2P6-2
Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 357-358
20-22 November, 2013

Detection of Ship Screw Deflection Using Small Element Number of Hydrophone Array

少数ハイドロフォンアレイを用いる船舶スクリュー軸振れ検出

Takuji Kawagishi[1‡], Keiichi Zempo[1], Koichi Mizutani[1], Naoto Wakatsuki[1], Tadashi Ebihara[1] and Youhei Kawamura[2] ([1]Univ. Tsukuba, [2]Curtin Univ.)
川岸 卓司[1‡], 善甫 啓一[2], 水谷 孝一[2], 若槻 尚斗[2], 海老原 格[2], 川村 洋平[3]
([1]筑波大院・シス情工, [2]筑波大・シス情系, [3]カーティン大)

1. Introduction

Marine vessels employ several screws for driving. These screws are usually connected to the engine and transmission via a drive shaft. If the shaft deflection occurs, the submerged bearing is often damaged as shown in **Fig. 1**(1). In the last several decades, the deflection of the ship screw shaft causes around 20 accidents per year such as engine failure or a ship sinking in the worst case. To avoid these accidents, general vessels have some monitoring systems, *e.g.* bearing temperature, vibration, and electric resistance. However, pleasure boats and fish boats cannot equip these monitoring system because of spatial and cost limitations. To evaluate the condition of the screw shaft, ships need to be jacked up at the dock.

The purpose of this study is to develop a detection system of ship screw deflection which is assumed to be installed in the harbor. By using a hydrophone array composed of a small number of elements, the proposal method would be able to detect and identify the screw-deflected ship without installing a monitoring system to each ship. **Figure 2** shows the conceptual scheme of the proposed method. As shown in the figure, several hydrophones are set on the bottom of a harbor. Received sound is processed by cepstrum analysis, and detection of screw deflection and identification of sound source are performed. For detection, support vector machine (SVM) is used to classify the cepstrum of screw sound in order to examine the ship of various types. For identification, direction of arrival (DOA) estimation is used to localize the deflected sounds. As a pilot study, the authors conducted experiments for detection and identification of the screw-deflection shaft sound using a test tank.

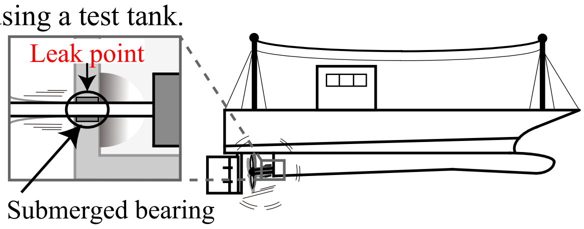

Fig. 1 Flooding caused by the screw deflection shaft

E-mail address: kawagishi@aclab.esys.tsukuba.ac.jp
mizutani@iit.tsukuba.ac.jp

2. Principle of Measurement

2.1 Detection of the screw deflection shaft sound

The screw shaft deflection is detected by SVM using the cepstrum of the recorded sounds. The cepstrum of recorded sound, $C_{\mathrm{cep}}(k)$, is calculated as

$$C_{\mathrm{cep}}(k) = \mathcal{F}^{-1}\left(\log\left(\left|\mathcal{F}\left(s(t)\right)\right|\right)\right), \quad (1)$$

where $s(t)$ is recorded sound, k is quefrency, and $\mathcal{F}(u)$ and $\mathcal{F}^{-1}(u)$ denote the Fourier transform and inverse Fourier transform of u, respectively. $s(t)$ is separated into microstructure spectra and spectral envelope by cepstrum analysis. The microstructure spectra provides the variation of the frequency spectrum and the fundamental frequency of sounds, and it is used to detect the abnormal states of rotating machines. It is expected that the cepstrum of the sound of screw deflection differs from the normal sound.

SVM learns several $C_{\mathrm{cep}}(k)$, to classify the sound of screw deflection and the normal sound. SVM is a modern technique of two class pattern recognition, and provides a high-accuracy classification with small amount of learning data.

2.2 Estimation of Direction-Of-Arrival (DOA)

The localization of the screw shaft deflection on specific ship is performed by DOA estimation(2). DOA is estimated from the time difference of arrival between each element. However, the conventional method could not be applied to this system directly due to the existence of continuous sounds**(3)**. To cope with this problem, we use the cross-power spectrum phase (CSP) analysis**(4)**

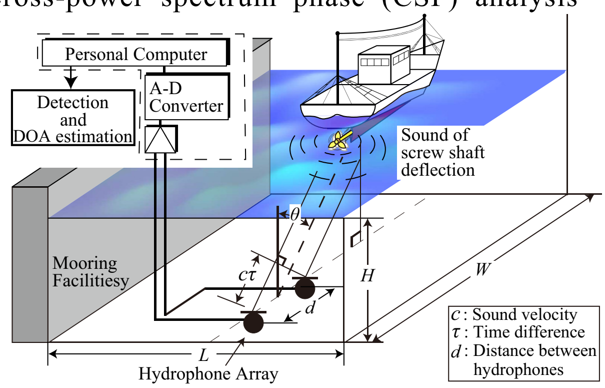

Fig. 2 Conceptual schemes of the proposed method

with a band-pass filter, which only passes the frequency band of screw sounds, calculated from spectral subtraction (SS).

