Research on Sand Dumping Detection Based on Sound Absorption in Seawater

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***Abstract*—Against the illegal dumping by dredging barges, a project which utilizes the principle of sound absorption in turbid seawater that achieves the frequency characteristic curve of underwater communication channel by transmitting sweep signal with constant amplitude periodically is put forward in this article. The particle concentration in seawater will change drastically when the dredging barge dumps sediment and the frequency characteristic curve will change with it. Then, it can be determined whether an illegal dumping is present by detecting the difference of the adjacent curves. The project is preliminarily proved practicable in theory via a series of simulations with MATLAB, according to the computing model of the coefficient of sound absorption in turbid seawater.**

Keywords—turbid seawater; sound absorption; sweep signal; underwater detection; dumping sediment

I. INTRODUCTION

Due to the illegal dumping sediment by dredging barges in harbor, the cost for cleaning and conserving the waterway is increasing considerably, which results in a huge economic loss. The measures taken generally at present, such as GPS positioning and installing cameras on a barge, have failed to regulate the behavior of dredging barges effectively. On one hand, cameras are damaged on purpose or the shooting angle is changed by the operators on barge. On the other hand, the pick-up heads are hard to capture the sights underwater as a result of the high turbidity of seawater in the port area. Therefore, an accurate judgment cannot be made and valid evidence cannot be taken on barge's illegal dumping. And the method that installing a draft detection device on board [9] is unsatisfactory in practical application, because it's easy to be influenced by some environmental factors such as stormy waves.

In this paper, according to the theory of sound absorption in turbid seawater, a new project which utilizes underwater communication and information processing technology is presented. The system transmits and receives sweep signal periodically, and it determines that whether there is an illegal dumping through detecting the transformation of the frequency characteristic curves. Moreover, a series of calculations and simulations have been done with MATLAB, which has verified initially that the scheme is available in theory. These works above have laid the foundation for the further network design. In addition, some extended functions, such as measuring depth and concentration, can be developed on the basis of this network system.

II. THE PRINCIPLE OF SOUND ABSORPTION IN TURBID SEAWATER

The propagation loss of sound in seawater mainly consists of three parts, diffusion, absorption and scattering. And the propagation model of sound can be expressed as

$$I(x) = \frac{I_0}{x^n} e^{-2\alpha x}, \qquad (1)$$

where $I(x)$ is the sound intensity; I_0 is a constant which determined by the sound source; α is the total attenuation coefficient; n is related to the propagation condition, and in which n is chosen as 0 (plane wave propagation). That is to say, $I(x)$ can be expressed without diffusion as

$$I(x) = I_0 e^{-2\alpha x}, \qquad (2)$$

Due to the large number of sediment particles, the sound absorption in turbid seawater includes not only that in pure seawater, but also the viscous attenuation, scattering and heat conduction loss which caused by particles. The sound absorption in pure seawater is comprised of that in pure water and that caused by the relaxation in electrolyte solutions (mainly, $MgSO_4$ and $B(OH)_3$). Actually, the density of each particle is different from that of water, and a phase lag between particle and water will come into being when the sound travels in the turbid seawater, it leads to a boundary layer which has velocity gradient on the surface of the particle matter. And then, the velocity gradient will get the acoustic energy to be converted into heat. This mechanism is called viscous attenuation. In terms of scattering, a part of acoustic energy is scattered onto different directions by the particle matters, and it results in energy attenuation along the propagation path. It is shown that [6] heat conduction loss is tiny in the low-frequency band and it is negligible.

Generally speaking, the sound attenuation in turbid seawater is consisted of that in pure seawater, the viscous sound absorption and scattering which caused by particles. And the total sound attenuation coefficient can be expressed as

$$\alpha = \alpha_w + \alpha_v + \alpha_s, \qquad (3)$$

where α_w is the sound absorption coefficient in pure seawater; α_v is the coefficient of viscous sound absorption; α_s is the attenuation coefficient due to scattering.

