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Basic Research on Underwater Laser Ranging and Speed-measuring

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Abstract: This paper proposes one new method of calculating (1) the speed of AUV according to the distance measured by one laser range finder and (2) the angle between AUV head and the surface of underwater structure according to the different distances measured by two laser range finders. Besides discussing the selection of the laser type, this study tests computing speed, accuracy, range and other performance of underwater laser ranging method through a large number of experiments of simulating the process that the AUV gets close to and goes far away from the object in different postures. The results show that the accuracy for laser ranging has no major changes in the water medium. And the range of this method is affected by water quality, reflector materials, angle of reflection, etc.

Key words: Hovering AUV, Laser ranging, Underwater ranging.

I. INTRODUCTION

In recent years, Hovering AUV has been proposed out as a new concept of underwater vehicle. Its main feature is the capability of realizing the operation on a fixed point. Due to both of autonomous ability of traditional AUV and spatial mobility of ROV, it can be applied to the observation and operation around underwater structures. We have developed a hovering AUV and then found that in the process of getting close to target object, it is very hard for AUV to determine the distance and maintain a certain posture and distance relative to target object according to operational needs. One of the main technical difficulties in realizing autonomous control during that process lies in measuring the distance in a high accuracy. Previously, sonar is usually used to measure the distance between AUV and the objects. However, when the distance gets smaller, the accuracy of this method becomes poor, which not only affects operational efficiency but also creates possible risk of collision. This study proposes one new method of calculating (1) the speed of AUV according to the distance measured by one laser range finder and (2) the angle between AUV and underwater structure according to the different distances measured by two laser range finders.

Laser range finder is usually applied to measure the distance between two fixed points on land or the speed of cars. So far it has never been seen for underwater application in measuring the distance between moving objects and fixed objects. In water, because of smaller attenuation, acoustic wave has been applied extensively. And electromagnetic wave, due to maximum attenuation, had almost not been used in water. Owing to the attenuation coefficient between that of acoustic wave and electromagnetic wave, light wave can be applied within a limited range. In particular, owing to strong directivity and high measurement accuracy of laser, laser ranging and acoustic ranging can be used complementarily. [1][2]Nevertheless, the effect on measurement performance caused by aqueous medium or speed of AUV itself has not yet been verified either. Therefore, besides discussing the selection of the laser type, this study had a test of computing speed, accuracy, range and other performance of underwater laser ranging method through a large number of experiments of simulating the process that the underwater vehicle gets close to and goes far away from the object in different postures.

II. PRINCIPLE OF RANGING

1. Range finding

In this experiment, we adopt the ranging principle of laser range finder, which is calculating the distance l

[m] by measuring the propagation round-trip time between laser and target, as shown in Eq. (1).

$$l = t \times c \qquad (1)$$

c=2.25×108 [m/s] is the propagation velocity of light in water. According to different principles of measuring propagation time, laser ranging method can be divided into phase difference method type and pulse method type. In underwater application, laser beam experiences three refraction processes: from air (laser transmitter) to glass (airproof glass) then to water, see Fig.1. It is difficult to correct the ranging error produced by phase change in the refraction process. Therefore, pulse method is used in this study and its basic ranging principle is shown in Fig.1. However, in the refraction process it will produce time loss Δt [s]. Then we assume that the distance of laser propagation in air and in water are l_0 [m] and l [m] respectively, so propagation processing time t[s] can be expressed as Eq. (2).

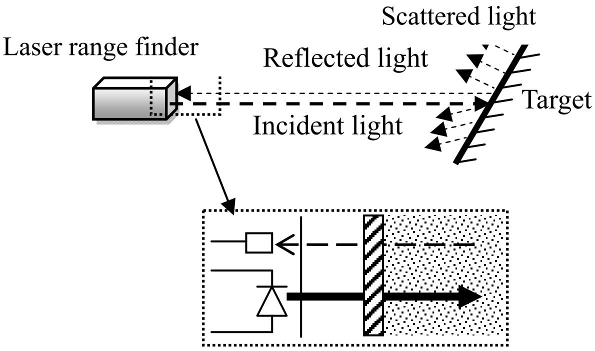

Fig.1. The principle of the ranging system

$$t = l_0 / c_0 + l / c_1 \qquad (2)$$

$$c_1 = c_0 / n \qquad (3)$$

c_0 and c_1 are the speed of light in air and in water respectively; n is the refractive index of media calculated through empirical equation Eq. (4)

$$n = 1.33333 + \frac{n_g - 1}{1 + \alpha t} \cdot \frac{P}{1013} \qquad (4)$$

n_g is refractive index of media in standard condition; α [℃$^{-1}$] is expansion coefficient; t [℃] is temperature and P [hpa] is pressure.

