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Visual Location Method Based on Asymmetric Guiding Light Array in UUV Recovery Progress

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***Abstract*—Vision-based recovery of the unmanned underwater vehicle(UUV) is a hard task due to complex underwater optical conditions. Based on the fork-carrying-pole recovery system, a visual positioning method based on asymmetric guiding light array is proposed. In this method, the guiding light array is detected and located by camera, so as to complete the recovery. This paper mainly solves three problems：Firstly, an asymmetric L-shaped guiding light array is designed based on the characteristics of underwater optical conditions and fork-carrying-pole recovery system; Secondly, in condition of different background light intensity, we proposed a set of detection methods for L-shaped light arrays. According to the change of background light, the threshold segmentation interval can be adaptively selected, and the segmentation threshold of light array image can be selected accurately. The pseudo light source can be eliminated by BLOB feature combined with logic regression. Thirdly, a 6-degree-of-freedom(6-DOF) pose estimation method of UUV is designed, and a location method of tracking after single Target Segmentation (TASTS) is proposed to improve the location method. This novel TASTS can solve the problem of tracking and positioning of partial target occlusion within 50%. Finally, the UUV recovery experiment is carried out. The experimental results show that this method improves the success rate of positioning, eliminates the close visual blind area of visual recovery. This method improves the accuracy, whose error is reduced from 0.5 m to 0.1 m in the final stage, and increases the rapidity rate of UUV autonomous recovery by 20%.**

Keywords—unmanned underwater vehicle; recovery system; underwater visual guiding; target detection; positioning method

I. INTRODUCTION

UUV is widely used in marine exploration, ecological monitoring and other fields. Using of surface ship can not guarantee the concealment of the recovery platform, and is vulnerable to the interference of surface waves. The recovery of UUV become very difficult in these complex marine environments. Therefore, it has become an important trend of UUV research to establish and realize the autonomous recovery system of UUV in underwater environment. In the automatic recovery technology of UUV, the long-distance tracking and positioning technology is relatively mature[1], but the accuracy and stability of close-range recovery stage is an urgent problem to be solved at present. Three kinds of detection sensors are needed in the underwater close recovery stage of UUV: visual detection sensor, acoustic detection sensor and electromagnetic detection sensor. Deltheil et al [2] compared the above three methods, and concluded that the visual detection sensor has strong anti-interference ability and high positioning accuracy to the external environment.

In the process of UUV close-range recovery, scholars from various countries have proposed a variety of vison-based docking methods. In order to solve the problem of selecting detection markers, Ghosh S et al confirmed that guiding light array is more suitable as a detection marker for underwater environment[3]. There are many design schemes for guiding light array: linear light array[4-5], circular light array[6], square light array[7] and so on. Linear light array is applied to the type recovery station of platform type, whose structure is quite simple and easy to maintain. However, when the central light of the linear light array is lost, linear light array may not provide the heading angle of the UUV, which will cause the failure of UUV recovery. Composed of multiple lights ,the circular and square light array lamp array can calculate the information of 4-DOF. However, this method is only suitable for recovery station with guiding cover as the target, and it may lead to the failure of UUV recovery when a part of the light source is blocked. L-shaped light array is proposed as in [8]. This method provides higher degree of freedom and has ability to solve the problem of positioning of partial target occlusion. However, most of the vision-based UUV recovery experiments are carried out under the condition of constant background light intensity. Meanwhile, in the real underwater environment, the occlusion mode of light source is various, and the engineering application of vison-based recovery of UUV is subject to many qualifications.

To solves the problem of variable background light intensity and positioning of partial target occlusion in the recovery process, the improved adaptive background target detection method and the TASTS method of strong anti-occlusion is proposed. This paper is organized as follows. In Section2, we describe the design of the visual guiding device. Section 3 describes detailed description of the proposed detection methods for L-shaped light arrays, in condition of different background light intensity. Section 4 provides location method under the condition of partial target occlusion. Section 5 provides experiment of UUV recovery provides a performance comparison with previous methods. Finally, we deliver our conclusion in Section 6.