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III. Choosing the Computational Models

A. The Model of Sound Absorption in Pure Seawater

The semi-empirical formula for calculating the sound absorption coefficient in clear seawater summarized by Schulkin and Marsh [2] is written as

$$\alpha_w = \left[A \frac{S f_T f^2}{f_T^{\,2} + f^2} + B \frac{f^2}{f_T} \right] \left(1 - 6.67 \times 10^{-5} d\right) \quad (Nepers/m), \tag{4}$$

where $A = 2.03\times10^{-6}$ and $B = 3.38\times10^{-6}$; S is the salinity of seawater / ‰; f is signal frequency / kHz; T is the sea temperature / ℃; d is the depth of transmitter and receptor under the sea / m; f_T is the relaxation frequency / kHz which is defined by

$$f_T = 21.9 \times 10^{6 - \frac{1520}{T+273}}, \tag{5}$$

(Note: 1 *Neper* = 8.686 *dB*)

In fact, the measurements are larger than the calculated values from formula (4) below 5 *kHz*. The lower the frequency, the larger the gap becomes. And the reason can be interpreted as that there are other relaxation mechanisms at low frequencies, and the relaxation frequency is about 1 *kHz*. The semi-empirical formula in low frequency band given by Thorp [10] is that

$$\alpha_{wL} = \frac{0.102 f^2}{1+f^2} + \frac{40.7 f^2}{4100+f^2} \quad (dB/m), \tag{6}$$

B. The Model of Viscous Sound Absorption

The calculation formula improved by Urick [1] in 1948 based on Lamb's model is the most usual model for computing the coefficient of viscous sound absorption at present. On the premise of the assumption that the particle concentration is not high, the interaction effect among neighboring particles is ignored in Urick's theoretical analysis. However, the interaction effect is significant in this study, because a particle cloud with high concentration will arise after an illegal dumping by a barge. In this paper, a better formula developed by Tang Yingwu [5] who is a researcher of the CAS is adopted, that is

$$\alpha_v = \frac{\varepsilon(1-\varepsilon) k_c (\sigma-1)^2}{2} \frac{\varphi\zeta}{(\varphi\zeta)^2 + (\sigma+\varphi\tau)^2} \quad (Nepers/m), \tag{7}$$

where ε is the volume concentration of suspended particles; k_c is the acoustic wavenumber in the fluid; φ, σ, τ and ζ are non-dimensional parameters. And they are defined as follows.

$$\varepsilon = PC/\rho_s, \tag{8}$$

$$k_c = \omega / c, \tag{9}$$

$$\beta = \sqrt{2\nu/\omega}, \tag{10}$$

$$\sigma = \rho_s / \rho_0, \tag{11}$$

$$\tau = \frac{1}{2} + \frac{9\beta}{4a}, \tag{12}$$

$$\zeta = \frac{9\beta}{4a}\left(1 + \frac{\beta}{a}\right), \tag{13}$$

$$\varphi = \left[1 - \frac{3}{4}\left(\frac{6\varepsilon}{\pi}\right)^{1/3} - \frac{1}{4}\left(\frac{6\varepsilon}{\pi}\right)\right]^{-1}, \tag{14}$$

In which PC is the mass concentration of particle matter / (kg/m^3); ρ_s is the density of each particle / (kg/m^3); c is the acoustic velocity / (m/s); ω ($= 2\pi f$) is the angular frequency / (rad/s); ρ_0 is the seawater density / (kg/m^3); a is the average radius of particles / m; ν ($= \mu/\rho_0$) is the liquid coefficient of kinematic viscosity; μ is the dynamic viscosity of seawater which can be calculated by

$$\mu = \mu_0 (1 + C\sqrt{Cl_V} + D\,Cl_V), \tag{15}$$

And in Formula (15), μ_0 is the dynamic viscosity of pure water / (Ns/m^2); moreover, C, D and Cl_V can be determined respectively by Formula (16), (17) and (18).

$$C = \frac{0.5185T + 1.0675}{10000}, \tag{16}$$

$$D = \frac{0.33T - 25.91}{10000}, \tag{17}$$

$$Cl_V = Cl \times \rho_0 / 1000, \tag{18}$$

where Cl is the chlorinity of seawater / ‰.

C. The Model of Scattering Attenuation

J. Sheng and A. E. Hay [3] have constructed a high-pass model for the attenuation coefficient due to scattering which can be written as

$$\alpha_s = \frac{\varepsilon K_\alpha (k_c a)^4}{a[1 + \xi (k_c a)^2 + \frac{4}{3} K_\alpha (k_c a)^4]} \quad (Nepers/m), \tag{19}$$

where ξ is an adjustable constant ≥ 1, and the value is chosen as 1 usually. The parameter

$$K_\alpha = (\gamma_k^{\,2} + \gamma_\rho^{\,2}/3)/6, \tag{20}$$

where γ_k and γ_ρ are the usual compressibility and density contrast which given by

$$\gamma_k = (k' - k)/k, \tag{21}$$

$$\gamma_\rho = 3(\rho_s - \rho_0)/(2\rho_s + \rho_0), \tag{22}$$

In Formula (21), k' is the bulk compressibility of particle; k is the bulk compressibility of water.