3. Experiments

To evaluate the performance of the proposed method, we conducted two experiments at test tank. The size of the water tank was $L \times H \times W = 0.8 \times 0.4 \times 0.2$ (m^3). As the vessel model and the hydrophone array, submersible motor (Submarine Motor; 70153, Tamiya) and hydrophones (H1a; AQUARIAN) located with distance of d = 0.2 m, were used. The sound velocity was assumed to be 1,500 m/s. The screw deflection was simulated by bending the shaft of submarine motor. The screw sound was recorded with 48 kHz of sampling frequency for detection of the screw shaft deflection sound, and 196 kHz for DOA estimation. By changing the voltage applied to the motor, the rotational speed of the screw was controlled in 6 patterns from about 1,200 to 2,800 (rpm).

Figure 3 shows the received sound, amplitude spectra, cepstrum of normal, and deflected screws, respectively. In this figure, the rotational speed was 2,215 rpm (36.9 Hz). Focusing on the difference of cepstrum in Fig. 3(c) and 3(c'), we found that there are a difference around 3,300 and 3,900 in quefrency, for 5 rotational patterns. Several reasons can be considered; the screw shaft deviation from the center of gravity, and the vibration caused by the screw fins. **Table 1** shows the results of SVM classification with cross validation for each 15 sample of 6 patterns sounds. From the SVM classification, 90.3% of the discriminate rate was marked by the conditions of the same rotational speed. **Figure 4** shows the results of DOA estimation from the direction of the hydrophone array. The SS-CSP method could estimate the correct DOA compared to the CSP method, and it could estimate in the range of 0-25 (deg). However, error around 40 (deg) becomes large due to the effect of the sound reflected from water surface and walls. Therefore, the proposed method may be utilized for detection of screw shaft deflection sounds, and identification of deflected ships.

4. Conclusions

The purpose of this paper is to develop a detection system of screw shaft deflection. From the experimental result, it was found that SVM could classify the screw shaft deflection at the discriminate rate of 90.3%. Moreover, the possibility of DOA estimation to localize screw-deflected ships was suggested.

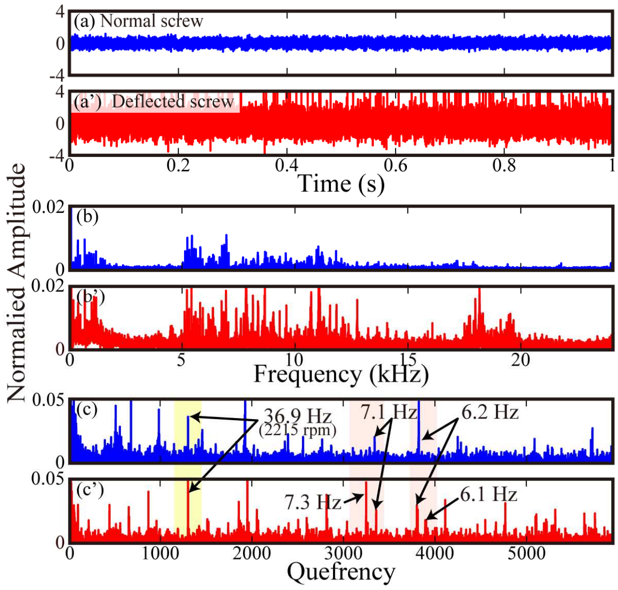

Fig. 3 Results at 2215 rpm; (a)Received waveform, (b)Amplitude spectrum, and (c)Cepstrum.

Table 1 Discrimination results of SVM

	Result of value of the detection		Total
	Normal Screw	Deflected Screw	
Normal Screw	(a) 64	(c) 26	90
Deflected Screw	(b) 0	(d) 90	90

Accuracy: (a+d) / (a+b+c+d) = 90.3 %

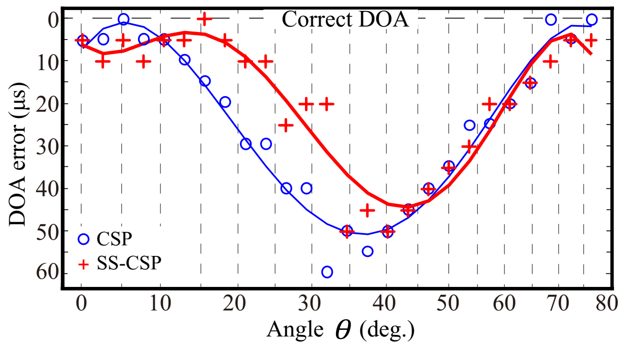

Fig. 4 Results of DOA estimation
(The DOA error of 0 is correct-DOA.)

References

1. H. Shiihara: J of the JIME, **44** (2009) 73. [in Japanese].
2. K. Mori, H. Ogasawara, T. Nakamura, T. Tsuchiya, and N. Endoh: Jpn. J. Appl. Phys. **52** (2013) 07HG02.
3. L. Fillinger, A. Sutin and A. Sedunov: J. Acoust. Soc. Am. **129** (2011), 774.
4. K. Zempo, T. Ebihara and K. Mizutani: Jpn. J. Appl. Phys. **51** (2012) 07GB09.