논문 2011-48TC-1-4

최대우도 검파에 기반한 파라메트릭 어레이 소나 시스템

(Parametric Array Sonar System Based on Maximum Likelihood Detection)

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요 약

소나 시스템은 항해와 해양 탐사, 수중 통신 등에 사용되며 정확성과 신뢰성을 향상시키기 위해 다양한 통계적 신호처리 기법들이 사용되고 있다. 수중에서의 다중 경로 특성은 검파 및 통신을 수행하는데 있어 열악한 환경을 제공한다. 파라메트릭 어레이 트랜스듀서의 고 지향성을 이용하면 다중 경로의 영향이 최소화될 뿐만 아니라, 파라메트릭 배열에 적합한 최적 검파기법을 사용하면 통신 성능이 향상된다. 본 논문에서는 on-off keying 통신 신호 검파를 위해 최대우도법(Maximum likelihood method)을 사용하였으며, LabVIEW 기반으로 파라메트릭 배열 트랜스듀서를 사용한 소나 시스템을 구현하여 시스템의 성능을 검증하였다. 또한, 다양한 트랜스듀서의 특성을 반영할 수 있는 GUI 소프트웨어도 설계 및 구현되어 다양한 소나 시스템의 성능 평가의 용이성을 증가시켰다. 본 논문에서 제안된 시스템은 실험실내에서의 다양한 모의실험이 가능하여 실제 해양 장비의 개발에 소요되는 비용과 시간을 감소시키는데 기여할 것으로 기대된다.

Abstract

In the underwater communications, transmitted acoustic signal is corrupted by interference from multipath. A parametric array transducer is capable of radiating a narrow beam with very low sidelobe levels. In certain cases, the parametric array transducer can help the multipath problem. To improve the performance of the underwater communications, the statistical signal processing methods will be required. In the paper, the communication system using a parametric array transducer was demonstrated. To detect the received signal of the communication system based on the on-off keying, the maximum likelihood method using averaged signal for a particular window size is used. The communication system has GUI using LebVIEW which allows the user to change the parameter. The GUI can also be easily modified based on the characteristics of a parametric array transducer. The implemented system can effectively evaluate the performance of the parametric array transducer.

Keywords: *Sonar, Parametric array, Underwater communication, Maximum likelihood*

I. Introduction

The sonar system has an important role in underwater communication. In the underwater communications, transmitted acoustic signal is corrupted by interference from multipath[1]. A parametric array transducer is capable of radiating a narrow beam with very low sidelobe levels[2]. In certain cases, the parametric array transducer can help the multipath problem. To improve the performance of the underwater communications, the statistical signal processing methods will be required.

In the thesis, the communication system using a parametric array transducer was demonstrated. The on-off keying scheme was applied to modulate the

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※ This work was supported by Defense Acquisition Program Administration and Agency for Defense Development under the contract UD100002KD.
접수일자: 2010년12월19일, 수정완료일: 2011년1월13일

signal[3]. For a good communication, the maximum likelihood method using averaged signal for a particular window size is used in the system.

The system is composed of a parametric array transducer, a NI PXI system, a microphone, a power amplifier, a PC with DAQCard, and the control software developed by LabVIEW 8.5. The communication system has GUI which allows the user to change the parameter. The GUI can also be easily modified based on the characteristics of a parametric array transducer. The implemented system can effectively evaluate the performance of the parametric array transducer.

Section Ⅱ gives a brief overview of the detection algorithm. Section Ⅲ presents the implemented transmitter, receiver and the experimental results. Finally, Section Ⅳ describes some of the research results.

Ⅱ. Maximum Likelihood Method

The decision rule defined as[4]

$$d(z)=\begin{cases} d_1 & \text{if } p(z|m_1)>(z|m_2) \\ d_2 & \text{if } p(z|m_2)>(z|m_1) \end{cases} \tag{1}$$

$$\begin{aligned} m_1 &: z=n \\ m_2 &: z=s+n \end{aligned} \tag{2}$$

where the observation of m_1 is the zero-mean unit-variance gaussian random noise, the observation of m_2 is $s+n$, s is the mean value.

