The water-tank test of novel underwater positioning system based on sensor networks

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Abstract: To provide highly precise position information for autonomous navigation of AUV in large-scale area, we are developing one new underwater positioning system based on sensor networks. In this system, we set many standard stations on the sea surface and use GPS-sound positioning. To lower the cost of nodes and simplify signal processing, we have proposed a new method based on Sound Propagation Loss (SPL).This study discussed a new information integration method to solve the problems: (1) transmission path of sound may be blocked by some obstacle; (2) underwater nodes may get broken.

Key words: Underwater positioning system, Sound Propagation Loss, Sensor networks , Water-tank test.

I.INTRODUCTION

To provide highly precise position information for autonomous navigation in large-scale area, we are developing one new underwater positioning system based on sensors networks.

In this system, we set many standard stations on the sea surface and used GPS-sound positioning. The positioning precision of KGPS has become higher over the years，which assures that our standard station can be located. In this research, we have proposed a novel method based on Sound Propagation Loss (SPL) to lower the cost and simplify signal processing. To validate the SPL method, we have finished amounts of water-tank and sea tests. However, the major problem of this method comes from influences of background noise and reflected waves. [1][2] Moreover, in fact transmission path of sound may be blocked by some obstacle or underwater nodes may get broken, which results in great decrease of the positioning accuracy. To solve the problem, based on information communication between sensor network nodes, this paper proposed the information integration method of mean value method, and verified its performance in the water tank tests.

II.PRINCIPLE

1. Ranging

Based on acoustic wave energy attenuation, the system measures distance between transmitter and receiver. According to sonar equations, as we know Transmission voltage Tv [V], Propagation Loss PL [dB] can be obtained by measuring Receiving voltage Rv [V] as Eq. (1).

$$PL = 20\log(Tv)+Tx+Tg+Rx+Rg-20\log(Rv) \qquad (1)$$

Tx/Rx: Transmission/Receiving sensitivity [dB]

Tg/Rg: Transmission /Reception gain [dB]

Usually，Rv can be measured with FFT to the first non-reflective pulse of receiving wave and this method has a high accuracy. But when there are so many reflectors around, without receiving stationary non-reflective pulse, Rv can be estimated with FFT analysis of receiving energy. Though the measuring accuracy of this method is lower than the former, it can be used in long distance measurement. In accordance with measuring range and measuring environment, the two methods can be combined to use.

On the other hand, PL [dB] can be estimated the sum of diffusive loss log(R) and attrition loss αR as Eq.(2).

$$PL = 20\log(R) + \alpha R \quad (2)$$

R: propagation distance [m]，got by solving Eq. (2).

α :attenuation coefficient，which is a constant when sound wave cycle and propagation environment are certain, and can be calculated according to empirical formula or measured in the experiments.

Various measuring environment and systems will bring systematic error in above methods. Therefore, the methods need to be corrected in the experiments.

2. Positioning

In this paper，we adopted the principle of LBL(Long Base Line), and only used ranging principle of propagation loss replacing the original transmission time positioning , as shown in Eq. (1).We took two-dimension positioning for example, as shown in Fig.1.

P (X_P, Y_P): sound source; T_{Dn} (X_{TDn}, Y_{TDn}): receiver;

Rn: the measured distance between TDn and P.

The Coordinate of false sound source P1 (X_{P1}, Y_{P1}) can be obtained by solving Eq. (3).

$$\begin{cases} (X_{TD1}-X_{P2})^2+(Y_{TD1}-Y_{P1})^2=R1^2 \\ (X_{TD2}-X_{P1})^2+(Y_{TD2}-Y_{P1})^2=R2^2 \end{cases} \quad (3)$$

The coordinate of sound source (X_{Pn},Y_{Pn}) can be calculated with any two receiving signals.

The coordinate of sound source(X_P，Y_P) can be calculated as Eq. (4).with the mean value method.

$$\begin{cases} X_P = \sum X_{Pn} / N \\ Y_P = \sum Y_{Pn} / N \end{cases} \quad (4)$$

N: the number of receiving node.

