Journal of
Ship&Ocean Technology

SOTECH Vol. 8, No. 3, pp. 18 ~ 25, 2004

A New Sound Reception System using a Symmetrical Microphone Array and its Numerical Simulation

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Abstract

Sound reception system is required to detect the sound and the quadrantal direction of the other ship's horn sound, to overcome the effects of enclosed wall for navigation space, functioning as a sound barrier. However, the realized systems can only provide quadrantal information of the other ship.

This paper presents a new arrangement of microphones, having geometrically symmetric deployment with the same distances between sensors and the same angles between adjacent sensors with respect to the geometrical center. The sound pressures received at microphones are transformed into the related envelope signals by applying Hilbert transform. The time delays between microphones are estimated by the correlation functions between the derived envelope signals. This envelope base processing mitigates the noises related to the reflection by ship and sea surface. Then, the directional information is easily defined by using the estimated time delays.

The suggested method is verified by the generated signals using boundary element method for a small ship model with sea surface wave. The estimated direction is quite similar to the true one and therefore the proposed approach can be used as an efficient sound reception system.

Keywords: sound reception system, hilbert transform, time delay, horn sound.

1 Introduction

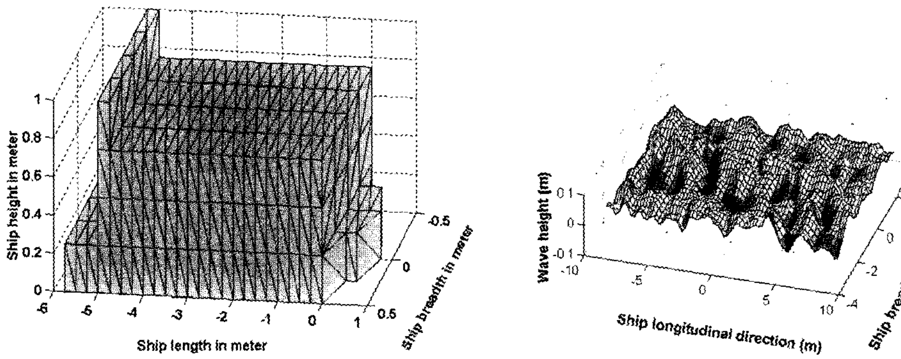
The navigational control space has been enclosed to keep comfortable space for captain and crews without various weather conditions. This leads to the hearing problem of sounds from other ships and external sound of own ship. To overcome this drawback, the international safety body (SOLAS Chapter 5, Regulation19) has defined the requirement for sound reception system as the following, "when the ship's bridge is totally enclosed and unless the Administration determines otherwise, a sound reception system, or other means, to enable the officer in charge of the navigational watch to hear sound signals and determine their direction."

The existing system has the arrangement of microphones at bow, stern, port and starboard, and 4 lights according to the microphone locations. The system shows bright light at bow or stern positions according to the difference of sound pressure levels or time delay difference between the sound signals at the related microphones. The other bright light is illustrated at port or starboard sides according to the aforementioned concepts.

Therefore, one can estimate that the quadrant of the horn signal from the other ship. Henceforth, the existing system cannot resolve the directional information and have difficulty to resolve the sound from coming ship and own ship. Moreover the calibration requires another ship to check the localization performance.

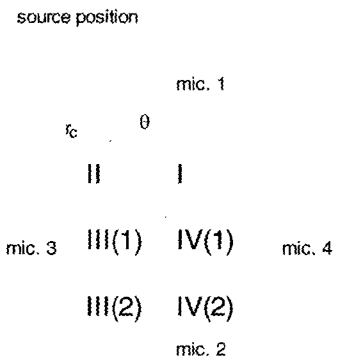
This work is focused on the new configuration of sound reception system to resolve the described problems. The essential idea is the symmetric arrangement of microphone array to avoid the ambiguity of the time delay information. This symmetric array is proved to be quite useful to mathematically estimate the time delays related to the directional information. The correlation function (Bendat and Piersol 1986) based on envelope signals are also proposed to obtain time delays in rather noisy conditions due to the reflections by ship structure and sea surface with waves.

