Development of a New Underwater Positioning System Based on Sensor Network

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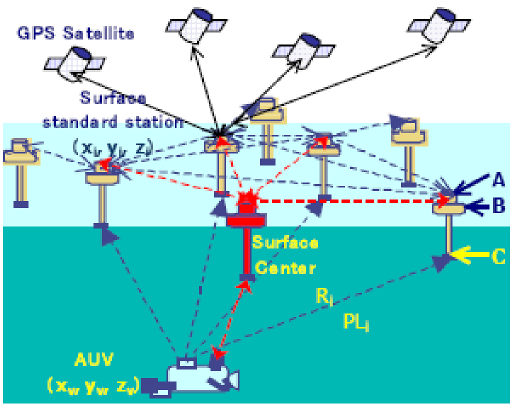
Abstract: In those days, the performance of underwater robot is improving because requirements for it are becoming higher and more complex than before. For those work, a highly precise and wide regional underwater positioning system is indispensable. However, the conventional positioning system that has three standard stations, is applicable for the field with no obstacle, because its principal depends on the time based measurement. Therefore, we developed a new underwater positioning system based on sensor network technology that is using a lot of standard stations equipping hydrophone and GPS sensor on the water surface. And decreasing the cost of sensor, we applied a simple method for measurement of distance, which is using sound power level. Therefore, this study has started with confirming the new principal for underwater positioning method. This paper is showing the availability with theoretical analysis and the performance of new method under the noise and reflection of sound in the water, and suggestions for the measures and an error compensation method.

Keywords: Underwater Positioning, Sensor Network, Propagation Loss, GPS-Sound

I. INTRODUCTION

In latest marine exploring technologies, the underwater positioning system for wide area and long term becomes a very important subject to improve reliability of the results. In the conventional positioning system based on the measurement of time difference, transponders which is set on a sea floor or array receiver on the mother ship becomes standard station. The positioning area of this system is roughly a circle around standard station with a radius of same value as the depth of standard station. So, it does not correspond to the underwater navigation of long distance. Also, each standard bureau cannot receive it at the same time by the ruggedness in bottom of the sea, which will influences the measurement accuracy. To solve these problems, we proposes hear a new measurement system. The new positioning system enables the long distance measurement by use of sensor network, that is, increasing the number of standard station.

First of all, the new positioning system suggests use of the surface standard station instead of the bottom of the water to omit bottom of the sea construction. The distance from each standard station to an inquiry ship is measured by underwater sound. A lot of surface standard stations reset up to compose a sensor which enable long distance measurement. Secondly, the position of each surface standard station is measured by sea DGPS and DPS-RTK which are maturity technology. Finally it is transmitted this position data by a blow to th e inquiry ship's side by sensor center (Fig. 1).



A:GPS Antenna,Control,B:Buoy,
C:Underwater Mic.

Fig.1 Concept of new poisoning system

The key point of the new positioning system depends underwater positioning technique based on a cheap sound sensor. The conventional positioning technique is based on propagation time or phase difference, so a highly precise atomic clock is needed for each standard station to identification time. In addition, encoded modulation unit and transmit and receive unit must be installed in each standard station to communicates with the inquiry ship. As a result, it is general to use a transponder expensive as about many millions of yen. Which is clearly unsuitable for the sensor networking of our new system. Therefore this study suggests a new underwater positioning technique based on the propagation loss of the sound wave. In the following, we will explain the positioning method and the measurement result in detail.

Our study used both simulation and water tank experiments. And examined positioning precision and influence by the noise and reflection wave and inspected practical use possibility of the propagation loss positioning technique.

II. Principle of measurement

It is called propagation loss that the sound pressure level damps as distance parts when a sound propagates. Propagation loss is composed of a diffusion loss, an absorption loss and a reflection loss. The diffusion loss is proportional to the square power of propagation distance. The absorption loss is proportional to propagation distance, and the reflection loss is proportional to reflection frequency. In the case of the direct reception wave, the reflection loss becomes zero. Then the relations of propagation loss (PL [dB]) and propagation distance (R[m]) can be presented as follows.

$$PL = 20\log10(R) + \alpha R \quad (1)$$

Here, loss coefficient α[dB/m] is calculated by

$$\alpha = \frac{0.11fr^2}{1+fr^2} + \frac{44fr^2}{4100+fr^2} + 3\times10^4 fr^2 \quad (2)$$

, fr[kHz] is transmission frequency.

On the other hand, when the sound wave is sent and received through voltage signal, PL can also be calculated through those voltage values as equation (3).

$$PL = 20\log10(Tv/Rv) + Tg + Tx + Rg + Rx \quad (3)$$

The signals in right side of equation (3) are defined as follows:

Tv[V] : transmission voltage

Rv[V] : reception voltage,

Tg[dB]: Transmission gain

Tx[dB]: Transmission sensitivity

Rg[dB]: Reception gain

Rg[dB]: Reception sensitivity

Tv[V], Rv[V] are measured datas and the other 4 are all constants.

