Experimental Study for Feature Extraction of Diver with Atmospheric Diving Suit

LI Sichun
Acoustic Science and Technology Laboratory
Harbin Engineering University
Harbin 150001, China
College of Underwater Acoustic Engineering
Harbin Engineering University
Harbin 150001, China
lisichun@hrbeu.edu.cn

HU Bo
Acoustic Science and Technology Laboratory
Harbin Engineering University
Harbin 150001, China
College of Underwater Acoustic Engineering
Harbin Engineering University
Harbin 150001, China
hubo@hrbeu.edu.cn

ZHOU Weicun
College of Underwater Acoustic Engineering
Harbin Engineering University
Harbin 150001, China
Shanghai Huawei Technologies Co., Ltd.
Shanghai 201206, China
julianroma@126.com

LIU Zhao
College of Underwater Acoustic Engineering
Harbin Engineering University
Harbin 150001, China
Kunming Shipborne Equipment Research and Test Center
Kunming 650051, China.
lz19890315@126.com

***Abstract*—To find acoustic signature of diver equipped with atmospheric diving suit (ADS), a logarithmic normalized frequency-domain multi-band matched-filter (LNMF) algorithm is presented, which can mitigate the influence of the background noise and short-duration transient interference. Based on experimental study, test data of a diver equipped with ADS was recorded and analyzed in time-domain, frequency-domain and time-frequency domain, and the results showed that the diver's exhaust periodicity is about 5s, diver acoustic characteristics are a wide frequency spectrum, the band width is about 60kHz during the exhaust phase. The exhaust repetition frequency of a diver with ADS was extracted using the proposed algorithm. The experimental results show the exhaust repetition frequency is about 0.2Hz, which corresponds to the exhaust rate of the diver with ADS, and verify the effectiveness of LNMF on exhaust frequency feature extraction in a complex underwater environment. In addition, statistical analysis results of the exhaust repetition frequency are in the interval between 0.13Hz to 0.2Hz. The proposed algorithm can also be used to diver with open circuit breathing systems.**

Keywords—acoustic signal of diver with atmospheric diving suit; exhaust sound frequency feature; logarithmic normalized frequency-domain multi-band matched-filter; feature extraction

I. INTRODUCTION

Underwater divers are one of the primary threats to anti-terrorism and underwater security in recent years. Most research focus on divers using open-scuba apparatus [1-6], pay less attention to divers equipped with atmospheric diving suit (ADS) [7] which is most used for work on underwater rescue, underwater salvage, ocean drilling rigs, photographic surveys, and other underwater operation.

Atmospheric diving suit include steel helmet connected with air pump through a conduit, diving suit, copper boots, Lead weights and a telephone communication with the ground commander. A ground air pump along a air supply conduit provides air supply for the diver with ADS. When the diver exhaling gas accumulated a certain amount, the accumulation of gas automatically discharged into the water from the unidirectional exhaust pipe, and a cloud of bubbles is ejected into the water. Photograph of a diver with ADS is shown in figure 1.

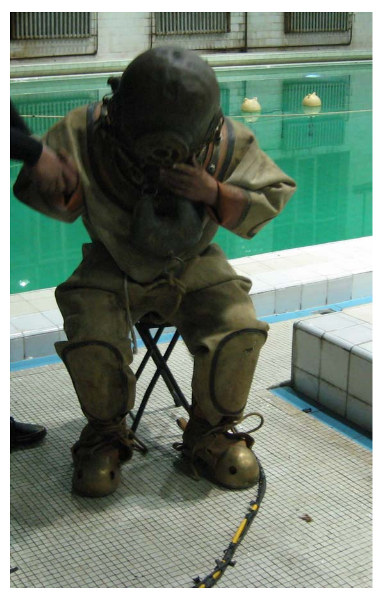


Fig. 1. A diver with atmospheric diving suit

978-0-933957-43-5 ©2015 MTS

The focus of this paper is analysis and feature extraction of a diver with ADS. The time domain, frequency domain, and time-frequency domain characteristics of acoustic signals from diver with ADS are presented. A logarithmic normalized frequency-domain multi-band matched-filter technique is proposed. Experimental results show the effectiveness of LNMF on exhaust repetition frequency feature extraction of diver in a complex underwater environment.