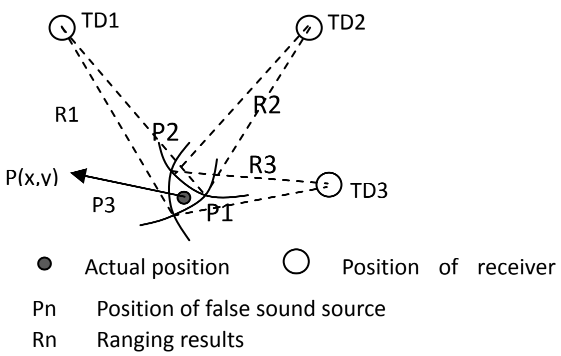


Fig.1. Ranging principle

Measuring accuracy increases with increase of number of effective node. In addition, blocking of obstacle or node fault can also cause a low accuracy.

Moreover, it is necessary to set up Voltage Threshold (VT) of receiving signal. When receiving signal of some node is less than VT, it is essential to stop using the data. On the contrary, the data can be brought into use. It can not only continuously update to use high accuracy node, but also eliminate the error messages caused by obstacle.

III. WATER TANK EXPERIMENTS

To guarantee the availability of ranging principle, we have completed the experiments in deepwater tank, as shown in Fig.2..

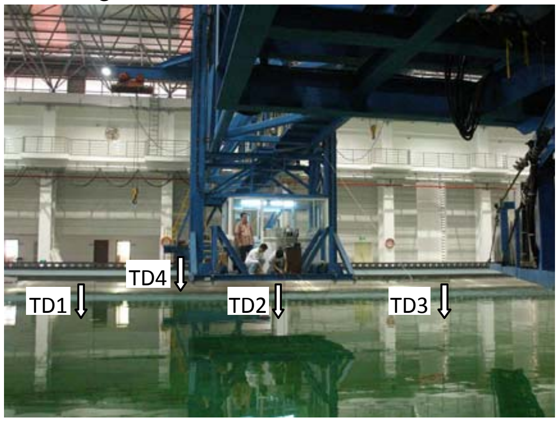


Fig.2. Experimental environment

Waveform of transmission signals is shown in Fig.3. The equipments include signal generator, power amplifier, signal acquisition unit, three hydrophones and transmitting transducer(20kHz-40kHz), see Fig.4..

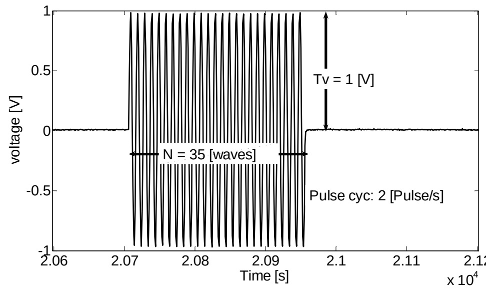


Fig.3. Waveform of transmission signals

(a) Measuring system

(b) Hydrophone

(c) Transmitting transducer

Fig.4. Measuring system and sensors

1. Error correction method

We put sender and receiver vertically under water, and regulated its interval R from 1[m] to 6[m].We recorded Rv every 1[m], and got error correction coefficient compared with actual distance

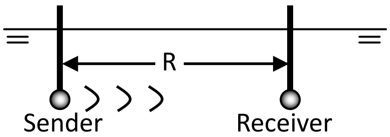


Fig.5. Error correction method

2. Positioning

Fig.6. shows three hydrophones is arranged along a straight line with the interval of 5[m]. We change the position of generator from P1 to P7, and separately record receiving signals of TD1-TD3 for 20 times. In data processing, we also analyze the position accuracy at different angles, discuss correction accuracy of mean value method and improve the accuracy by setting up VT

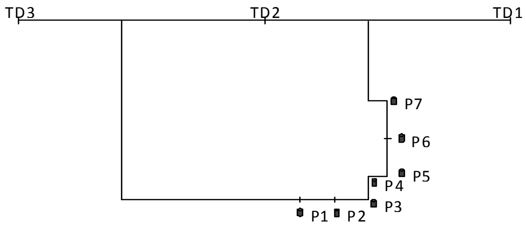


Fig.6. Sensor placement

IV. DATA PROCESSING

1. Error correction

Fig.7. shows a set of data in the experiments, where the background noise is about±0.04[V].