The conditional probability density of z given m_1 or m_2 as

$$\begin{aligned} p(z|m_1) &= \frac{1}{\sqrt{2\pi}} exp\frac{-z^2}{2} \\ p(z|m_2) &= \frac{1}{\sqrt{2\pi}} exp\frac{-(z-s)^2}{2} \end{aligned} \tag{3}$$

The decision regions are

$$\begin{aligned} Z_1 &= \{z : p(z|m_1)>p(z|m_2)\} \\ Z_2 &= \{z : p(z|m_2)>p(z|m_1)\} \end{aligned} \tag{4}$$

The likelihood ratio $\Lambda(z)$ defined as

$$\Lambda(z)=\frac{p(z|m_2)}{p(z|m_1)} \tag{5}$$

Then Z_1 and Z_2 may be defined as

$$\begin{aligned} Z_1 &= \{z : \Lambda(z)<1\} \\ Z_2 &= \{z : \Lambda(z)>1\} \end{aligned} \tag{6}$$

It can be expressed shortly

$$\Lambda(z) \underset{d_1}{\overset{d_2}{\gtrless}} 1 \tag{7}$$

Using above the equations, the problem can be solved

$$\begin{aligned} \Lambda(z) &= \frac{p(z|m_2)}{p(z|m_1)} \\ &= \frac{(1/\sqrt{2\pi})\exp[-(z-s)^2/2]}{(1/\sqrt{2\pi})\exp[-z^2/2]} \\ &= \exp\frac{-[(z-s)^2-z^2]}{2} \\ &= \exp\frac{(2z-s)}{2} \end{aligned} \tag{8}$$

The decision rule can be written as

$$\exp\frac{(2z-s)}{2} \underset{d_1}{\overset{d_2}{\gtrless}} 1 \tag{9}$$

Take the natural logarithm of (9)

$$\frac{2z-s}{2} \underset{d_1}{\overset{d_2}{\gtrless}} 0 \tag{10}$$

Then (11) is obtained

$$z \underset{d_1}{\overset{d_2}{\gtrless}} \frac{s}{z} \tag{11}$$

and the decision regions can be defined as

$$Z_1 = \left\{ z : z < \frac{s}{2} \right\} = \left(-\infty, \frac{s}{2} \right)$$
$$Z_2 = \left\{ z : z > \frac{s}{2} \right\} = \left(\frac{s}{2}, \infty \right) \quad (12)$$

Fig. 1 illustrates the signal that is obtained by the experiment. The experiment setup is explained in section Ⅲ.

To detect the signal, averaging technique was applied, additionally. The averaged signal is obtained by

$$m_1 : z = \frac{1}{N}\sum_{i=1}^{N} |s_{1i} + n_{1i}|$$
$$m_2 : z = \frac{1}{N}\sum_{i=1}^{N} |s_{2i} + n_{2i}| \quad (13)$$

where N is the sample number.

The average value of the signal as shown in Fig. 2 is obtained based on (13).

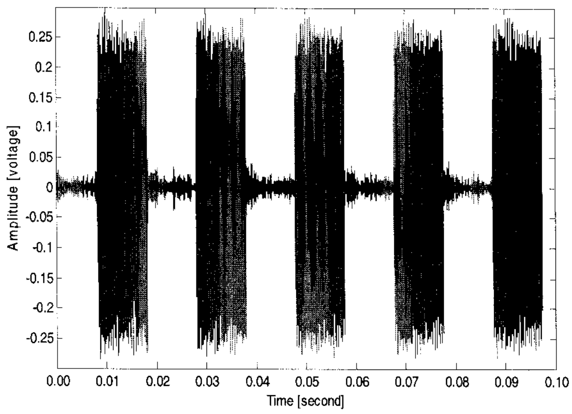


그림 1. 계측된 신호

Fig. 1. Measured signal.