To verify the method, sound propagation models between microphones and horn sound are estimated by using boundary element method (Kirkup 1998, Attenborough and Boulanger 2003) which is well known approach to analyze sound propagation problem considering sea surface. Then the sound pressure signals are estimated by the convolution between the impulse response functions corresponding to the sound propagation models and realistic horn signals. The proposed method is applied to the derived sound pressure pattern to estimate the horn direction, and the estimated direction comes out to be quite similar to the real direction. Hence, the sound reception system, having the proposed routine, can be used as a more useful tool than the existing system.



(a) Simplified container ship model. (b) Example of sea surface.

Figure 1: General situation of container ship and sailing condition with waves.



Region	τ_{21}	τ_{43}
I	+	-
II	+	+
III(1)	-	+
III(2)	-	+
IV(1)	-	-
IV(2)	-	-

Figure 2: Conventional configurations for quadrant finding of sound reception system.

2 Derivation of a new direction finding method

2.1 Conventional configuration of sound reception system

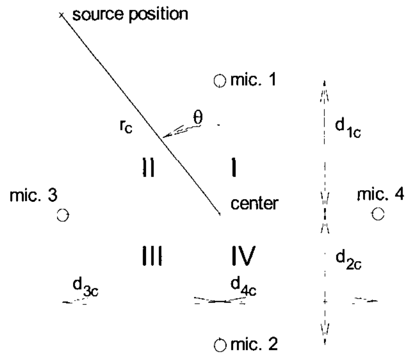
Figure 1(a) illustrates a simplified container ship model that is meshed with triangular shape for boundary element method. Figure 1(b) shows an example of sea surface with waves. As earlier mentioned in the introduction, the pressure signals could not guarantee the level difference according to the distance from the source to the microphones because of the reflection by ship structure and sea surface. Henceforth, this section investigates the time delay terms between sensors.

Figure 2 represents the quadrant relations between the source and the receivers according to the signs of the time delays between sensors. Here the time delays are defined as the following.

$$\tau_{21} = \frac{(\text{distance between mic. 2 and source}) - (\text{distance between mic. 1 and source})}{\text{speed of sound}} \quad (1)$$

$$\tau_{43} = \frac{(\text{distance between mic. 4 and source}) - (\text{distance between mic. 3 and source})}{\text{speed of sound}} \quad (2)$$

Based on these interpretations, one can easily define the quadrantal information of horn source. For the detailed directional information, one can apply scanning procedures to the estimated time delays. Those scanning methods such as beamforming and MUSIC (Multiple Signal Classification) etc.(Johnson and Dudgeon 1993) are well known in array signal processing. However, it leads to time consumable calculations and does not guarantee the reasonable results due to many local optima of the estimated functions by the scanning methods.



Region	τ_{21}	τ_{43}
I	+	-
II	+	+
III	-	+
IV	-	-

Figure 3: New configurations for the detailed direction finding of sound reception system.

2.2 New configuration of sound reception system

Though the conventional array can give quadrantal information, the detailed directional information cannot be proposed. To overcome this drawback, this paper introduces a new arrangement of microphones, as in Figure 3. Here, the distances and angles between sensors are the same as d_{ad} and θ_{ad}, respectively, in terms of the following.

$$d_{ad} = d_{1c} = d_{2c} = d_{3c} = d_{4c} \quad (3)$$

$$\begin{aligned}\theta_{ad} &= \angle(\text{mic.}1, \text{center}, \text{mic.}3) \\ &= \angle(\text{mic.}3, \text{center}, \text{mic.}2) \\ &= \angle(\text{mic.}2, \text{center}, \text{mic.}4) \\ &= \angle(\text{mic.}2, \text{center}, \text{mic.}1) \\ &= 90^0\end{aligned} \quad (4)$$

Based on the above relations, the directional information θ in Figure 3 can be obtained by the following equation,

$$\theta = \tan^{-1}\left(\frac{\tau_{43}}{\tau_{21}}\right) \quad (5)$$

This means the limit sampling frequency must be greater than the inverse of possible maximum time delays τ_{21} or τ_{43}. Henceforth, the higher sampling frequency produces the higher directional resolution.