It is clear that he propagation distance R can be obtained from transmission and reception voltages.

III. Experimental confirmation

To verify above motioned positioning method based on propagation loss, we constructed ultrasonic signal transmission and reception system and carried out the experiments in ultrasonic tank of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and in wave motion tank of Tokyo Univ. of Marine Science & Technology (TUMSAT).

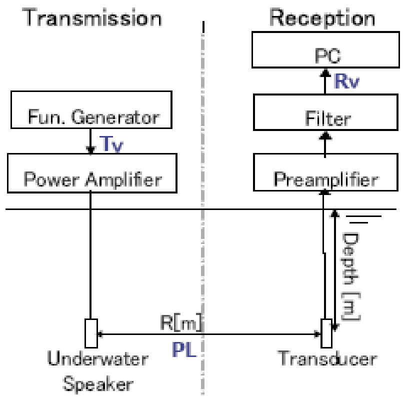


Fig.2 Experimental system

Figure 2 shows the outline of the experimental system. The transmission unit consists of a function generator to generate a transmission signal, a power amp to amplify the signal to a necessary level and a sound transducer. The reception unit consists of a sound transducer, a pre-amplifier, a filter and a Computer for data recording. The signal flow is shown in figure.

Figure 3 shows the Ultrasonic tank which is a cubic shape of 9m(W) × 9m(L) × 9m(D) , and is covered with sound absorption material on tank wall.


Fig. 3 Ultrasonic tank in JAMSTEC

Figure 4 is the wave motion tank, with size of 10m(W)×50m(L)×2m(D)

Fig.4 Wave motion tank in TUMSAT

In this study, omni-directional transducer is used. The frequency transmission sound wave is 20kHz and the sampling frequency of received signal is 200kHz.

When starting the experiment, we take down each transducer into water tank with cable. The distance between two cables is measured correctly. Then function generator is switched and both of transmission and received voltage are recorded. In the next section, we show the data treatment and results.

IV. Data processing

In this section, we explain how to calculate distance R from recorded wave signal. The accuracy of the calculated distance depends on the accuracy of reception wave. In the water tank experiment, received data is a synthesized signal of direct wave, reflected wave and noise. To calculate the distance more accurately, we firstly use band pass filter to reduce the influence of noise, then we separate the direct wave from received data and calculate signal power with FFT. Using this data and transmitted signal data, we calculate the distance. But the results include system error, so finally we compensate it and get collect distance. We will show the detail of data separation and compensation from this data processing.

1. Separation of useful data

Fig. 5 is an example of received signal data. We notice that the wave has two features. One is that there is a transition part before standing wave, which is marked as T-zone. The another is that the wave started by simple direct wave, and the compound wave including both direct and reflect waves appears after a little wile. The time delay of the compound wave difference depends on the measuring distance and the size of water tank. Any way we should pick up the pure direct wave enclosed with dotted line in Fig.5 to get R.

As the transmission wave determined by ourselves and the pro-treated received wave are obtained, the distance R can be calculated using equation (1) and (3).

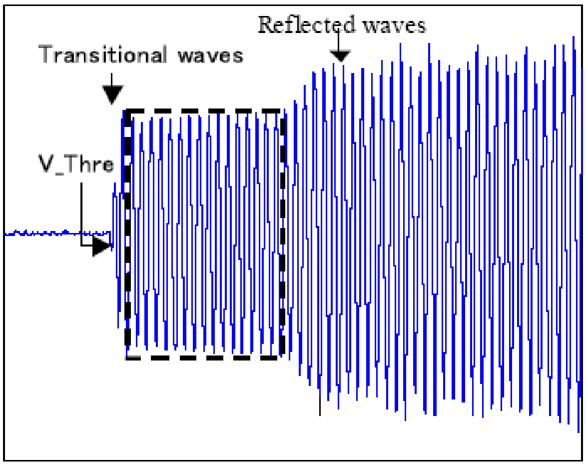


Fig. 5 Example of Reception Wave

2. Error compensation

The blue line in Fig. 6 shows the calculated distance based on received data and red line is estimated output of received signal from real distance. We consider that the error is depending on a difference between the theoretical value and real value of sensitivity or accuracy on measuring equipments, namely system error. When system error exists, the propagation loss is measured larger than theoretical value and the distance is calculated longer than real distance. So we must estimate the system error and compensate measured data with it.

