Experimental Study on Target Characters of Divers

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***Abstract*—Experimental results of diver's time-frequency characteristics such as target strength, radiated source level, breathing sound power spectrum and envelope spectrum are presented in this paper, which provide significant references to the development of diver detection systems. Target strength was measured using different incident wave frequencies, while the diver maintained different orientations. Power spectrum and envelop spectrum of diver's exhalations were employed to analyze the characteristics for the sound of breathing in different frequency bands and at different breathing cycles. The results show that the oxygen tank contributes more to target strength than lung and breathing bubbles. The results also indicate that the characteristics of breathing sound vary in frequency band and high frequency band is better suited for diver detection. One of the findings of the experiment is that the diver detection improves when the breathing cycle of the diver increases.**

Keywords—diver detection; target strength; target characters

I. INTRODUCTION

Divers can cause great destructiveness to marine infrastructure such as bridges, power plants, port, and harbor facilities etc. which are very costly assets of any country [1-2]. Thus, early detection and persecution of these underwater threats are very important. Underwater surveillance can be performed using electromagnetic, optical waves or acoustic waves. Acoustic waves used in active or passive mode are considered the most effective carrier for these underwater systems. In acoustic active detection, the main unknown in assessing the feasibility of active sonar for diver detection is the target strength of the diver. The target strength has many contributing factors including tanks, buoyancy control, wet or dry suit, etc. Furthermore, it varies with orientation, aspect angle and frequency [3-4]. The detection range of a diver mainly depends on the target strength and very little data is available in the literature on this topic. Most of the researchers give results for marine mammals [5-7] or for a single incident wave frequency [8-9]. In acoustic passive detection, target characteristics of the breathing sound are the main basis for diver recognition [10-11]. Characteristics of the breathing sound are related to the scuba types (open-circuit or close-circuit) and the diver's motion and actives [12-13]. When envelop spectrum approach is used to analyze the breathing sound characteristics, different frequency components and different breathing cycles have different contributions to the results.

In this paper, we address the problem of obtaining diver target strength versus incident frequencies in different orientations and other important characteristics and parameters for diver detection. A wetsuit diver equipped with an open-circuit scuba was taken as the object under study and Lake Trails were conducted. We measured the diver target strength for three different postures using different frequencies in 20-60 kHz band. Diver' breathing sound was recorded during the Lake Trails and its characteristics were investigated by applying power spectrum, waveform envelope in time and frequency domain and some other methods.

The rest of this paper is organized as follows: Section II we detail the setup of our Lake Trails. Experiment results of target strength measurement and target characteristics observation are separately presented in Section III and Section IV. We conclude with directions for future work in Section V.

II. EXPERIMENT SETUP

Experiments were conducted at Songhua Lake, in Jiling Province, China. The diver employed for this experiment was male, had a height of 175 cm and weighed 80 kg. He was wearing a 5 mm thick nylon wetsuit, equipped with open respirator and 12 L large oxygen bottle made of aluminum alloy.

Fig. 1(a) shows the target strength measurement schematic, diver maintained three different orientations for the experiment. In the first orientation, the diver was facing to the transmitting transducer. In the second case, he was showing a side to the transmitting transducer. In the third orientation, he was lying down head-on to transmitting transducer. The transducer sent CW pulse signal from 20 kHz to 60 kHz, each pulse contained 10 sinusoid periods at a particular frequency. The frequency of the pulse was stepped by 1 kHz. A hydrophone was used to receive the direct and echoed signals. The transmitting transducer, receiving hydrophone and target were deployed at 6m depth in one line. The distance between transmitting traducer and receiving hydrophone was 1 m while receiving hydrophone and target were 3.5 m apart from each other.

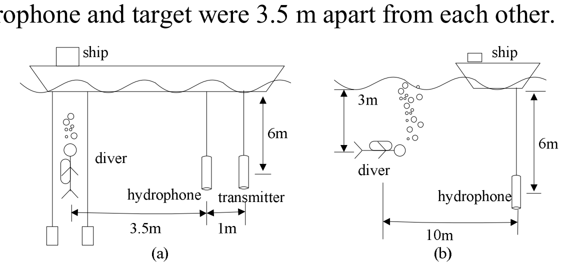

Fig. 1. Schematic of (a) target strength measurement (b) target characteristics observation.

