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Underwater unknown acoustic source localization based on Sound Propagation Loss : theory analysis and simulation results

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Abstract: A new method based on SPL to estimate the position of unknown acoustic source was put up forward. And theoretical analysis and computer simulation has been used to analyze the accuracy of underwater sound source localization which is interfered by water background noise and multipath reflection. Using simulated data of two different real marine sound sources, we show that when the sound source is far from hydrophone array(greater than 200 meters), the accuracy of this method is high, up to 1 meter. However, with the distance decreasing, the intense reflection of offing brings multipath reflection interference and a correction based on decline analysis of multi-centre frequency of sound source was proposed which can increase localization accuracy by 10%-30%. Therefore, for short-range localization, use of a combination of passive sonar and this method can achieve a good accuracy. The research results verify the effectiveness of the function relationship between acoustic attenuation and the propagation distance in underwater unknown sound source localization. Especially it is advantageous on the remote positioning and can be combined with high accuracy passive positioning to realize great-range and high-accuracy location search.

Keywords: Unknown Sound Source； Sound Propagation Loss(SPL)；Sound Pressure；Characteristic Frequency

1. INTRODUCTION

Acoustic positioning technology concerns the safety and efficiency of underwater operation. Previous acoustic positioning cannot satisfy the needs in scientific research, marine exploration, underwater operation and biological targets monitoring. The primary and new demand is how to locate the unknown acoustic source.

The aim of sound source localization is to estimate the Cartesian coordinates of the source or the speed of the moving source. Many algorithms have been put up forward for sound source localization. Approaches using distributed microphone network are presented. In addition, approaches based on energy Measurements have also been studied in recent years. But in the ocean, there is still no appropriate sound source localization algorithm. Now the time-difference-of-arrival estimation methods, such as Super Short Base Line system (SSBL) and Lone Base Line system (LBL) are widely accepted, but these methods have large errors in noisy and multipath reflections condition. In recent years, wireless sensor networks and Sound Propagation Loss (SPL) has been studied. However, due to the complicated data processing and the limitations of localization algorithm, the accurate position of unknown source cannot be achieved.

In this paper, we put up forward a new method based on SPL to estimate the position of unknown acoustic source, and we carry on the research, using theoretical analysis and computer simulation, to analyze the acoustic pressure of underwater sound signal which is interfered by water background noise and multipath reflection. According to the results, we got functional relation between acoustic pressure attenuation of the unknown source and the propagation distance. Then we have done preliminary calculation and analysis in the accuracy of the unknown acoustic source localization, which provides theoretical basis for large scale and low cost acoustic positioning technology and offers a new approach for tracking the movement of complicated underwater source, such as the unknown sailing noise, underwater construction noise, biological noise, natural disasters noise.

The waveform and frequency spectrum of echo signal of each node are analyzed and when we use the single center frequency of acoustic pressure information in short range, the accuracy of localization is not high. To solve this problem, we extract multiple center frequency of acoustic pressure information, optimize the information and eliminate the incorrect acoustic source information. Then we can obtain the position of unknown acoustic source with the SPL algorithm. The computer simulation results also show that extracting single center frequency of acoustic pressure information has enough precision in the long distance. But when the distance between acoustic source and hydrophone array becomes short, owing to the powerful interference of reflection wave and the phase difference between directed wave and reflected wave, extracting one center frequency of acoustic pressure information cannot meet the accuracy needs. Then we extract multiple center frequency and optimize the results, which greatly reduces the errors.

2. PRINICIPLE

2.1. Sound Propagation Loss

SPL mainly includes two sections: Extended Loss and Absorption Loss, show as (1).

$$PL = 20\log 10(r) + \alpha r + \Delta \qquad (1)$$

Extended Loss: $\mathrm{PL} = 20\log$ (2)

Absorption Loss: based on experimental formula, determined by α .

When sound transmits with electrical signal, following equation (2) can be obtained.

$$PL = 20\log 10(Tv/Rv) + Rx + Rg \qquad (3)$$

Where, Tv [V] is Transmission voltage, Rv [V] is Reception voltage, Rx [dB]: Reception sensitivity, Rg [dB] is Reception gain. Rv is measured data and other 4 are all constants.

By solving the equations (1) and (3) simultaneously, (4) can be obtained.

$$20\log 10(Tv/Rv) + Rx + Rg = 20\log 10(\mathrm{r})$$

(4)

We got the relations between propagation distance r and T_v, R_v. By measuring R_v at different distances and through the following mathematical model, source coordinates was got.