Now let us set the system error as Δ, and modify equation (3) to the follows.

$$PL' = 10\log 10(Tv/Rv) + Tg + Tx + Rx + Rg - \Delta \qquad (4)$$

Where PL' is different to PL of equation (3). So, if system error Δ is known beforehand, one can calculate distance R by PL' more asymptotic to real value. The system error Δ can be obtained through experiments as follows.

$$\Delta = 10\log 10(R_0 / R) \qquad (5)$$

Where R_0 is real value of distance and R is its measurement value using equations (1) and (3).

In Fig.6, the doted line is the result of compensation, which is almost as same as actual.

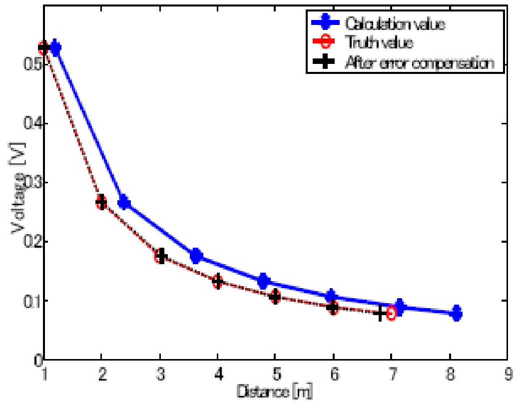


Fig.6 Error compensation

V. Accuracy

When we apply this method to AUV, we should know its accuracy and factor of influence. In this section we evaluate those performance from experimental results.

1. Accuracy

Figure 7 shows the results of evaluation of accuracy for this method and time difference method. In this method, the data is obtained under 0.05V of threshold level and sampling frequency is 1 ms, and in time difference method, we measured time difference of transmitted signal and received signal under same threshold level. It shows both methods have same accuracy in overall range except 7m' s case. In 7 m's case, the path length of direct wave is comparably equal to reflected wave. So this method could not distinguish the difference clearly and caused to big error.

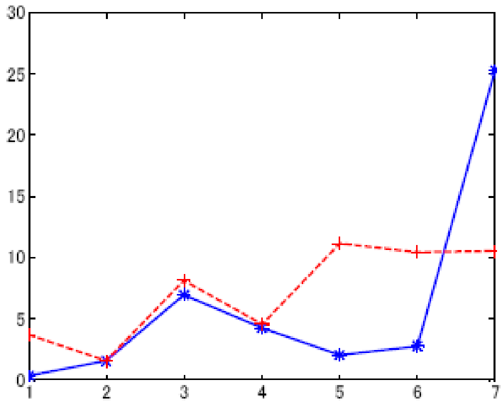


Fig.7 Comparison of accuracy between time method and propagation loss method

2. Influence of reflected wave

In the former experiment, the influence of reflection from side wall were showed. Actually, reflection from a water surface or water floor is also added to direct wave. Then we examined the level of influence with the experiment. The distance of transmitter and receiver were fixed at 3m, and depth of them was changed from 1m to 8m. Every 1m we checked accuracy. The result is shown on Fig. 7. Generally, the accuracy is improved with decreasing reflection and becomes worse with increasing of reflection. However the number of sampled data has another influence. In Fig.8 red line is short sampling duration and blue (dotted) line is long sampling duration. This result says in case of strong reflection, less data number comes to higher accuracy and in weak reflection, more data comes to higher accuracy.

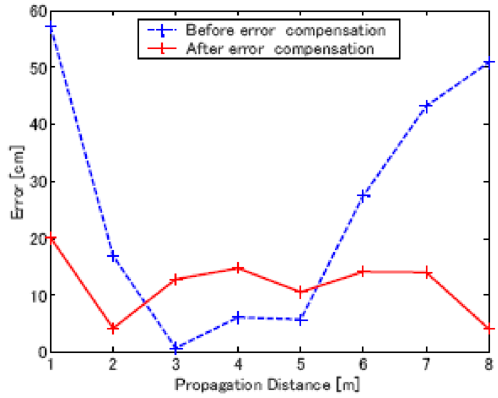


Fig.8 Relation of sampled data number and error

VI. CONCLUSION

As the new position detecting method for AUV, we proposed ultra sonic propagation loss method. It is using a ratio of power between transmitted signal and received signal. In this study, we confirmed the availability of the principal, made clear the problem of this method and established data processing method.

We are thinking we can have a high accurate, low cost, easy operation positioning system with combining this method to sensor network technology. Considering the result of this study, we are going to step up to multi –sensor system.

REFERENCES

[1] Japan Marine Science and Technology Center, Manned research submersible SHINKAI 6500 User's Guide

[2] Shigeru Ando, Yosuke Tamura etc. Sensor network technology, Tokyo Denki University Press 2005

[3] Marine Acoustics Society of Japan, The basics and application of Marine Acoustics, Seizando 2004