Study on Detection Scheme of Direction of Ship Whistle in the Frequency Domain

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Abstract: In this paper, we propose a sound reception system (SRS) using a phase difference of whistle signals from four microphones installed on a ship. The phase difference is obtained in the frequency domain. The proposed system detects the direction of the received whistle signal and indicates the direction of other ships. Also, we implement the SRS using a digital signal processor chip and verify the operation of the proposed SRS.

1. Introduction

Whistle signals are effectively used to inform on the danger of collision in the ocean when the visibility on a ship is not sufficiently guaranteed. However, when the bridge is closed, it is difficult to recognize the ship whistle of other ships. In order to overcome the problem, the sound reception system (SRS) had been adopted in the amendment of SOLAS chapter 5 safety of the navigation in 2000 [1]. The SRS is used to receive whistle signals of other ships and detect the direction of the ships so that the SRS enables the ship avoid the collision from other ships on the voyage route. Also, the requirements of the SRS are described in IMO resolution MSC.86 (70) [2].

For the analog SRS, since it is sensitive to other noise sources such as the wind, the sound of the waves, and reflected signals by obstacles in a ship, the performance is severely degraded. Therefore, SRS based on digital signal processing has been developed [3]. The requirements and test procedure for the digital SRS are described in ISO 14859 [4].

In [5], the SRS detects the direction of the received whistle signal by utilizing the ratio of the magnitude of the received whistle signal. However, even though the magnitude of the generated whistle signal is not varied, the magnitude of the received signal of the SRS can be varied due to the noisy environments. Therefore, in this paper, we propose an improved SRS using a phase difference of whistle signals based on the frequency domain analysis. Also, we implement the SRS using a digital signal processor (DSP) chip and verify the operation of the proposed SRS.

This paper is organized as follows. In section 2, the configuration of the system is described and then, the proposed algorithm and implemented results are presented in section 3. Finally, the conclusions are described in section 4.

2. Proposed Scheme

Figure 1 shows the configuration of the proposed SRS. The four microphones are installed on a ship and receive whistle signals from the corresponding direction of each microphone. The received whistle signals are converted into digital signals for analog-to-digital converters (ADCs) and the direction of the whistle signal of the ship is detected in the DSP. Hence, the detection algorithm is implemented by software in the DSP.

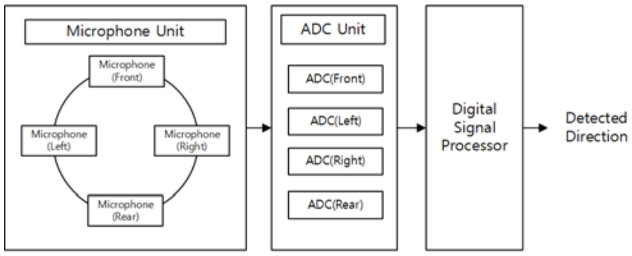

Figure 1. Block diagram of the proposed system

Figure 2 shows the block diagram of the proposed detection scheme. The ADC output of each microphone is input into the fast Fourier transform (FFT) block. By using FFT, we can easily obtain the transformed signal into the frequency domain. Since the received signal includes unwanted signal components of the outside bandwidth of the whistle signal, the unwanted frequency components of the received signal can be removed from the FFT output. And then, peak values of the magnitude responses for the filtered signals are detected. Then, we can obtain the frequency indices corresponding to the detected peaks.

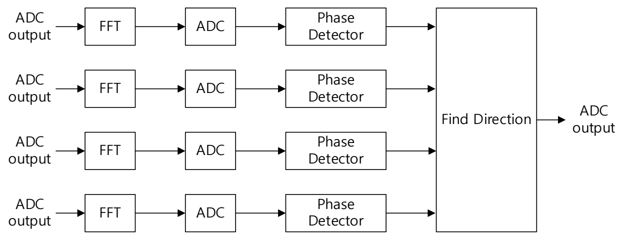

Figure 2. System flow diagram

Next, we find the phase values corresponding to the resulting frequency indices. The obtained phase values indicates the phase of the received whistle signal. Finally, the

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obtained phase values are sorted in descending order and the phase difference between two largest phase values is calculated. The phase difference is proportional to the received angle of the received whistle signal for a given whistle frequency. According to the calculated phase difference, we define an appropriate decision region for eight directions. Also, the phase difference can be varied according to the used whistle frequency. Therefore, we can improve the detection performance of the SRS by adaptively selecting the threshold value for the detected frequency index.

Figure 3 shows an example of the configuration for the SRS. In Figure 3, the received whistle signal heads to the left microphone and then the phase difference is maximized.