II. FREQUENCY-DOMAIN MULTI-BAND MATCHED-FILTER

Fig. 2 shows the main block diagram of frequency-domain multi-band matched-filter (MF) and the spectrum of the MF output [8].

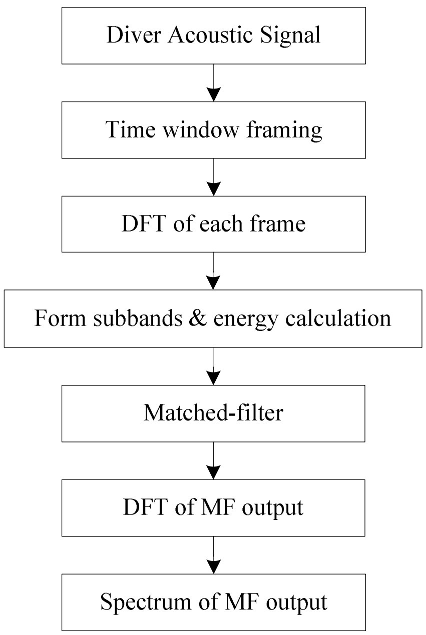


Fig. 2. Diagram presenting the main blocks of frequency-domain multi-band matched-filter

The time domain observed acoustic signal of diver $x(t)$ can be expressed as

$$x(t) = h(t) * s(t) + n(t) \tag{1}$$

Where $s(t)$ is the acoustic signal produced by underwater diver, $n(t)$ is the background noise, and $h(t)$ combines the information from both the sound propagation channel attenuation and transmission path delay [9].

The sampled signal $x[k]$ is given by

$$x[k] = x(t)\,|_{t=kT_s}\,, \qquad k = 0,1,2,\cdots \tag{2}$$

Where T_s is a sampling interval.

MF [10] use a sliding window to segment $x[k]$ into several frames (suppose M frames), the time length of each frame is T_f, then transfer each time-domain frame into frequency-domain using FFT. A component in $[f_L,\ f_H]$ frequency range of high SNR can be selected for MF.

Let $B = f_H - f_L$, break $[f_L,\ f_H]$ into N subbands and calculate the total energy of each subband, that is

$$E_x = \begin{bmatrix} \|X_{1,1}\|^2, \|X_{1,2}\|^2, \cdots, \|X_{1,n}\|^2, \cdots, \|X_{1,N}\|^2 \\ \cdots\cdots \\ \|X_{m,1}\|^2, \|X_{m,2}\|^2, \cdots, \|X_{m,n}\|^2, \cdots, \|X_{m,N}\|^2 \\ \cdots\cdots \\ \|X_{M,1}\|^2, \|X_{M,2}\|^2, \cdots, \|X_{M,n}\|^2, \cdots, \|X_{M,N}\|^2 \end{bmatrix} \tag{3}$$

where $\|\bullet\|$ takes the Frobenius norm, $m = 1,2,\cdots M$ is frame number, $n = 1,2,\cdots,N$ is subband number, $X_{m,n}$ is the spectrum of mth frame and nth subband of the measured signal.

Suppose the energy of the reference signal is E_s, then

$$E_s = \left[\|S_1\|^2, \|S_2\|^2, \cdots, \|S_n\|^2, \cdots, \|S_N\|^2\right] \tag{4}$$

where S_n, $n = 1,2,\cdots,N$ is the spectrum of nth subband of the reference signal.

III. LOGARITHMIC NORMALIZED FREQUENCY-DOMAIN MULTI-BAND MATCHED-FILTER

By (3) and (4), the SMF (Standard MF) output can be designed as

$$Y(m,\ 1{:}N) = \frac{E_x(m,\ 1{:}N)E_s^T}{E_s E_s^T}, \quad m = 1,2,\cdots,M \tag{5}$$

where Y denotes the SMF output and there will be a peak of Y when diver exists, T is transpose.