The simulation result in Figure 2 shows that the attenuation coefficient due to scattering $\alpha_s << \alpha_w$ and α_v at low frequencies, and it is insignificant. Therefore, the total sound attenuation coefficient can be rewritten as

$$\alpha = \alpha_w + \alpha_v, \tag{23}$$

IV. Designing Scheme

The transmitter sends a sweep signal with constant amplitude periodically, and its frequency increases linearly from 1 *kHz* to 200 *kHz*. Then the envelope curve of the received signal will be acquired after rectification, filtering and demodulation at the receiving end. As a matter of fact, this envelope can be regarded as the frequency characteristic curve. A difference curve can be achieved by subtracting the two temporally adjacent curves. Assume that a dredging barge is dumping illegally, and the particle concentration will change drastically in a certain area, which gives rise to a great gap between the current envelope curve and the previous one. As a matter of course, it will hump the difference curve, the larger the contrast, the steeper the ridge. Further, it can be determined whether an illegal dumping is happening by comparing the peak value of the difference curve with a given threshold value.

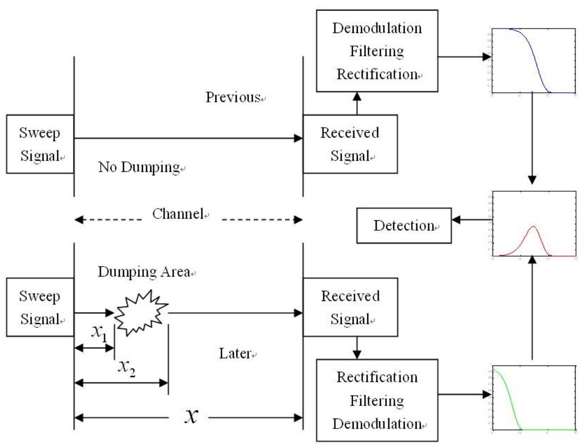

Fig. 1. Schematic diagram of detection an illegal dumping

Compared with the method of single measurement, the way of measuring twice successively has a higher sensitivity and reliability. Supposing that two dredging barges dump sediment in succession in a short time in the same region, the particle concentration in waters continues to remain at a higher level for a while after an illegal dumping by the former barge, and the system is always in the status of "warning". Then, the concentration will have an acute change again when the later barge is dumping, but the system is not able to distinguish the behavior of dumping this time if the single measurement is put to use. However, the method of measuring twice temporally that applied in this article is sensitive to the variation of concentration, and it is capable of detecting the unlawful action accurately. Besides, utilizing a sweep signal instead of a single-frequency signal is sure of obtaining the peak of the difference curve, furthermore, the bandwidth of signal can be improved, and which may reduce the interference due to frequency deviation and multipath effectively. As a consequence, both the method of measuring twice and the design of using sweep signal are in a position to guarantee the reliability and stability.

V. Simulation and Discussion

A. Setting Parameters

In a setting of Xiamen Harbor, considering the real environmental data and the theoretical results from the dumping models [7~8], those basic parameters may be set as follows.

Considering the average temperature of the sea surface in Xiamen over the past year, the value of T is chosen as 21.5; the seawater density ρ_0 and the density of each particle ρ_s are determined severally as 1025 and 2650; according to the research [13], the value of a may be determined as 2.5×10^{-6}; and in order to gain a better detection result, the devices are suggested to be installed at the depth of 10 meters under the sea, this is to say d is valued as 10; since the width of waterway ranges from 180 *m* to 300 *m*, the distance between transmitter and receptor *dis_tr* would be better to be set to 300; the effective width of the particle cloud *dc* ranges from 5 *m* to 10 *m*; with a conservative estimate, the mass concentration of particle matter *PC* is over 10 kg/m^3 generally; the concentration of particle matters without dumping is below 0.1 kg/m^3.