Besides, the distance between source and center can also be estimated by the scanning procedure such as beamforming and MUSIC etc. (Johnson and Dudgeon 1993). However, in these methods the sensitivity to the distance is quite low and the related functions have many local optima. Therefore, it cannot be very useful in a real situation where one have some measurement noise and reflection effects.

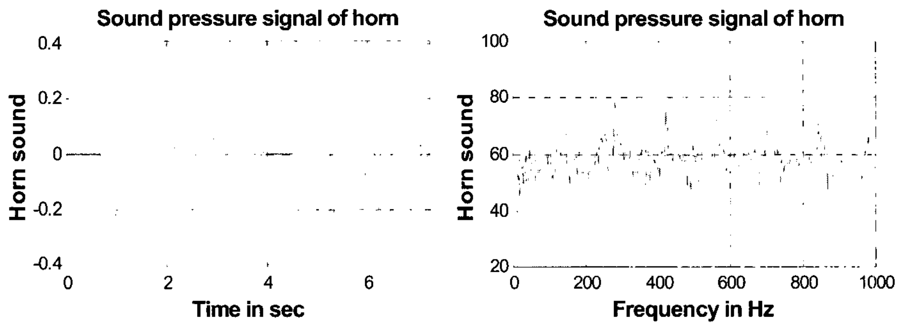


Figure 4: General signal patterns of horn signal in time and frequency domain.

3 Effective estimation of time delay

To obtain the time delays, one can use correlation of the horn sound signals that consist of envelope and fluctuating patterns (Figure 4). Then the phase information is distorted by the reflections due to ship structure and sea surface, but the envelope have the information of the distance between the horn and the microphones. So, this paper will use the correlation signals of envelope signals, to obtain the time delays between microphone signals.

The envelope signals can be obtained by using Hilbert transform (Bendat and Piersol 1986) that is defined by $H(p(t))$ for the sound pressure signals. Then one can obtain analytic signals $p_a(t)$ as:

$$p_a(t) = p(t) + iH(p(t)) \quad (6)$$

The envelope can be written as

$$p_{env}(t) = |p_a(t)| \tag{7}$$

Then, the following correlation function based on envelope signals can be estimated.

$$R_{i1}(\tau) = \frac{1}{T}\int_0^T p_{(1)env}(t)p_{i(env)}(t-\tau)dt \tag{8}$$

Finally, the required time delay corresponds to the time delay at the maximum correlation value.

Table 1: Geometrical parameters for analysis of sound propagation.

Variable	Value	Remark
Length between perpendiculars	6.5m	Ship parameters
Breadth	1.0m	
Height above waterline	1.0m	
Deck height above waterline	0.25m	
Hold height above waterline	0.75m (considering container loading)	
Significant wave height	0.2 m	Wave conditions
Wave direction	45^{O}	
Sea surface range	(-10m ~ 10m, -3m ~ 3m)	
Stern center	(-6.0m , 0.0m , 0.0m) (with respect to sea surface)	Relative location of ship
Number of mesh	3782(Triangular shape)	Boundary element modeling and analysis
Number of node	1987	
Resolution in space	0.25 m (in x and y directions)	
Frequency resolution	0.4Hz	
Sound source location	(8 m , -2 m , 1.2 m)	
Microphone locations	(-4.5m, 0.0m, 1.2m), (-5.5 m, 0.0m, 1.2m), (-5.0m, 0.5m, 1.2m), (-5.0m, -0.5m , 1.2m)	

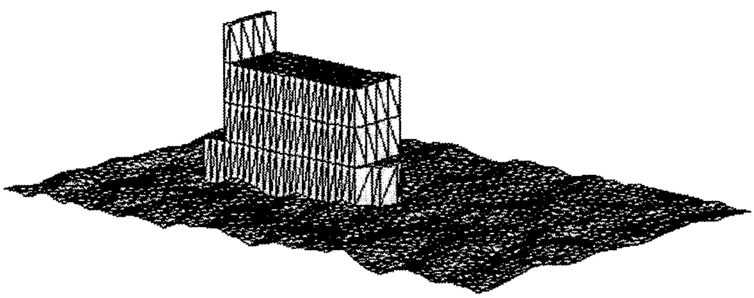


Figure 5: General situation model with a ship(Figure 1a) and related wave condition(Figure 1b).