The output of SMF is a Non-stationary process with large energy fluctuation in each frame, To improve the capability of SMF, we proposed LNMF output, that is

$$\begin{cases} Z(m,\ 1{:}N) = 10\lg \dfrac{Y(m,\ 1{:}N)}{\max\left[Y(m,\ 1{:}N)\right]} \\ G(m,\ 1{:}N) = Z(m,\ 1{:}N) - \left\|Z(m,\ 1{:}N)\right\|_{\min} \end{cases} \tag{6}$$

where G denotes the LNMF output and there will be a peak of G when diver exists. $m = 1,2,\cdots M$ is frame number, N is subband number, $\|\bullet\|$ takes the Frobenius norm.

Using DFT on LNMF output, obtain the envelope spectrum curve. When diver with ADS exists, there will be a maximum value, it is the exhaust repetition frequency signature of a diver with ADS.

IV. Experimental Study

The experiment was carried on test tank in Harbin Engineering University. Experiment instrumentation includes a B&K8106 hydrophone, B&K2636 measuring amplifier, PF-1U-8FA Precision Filters, B&K Pulse 3660D which is used to collect and record the acoustic signals of a diver with ADS, and signal processing equipment which is used to analyze data preliminary. The sampling rate is 102.4*2.56kHz. The picture of test site and system are shown in Fig. 3. Fig. 4 shows the schematic diagram of testing field.

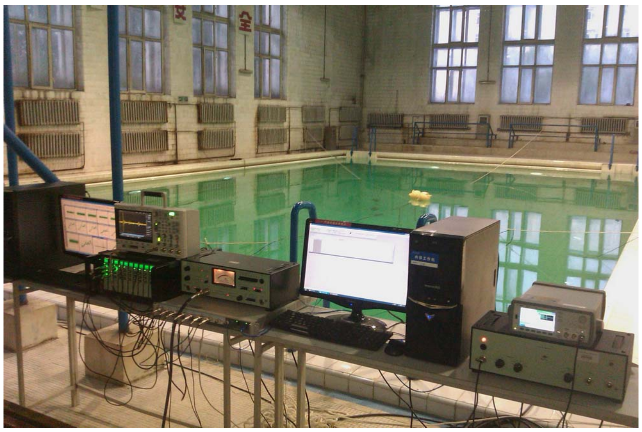


Fig. 3. Photograph of the trial site in Harbin Engineering University test tank and measurement system

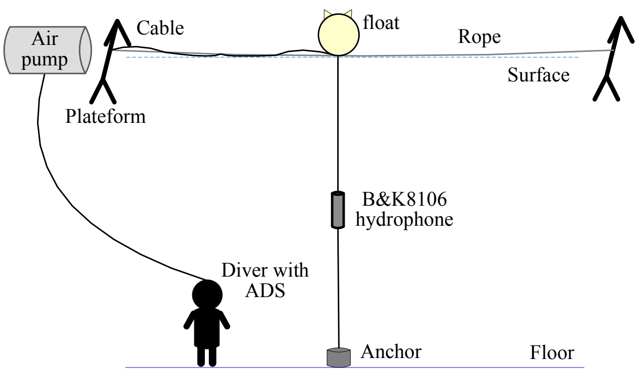
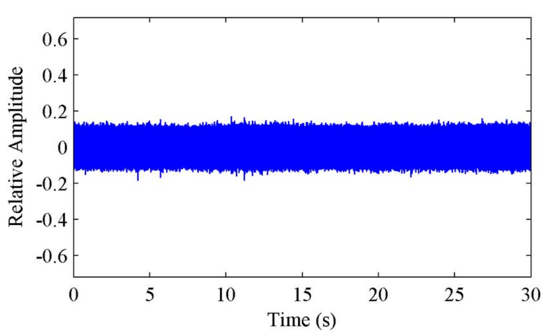
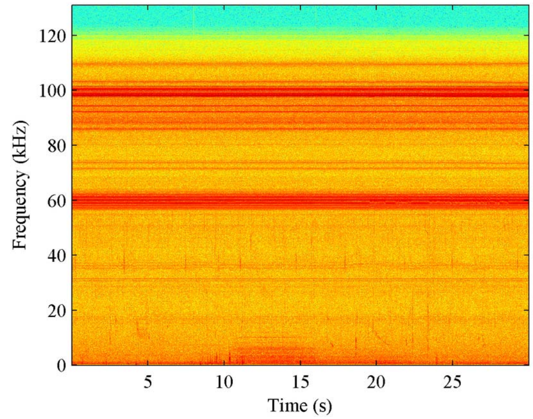