II. DESIGN PROCESS OF VISUAL GUIDANCE DEVICE

The design flow of the visual guiding and positioning device is introduced in the background of the fork-carrying-pole recovery. The design drawings of various light arrays are given, as shown in Fig.1. All the lamp array schemes are compared and the results are shown in Table 1. A contrastive analysis of linear

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light array[4], circular light array[6] and asymmetric light array shows that using asymmetric light array has more advantages in fork-carrying-pole recovery system. Because the light array is located at the bottom of the camera, multiple heading angles will be calculated under the same pose by using the symmetrical guiding lamp array ring and linear lamp array, which may lead to the failure of UUV recovery. The design of asymmetric guiding light array can make the degree of freedom of positioning up to 6-DOF with low cost. Fig.2 shows the design drawing of the visual system and the detail parameters of the light array. Different from 30cm spacing of light A, light B and light C, the spacing of light C and light D is 40 cm. This design with different spacing can distinguish between light B and light D in the image in the case of loss of target light A.

III. TARGET DETECTION

A target detection method for guiding light array under the condition of changeable background light intensity is proposed. The following are examples of target detection processes in two different light intensity. The left and right columns in Fig.3(a) are light array pictures in dark background and bright background respectively. In fig.3(b), the red interval shows the interval self-adaptive selection for threshold segmentation, and the threshold of the red interval can be obtained by OTSU method[9]. The adaptive threshold segmentation method is divided into the following 4 steps:

- Count the gray value of the original image I_0 , and compute he histogram of the gray value .
- Obtain all the extreme points in the gray histogram, and record the extreme point with the highest gray value of T_0 0t in addition to the highest brightness.
- Take all gray values greater than T_0 in image I_0 , and store them in array A.
- Compute the optimal segmentation threshold T_1 in array A by using the traditional OTSU method, and the segmented image can be obtained by threshold segmentation of the original figure I_0 .

Binarization image is obtained through the above adaptive threshold segmentation, and the image contains pseudo-light sources due to factors such as reflection, bubbles and so on. Based on the analysis of BLOB convexity, compactness, roundness and other characteristics, and combined with logical regression, the pseudo-light sources caused by reflection and other factors are eliminated. The final light source detection results are shown in Fig.3(c).

Table 1 Comparison of light array design schemes

Shape / Property	circular	linear	L-shaped
Cost of light	high	high	low
symmetry	symmetric	symmetric	asymmetric
DOF	4-DOF	3-DOF	6-DOF

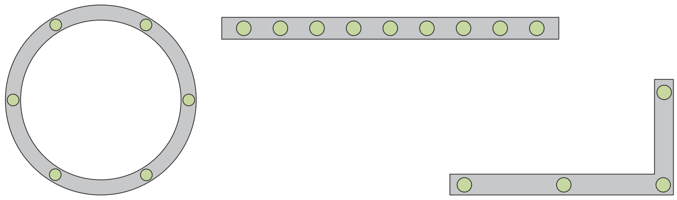


Fig.1 Different structures of light array

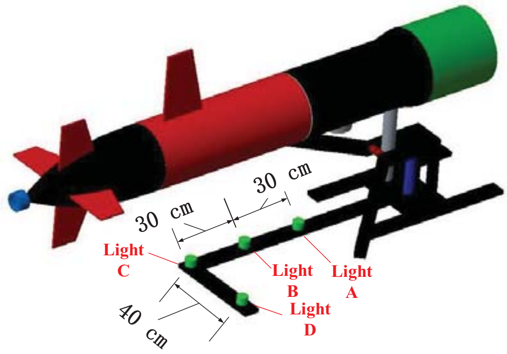


Fig.2 Design drawing of the visual recovery system

IV. LOCATION METHOD

Location method under the condition of partial target occlusion is proposed.