2.2 Mathematical Model

Set the surface nodes as Ni（x_i, y_i, z_i）(i=1,2,3,4),and sound source as P(x, y, z), build the equation (5) and （6）,By measuring R_v at Ni and through equations (5) and (6), source coordinates was got.

$$\begin{cases} (x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = r_1^2 \\ (x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2 = r_2^2 \\ (x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2 = r_3^2 \\ (x-x_4)^2 + (y-y_4)^2 + (z-z_4)^2 = r_4^2 \end{cases} \qquad (5)$$

$$\begin{cases} 20\log 10(Tv/Rv_1) + Rx + Rg = 20\log 10(\mathrm{r}_1) \\ 20\log 10(Tv/Rv_2) + Rx + Rg = 20\log 10(\mathrm{r}_2) \\ 20\log 10(Tv/Rv_3) + Rx + Rg = 20\log 10(\mathrm{r}_3) \\ 20\log 10(Tv/Rv_4) + Rx + Rg = 20\log 10(\mathrm{r}_4) \end{cases} \qquad (6)$$

3. NUMERCIAL SIMULATION

3.1. Simulation Conditions

3.1.1 Sound source

Use two different signals : submarine propeller noise and marine life sound.

3.2 Simulation Contents

3.2.1 Layout of hydrophone array.

Four hydrophones can be set up in Figure 1. We can establish OXY coordinate system, as shown in Figure 1. Then nodes coordinate: Node1（-30,0,0）、Node2(-10,0,10)、Node3(10,0,0)、Node(30,0,0).

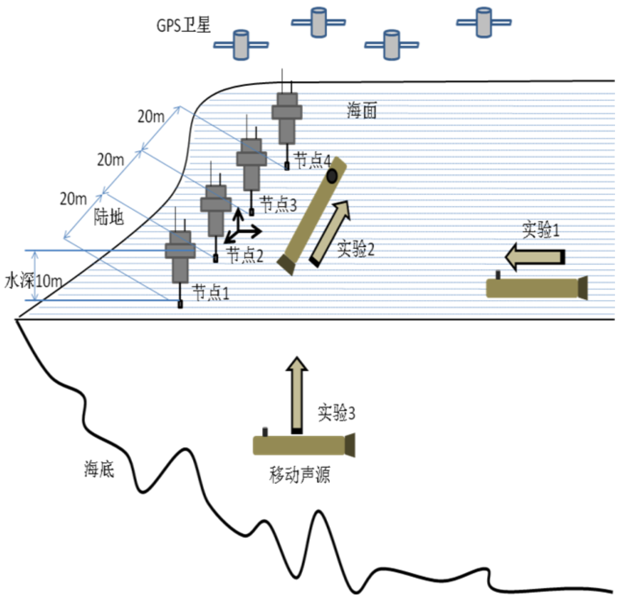


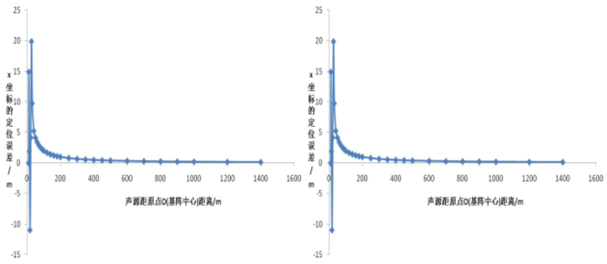
Figure 1 Layout of hydrophone array and simulation contents

3.2.2 Contents

(1) Sound source moves from far and near in XOY plane, the vertical distance of 10 meters to the X axis, along negative direction on X axis, verifying the influence of directivity of hydrophone on positioning accuracy.
(2) Sound source moves from far and near in XOY plane, along Y axis, verifying the influence of distance between sound source and array on positioning accuracy.
(3) Sound source moves from far and near in YOZ plane, the vertical distance of 10 meters to the Z axis, along negative direction on Z axis, verifying the influence of reflected wave on positioning accuracy.

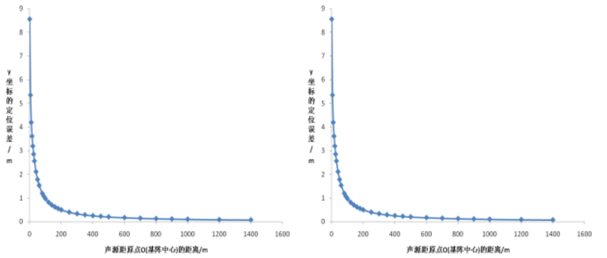
3.3 Simulation results

(1) Simulation content (1) results are shown in Figure 2, when the distance between hydrophone array and sound source is greater than 200 meters, error in X axis is less than 1 meter; However, when the distance is less than 200 meter, the directivity of hydrophone array changes , which results in error in X axis increases sharply, up to 20 meters, about one-tenth of slope distance. Error in Y and Z axis is so small that related error figures is not given.
(2) Simulation content (2) results are shown in figure 3, when the distance between hydrophone array and sound source is greater than 200 meters, error in Y axis is less than 1 meter.; However, when the distance is less than 200 meter, error increases gradually, up to 8.5 meter. Error in X and Z axis is so small that related error figures is not given.
(3) Simulation content (3) results are shown in Figure 4, when the distance between hydrophone array and sound source increases , the phase difference of direct wave and reflected wave fluctuates among "greater than one times wave length----- half-wavelength----less than one times wave length", which results in error in Z axis fluctuates among "large ---small---large"; when the distance is greater than 200 meters, the phase difference goes towards zero, error goes towards 10 meters. Error in X and Y axis is so small that related error figures is not given.