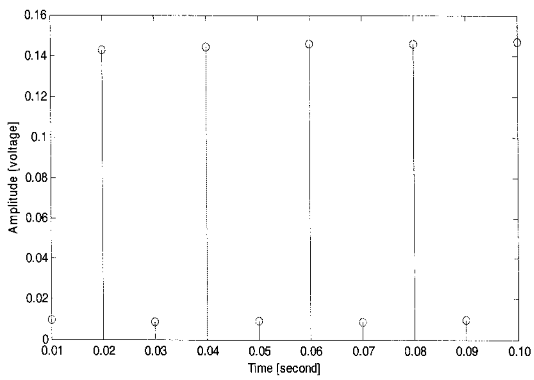


그림 2. 신호의 평균 값

Fig. 2. The average value of the signal.

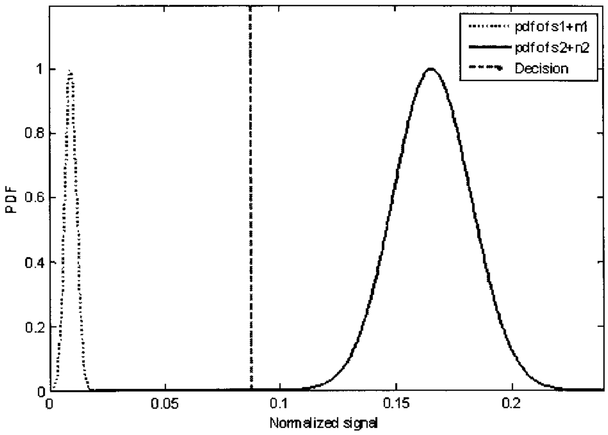


그림 3. 신호의 확률 밀도 함수

Fig. 3. The probability density function of the signal.

As shown in Fig. 2, the signal is absolute and averaged. Fig. 3 illustrates the probability density function of the averaged signal. The averaged value of the signal has Gaussian density function.

The decision rule from the ML method is

$$z \mathop{\gtrless}_{d_1}^{d_2} \frac{(s_2 + s_1)}{2} \quad (14)$$

where s_1 and s_2 are mean values.

The standard deviations of $s_1 + n_1$ and $s_2 + n_2$ are 0.0025 and 0.0169, respectively. The means of $s_1 + n_1$ and $s_2 + n_2$ are 0.0094 and 0.1658, respectively. Hence, if $z > 0.0876$, we decide d_2 and if $z < 0.0876$, we decide d_1.

Ⅲ. Implemented System

1. Transmitter

The parametric array sonar system consists mainly of transmitter and receiver. The block diagram of the transmitter is shown in Fig. 4.

The transmitter is composed of a parametric array transducer, a NI PXI system and a power amplifier. The PXI system plays a role in the modulation and the digital to analog conversion (DAC). The control software is programmed by LabVIEW 8.5. A brief

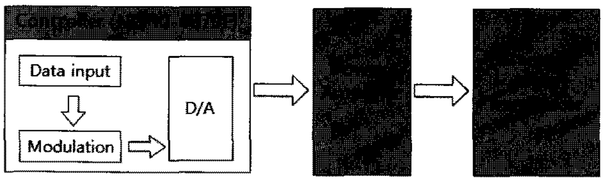
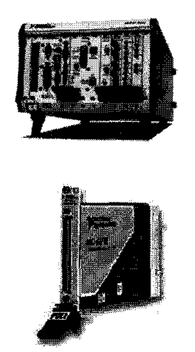


그림 4. 송신기의 블록다이어그램
Fig. 4. Block diagram of the transmitter.

표 1. 송신측에서 사용된 PXI-6070E의 사양
Table 1. Specifications of PXI-6070E.

Item	Description
Output Resolution	12 bits
Output Rate	1 MS/s
Output Range	±10 V
FIFO Buffer Size	2,048 samples



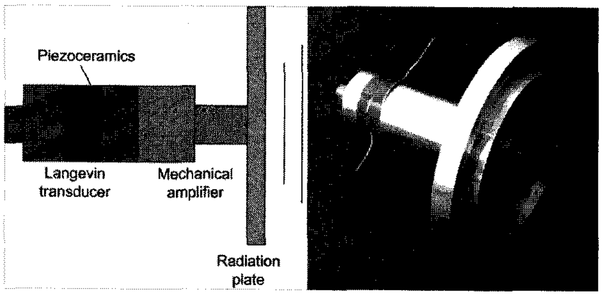


그림 5. 파라메트릭 어레이 트랜스듀서 및 구조
Fig. 5. Structure of the prototype parametric array transducer.

overview of the NI PXI system is shown in Table 1.