Fig. 4. Testing field schematic diagram

Acoustic environmental noise was collected before diver into the water. Fig. 5 shows its time-domain waveform and time-frequency spectrogram.



(a) Time-domain waveform

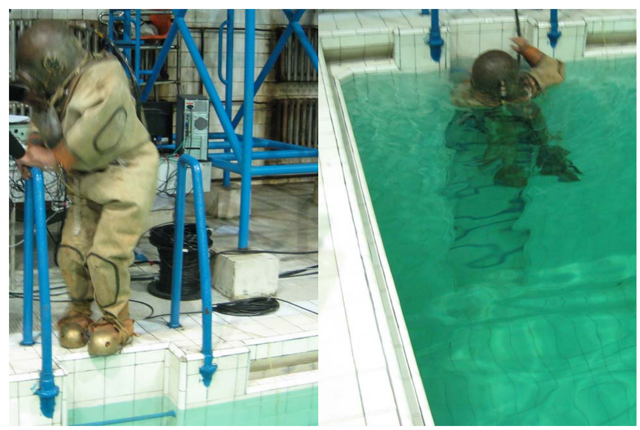


(b) Time-frequency spectrogram

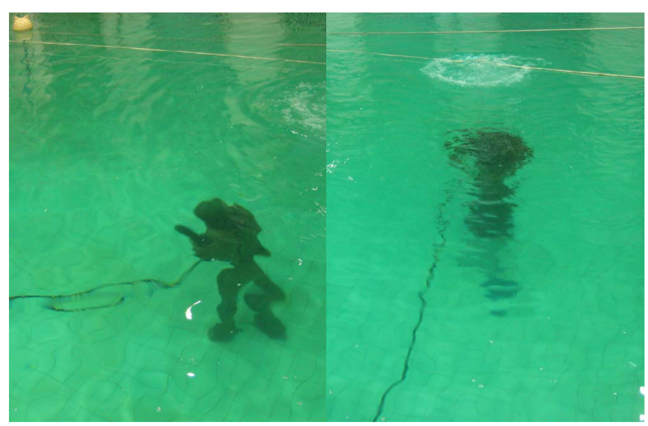
Fig. 5. Acoustic environmental noise

It is apparent from Fig. 5(b) that there are strong noise around 60kHz and 100kHz at the time of testing.

In the test, a long pipeline connects diver's helmet to air pump which provides air supply for diver. The experiment scenes are shown in Fig. 6.



(a) From the shore enter into the water



(b) Walking in the bottom and discharge bubbles into the water

Fig. 6. Tank experimental scene photos of a diver with ADS

The experimental data was obtained in the test tank. Fig. 7 shows a typical time-domain waveform of a diver with ADS.

From the data the exhausting average periodicity can be evaluated that it is about 5s. It presents that there are high background noise and strong pulse interference in the signal of diver with ADS. The time-frequency spectrogram is shown in Fig. 8, the periodic broadband nature of the diver exhausting is clearly visible, the band width is about 60kHz during the exhaust phase.

