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Underwater robots detection based on image segmentation[1]

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Abstract. The segmentation and detection technology of underwater image under the condition of lighting environment is analyzed. Firstly, the basic process of image segmentation based on grey scale is proposed. Secondly, on the basis of the traditional grey processing and Hough transform circle detection method, we propose improvements of the image segmentation method based on improved grey processing, multi-threshold segmentation method based on sliding window, and traditional point Hough transform circle detection method. Finally, the methods proposed in the paper are tested according to contrast experiments under uniform light and uneven illumination and also contrast experiments of circle detection method before and after improvement. In the contrast experiment under uniform illumination, the segmentation results based on the grey method indicate that indexes FOM (Figure of merit), UM (Uniformity measure) and GC (Gray-level contrast) are higher than those of the image segmentation results after grey processing of (National Television System Committee) method. In the contrast experiment under uneven illumination, multi-threshold segmentation of sliding window method can reduce the error caused by the similar grey values and refine the difference among the grey values around the target area. In the contrast experiments of circle detection method before and after improvement, the improved method can completely eliminate image edge distortion. Compared with the traditional technology, the improved method is more effective in underwater light image detection.

Key words. Image segmentation, target location, underwater robot, illumination image.

1. Introduction

Accounting for nearly 3/4 of the earth's area, the ocean is rich in biological resources, mineral resources and so on, thus it is a very important resource treasure for human beings [1–2]. For China, which is not rich in per capita resources, the development of marine resources is of special significance [3]. As the important tool for ocean development, the underwater robot has become increasingly important in recent years' study. The main task of underwater robot is to get various kinds of

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information in the underwater environment. Moreover, getting excellent shot of the target information is essential to make the corresponding operating decision [4–5]. For the target detection system of underwater robot, it can accurately and quickly separate the object from the image sequence and extract the target information, which is the premise of the target location and target tracking [6]. Therefore, in this paper, the underwater robot acquisition image research is mainly including two aspects as underwater light image segmentation and target circle detection.

Researches on the image segmentation technology and underwater robot target detection technology are not uncommon at home and abroad. Image segmentation is a basic machine vision technology, which is the research foundation of the target detection technology. The study of underwater image segmentation methods by many scholars at home and abroad are mainly focused on the research and improvement of the following methods: adaptive threshold method, segmentation method based on edge detection, region growing method, watershed method and method based on Fuzzy Theory [7–9]. Usually, there are taken overall consideration of the computation and segmentation of the above five methods, developed the improvement method of the grey progressing based on minimum calculating volume of adaptive threshold method to increase the grey level difference between target area and background area in the image, and then obtained the final image segmentation results by using the method of double spike threshold segmentation. In order to detect man-made objects in underwater video images, a lot of researches have been done in recent years: Kamal et al. [10] proposed target extraction algorithm taking use of the invariant features and Barat et al. [11] used the visual attention mechanism to form a saliency map for obtaining the possible target area.

Owing to the existence of suspended matter, scattered refraction and absorption effect of aqueous medium on light, the underwater illumination image is often shown as low contrast value and low signal-to-noise ratio, with partial color distortion of the image and other features. When underwater robot is doing image acquisition, the illumination conditions are different. So, this paper will study the image segmentation method in two conditions as uniform illumination and uneven illumination. Under uniform illumination, the image segmentation based on the adaptive threshold method of the NSTC method has problems as adhesion of target and background, emerging more interference area, etc. To solve these problems, this paper proposes a new method of underwater image segmentation based on the improved image grey progressing. In the condition of uneven illumination, the global adaptive threshold method for image segmentation will cause incomplete segmentation of the object and other problems [12]. A method of multi-threshold segmentation based on sliding window is proposed in this paper to solve the problems. Meanwhile, due to the local distortion of the image edge in the image segmentation results, the precision of the circle detection is low, which will further affect the precision of the final target location. In order to improve the accuracy of circle detection, this paper improves the traditional point Hough transform circle detection method to eliminate irregular edge lines, which can reduce the effect of irregular edge segment of circle detection results. Finally, this paper lists the results of a contrast experiment among the proposed three methods and verifies the validity of the three methods.

2. Methodology

2.1. Underwater image segmentation based on the improved image grey progressing

The flow diagram of the proposing method of underwater image segmentation based on the improved image grey progressing is shown in Fig. 1.