We express the measuring distance as l'[m], see Eq. (5) , Ranging error as Δ, see Eq. (6).

$$l' = tc_g \qquad (5)$$

$$\Delta = l' - l = (l_0 / c_0 + l / c_1)c_g - l = l_0 / n_g + (c_g/c_1 - 1) \qquad (6)$$

c_g is propagation velocity in aqueous medium under standard condition, l_0/n_g is constant error, measured by error correction experiment and $(c_g/c_1-1)l$ is error with the change of distance, corrected by the linear correction method.

2. Measuring angle and speed

Based on the ranging above, using two laser range finders of parallel arrangement we can separately measure the distance, and then calculate the angle between AUV and target as Eq. (7).

$$\tan\alpha = \frac{d}{|l_1 - l_2|} \qquad (7)$$

α is the angle between centerline of laser and normal of target and d is the distance between two parallel laser beam.

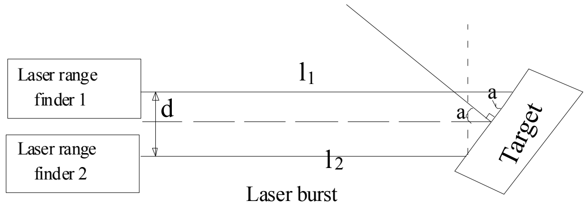

Fig.2. The principle of measuring angle

As shown in Fig.3, the target has moved from position a to position b in time T[s].By means of the cosine-theorem, we can give Eq. (8).

$$\bar{v} = \frac{\sqrt{l_a^2 + l_b^2 - 2l_a l_b \cos\alpha}}{t} \qquad (8)$$

$\alpha = \beta_2 - \beta_1$ and $\bar{v}$ is average speed in time T.

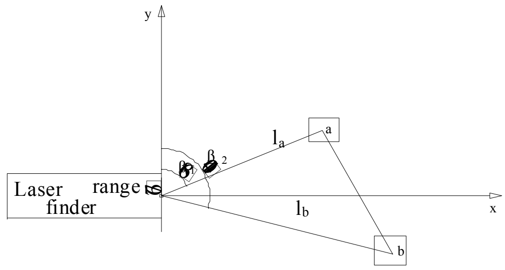

Fig.3. The principle of measuring average speed

However, when the underwater vehicle is moving, this method can only calculate the average speed for a period and can't tell the instantaneous speed at a given moment of time.

III. WATER TANK EXPERIMENTS

This experiment has been completed in underwater trial tank (depth:9[m],diameter:8[m]). We select and use pulsed laser range finder: DLE-B30 produced by DIMETIX Company. The measuring range of this instrument is 0.05-65[m] in air and its measurement error can reach up to ±5.0 [mm].

1. Experimental contents

A.Ranging accuracy and range

As shown in Fig.4, with vertical incidence to the reflector, laser range finder has recorded the data of 0-8[m] with the interval of 0.5 [m].

Fig.4. Ranging experiments

B.Effects of incidence angle

As shown in Fig.5., range and accuracy has been tested by regulating the angle between incident laser beam and normal line of reflection (incidence angle:0°, 30°,45°, 60°).

Fig.5. Regulation method of incidence angle

C.Continuous ranging

We designed that laser range finder was disposed vertically and went close or away from reflector, then collect data continuously.

D.Effects of water tightness processing

We investigated the variation of measurement range before and after water tightness processing.

2. Experimental results

A.Ranging accuracy and range

Measured value is compared with truth value in Fig. 6.. Error of this method becomes bigger with the increasing distance and is proportional to the distance. Its largest measured distance in water can rise to 5.5[m], which is about 1/11 in air.

B.Effects of incidence angle

With the increase of the incidence angle, measuring range changes greatly. As shown in Fig.7, range is about 2/3 of maximum measuring range at the angle of incidence of 30 degree and when the incidence angle is 60 degrees, range decreases to only 1/2 of maximum range. But position accuracy has no significant change.