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Fig. 1(b) shows the target characteristics observation schematic, the diver kept normal breathing rhythm and the signal was acquired by the hydrophone. The diver stayed stationary at a depth of about 3 m from the receiver located 10 m away at depth of 6 m.

III. Experiment Result of Target Strength Measurement

Oxygen tanker can be modeled as a finite rigid cylinder. The scattering intensity for this kind of object varies with frequencies and orientations/incident angles [14]. We used different frequencies in 20-60 kHz band for measurement of the change in scattering intensity with frequencies. To determine the effect of orientations/incident angles on the scattering intensity, the diver kept three representative postures/orientations as we illustrated before. Target strengths of these different orientations are shown in Fig. 2. As we can see, target strength varies with changing frequencies and incident angles (postures). In the first case (diver facing the transmitter), target strength of -5 dB to -13 dB re 1 m at frequencies from 20 kHz to 60 kHz is obtained. The averaged value is about -8.9 dB for this case. In the second case (diver showing side to transmitter) -3 dB to -14 dB target strength is obtained with mean of about -9.2 dB. These two postures have similar level of target strength, and are much higher than that of the third case when the diver is lying down head-on to transmitter. In the third case, target strength of -15 dB to -24 dB is obtained with mean of about -19.8 dB.

In all of these three conditions, diver's exhalations are almost the same, thus we can attribute the target strength changes to changes in posture/orientation. For the first two postures, scattering area and wave incident angles of the diver's lung and air tank do not change very much, so the target strength values of these two postures are very close. However, for the diver lying down head-on to transmitter, the scattering area and wave incident angles are different from that of the former two postures. Consequently, the target strength for this case is lower than that of the former two postures as shown in Fig. 2.

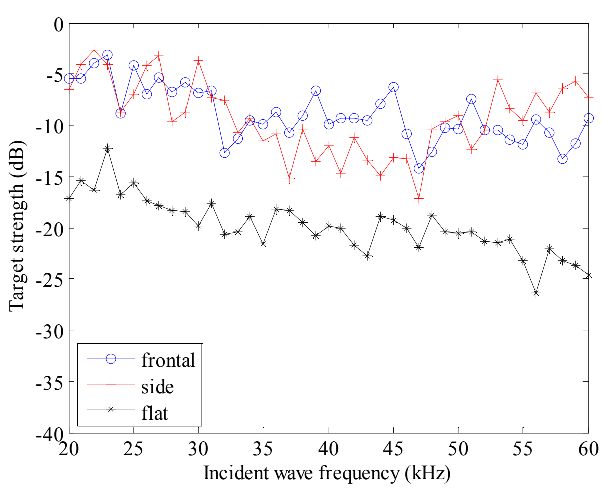


Fig. 2. Target strentgh curves on different incident wave frequencies and orientations.

IV. Experement Result of Target Characteristics Observation

A. *Power Spectrum Features*

During the experiment, we recorded the breathing sound and ambient background noise separately. Their power spectrum curves are shown in Fig. 3.

