Basic Research on a New Method for Underwater Localization Based on Machine Vision

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Abstract: With the increasing needs for ocean investigation and new energy development, the application of autonomous underwater vehicle (AUV) has attracted more and more attention. Most of these attentions focus on the motion performance of AUV in large-scale operating environment. However, the observation for special underwater structure, as one important application of AUV, hasn't got enough research by our investigation. To realize the observation and operation of AUV around complex structures, we have developed one hovering AUV system, in which the issue of determining and control of horizontal x-y position becomes the bottleneck technique. To solve this problem, we introduce the machine vision into underwater application and verify its feasibility and basic characters.

Key Words: AUV, machine vision, underwater localization, light source, image processing

I. FOREWAORD

With the increasing needs for ocean investigation and new energy development, the application of autonomous underwater vehicle (AUV) has attracted more and more attention. Most of these attentions focus on the motion performance of AUV in large-scale operating environment.[1] However, the observation for special underwater structure, as one important application of AUV, hasn't got enough research. [2] To realize the observation and operation of AUV around complex structures, we developed one hovering AUV system, in which the issue of determining and control of horizontal x-y position becomes the bottleneck technique for keeping AUV's security and stability. The common acoustic positioning system owns very low accuracy because of big background noise and strong reflection wave in limited and closed space and the common INS (inertial navigation system) produces much bigger error because AUV has a low speed around obstacles. To solve the localization issue in complex unstructured environment, we propose one method of machine vision in underwater application. That is (1) to localize the object by camera mounted on AUV observing the light source array fitted on underwater object; (2) to localize AUV by camera mounted on mother-ship observing the light source array fitted on AUV.

However, it is necessary to consider the differences of propagation medium and object between in our application and in common application. Different attenuation coefficients, scatterings and background lights between underwater and on land may bring beneficial or harmful effect on image processing, Besides, the observation object in our research is underwater vehicle of low speed and various postures.

To be aimed at the above uncertainty, this paper verifies the feasibility of machine vision in underwater application and discusses basic performance of this method.

II. PRINCIPLE

1. System organization

This underwater vision system consists of light sources, camera, lens, image acquisition card and data processing computer. The light sources are placed in humid environment while other equipment in dry environment such as in compressive cabin or above water, as is shown in Fig.1. The light is projected on the camera's image sensor after multiple refractions The analog signal produced by image sensor are transformed into digital signal by image acquisition card and then processed in PC.

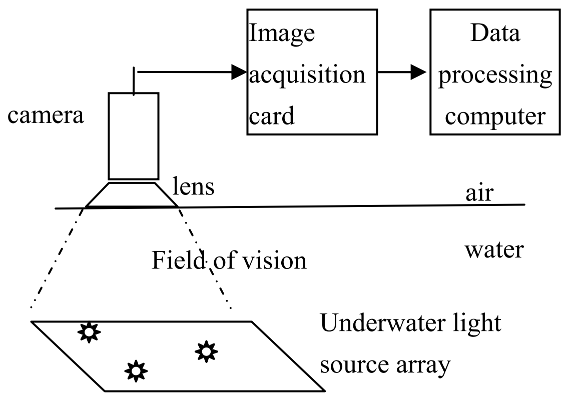


Fig.1. System organization

2. Image acquisition and processing

The first step is to capture and save one RGB image by camera. The second step is to transform the image into gray level image and de-noise by preset threshold value. The third step is to erode by preset erosion parameter. Final step is to compute the 2-D coordinates of the images of light sources in pixel reference frame (PRF) by searching algorithm.

3. Coordinate transformation

As the underwater vehicle is one object whose position and posture are both various in 3-D space, we need one array composed by at least 3 light source of fixed distance among them to localize them. PRF is shown in Fig.2. The origin O is in the top left corner, while the positive direction of x and y axis is respectively rightward and vertically downward. The points of a_1, a_2, a_3 are the images of each center of three light sources and the point of V is the image of their geometric center. The coordinates of V in global reference frame (GRF) are obtained sequentially by the following equations.

$$l_i=\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2}\ (i=1,2,3) \qquad (1)$$

$$k_i = L_i / l_i \qquad (2)$$

$$k = (k_1+k_2+k_3)/3 \qquad (3)$$

$$(x'_i, y'_i) = (kx_i, ky_i) \qquad (4)$$

$$\begin{cases} X_v = k * (x_1 + x_2 + x_3)/3 \\ Y_v = k * (y_1 + y_2 + y_3)/3 \end{cases} \qquad (5)$$

Where (x_1, y_1), (x_2, y_2), (x_3, y_3) are coordinates in PRF of images of light sources. l_i and L_i (known) represent the distance among them respectively in PRF and GRF. k_i and k are respective calibration