The prototype parametric array transducer is developed by vibration/acoustics and transducers laboratory of Pohang University of Science and Technology[5]. Fig. 5 shows the structure of the prototype parametric array transducer.

The prototype parametric array transducer has 82 kHz and 122 kHz resonance frequencies, and its size is 50mm x 50mm.

2. Receiver

The block diagram of the receiver is shown in Fig. 6. The receiver is composed of a microphone, power amplifier and a PC with DAQCard. The transmitted signal has 40 kHz difference frequency because of the

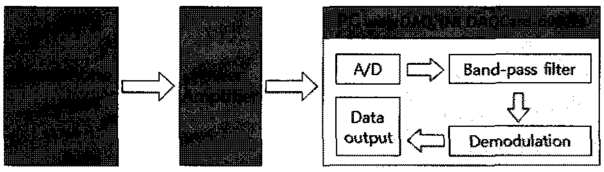
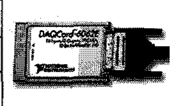


그림 6. 수신기의 블록다이어그램
Fig. 6. Block diagram of the receiver.

표 2. 수신측에서 사용된 DAQCard-6062E의 사양
Table 2. Specifications of DAQCard-6062E.

Item	Description
Input Resolution	12 bits
Output Rate	500 kS/s
Input Range	±0.05 to ±10 V
FIFO Buffer Size	2,048 samples



parametric array transducer characteristic[6]. The received signal is amplified through a power amplifier. In the PC, signal is sampled, filtered and demodulated. To remove the sampling noise, band-pass filter (38 kHz, 42 kHz) is used[7].

A brief overview of the NI PXI system is shown in Table 2.

3. Experimental Result

A simple communication experiment has been carried out in the air[8]. The signal was generated by on-off keying modulation scheme. The primary frequencies are 42 kHz and 82 kHz, respectively. The

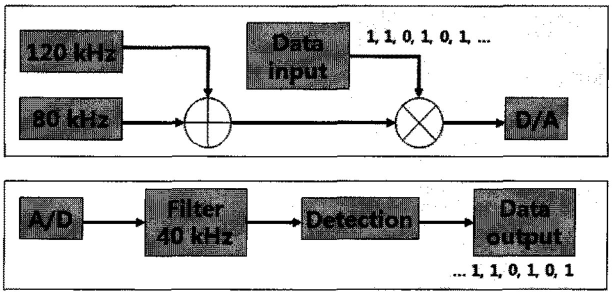


그림 7. 실험 시스템 구성도
Fig. 7. Block diagram of the experiment.

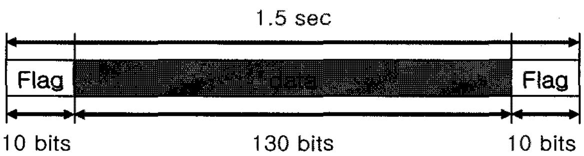


그림 8. 전송 신호의 프레임 구조
Fig. 8. The structure of the signal frame.

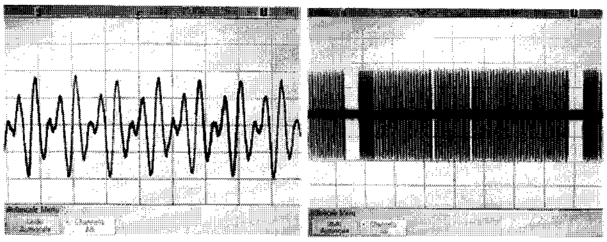


그림 9. (a) 변조된 신호, (b) 오실로스코프에서 계측된 한 프레임 길이의 신호
Fig. 9. (a) The modulated signal and (b) a period of frame measured by oscilloscope.