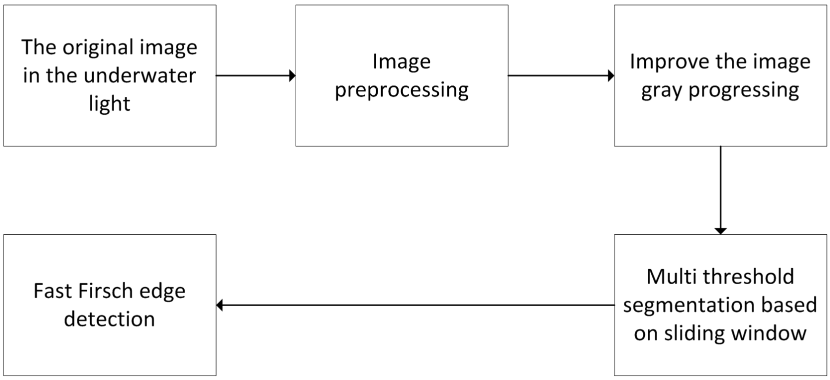

Fig. 1. Flow diagram of image segmentation based on image grey progressing

In this paper, the particular steps are changing the grey weight value of R, G, B to increase the difference of grey level between target and background, then doing threshold value segmentation to the grey image by using the classical double spike method and getting the final image segmentation results. The specific implementation steps are like this: Classification of object and background → image information statistics → three channel weight adjustment. The following understanding can be done from these three steps. Classification of target and background: The underwater light image is converted into the HSI (Hue, Saturation, Intensity) model [13]. Firstly, in the HSI model, the H and I channel information are quantized, respectively, to the range of [0,225]. Then, the classical Otsu threshold method is used to roughly classify the target and background of the pseudo grey level image of the H and I channels respectively. Image information statistics: Do image information statistics [14] of underwater light image in RGB model to get the grey average and standard deviation of all the pixels in the target area of the R, G, B three channels and background area. Weight adjustment of the three channels: Set the grey level differential measure threshold as $T_{\max}$ and $T_{\min}$. Then compare the difference between the average value of the target area and the background area in the three channels to $T_{\max}$ and $T_{\min}$, respectively. Combine the concentration degree of grey value in the region reflected by the standard deviation and change the values of r, g, and b

$$Y = [r\,g\,b]\,[R\,G\,B]^{\mathrm{T}} \tag{1}$$

so as to meet the formula of $r + g + b = 1$. Determined from experiment, $T_{\max}$ is set as 120 and $T_{\min}$ is set as 50.

On the basis of the traditional method, this paper proposes a multi-threshold image segmentation method based on sliding window. Compared with the former method, the improved method can only handle the pixels of target area within the scope of the processing, greatly reducing the scope of the image processing needs handling, which can save the processing time to a great extent, specific steps are as follows:

Firstly, determine the range of the target area and set up the sliding window. The target area is the classification result of the target and background in H channel, which is shown as $\mathrm{O}_{(\mathrm{iH},\mathrm{jH})}$ hereinafter. Gradually expand the scope of the target area on the basis of $\mathrm{O}_{(\mathrm{iH},\mathrm{jH})}$, which ensures the relative integrity of the segmentation results. According to the camera imaging model, the calculation formula of the sum of the number of pixels in the image under different distances is obtained on the basis of the size of the sphere object:

$$A = \pi \left(\frac{f \cdot r}{Z_{\mathrm{C}} \cdot k} \right)^2 . \tag{2}$$

In the formula, r represents the real radius of the object, f expresses the camera focus and k is the scale factor of camera. The parameters f and k can be acquired by camera calibration; Z_{C} indicates the distance of camera and the object, and as the distance can be changed, it is the critical factor affecting the value of A. A large number of experiments show that the light condition in the process of imaging is relatively uniform when the distance Z_{C} between the camera and target is greater than or equal to one meter, the light condition in the process of imaging is more uniform.

According to whether the illumination is uniform, the threshold value segmentation of double spike method and the multi-threshold segmentation method based on sliding window are respectively used for image segmentation, getting the final segmentation results.

2.2. Research on circle detection method of underwater sphere target

Hough transform is a widely used circle detection method at present, which can make use of the target area that is composed of the target edge pixels, or detect the object with known shape in the image [15]. The classical thought of Hough transform is that it implements image segmentation, edge detection and other operations to the underwater original image, forming a closed curve that is similar to the circle by connecting the edge pixels of the target. A set of points on the circumference in the image space forms a set $\{(x_i, y_i)\,,\ i = 1, 2, 3, \cdots, n\}$ that is transformed to the parameter space (a, b, r) according to the formula

$$(x-a)^2 + (y-b)^2 = r^2 . \tag{3}$$

It is known from the above formula that the equation can be represented as a three-dimensional cone in the spatial coordinate system, and the corresponding relationship between the image space and parameter space is that an arbitrary point (x_i, y_i) on the circumference in the image space corresponds to a three-dimensional cone in the parameter space (a, b, r), forming a conical surface cluster.