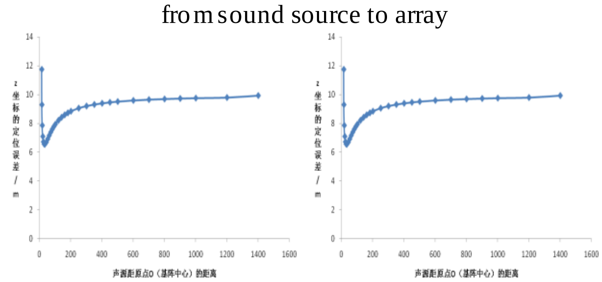
(a) Submarine propeller noise (b) Marine life sound.

Figure 2 x-coordinate positioning error with distance from sound source to array



(a) Submarine propeller noise (b) Marine life sound.

Figure 3 y-coordinate positioning error with distance from sound source to array



(a) Submarine propeller noise (b)Marine life sound

Figure 4 z-coordinate positioning error with distance from sound source to array

4. ERROE CORRECTION

4.1 Correction Method

when the distance between hydrophone array and sound source is less than 200 meters, by using positioning method based on single characteristic frequency , significant error may occur, even cannot solve position equation .Due to the intereferncein close enviroment,t he phase difference of direct wave and reflected wave fluctuates among "greater than one times wave length----- half-wavelength----less than one times wave length" that results in Rv cannot be calculated easily. To solve this problem, we selected more characteristic frequency, and analyzed sound pressure loss in different characteristic frequency. As shown in Figure 5, In the received signal spectrum, more characteristic frequency has been selected and sound pressure can be calculated, then according to Section 2.2 mathematical model, the sound source coordinate can be got, at last weighted average.

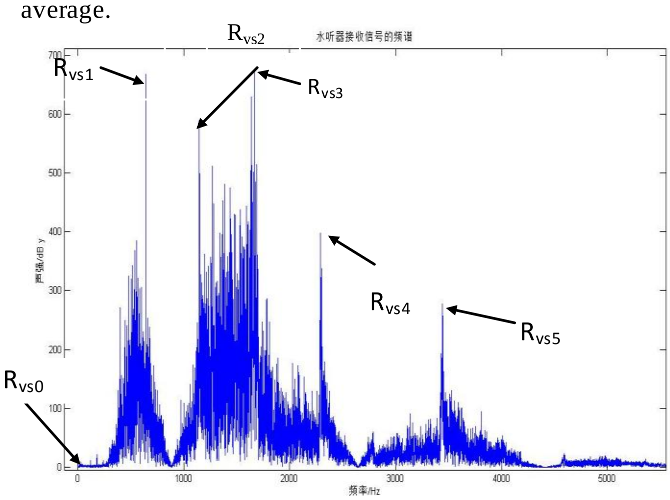


Figure 5 Collection of multi-centre frequency

4.2 Corrected Results

Corrected results of simulation content (2) are shown in Figure 6,compare using single characteristic frequency (Rv_0), three characteristic frequency (Rv_0,Rv_1,Rv_3) and five characteristic frequency (Rvs_0, Rvs_1, Rvs_2, Rvs_3, Rvs_4, Rvs_5.)The results show that using more characteristic frequency can effectively eliminate impractical position equation, the positioning accuracy at close ranges has been improved.

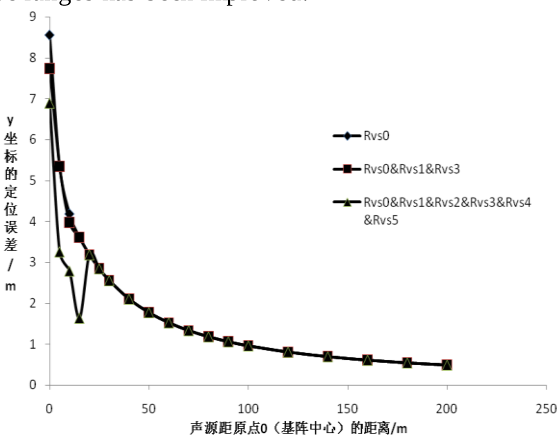


Figure 6 Corrected results of multi-centre frequency

5. CONCLUSION

In a previous work basis of underwater positioning method based on wireless sensor networks, A mathematical model of Underwater unknown acoustic source localization was put forward. And by using two different types of measured sound, By means of computer simulation, analyzed the positioning accuracy influenced by background noise and multipath reflection. The simulation results show that when the distance between the hydrophone array and sound source is so long, the accuracy of the method based on SPL is high, However, when the distance is short, the accuracy is very poor. On this basis, localization model based on multiple characteristic frequency was put forward and unanswered questions of positioning equation can be effectively solved, moreover this method has a certain correction effect to locating at a close range.

In future work, we will further discuss correction method to reduce the influence by phase difference and improve positioning accuracy. Topological structure of hydrophone array has an important effect on improving positioning accuracy and we prepare some relevant experiments to verify it.

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