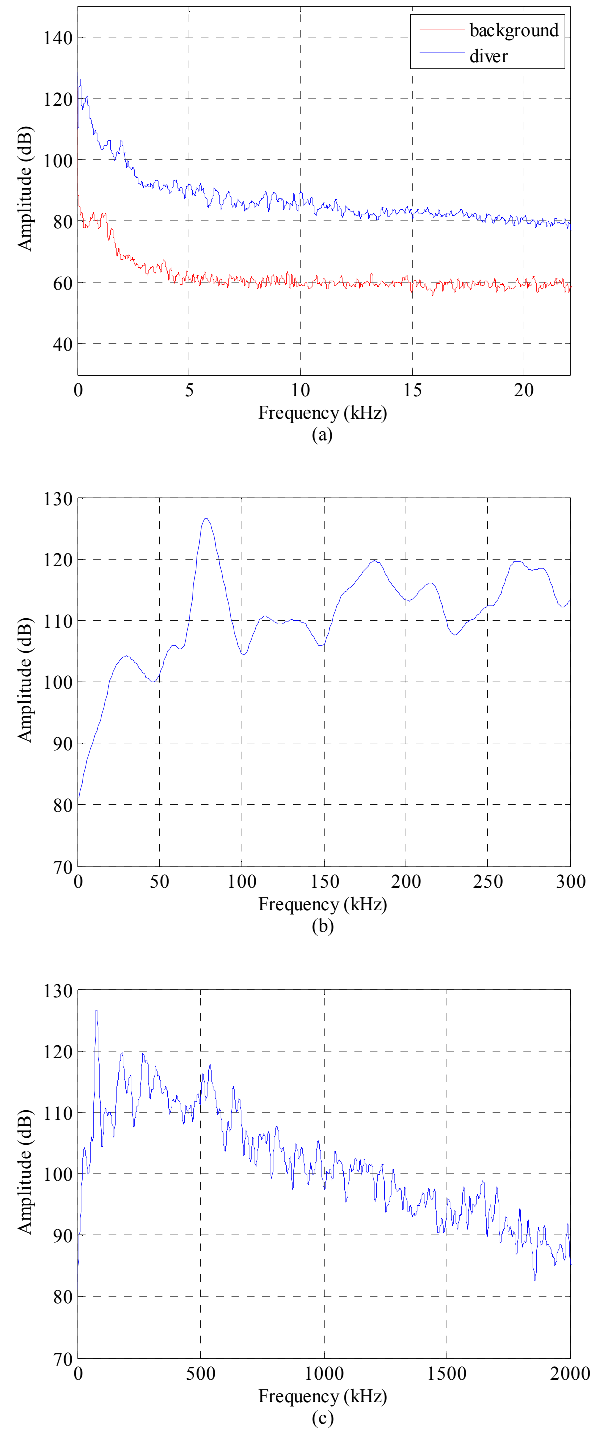


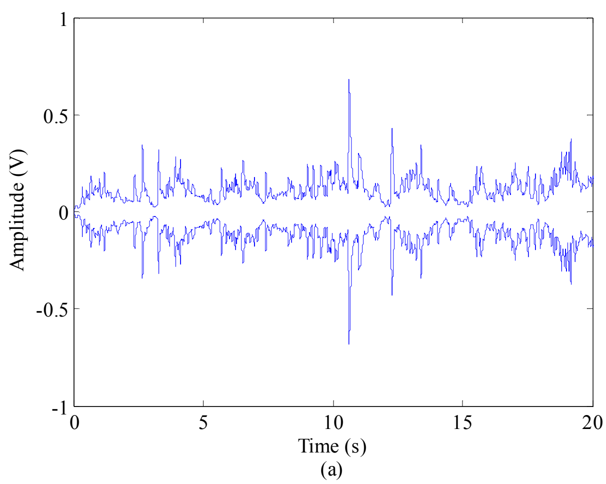
Fig. 3. Power spectrum of (a) background noise and breathing sound (b) breathing sound in 0-300 Hz (c) breathing sound in 0-2 kHz.