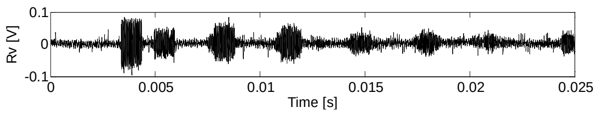


Fig.7. A set of data in the error correction experiments

Here, error was corrected with a linear method as Eq.(5).With the analysis of corrected data, we got the corrected parameter of each receiver, see Table1. Fig.8. shows the corrected results of measuring error of TD1.

$$R = aR' + b \qquad (5)$$

R: truth value; R': measured value.

Table 1.The corrected parameter of every receiver

Number of receiver	a	b
TD1	1.077	0.333
TD2	1.078	-0.112
TD3	0.417	5.315

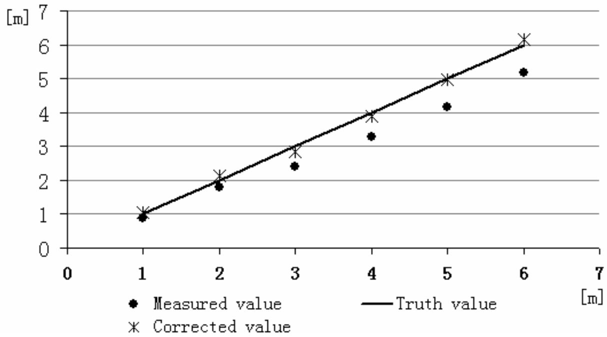


Fig.8. Corrected results of measuing error（TD1）

However, when several receivers are arranged on a small scale, they become reflectors each other, which results in decrease of accuracy. In fact, the accuracy is only ±0.5[m] in the positioning experiments.

2. Positioning with mean value method

As shown in Fig.9., we found that in front part of every set of data, neat direct waves can be received, so we can calculate the distance between sound source and receiver with the first method shown in II.PRINCIPLE.

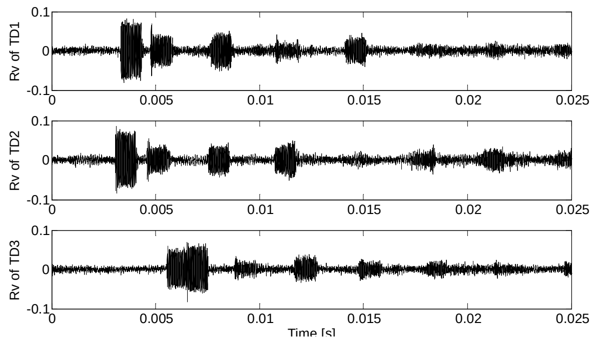
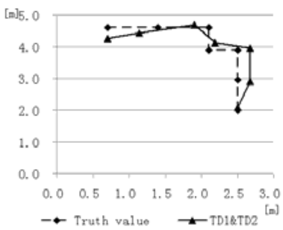


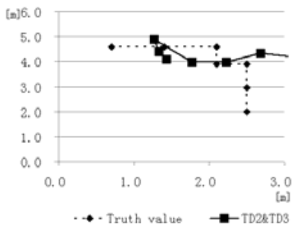
Fig.9. A set of data of sound source: P4

Fig.10. shows the comparison of positioning results(solid line) and truth value(broken line). The results demonstrate: (1) when the projection of sound source locates the position between two nodes, it can achieve high positioning accuracy, as shown in Fig.10 (a), (c). Therefore, when the projection of sound source leaves the position, it is so necessary to replace next node; (2) The nearer sound source located from node, the higher accuracy system can achieve, positioning accuracy in Fig.10(a) is better than in (c).This depends