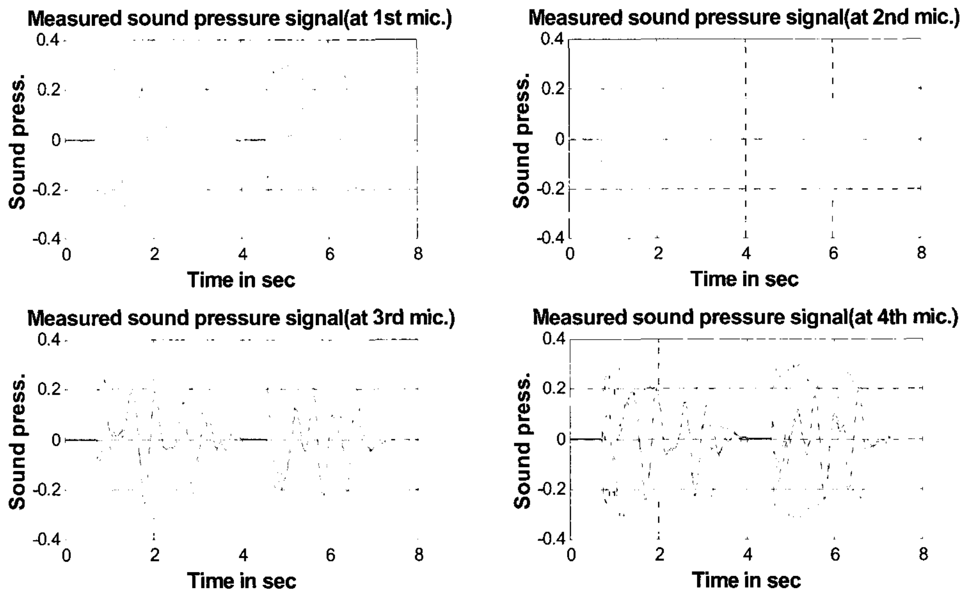


Figure 6: Estimated sound pressure signals at each microphone.

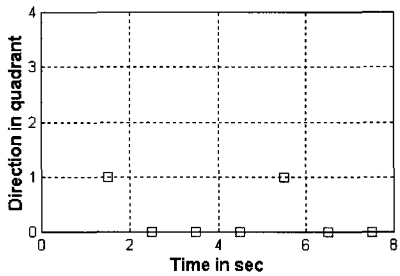


Figure 7: Results of direction findings in quadrant domain by the comparisons of sound pressure levels at microphones in conventional method. (Number 0 in the direction-in-quadrant axis stands for the no estimation case.)

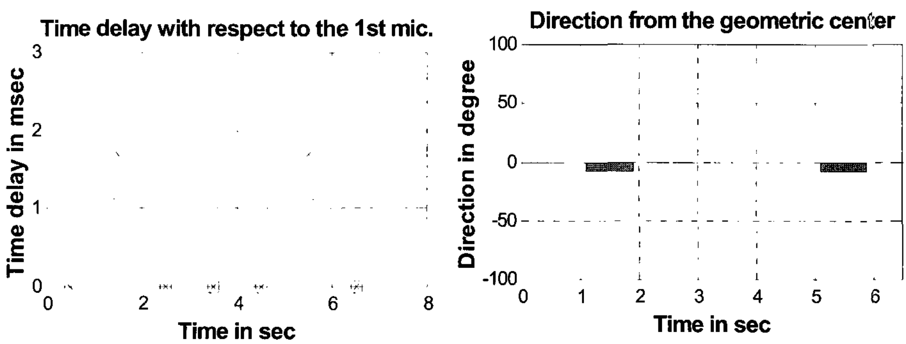


Figure 8: Results of time delay estimations and direction findings at each time-segmentation. (circle: time delay between mic.2 and mic.1, cross: time delay between mic.3 and mic.1, rectangle: time delay between mic.4 and mic.1) (Time delay 0 in the time-delay-in-msec axis stands for the no estimation case.)