A. 6-DOF Pose Estimation

Estimate the pose of UUV. On the premise that ABCD's pixel coordinates are known, the hypothetical rotation plane method proposed can be used to determine the transverse distance, longitudinal distance, heading angle and height of UUV relative guiding light array. The judging algorithm of the target light source is as follows:

- Define the central coordinates of the four light source targets are define as A, B, C and D. Take the line segments between two points in all points, l_{AB} , l_{AC} , l_{AD} , l_{BC} , l_{BD} , l_{CD} .
- Calculate the angle Δ between the lines in which any two segments are located. Select a line that makes the angle $\Delta \le 5^{\circ}$, and this line makes the three points almost collinear. Target D can be distinguished.
- From the above, compute the spacings ρ between D point and the other three points respectively. The point with the maximum value $\rho_{\max}$ is point A, and the point with the minimum value $\rho_{\min}$ is point C. The rest is point B.

The hypothetical rotation plane method is as follows:

Calculate height: The height of UUV relative guiding light array can be determined according to any two light source targets. The height value can be calculated by taking light A and light C as examples. According to the principle of triangle similarity, the height of UUV relative guiding light array H can be calculated using the following formula (1):

$$H = \frac{f \bullet D_{ac}}{r_{ac}} \tag{1}$$

Where, f is focal length, and D_{ac} is the distance between light A and light C in world coordinate system. The points corresponding to light A and light B are $I_A(x_1, y_1)$ and $I_C(x_2, y_2)$ in image coordinate system, The distance between the two points is r_{ac}.

Calculate heading angle: The guiding light array angle shown in figure 4 is defined as a state where the heading angle is 0°, and the clockwise rotation direction is defined as the positive direction. Taking point A and point C as examples, the heading angle θ can be calculated by formula (2):

$$\theta=\begin{cases} -\tan^{-1}\left[(y_c-y_a)/(x_c-x_a)\right] & x_c > x_a \\ -\pi-\tan^{-1}\left[(y_c-y_a)/(x_c-x_a)\right] & x_c < x_a, y_c > y_a \\ -\pi/2 & x_c = x_a, y_c > y_a \\ \pi-\tan^{-1}\left[(y_c-y_a)/(x_c-x_a)\right] & x_c < x_a, y_c \le y_a \\ \pi/2 & x_c = x_a, y_c \le y_a \end{cases} \tag{2}$$

Where, the range of heading angle is $\theta \in (-\pi, \pi]$. (x_a, y_a) and (x_c, y_c) are the coordinates of the image points of light A and light C in the image plane coordinate system.

Transverse and longitudinal deviation: The coordinate deviations between the coordinates of the light B and the center point of the image can be calculated including longitudinal deviation and transverse deviation in the image plane coordinate system. Using the same derivation mode of formula 1, longitudinal deviation and transverse deviation of UUV relative guiding light array are obtained.

Transverse inclination and longitudinal inclination angle in special cases: It is proposed that when the heading angle is adjusted to 0°, the UUV longitudinal inclination angle can be calculated by fitting the minimum external rectangle of four lights and calculating the aspect ratio of the rectangle. Additionally, because the center of gravity of UUV is low and the angle of transverse inclination angle is about 3°, it can be approximately considered that the angle of transverse inclination is about 0°. So far, 6-DOF estimation of UUV has completed.

B. Improved Location Method

Determine the position of ABCD's pixels. According to the detection method proposed in previous research[8], the UUV can complete the attitude estimation relative to the recovery device, when one light is lost (the target loss is less than or equal to 25%). In order to improve the performance of the algorithm under the condition of target occlusion, TASTS is proposed. TASTS splits the asymmetric L-shaped light array into four target light sources for independent tracking, combined with the detection results to locate together, and Fig.5 shows the algorithm flow.