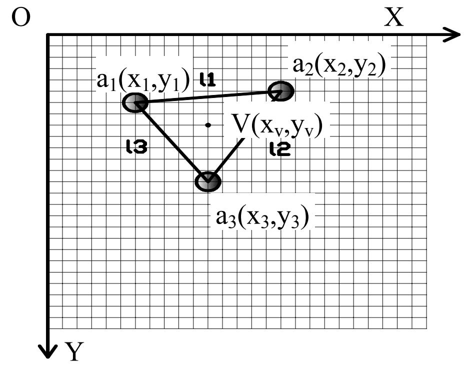


Fig.2. the images of light resources in PRF

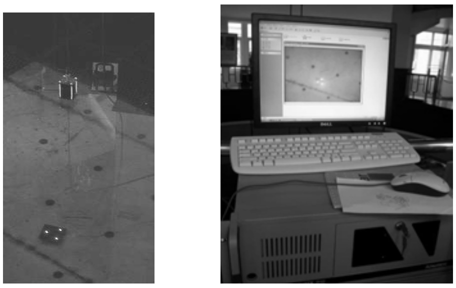
coefficient and their average. (x'_i, y'_i) is the projection coordinate of every light source on the plane which is vertical to the optics axis of camera lens and V is located in and (x_v, y_v) is the coordinates of V in GRF.

III. WATER TANK TEST

The water tank test is taken in the Sate Key Laboratory in Shanghai Jiao Tong University. The radius and water depth of the columniform tank is 8 meters and 7meters respectively. The light sources are 3 LED of power of 0.2 [w]. The camera is watertight processed SS-880HO produced by SHEPER in UK and the lens is CCD image sensor of resolution of 576 pixels by 768 pixels. The final images are processed in Halcon, one developing environment for machine vision produced by MVtec Corp.

The vision system is shown in Fig.3. Three LED are fitted in equilateral triangle array on one black and nonreflecting panel placed underwater with its vertical normal. The camera is on the water surface and its optics axis is pointing down. The procedure to obtain the real value of light sources' coordinate is as follows. First measure the 2-D coordinates of the three LED and their geometric center in Microsoft Paint, then compute the respective calibration coefficients and their average, which is multiplied by coordinate of the geometric center.

The propagation distance of light may affect results of image processing by affecting its energy attenuation. To verify the effect of working distance (WD) on object recognition rate (ORR) and positioning accuracy (PA), we adjust WD from 2 to 6 meters with interval of 1 meter between the plane and

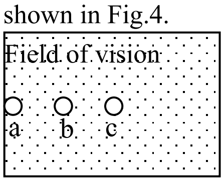


(a)underwater part (b) land part

Fig.3. vision system organization

camera lens.

The different horizonal positions of lignt source may induce the change of the angle of incidence (IA,the angle between line-of-sight of object and the optics axis of camera). To verify the effect of different IA on ORR and PA, we adjust the horizontal position respectively in the plane of 4[m] and 5[m] depth, as is shown in Fig.4.



a: edge of field of vision
b: quarter of field of vision
c: center of field of vision

Fig.4. different positions of light source panel

On the other hand, de-noising threshold value and erosion value are respectively adjusted in the image processing algorithm to watch the variation of ORR.

IV. TEST RESULT AND ANALYSIS

1. The effect of WD

A. Effect on ORR

Table 1 shows the relationship between ORR and WD when the panel is at b in Fig.4. Set de-noising threshold value Th=10 and erosion value E=1. The ORR varies because the incident light energy (ILE) decreases with the increase of WD. ORR is higher than 30% at the distance of 2-6[m]and reaches the maximum at the distance of 4[m].

Table 1 the relationship between ORR and WD

WD [m]	2	3	4	5	6
ORR [%]	40	80	90	70	30

Fig.5 lists the processed images at different WD. One light source point is mistaken as two points for too much ILE at WD of 2[m] while no light source can be recognized at WD of 6[m] because they are cleared after eroding for too little ILE. We deduce the fundamental reason for such case is that erosion value doesn't match well with ILE. So we will adjust the variant in V part.

