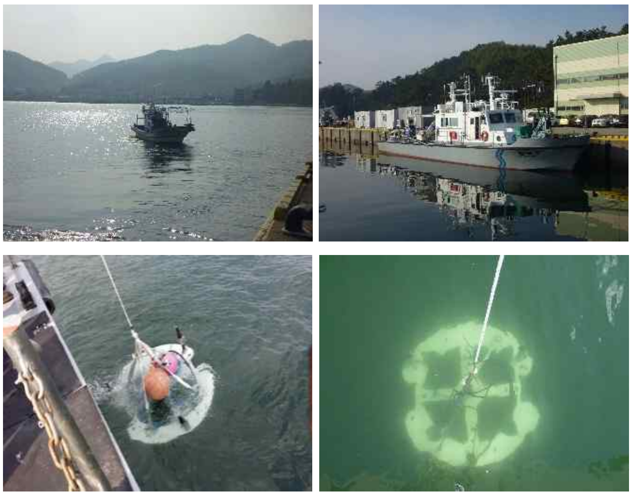

Fig. 11. Exprimental scene for the test and verification in a pier

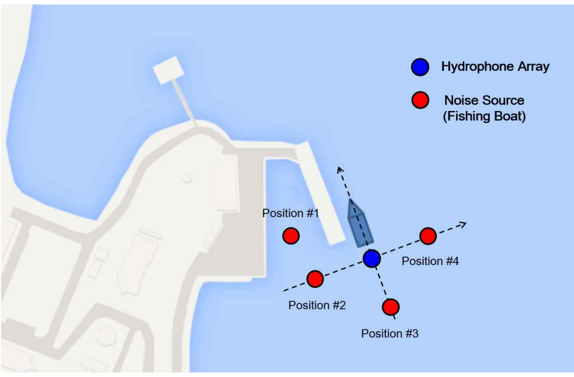

Fig. 12. Expriment configuration for the pier test

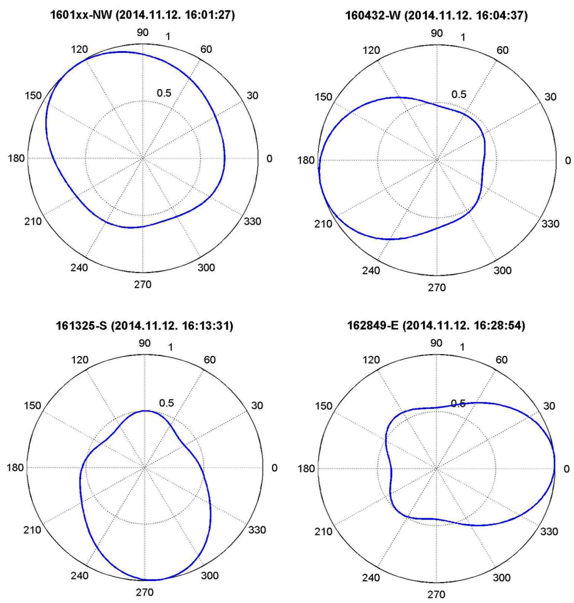

Fig. 13. Estimated beamforming power for the pier test at various source positions (a) northwest (position #1) (b) west (position #2) (c) south (position #3) (d) east (position #4)

IV. CONCLUSION

In 2014 KRISO developed a prototype of an underwater sound measurement module which will be installed in an ocean surface/bottom multidisciplinary geophysical observatory of KIGAM. It detects incoming hydroacoustic signal and estimates incident angles from all horizontal directions using a conventional beamforming algorithm. To get the efficient beam resolution under non-aliasing spacing condition, an array configuration is arranged to the star-shaped topology. It acquires acoustic signal and processes the signal in real-time. It is composed of a real-time processing device and other devices for storage, data transmission, power control and measuring underwater sound velocity. As a results of two experiments in a water tank and at a pier, the performance of the prototype module was verified through estimating the incident angles and detecting incoming acoustic signal from the underwater sound source.

As a future work, the amplifier will be upgraded for minimizing power consumption and optimizing gain control. Also the final model installed in the KIGAM system will be developed and be tested.

ACKNOWLEDGMENT

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