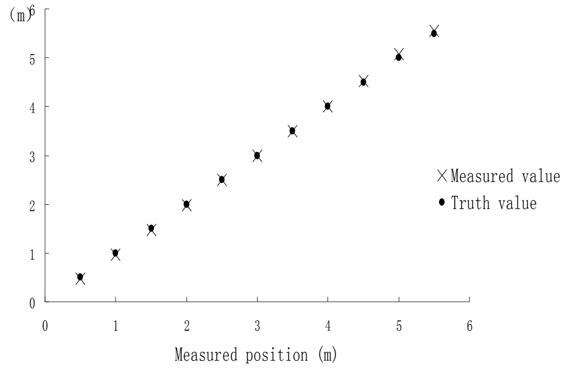

Fig.6. Ranging results compared with truth value

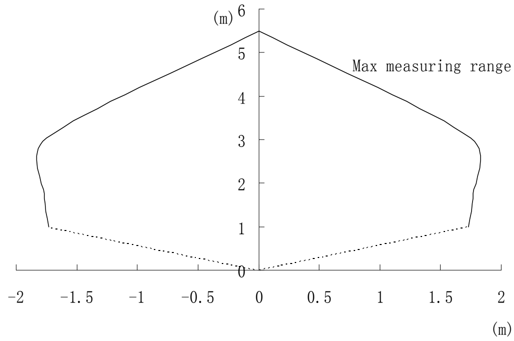

Fig.7. Relation between angle and range

C.Continuous ranging

Continuous ranging data has no marked change. Only with increasing distance, the time of data acquisition increases because of weaker reflected signal.

D.Effects of water tightness processing

It is proved by experiments that water tightness processing of laser lens will affect laser strength and then affect measuring range.

IV. ERROR CORRECTION

1. Error analysis

A. The speed of light error

As shown in Eq. (3), the speed of light in water is inversely proportional to refractive index affected by water pressure, water quality and water temperature, etc. Therefore, the variation of the speed of light in water will have an effect on the accuracy of ranging, and we call it "the speed of light error".

B. Instrumental error

The frequency of laser crystal oscillator is affected by environmental factors. In using laser range finder, ranging accuracy will be affected by the deviation between the actual frequency of modulated light and the standard frequency and its impact is proportional to the distance.

C. Time error

The time error has been fully discussed in II. Principle and can be modified with a method of linear error correction.

2. Correction method

Based on the error analysis, we proposed a method of linear error correction and got Eq. (9) on the relation of measured value and truth value.

$$y = kx+b \quad (9)$$

k and b are both affected by water temperature, water pressure, and water quality, etc. In this paper, by using a set of data at a 0 degree incidence angle, we got error correction coefficient: k=0.982, b=0.0488.

3. Corrected results

We can find corrected value is close to truth value, see Fig.10. Range error at different angles of incidence is separately shown Fig.11. (Forward direction of vertical axis: measured value is greater than truth value.)

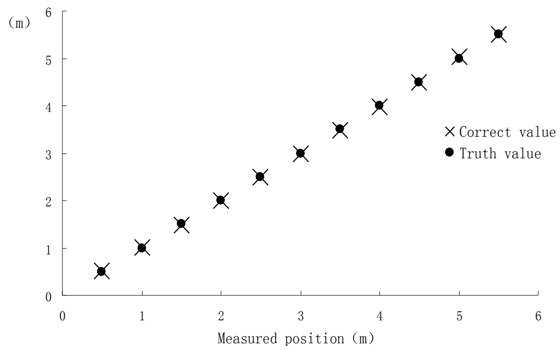

Fig.10. Ranging results after error correction compared with truth value

As the measured distance increases, the ranging accuracy has no significant change while errors are freely distributed on both sides of 0, see Fig.10.

As shown in Fig.11, we consider that the correction coefficient calculated at the angle of incidence of 0° can be applied at other degrees besides the accuracy of no significant change, about ±3[cm].

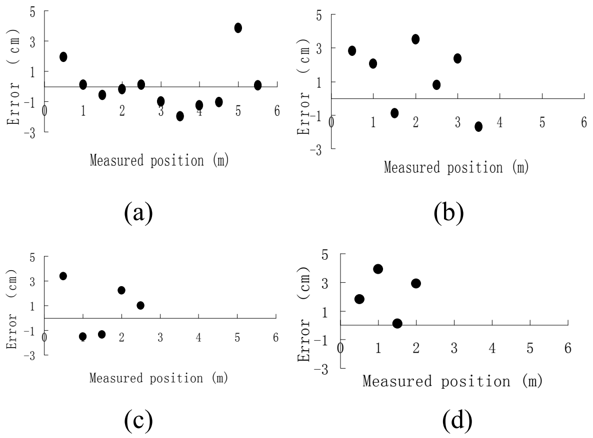

Fig.11. Range error at different incidence angle
(a) incidence angle:0° ; (b) incidence angle:30°
(c) incidence angle:45° ; (d) incidence angle:60°

V. CONCLUSION

This paper gave a method of underwater laser ranging based on the pulsed mode. With an analysis of experimental data, we have discussed the accuracy, range and other performance of this method and proposed an effective error correction method. The experiments confirmed the validity of this correction method. In future study, measuring range can be improved by selecting higher power laser or enhancing water tightness processing such as adopting optical glass airproof lens.

Underwater laser ranging can be used with acoustic ranging complementarily with high accuracy in continuous ranging at short distances. Besides application in hovering AUV at short distances, we will also consider it that the underwater laser ranging method is applied to underwater docking and other close ranging with high accuracy in the future research.

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