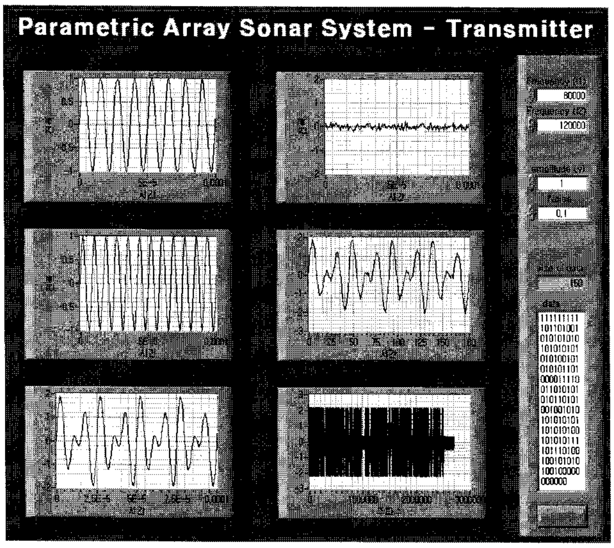


그림 10. 송신측 GUI 소프트웨어
Fig. 10. The GUI transmitter.

block diagram of the experiment is shown in Fig. 7.

The signal frame consists of 20 bits flag and 130 bits data as shown in Fig. 8 and it was sent repeatedly[9].

Fig. 9 illustrates the generated signal after ADC at the transmitter which is measured by an oscilloscope. Fig. 9 (a) shows the form of the modulated signal, and Fig. 9 (b) shows a period of the frame.

Fig. 10 illustrates the software to control the transmitter of the sonar system. The control software has GUI which allows the user to change the parameter as shown in Fig. 10. The user can control primary frequencies, the output voltage, the input data and an additional noise. An additional noise is useful in case of simulation for an arbitrary channel.

Fig. 11 illustrates the receiver of the parametric array sonar system. As shown in Fig. 11, the

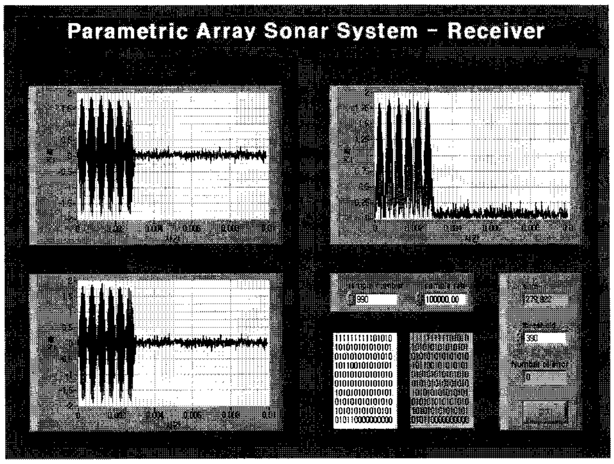


그림 11. 수신측 GUI 소프트웨어
Fig. 11. The GUI receiver.

receiver controller is designed to change the sample number, the sample rate and the detection level. To detect the signal, the measured signal was averaged for a particular window size before applying the maximum likelihood method. The window size is same as the sampling number as shown in Fig. 11.

Ⅳ. Conclusion

For the parametric array sonar system, the maximum likelihood method using averaged signal for a particular window size was presented. The algorithm can quickly and exactly detect the signal without error. For the underwater communication, the sonar system with the proposed algorithm is developed using a prototype parametric array transducer. The system is composed of the control software, a parametric array transducer, a NI PXI system, a microphone, a power amplifier and a PC with DAQCard. The control software designed by LabVIEW 8.5, could be modified easily, according to different parametric array transducers. The implemented system can effectively evaluate the performance of the parametric array transducer

Our results show that the maritime radar simulator and the parametric array sonar system could be potential approaches to improve the performance of ocean equipments.

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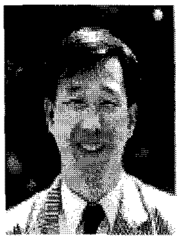

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