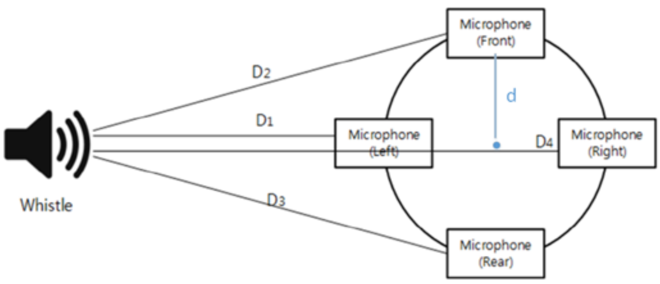

Figure 3. Example of Microphone Unit receives a whistle signal

From Figure 3, we can obtain the following Eq. (1).

$$D_2^2 \; = \; d^2 + (D_1 + d)^2 = 2d^2 + 2dD_1 + D_1^2. \quad (1)$$

where d denotes the distance of each microphone from the center of the microphone unit.
From Eq. (1), we can obtain the following Eq. (2).

$$D_2 - D_1 = \frac{2d^2 + 2dD_1}{D_2 + D_1} = \frac{2d^2}{D_2 + D_1} + \frac{2dD_1}{D_2 + D_1}. \quad (2)$$

On the ocean, on the other hand, the distance between the microphone and other ship is very large, compared to d. Therefore, we can assume that $D_1 >> d$, $D_2 >> d$, and $D_1 \approx D_2$. Then, Eq. (2) can be simplified as follows.

$$D_2 - D_1 \approx d. \quad (3)$$

Then, we calculate the phase difference between two adjacent microphones according to the used frequency and the distance of the microphone from the center of the microphone unit. Since the whistle signal has a single frequency, the whistle signal $x(t)$ can be represented by $x(t) = \cos 2\pi f_c t$ where f_c denotes the frequency of the whistle signal. Assuming that the received signal for the left microphone is $\cos 2\pi f_c t$, the received signal for the front or rear microphone, $r(t)$, can be written as

$$r(t) = \cos\big(2\pi f_c(t + \tau)\big) = \cos(2\pi f_c t + \theta). \quad (4)$$

Here, τ denotes the difference of the arriving time between left microphone and front/rear microphone and $\theta = 2\pi f_c \tau$. Using Eq. (4), τ can be calculated as

$$\tau = D_2 - D_1/v \approx d/v \quad (5)$$

where v denotes the speed of sound and v = 344m/s in air at the temperature of 21°C. Note that $v = 331.5 + 0.6T$ [m/s] where T denotes the temperature. Using Eq. (4) and (5), we can calculate the phase difference θ.

Figure 4 shows curves of the phase difference versus the frequency f_c of the whistle signal according to d.

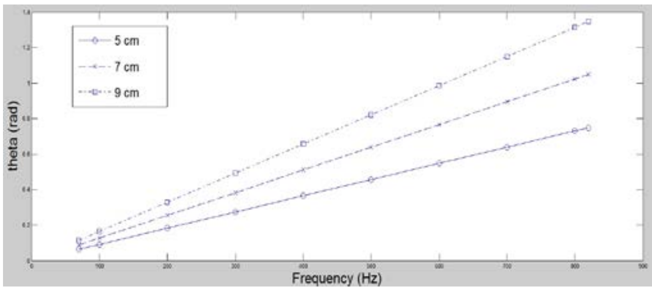

Figure 4. Phase difference versus the frequency f_c of the whistle signal according to d

3. Implementation

Figure 5 shows the implemented SRS. The proposed algorithm is implemented using the DSP. Table 1 shows the specification of the DSP chip used in the proposed system. Experiments were proceeded with microphones which are toward the four directions. We verified that the detector indicates the correct direction. The proposed algorithm shows better performance than that of the previous scheme using the ratio of amplitude of this whistle signal.

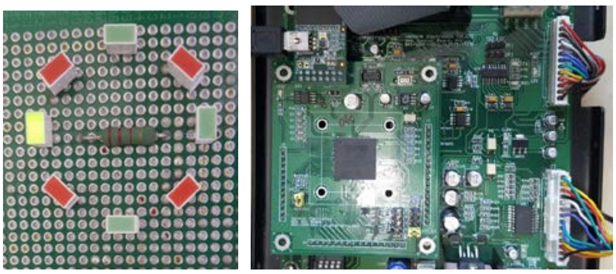

Figure 5. Implementation of the proposed SRS

Table 1. Specifications of the DSP chip

Item	Specification
Processing speed	Core performance up to 600 Mhz
Memory	SDRAM : 64MB x 2chips Flash memory : 4MB
Etc.	4 serial ports

4. Conclusion

In this paper, we propose a SRS using a phase difference of whistle signals from four microphones installed on a ship. The phase difference is obtained in the frequency domain. The proposed system detects the received direction of the whistle signal. Also, we implement the SRS using DSP chip. The proposed algorithm could solve problems due to time delay caused the distance difference. Therefore it can provide information of directions with less error. So, we can expect that accidents on the ocean can be prevented in advance.

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