The core of strategy TASTS is to determine the relative position of ABCD under the condition of the loss of lights. In this paper, the multi-target tracking method of Kalman filter combined with Hungarian matching algorithm is used to track four lights[10]. When the number of detected lights is greater than or equal to 3, the main output is the result of the detection algorithm. When the number of detected lights is 2, the relative position of ABCD couldn't be determined by the detection algorithm. By independent detection and tracking of the four lights, the detected target can be associated with the same target that is being tracked in previous frames, so the actual position of each light in the case of the loss of 2 lights can be determined. Then, the 6-DOF pose estimation method proposed in this section can be used to calculate the pose of UUV. Table 2 shows the results of calculating the pixel coordinate of ABCD target light source with TASTS location method, in the case of the loss of one light and two lights respectively. We may conclude that TASTS method can still calculate the pixel coordinate of ABCD in the case of the loss of 2 lights and locate. Therefore, the distance of blind area of camera recognition light array is reduced from 0.61m to 0.31m. The distance from camera to light array is 0.5m when UUV completes the recovery, which can be considered that the close blind area has been eliminated.

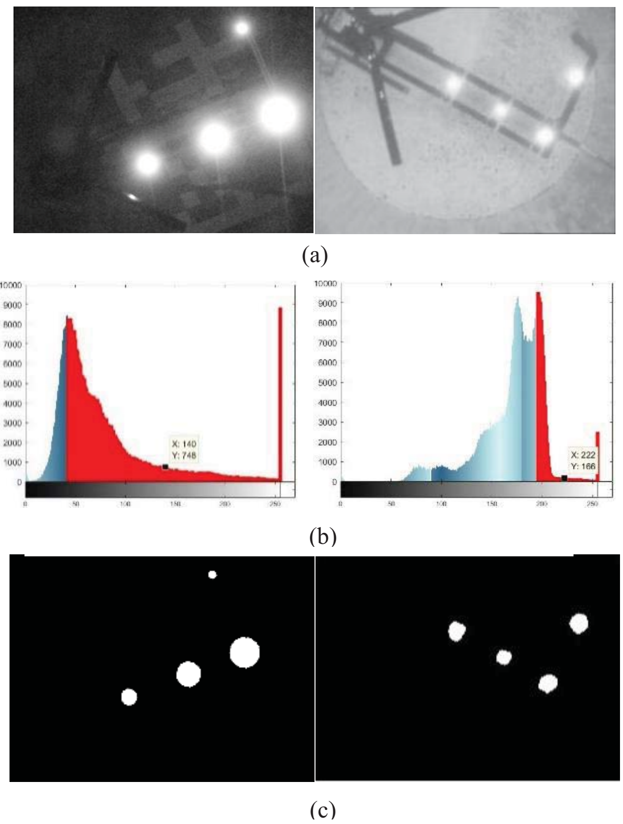


Fig.3 Target detection in different background light intensity

Fig.4 Image with UUV heading angle of 0°

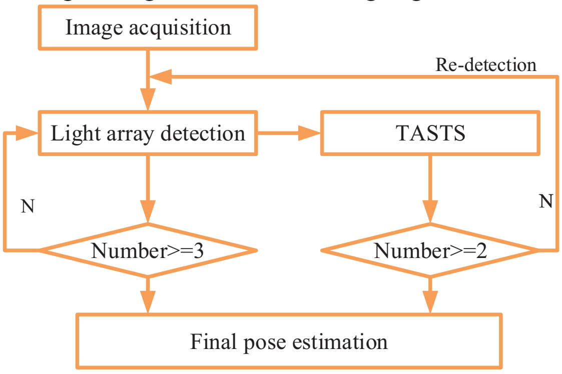


Fig.5 Flow chart of TASTS location method

V. EXPERIMENT OF UUV RECOVERY

Conduct pool experiment and data analysis. The size of the test pool is 10m×5m×5m. The recovery device is arranged at the bottom of the pool, and the UUV is randomly placed at a distance of less than 5 meters from the horizontal distance of the recovery device. Fig.6 shows the experimental scene. The recovery process is divided into four steps, which is shown in Fig.7. The detailed recovery process is as follows:

- Start the acoustic guiding and positioning system, and locate the UUV from a long distance. When UUV reaches the visual range of visual positioning, turn on the visual guiding and positioning system. With the help of the visual system, UUV can sail to the position above the recovery device.
- Turn off the acoustic guidance positioning system and use the visual positioning system to adjust the heading of UUV relative to the recovery device to about 0 °.
- Keep the UUV heading angle unchanged, and let the UUV fall vertically to the same horizontal position as the recovery device.
- Start the main thruster and let UUV move to the locking device. The locking device will capture and lock the recovery pole of UUV, finishing the UUV recovery.