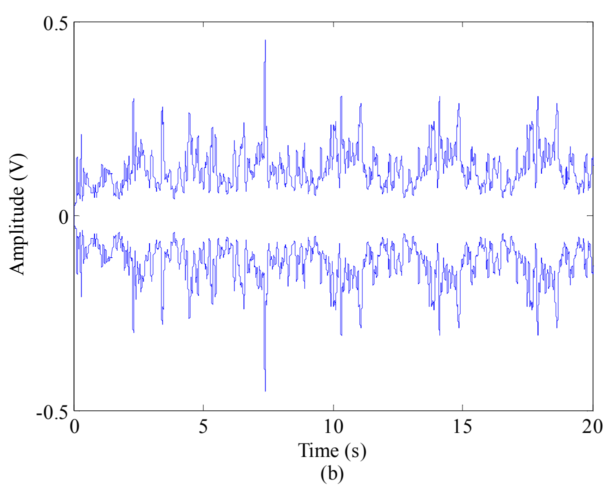
As Fig. 3(a) shows, power spectrum of the diver's breath sound is obviously higher than that of the background noise. Above 2 kHz it is stable while fluctuates heavily below 2 kHz. The frequency components within 60-80 Hz have the highest energy, as Fig. 3(b) shows. Fig. 3(c) shows that there is about 12 dB attenuation on every frequency doubling from 500 Hz to 2 kHz.

B. *Waveform Envelop Features*

Waveform envelopes of breathing sound are shown in Fig.4. For comparison, we demonstrated the envelopes of original signal and filtered signal respectively.

Fig. 4(a) shows the original signal envelope, as one can see, breathing rhythm can hardly be distinguished. From the earlier references, we know that breathing sound consists of expiration bubbles and regular vibrations. In order to investigate the features of these two different components, we processed the recorded breathing sound using the following steps. First, we filtered the raw signal through band-pass filter in different frequency bands and replayed the filtered signal. The results show that energy of the expiration bubbles largely lies in the low frequency band (below 2 kHz) while the energy of regulator vibration is mostly in high frequency band (over 2 kHz).





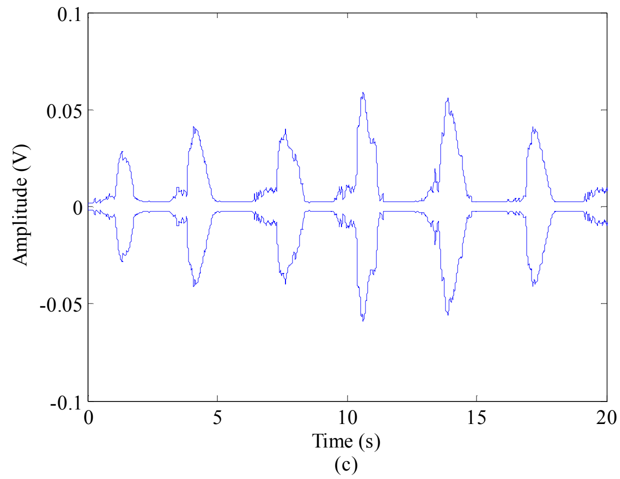


Fig. 4. Waveform envelopes of (a) original signal (b) low-pass filtered signal (c) high-pass filtered signal.

Followed by this result, the envelop features of these two components were observed in our second step processing. We separately filtered the raw signal using two different frequency bands in 0.01-2 kHz and 3-10 kHz. The waveform envelopes are shown in Fig. 4(b) and 4(c). Clearly, periodicity is much more distinct in high frequency band than that in low frequency band. This result indicates that the high band is the ideal choice for diver passive detection.

From Fig. 4(c), some other deductions can also be made. The figure shows that the breathing cycle lasts about 3 seconds. It also highlights that energy of expiration bubbles lies mainly in low frequency band despite presence of some energy in high frequency band also. As Fig. 4(c) shows, in every breathing cycle, the lower part is the expiration bubble and the higher part is the regulator vibration.

C. *Radiation Noise Source Level and Maximum Ddetection Range*

Nnumerous measurements of the diver's radiated source were used to obtain the average value of divers radiated noise level. This value comes to be about 116 dB.

We measured the maximum detection range for the diver without using any sophisticated signal-processing algorithms, and this range comes out to be about 70 meters. During the course, the diver swam away from the boat. It was found that the attenuation of the expiration bubbles with range is much faster than that of the regulator vibration. At the distance of 70 meters, only the regulator vibration noise can be observed. Waveform envelopes of the low and high frequency band signal at the furthest distance are shown in Fig. 5.