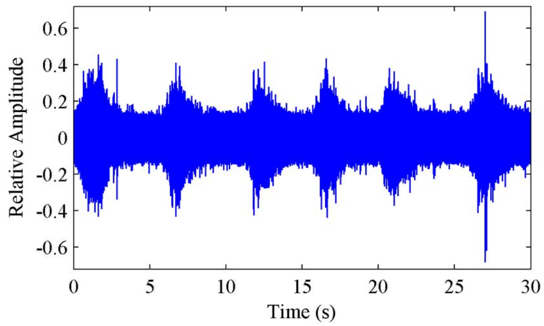


Fig. 7. Time-domain acoustic signal of a diver with ADS

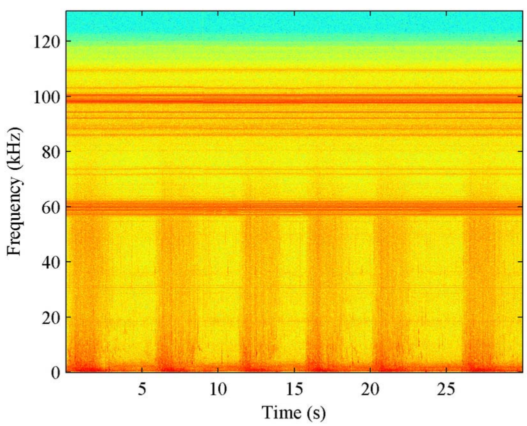


Fig. 8. Time-frequency spectrogram of a diver with ADS

Fig. 9 shows the spectra of a diver with ADS, ambient noise and difference between them. A frequency band with a high SNR can be provided from the spectrum of the difference for feature extraction.

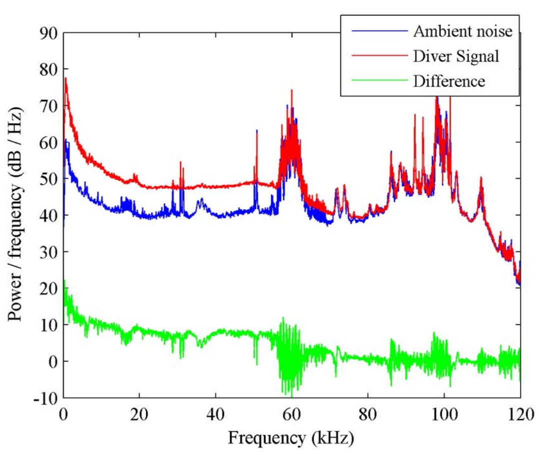


Fig. 9. Power spectral density of a diver, noise and difference

Select analysis total bandwidth B=500Hz~10.5kHz, segment B into 10 subbands. The signal processing uses a sliding window with frame duration Tf =1s.

According to (3) and (4), the total energy of each frame and each subband of the measured signal and the total energy of each subband of the reference signal is calculated, and then SMF output and LNMF output can be calculated by (5) and (6). Fig. 10 shows the comparison between SMF output and LNMF output.

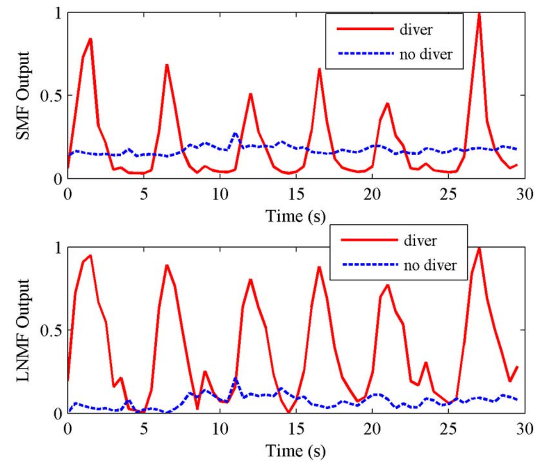


Fig. 10. Comparison between SMF and LNMF output

Comparing Fig. 7 with Fig. 10, the exhausting time and peak value time is consistent, it demonstrates the effectiveness and accuracy of multi-band matched-filter technique. The variation of the peak value of LNMF is more stable and smooth than SMF when diver exists.

Further, comparison between envelope spectrum of SMF and LNMF output are shown in Fig. 11.