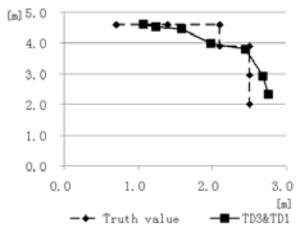
on the character that dissociation energy is diluted by the increase of propagation distance. Consequently, it is necessary to set up voltage threshold of receiving signal. When receiving signal of some node is less than Voltage threshold, it is essential to stop using the data. On the contrary, the data can be brought into use; (3) In addition, it is found that through mean value method can make the accuracy of results more higher, see Fig.10.(d)., which has obvious compensation to Fig.10(c). In a similar way, we can introduce that the system can achieve much high accuracy through taking an average of multiple data when some node gets broken or is blocked by obstacle.



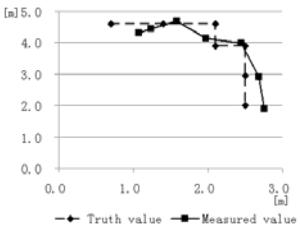
(a). Based on TD1&TD2



(b). Based on TD2&TD3

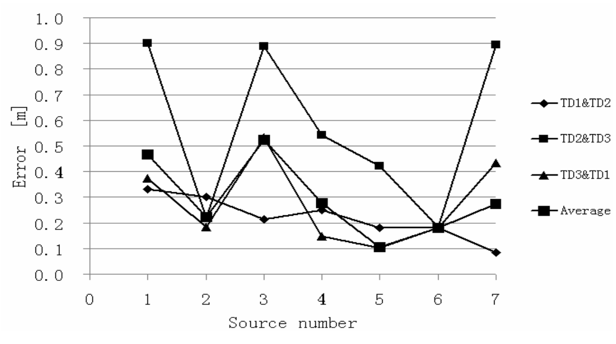


(c). Based on TD3&TD1

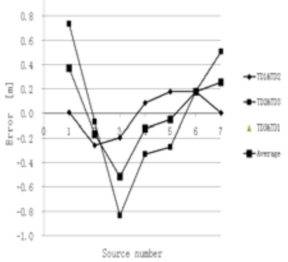


(d). Based on average value

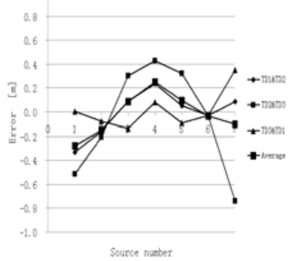
Fig.10. Positioning results compared with truth value



(a). The distance between measured value and truth value



(b). Error at X axis



(c). Error at Y axis.

Fig.11. Error analysis

3. The analysis of positioning error

The analysis of positioning error is shown in Fig.(11).. The results show: (1) The projection of sound source locates the position between two nodes, it can achieve the positioning accuracy about ±0.5[m] in accordance with measuring accuracy; (2) It can improve the positioning accuracy by mean value method.

V. CONCLUSTION

Based on the low-cost and easy-to-operate SPL ranging method proposed in the previous research and sensor networks positioning method which has the ability to communicate between nodes and extend positioning range, we have completed the first water tank positioning test successfully, and gave a new underwater positioning method. We also verified the basic characteristic and positioning accuracy of this method. In addition, we confirmed a positioning method based on average value, which possesses obvious corrective effect on the lower accuracy positioning signals.

In the future research of building sensor networks, we should consider the following things: (1)some way to judge the position relation between two nodes or node and sound source;(2) accuracy analysis of setting up threshold and prospective positioning;(3)the method of node replacement.

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REFERENCES

[1]. B. Fu, F. Zhang, M. Ito. et al (2009), Development of a new positioning system for underwater robot based on sensor network. J-AROB 14(1): 43-47.
[2]. B. Fu, F. Zhang, M. Ito. et al (2009), Development of a new underwater positioning system based on sensor network. J-AROB 13(1): 45-49.