Fig. 5(a) shows that the waveform envelopes of the low frequency band signal cannot be distinguished from the background noise. Only small spikes of signal at the high frequency band are visible at some points [see Fig. 5(b)]. This result demonstrates that the high frequency band is the ideal choice for passive detection of diver.

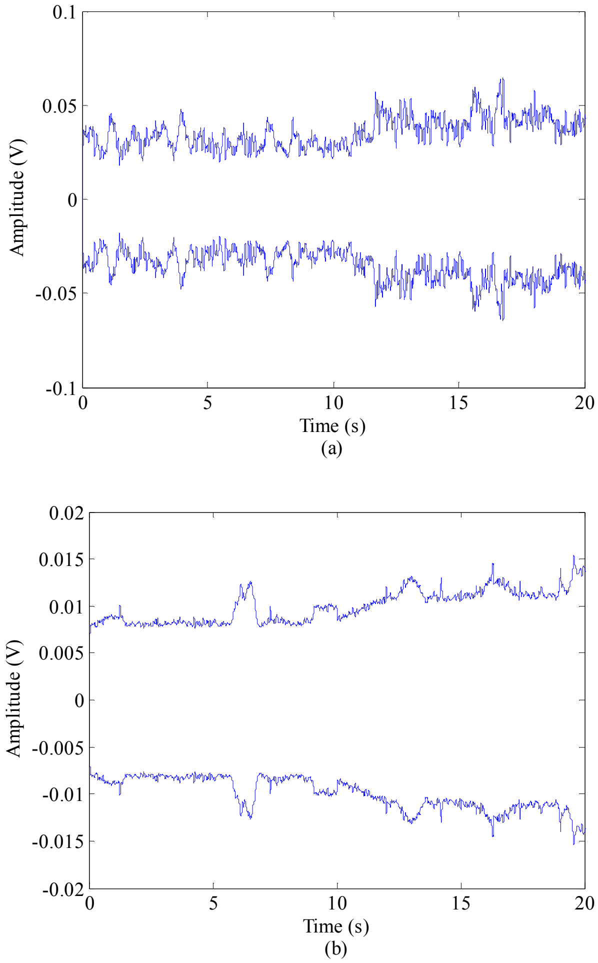


Fig. 5. Waveform envelopes of (a) low-pass filtered signal (b) high-pass filtered signal at the furthest distance.

D. Target Characteristics

Target characteristics of the breathing sound were observed using waveform envelope spectrum. We adopted a procedure for this as given in [15]. Results of processing for different conditions are shown in Fig. 6.

Fig. 6(a) shows the results of waveform envelop spectrum using different filter bands. Three bands were chosen: low band (0.01-2 kHz), high band (3-10 kHz) and whole band (original signal without filtering). Breathing sounds were filtered by band-pass filter of these bands. As we can see, there is an obvious peak of the "highband" curve between 0.3 and 0.4 Hz (diver's breathing rate is in this range). This result makes the high band believed to be the ideal choice for diver detecting.

Fig. 6(b) shows the results of waveform envelop spectrum using different sound sources. For comparison, four sound sources, likely to be present in background, were used: diver-breathing sound, blowing sound produced by humans, pumping sound from pumps and background noise. 20 cycles of each source signal were chosen and filtered with band pass filter at 3-10 kHz band. Obviously, the "diver" curve and the "blow" curve have an obvious peak between 0.3 and 0.4 Hz that matches the diver's breathing rate. While the "pump" and "background" curves have no features similar to this peak. Hence, this peak can be taken as an important mark for the diver detection and classification.

Fig. 6(c) shows the results of waveform envelop spectrum using different breathing cycles. For comparison, we have separately chosen three different numbers of cycles (3,5,10) of breathing sound to process. Comparing the curves, we can find that each one has a peak around 0.33 Hz. As we increase number of cycles in processing the peak gets sharper. As a result, we can infer that using more number of cycles improves the detection in envelop spectrum processing of diver's breathing sound. Practically, 10 cycles are enough to obtain a reasonable result.