B. The Coefficients α_w, α_v and α_s at Different Particle Concentrations

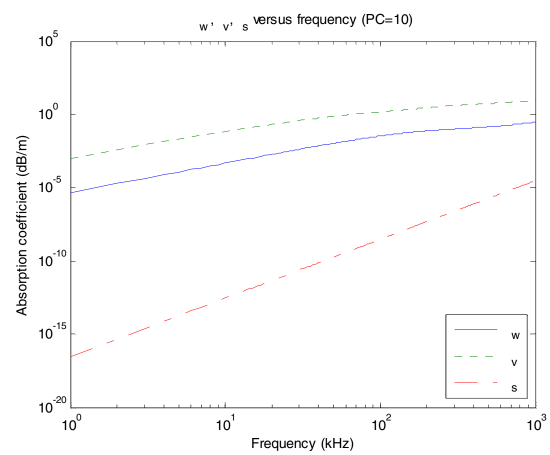

Fig. 2. The coefficient α_w, α_v and α_s versus frequency at the concentration of 10 kg/m^3

In the best case, the value of α_s is four orders of magnitude smaller than the other two attenuation coefficients seen in Figure 2. In other words, the attenuation coefficient due to scattering is so tiny that it can be neglected.

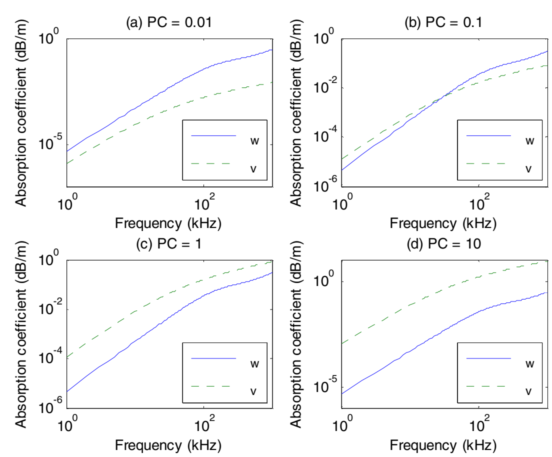

Fig. 3. The coefficient α_w and α_v versus frequency at different concentrations

The subgraphs (a), (b), (c) and (d) in Figure 3 are showing the curves of α_w and α_v versus frequency respectively at the concentration of 0.01, 0.1, 1 and 10.

It is obviously shown in Figure 3 that the values of α_w and α_v increase with the increase of frequency, as it were, the higher the frequency is, the severer the attenuation becomes. Moreover, the coefficient of viscous sound absorption α_v increases along with the particle concentration.

What's more, the subgraph for $PC = 0.01$ shows that $\alpha_v << \alpha_w$ and the mechanism of sound absorption in pure water is working mainly at the moment. The subgraph for $PC = 0.1$ shows that the curves of α_w and α_v are quite close, while the subgraphs for $PC \geq 1$ shows that $\alpha_v >> \alpha_w$. In brief, it is acceptable that the coefficient of viscous sound absorption must be taken into account for $PC \geq 0.1$.

C. The Total Attenuation Coefficient α at Different Particle Concentrations

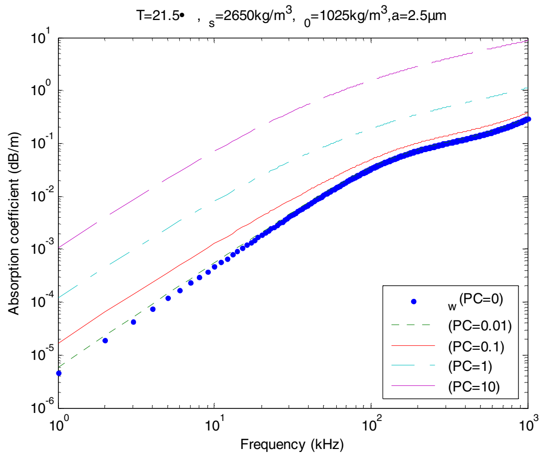

Fig. 4. The total attenuation coefficient α versus frequency at different concentrations

The total sound attenuation coefficient for $PC = 10$ is approximately 100 times as large as the one for $PC = 0.1$, it's a great gap. And according to knowing the particle concentration in the waters of Xiamen Harbor is under 0.1 kg/m^3 on a whole, while the one caused by an illegal dumping in a short time is much larger than 10 kg/m^3. All in all, it can be inferred from the analysis above that the total sound attenuation coefficient in seawater will vary extremely, which may give rise to a giant loss of the signal energy.