The recovery experiment is carried out by TASTS and detect-only location method respectively. The vertical positioning data can clearly reflect the specific situation of recovery in each stage. And the successful data can be selected for comparative analysis, which is shown in Fig.8. Let UUV keep a slow speed, and the control system were updated with a period of 0.5 sec. The detect-only location method will lead to inaccurate pose estimation in the fourth stage (depth is about 0.6 m) due to the visual blind area, which adds uncertainty to this stage; However, using TASTS location method to experiment, the fourth stage can obtain more accurate pose information. At the same time, because the time of the first and second stages of recovery is reduced, which proves that the proposed method has good performance in vision-based UUV recovery. In terms of time, the time of TASTS method is about 30s faster than that of only detect-only method, and the time efficiency of recovery is improved by about 20%. At the same time, the error of TASTS is only within the range of 0.1 m while the error of detect-only method is within 0.5m in the final stage. It is proved that the proposed method has good performance in vision-based UUV recovery

Table 2 Calculation of pixel coordinates of A,B,C,D

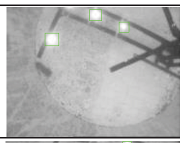
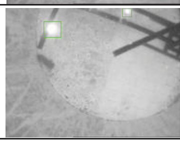
TASTS	Pixel coordinates of target light source
	A [519, 88] B [394, 36] C [268, -16] D [203, 145]
	A [535, 19] B [406, -35] C [276, -89] D [205, 84]

Fig.6 Experimental scene

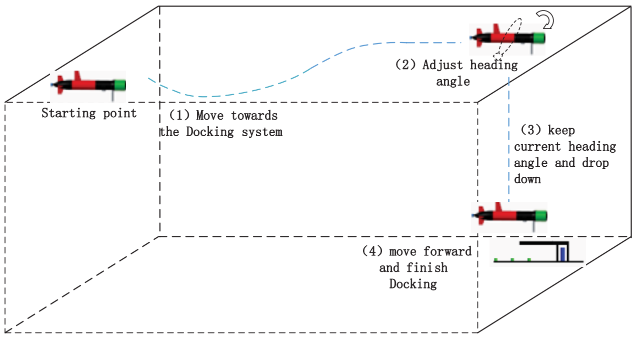


Fig.7 Schematic diagram of recovery process

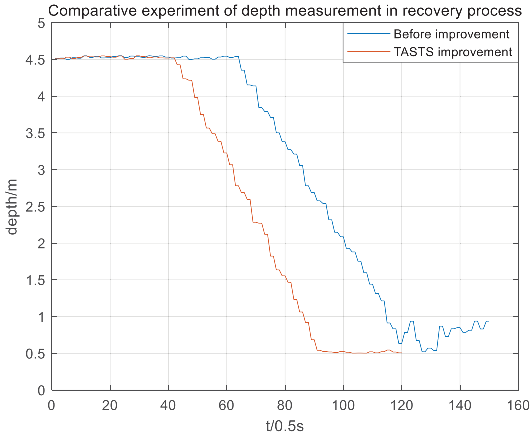


Fig.8 Comparative experiment of UUV recovery

VI. CONCLUSION

This research addresses vision-based recovery of the UUV in complex underwater optical conditions such as background light variation and targets occlusion. Firstly, the design of the recovery device is carried out, secondly, the algorithm design of the target extraction is carried out for the bright background and the dark background, and the multi-target tracking algorithm is used in combination with a prior light array model to design a TASTS algorithm with an anti-blocking property. Through experiment, the designed recovery system and algorithm have proved to have the value for engineering application.

Future work includes selection of more suitable multi-target tracking methods, and experimental verification of multi-scene, improvement of guiding light array scheme and so on.

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