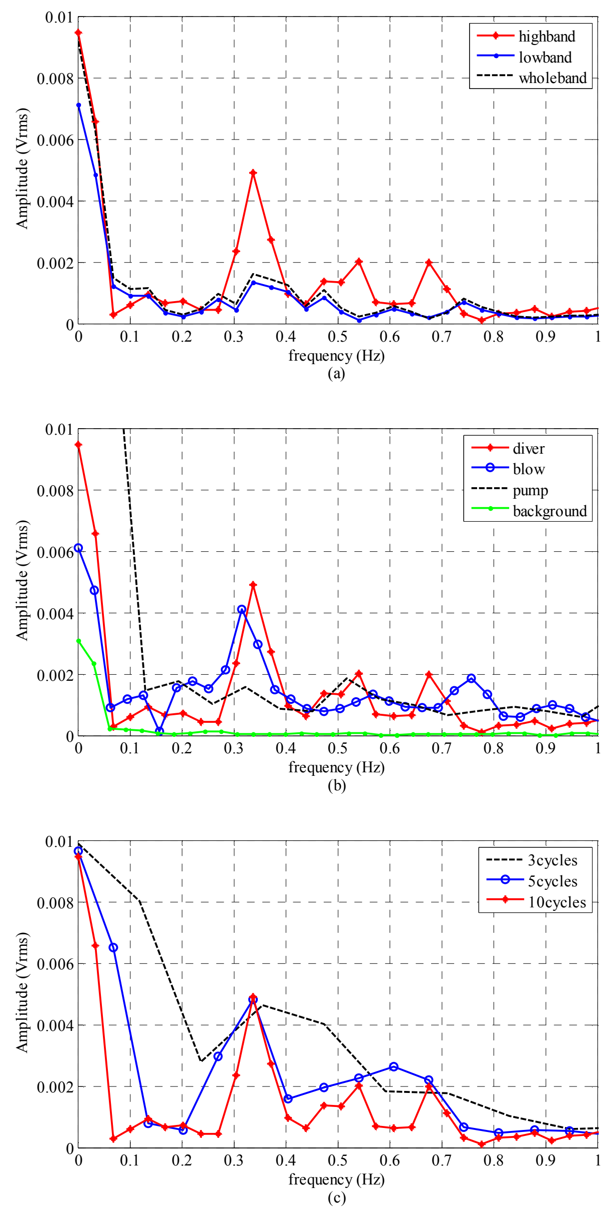


Fig. 6. Target characteristics in different conditions of (a) different frequency bands (b) different sources (c) different cycles.

V. CONCLUSIONS

Through experimentation in lake and detailed analysis of the experimental data, we have drawn some conclusions about the parameters of the wet suit and open-circuit scuba equipped divers, which are useful for preliminary system design of diver detection systems. These are as follows.

For active sonar detection, we obtained the diver target strength versus incident wave frequency in 20-60 kHz band for three different postures/orientations of the diver. The results indicate that lungs, breathing bubbles and oxygen tank are the main scattering sources of the incident wave, and oxygen tank contributes more to the target strength than the other two. Target strength would be affected by many factors including the incident wave frequency and diver postures/orientations (or wave incident angles).

For passive sonar detection, some significant results are obtained: the energy of air bubbles generated by the diver exhalation is mainly concentrated in low frequency band (below 2 kHz) while the energy associated with pulsation of the pressure-reducing valve is mainly concentrated at high frequency band (above 2 kHz). High frequency band, e.g. 3-10 kHz, is the recommended frequency band for passive diver detection as the periodicity of waveform envelope at this band is much more obvious than that at low frequency band, and the energy attenuation at high frequency band (regulator vibration) is much slower than that at low frequency band (expiration bubbles). Using more number of cycles improves the detection in envelop spectrum processing of diver's breathing sound. Practically about ten cycles are enough to obtain a good performance.

For future works, we are planning to use the vector hydrophone to draw the diver's moving track.

ACKNOWLEDGMENT

This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation, the National Natural Science Foundation of China under Grant No. 1127407 and National High Technology Research and Development Program of China under Grant No. 2009AA093601-2.

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