4 Verification

4.1 Ship and wave model

For the boundary element analysis, very simplified model is defined. Figure 1 illustrates a general geometry for a simplified ship and wave model. Table 1 describes general parameters for the modeled ship and wave conditions.

In these conditions, the possible maximum time delay becomes the maximum distance between sensors divided by speed of sound, *1m/(speed of sound).* So, the sampling frequency should be larger than 340Hz. Here, 10000Hz is selected as the sampling frequency to ensure enough resolution in the considered direction.

4.2 Results by using boundary element method

Sound propagation problem including sea surface has been solved by using boundary element method (Attenbourough and Boulanger 2003). This work also applies the boundary element method (Kirkup 1998) to the sound propagation considering sea surface with waves.

The frequency contents of the horn signals in Figure 4(a) are illustrated in Figure 4(b) by Fourier transform, up to 1kHz. This means the exact simulations based on boundary element method require very small mesh generation. However, due to the restriction of computation facility, the space resolution is defined as 0.25m(See Table 1) and therefore the upper frequency becomes about 680Hz, when the two node points are located within one wavelength. Whereas, the peak frequency components of horn sound in Figure 4(b) correspond to between 140Hz and 600Hz. Hence, the boundary analysis to estimate impulse response function between source and the microphones was performed at from 140Hz to 600Hz for the simplified situation illustrated in Figure 5 and Table 1.

After the analysis, the impulse response functions are estimated by using the sampling frequency of 10kHz to ensure the resolution in direction. The estimated impulse responses and reference horn signals in Figure 4 are convolved to estimate the sound pressure signals at each microphone (See Figure 6).

Figure 7 displays the directional information in quadrant domain by comparing the sound pressure levels between microphones that is the main concept of a conventional sound reception system. The results show the first quadrant as external sound source.

Figure 8 displays the derived time delays using correlation function between the envelope signals at the first microphone and those at the other microphones, for the time record segmentations of 1second period, respectively. The true angle is -8.75^0 (arc tangent of (-2/13)), described in the Table 1, and the estimated direction is about -7.85^0. The error attributes to the reflections by sea surface and ship structure, and the time-delay resolution by sampling frequency. However, this could be considered as reasonable result to localize the direction of source in real ship operating conditions. Comparing with the Figure 7, one can conclude this method can obtain more exact directional estimation with the same number of microphones.

5 Concluding remarks

The physical interpretation of the existing sound reception system has been investigated by analyzing the properties of microphone arrangement. Based on that work, one can conclude the conventional configuration of array can localize the source in quadrantal direction and requires a modification of array configuration to obtain the detailed directional information. The new configuration with symmetrical configuration of microphones has been verified by the simulation using boundary element method and proved to be reasonable to localize the directional information. In signal processing view, the time delays between sensors can effectively be estimated by using correlation function based on the envelope signals of sound pressure signals.

References

Attenborough, K. and P. Boulanger. 2003. Effects of surface roughness on outdoor acoustics, Internoise 2003, 3373-3380.

Bendat, J.S. and A.G. Piersol. 1986. Random Data: Analysis And Measurement Procedures, Second edition, John Wiley & Sons.

Johnson, D.H. and D.E. Dudgeon. 1993. Array Signal Processing: Concepts And Techniques, Prentice-Hall, Inc.

Kirkup, S. 1998. The Boundary Element Method In Acoustics, Integrated sound software.

SOLAS Chapter 5, Regulation 19 Carriage Requirements For Shipborne Navigational Systems And Equipment.