D. The Attenuation Factor γ (=I_x/I_0) at Different Particle Concentrations and Effective Wid

Seen in Figure 1, the received signal strength without dumping is given by

$$I_1(x) = I_0 e^{-2(\alpha_w+\alpha_{v1})x}, \tag{24}$$

where α_{v1} is the coefficient of viscous sound absorption without illegal dumping, and the particle concentration is quite low at this time.

Then, the received signal strength will have a huge change after dumping, which is written by

$$I_2(x) = I(x_2) e^{-2(\alpha_w+\alpha_{v1})(x-x_2)}, \tag{25}$$

considering the forms

$$I(x_2) = I(x_1) e^{-2(\alpha_w+\alpha_{v2})(x_2-x_1)}, \tag{26}$$

where α_{v2} is the coefficient of viscous sound absorption at a higher concentration after dumping, and

$$I(x_1) = I_0 e^{-2(\alpha_w+\alpha_{v1})x_1}, \tag{27}$$

Formula (25) can be rewritten as

$$I_2(x) = I_1(x) e^{-2(\alpha_{v2}-\alpha_{v1})\Delta x}, \tag{28}$$

where $\Delta x = x_2 - x_1$ is the effective width of the particle cloud.

Further, $\alpha_{v2} >> \alpha_{v1}$ shown in Figure 4, it is proper that $\alpha_{v2} - \alpha_{v1} \approx \alpha_{v2}$, and dividing both sides of the equation by I_0, finally, we have the form

$$\gamma_2 = \gamma_1 e^{-2\alpha_{v2}\Delta x}, \tag{29}$$

Formula (29) shows that the proportional coefficient between γ_1 and γ_2 is just connected with the concentration of particle cloud (α_{v2}) and the effective width of cloud (Δx), and it has nothing to do with the location of dumping.

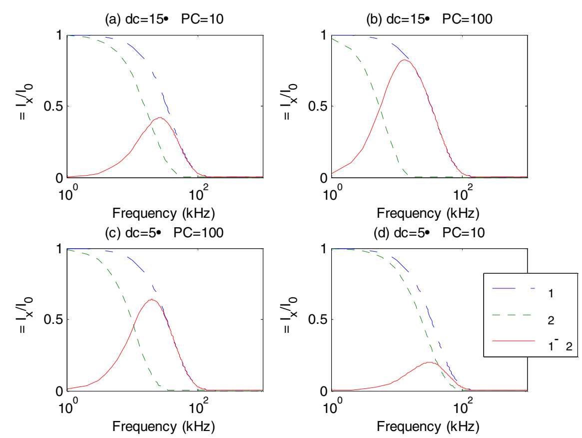

Fig. 5. γ (=I_x/I_0) versus frequency at different particle concentrations and effective widths

Actually, Figure 5 shows the frequency characteristic curves of the changing channel caused by dumping, in which the received curve of γ_1 expresses the lawful status, and the one of γ_2 represents the illegal status, and the curve of $\gamma_1 - \gamma_2$ is the difference cure described above.

Comparing Subgraph 5(a) with 5(b), and contrasting 5(c) and 5(d) as well, it is obvious that the higher particle concentration is, the more gibbous the difference curve becomes. Similarly, we may find that there is a positive correlation between the convexity of the difference curve and the effective width of cloud increases via comparing Subgraph 5(a) with 5(d) and contrasting 5(b) and 5(c). In the conservative case, seen in Subgraph 5(d), the difference curve ($\gamma_1 - \gamma_2$) still has a higher ridge, which is enough to judge the transformation of the two curves (γ_1 and γ_2).

In order to facilitate the processing and judgment, an analog-to-digital conversion is designed to be done (seen in Figure 6).

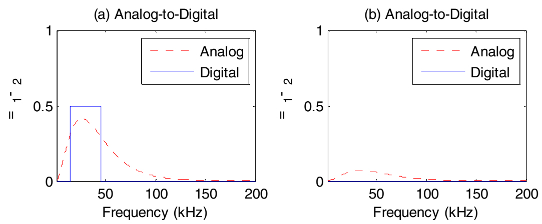

Fig. 6. Analog-to-digital conversion for $\gamma_1 - \gamma_2$

In Figure 6, the threshold value is chosen as 0.3 tentatively, if the value of $\gamma_1 - \gamma_2$ is larger than the threshold, the output high, otherwise the output low. Thereout, the analog signal is converted into a digital signal. Meanwhile, the proposition that whether there is an illegal dumping is tuned into a digital sequence consists of the number of 1s and 0s. Ultimately, it can be determined that an illegal dumping is present as soon as a rising edge is detected. Subgraph 6(a) shows that an illegal dumping is happening, while Subgraph 6(b) says that there is no unlawful action.