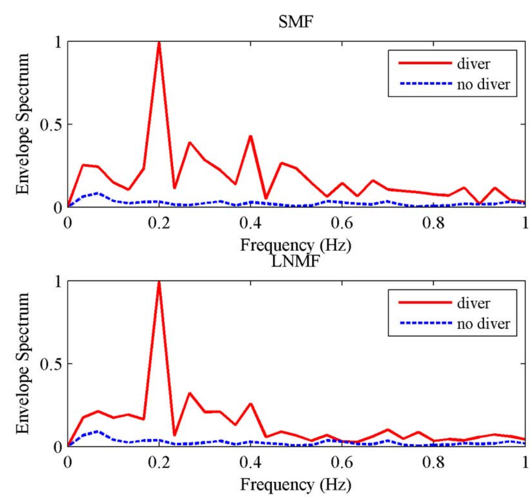


Fig. 11. Comparison the envelope spectrum of SMF & LNMF output

In Fig. 11 the feature of a diver with ADS and ambient noise (no diver) is displayed. It is clear that there is a high peak around the exhausting frequency of the diver while it is not present for the ambient noise (no diver). The exhaust frequency feature of diver with ADS is about 0.2Hz. The interference peak of LNMF envelope spectrum is less than SMF. Obviously the LNMF has more advantage in same situation.

V. CONCLUSION

Based on experimental study, underwater acoustic radiation signals from a diver with ADS was measured and analyzed. Studied on LNMF algorithm which has been used to extract feature of the exhaust repetition frequency of underwater diver with ADS successfully. Verified that LNMF is more effective than SMF in mitigate the influence of ambient noise and short-duration transient interference, and has better feasibility through comparison of the performance between them. The experimental results show that the key factor of underwater sound from a diver with ADS is exhaust sound, diver's acoustic characteristics has intermittent, a wide frequency spectrum during the exhaust process, and low exhaust repetition frequency.

ACKNOWLEDGMENT

This work was funded by Changjiang Scholars and Innovative Research Team in Universities of Ministry of Education of China (Grant No. IRT 1228). The International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation. The Pre-Research (Grant No. 51303020308-2).

REFERENCES

[1] R.Stokin, A. Sutin, S. Radhakrishnan, M. Bruno, B. Fullerton, A. Ekimov, and M. Raftery, “Feature based passive acoustic detection of underwater threats,” Proc. of SPIE, 2006, 6204: 620408-1-10.

[2] D. M. Donskoy, N. A. Sedunov, A. N. Sedunov, M. A. Tsionskiy, “Variability of scuba diver's acoustic emission,” Proc. of SPIE, 2008, 6945: 694515-1-11.

[3] C. A. Radford, A. G. Jeffs, C. T. Tindle, R. G. Cole, J. C. Montgomery, “Bubbled waters: the noise generated by underwater breathing apparatus,” Marine and Freshwater Behaviour and Physiology, 2005, 38(4): 259-267.

[4] A. Sutin, H. Salloum, M. DeLorme, N. Sedunov, A. Sedunov, M. Tsionskiy, “Stevens passive acoustic system for surface and underwater threat detection,” IEEE International Conference on Technologies for Homeland Security, 2013, 195-200.

[5] R. K. Lennartsson, E. Dalberg, L. Persson, S.Petrovic, “Passive acoustic detection and classification of divers in harbor environments,” MTS/IEEE Oceans' 09, Biloxi, MS, 2009.

[6] H. Lohrasbipeydeh, T. Dakin, T. A. Gulliver, C. D. Grasse, “Passive energy based acoustic signal analysis for diver detection,” Oceans' 14, St. John's, 2014.

[7] K. Doug, "Atmospheric diving suits–new technology may provide ADS systems that are practical and cost-effective tools for conducting safe scientific diving, exploration, and undersea research,” Proc. of the American Academy of Underwater Sciences 30th Symposium, 2013.

[8] K. W. Chung, H. Li, A. Sutin, ”A frequency-domain multi-band matched-filter approach to passive diver detection,” Proc. of ACSSC, 2007, 1252-1256.

[9] X. Chen, U. Tureli, “Passive acoustic detection of divers using single hydrophone,” Proc. of 40th Asilomar conf. On Signals, Systems and Computers, 2006, 554-558.

[10] X. Chen, R. Wang, U. Tureli, “Passive acoustic detection of divers under strong interference,” MTS/IEEE Oceans'06, Boston, MA, 2006.