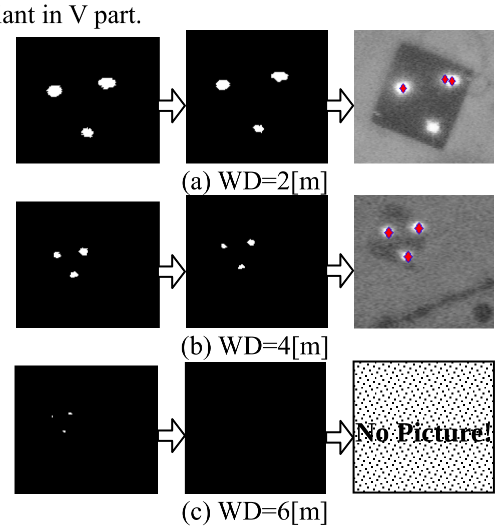


Fig.5. processed images at different WD

B. Effect on PA

The relationship between PA and WD is shown in Table 2, which includes X error ΔX, Y error ΔY, distance error ΔD between measured value and real value of V's coordinates and system accuracy (SA, the ratio of size of field of vision to pixel numbers of CCD sensor) varying with WD. The data are obtained when the panel is at b and Th=10, E=1. Apparently PA varies nearly in direct proportion with SA.

Table 2 relationship between PA and SA

WD[m]	Error(cm)			Δ
	ΔX	ΔY	ΔD	
2	0.34	0.69	0.78	0.19
3	1.19	1.07	1.63	0.29
4	1.88	1.74	2.56	0.38
5	3.07	2.73	4.16	0.47

2. Effect of IA

A. Effect on ORR

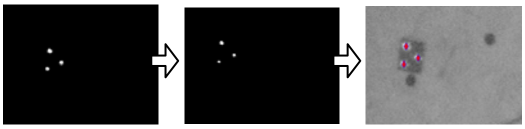
Table 3 shows ORR value when IA varies at different points a, b and c. Set Th=15, E=1. ORR at b (IA is about 5 degrees) reaches highest while ORR at a and c are lower.

Table 3 relationship between ORR and IA

Depth[m]	a	b	c
4	40%	90%	60%
5	10%	80%	30%

Fig.6 shows the processed images when light source array is respectively placed at a, b and c of the plane in the depth of 4[m]. As is shown, the images of light sources get smaller with the decrease of IA (a→b→c) in the first column (de-noised images) while the images at b is bigger than that at a and c. There are two reasons: (1) When IA is big (at a), there are many flecks around images of light source cause by water medium scattering. These flecks will disappear after eroding so that the original images will become much smaller. (2) When IA is small (at c), although ILE is bigger, the images of light sources is very concentrative for the less effect of water scattering. In this case, the image may be cleared finally if being processed by the same erosion value. Based on above analysis, we suggest that the horizontal position of light source in field of vision should be one reference to figure out the image processing parameters.

Position a



Position b

Position c

Fig.6. processed images in different incident angles

B. Effect on PA

Based on recognized image, we analyze IA's effect on PA. Table 4 shows the different PA at a, b, and c of the plane in depth of 4[m]. Apparently PA deteriorates with the increase of IA. So we conclude that WD increases with the increase of IA on the same horizontal plane, which finally affects PA.

Table 4 relationship between PA and IA

Position	Error(cm)			WD[m]
	ΔX	ΔY	ΔD	
a	0.86	2.32	2.47	4.11
b	1.34	1.28	1.85	4.02
c	1.26	0.73	1.45	4.00

V. OPTIMIZATION OF IMAGE PROCESSING PARAMETERS

As mentioned ahead, it is necessary to adjust Th and E to adapt different working conditions. This part compares the different ORR before and after optimizing the two parameters at WD of 2-5[m], as is shown in Fig.7. The optimized ORR reaches higher than 50%, which can meet the basic requirements for AUV's hovering and operating.

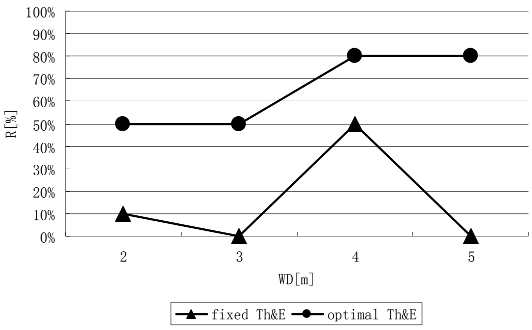


Fig.7. ORR before and after optimizing Th and E

In future, we can determine the optimized value of Th and E in different working conditions by experiment in advance and realize self-adaptive adjust of the two parameters in image processing algorithm by looking up preset tables.

VI. CONCLUSION

This paper introduces machine vision into underwater application and verifies its feasibility and basic characteristics by water tank test.

The test results show work distance and incident angle's material effect on object recognition rate and positioning accuracy and confirm the improvement of object recognition rate after optimizing the de-noising threshold value and erosion value. With the optimized parameters, object recognition rate can reach above 50% and positioning accuracy 2.5 centimeters in the work range, which can meet the requirement for AUV operating in limited and complex environment.

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