VI. SUMMARY

In this paper, we start from the theoretical model of sound absorption in turbid seawater, and bring forward a new detection model that measuring twice with a sweep signal. And the practicability has been proved preliminarily in theory via a series of soft simulations and calculations.

Frankly speaking, there are some shortcomings in this article. On one hand, we have made use of the calculation model for suspended particulate matter, and the particles are regarded as relatively silent on a macro, however, the particles caused by dumping are athletic in the direction perpendicular to the propagation direction, the downward movement obviously will take away part of the sound energy. Without a doubt, ignoring this part of the loss does not affect our conclusion. Additionally, numerical simulations for the dumping model have not been done, and some follow-up work is required to improve and perfect the model.

In allusion to the problem that the sweep signal with the wide frequency range from 1 *kHz* to 200 *kHz* is difficult to be produced in engineering, an improvement is come up now. In consideration of the peak of the difference curve appears usually at the frequency of 20 *kHz* to 40 *kHz*, and the value of the difference curve progressively approaches to zero when the frequency larger than 100 *kHz*. Consequently, the frequencies may be designed from 20 *kHz* to 40 *kHz*, and it is relatively easy to come true in practice.

The next study will focus on the characteristic parameters extraction and analysis via the Hilbert-Huang Transform, and continuous-time convolution will be used to achieve the characteristics of energy attenuation. In addition, a new underwater acoustic channel model with particle matters in our study has to be worked up by researching and modifying BELLHOP model.

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REFERENCES

[1] Urick R J, "The absorption of sound in suspensions of irregular particles," *J. Acoust. Soc. Amer.*, vol. 20, no. 3, pp. 283-289, 1948.

[2] Schulkin M, Marsh H W, "Sound absorption in sea water," *J. Acoust. Soc. Amer.*, vol. 34, no. 6, pp. 864-865, 1962.

[3] SHENG Jinyu, Hay A E, "An examination of the spherical scatter approximation in aqueous suspensions of sand," *J. Acoust. Soc. Amer.*, vol. 83, no. 2, pp. 598-610, 1988.

[4] PENG Linhui, WANG guibo, "Sound attenuation in suspended particle matter seawater of Chinese sea offshore," *ACTA ACUSTICA*, vol. 33, no. 5, pp. 389-395, 2008.

[5] TANG Yingwu, XU Yunxian, "Propagation of sound wave in concentrated suspensions," *ACTA ACUSTICA*, vol. 8, no. 4, pp. 220-226, 1983.

[6] Urick R J, Ament W S, " The propagation of sound in composite media," *J. Acoust. Soc. Amer.*, vol. 21, no. 2, pp. 115-119, 1949.

[7] MAO Genhai, CHENG Weiping, "Motion mechanism of particle clouds formed by dumping dredged material into quiescent water," *Journal of Zhejiang University*, vol. 39, no. 11, pp. 1663-1668, 2005.

[8] YING Xinya, Juichiro AKIYAMA, "Modeling of motion of particle clouds formed by dumping dredged material," *China Ocean Engineering*, vol. 15, no. 1, pp. 85-96, 2001.

[9] WENG Yuezong, XU Jianfeng, "Development and application of draft monitoring system for dredging barge," *Journal of Shanghai Maritime University*, vol. 31, no. 2, pp. 28-31, 2010.

[10] MA Dayou, "Handbook of acoustics," *Beijing: Science Press*, 2004.

[11] LIU Yongwei, LI Qi, "Research on calculating and measuring sound absorption in turbid seawater," *Journal of Harbin Engineering University*, vol. 31, no. 11, pp. 1472-1477, 2010.

[12] LIU Yongwei, LI Qi, "The correlation of sound absorption in turbid seawater with temperature, salinity and pressure," *Technical Acoustics*, vol. 31, no. 2, pp. 156-161, 2012.

[13] SUN Xiangqing, "Sediment siltation analysis and calculation of west harbour Xiamen," *Journal of Oceanography in Taiwan Strait*, vol. 8, no. 4, pp. 376-382, 1989.