2.3. Improvement of circle detection method

In this paper, the traditional Hough transform circle detection method has been improved. Firstly, segment the edge of the target. As shown in Fig. 2 below, the edge of the image is segmented to prepare for the next step firstly. In Fig. 2, taking the point O (which can be any point) in the target area as the benchmark, the target edge angle is divided into 16 sections. Picking point O as the center point of the target edge, the formula mode of the coordinate value in the image is

$$\begin{cases} \bar{x} = \frac{1}{A_r} \sum x, \\ \bar{y} = \frac{1}{A_r} \sum y. \end{cases} \tag{4}$$

In the formula, A_r represents the number of all pixels on the edge of target, and x, y are the coordinate value of the target edge pixels in the image.

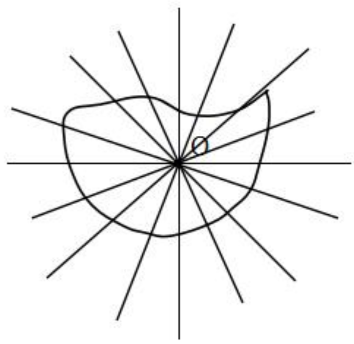

Fig. 2. Fragment diagram of the target edge

Secondly, judgment of sectional edge: judge each section of the edge to achieve the purpose of distinguishing the deformation edge and the edge area that meeting the requirements of the circle detection. Thus reduce the influence of the deformation edge on the accuracy of circle detection [16]. The specific steps are as follows.

Start from the pixel at the bottom left corner, the initial position of the line segment the pixel belongs to is determined, scanning the line segment point by point. In this paper, the circle fitting method is used to judge whether the current edge meets the circle detection requirements. Set the coordinate values as $\{\{x_i, y_i\}, i = 1, 2, 3, \cdots, n\}$ of the pixel points on the edge of any segment. Conducting circle fitting to the pixel points on the same edge, that is, evaluating the center point (x_O, y_O) and the radius R corresponding to these points to minimize the objective target functional formula

$$F=\sum_{i=0}^{n}\left((x_i-x_{\mathrm{O}})^2+(y_i-y_{\mathrm{O}})^2-R^2\right)^2 . \tag{5}$$

Calculating the partial derivative of F with respect to x_{O}, y_{O} and R separately and solving the following equations we obtain

$$x_{\mathrm{O}}=\frac{A_2C_2-B_2C_1}{A_1B_2-A_2^2},\quad y_{\mathrm{O}}=\frac{A_2C_1-A_1C_2}{A_1B_2-A_2^2}, \tag{6}$$

$$R^2=\frac{1}{n}\sum_{i=0}^{n}\left((x_i-x_{\mathrm{O}})^2+(y_i-y_{\mathrm{O}})^2\right) . \tag{7}$$

Here, A_1 and A_2 are the minimal and maximal distances between the pixel and target point, B_1 and B_2 are the minimal and maximal regional areas, and C_1 and C_2 are the average tray-level of background and target regions.

In the same way, the center point $(x_{\mathrm{O}}, y_{\mathrm{O}})$ and radius R of the circle corresponding to the sixteen line segments can be obtained, respectively.

To determine whether the current edge meets the requirements of the arc segment, that is, if the conditions of $R < R_{\max}$, and $F < R_{\mathrm{T}}$ (the set threshold) are met, the current edge is acceptable, otherwise, the edge is not acceptable. After scanning the sixteen edges, cluster all the parameters of the arc section that meets the requirements, and then conduct Hough transform circle detection to the clustered image pixel point, finally get the target circle detection results.

3. Result analysis and discussion

3.1. Contrast experiment underuniform illumination

Employing the underwater color camera OUTLAND UWC325, the size of the acquisition image was 352×288, and the experiment was carried out in 4 m×3 m×2 m water tank. In the experiment, the sphere object was suspended at 1 m from the water surface, and the same conditions were set in the following experiments. When the image is collected, open the two underwater lamps that have equal distance to the camera, to ensure adequate and uniform illumination. Figure 3 shows the contrast experiment results of red image segmentation. Diagram (a) represents the original light image, and diagrams (b) and (c) respectively show the grey results by using NTSC method and corresponding threshold segmentation results of double spike method, and diagrams (d) and (e) express the grey results by using the improved grey method and the corresponding threshold segmentation results of double spike method.

As can be seen from the diagrams, there are adhesions and distractors on the red sphere in the background after the threshold segmentation of the grey image by using NTSC method, and the edge of the sphere is rough. The diagram (e) shows

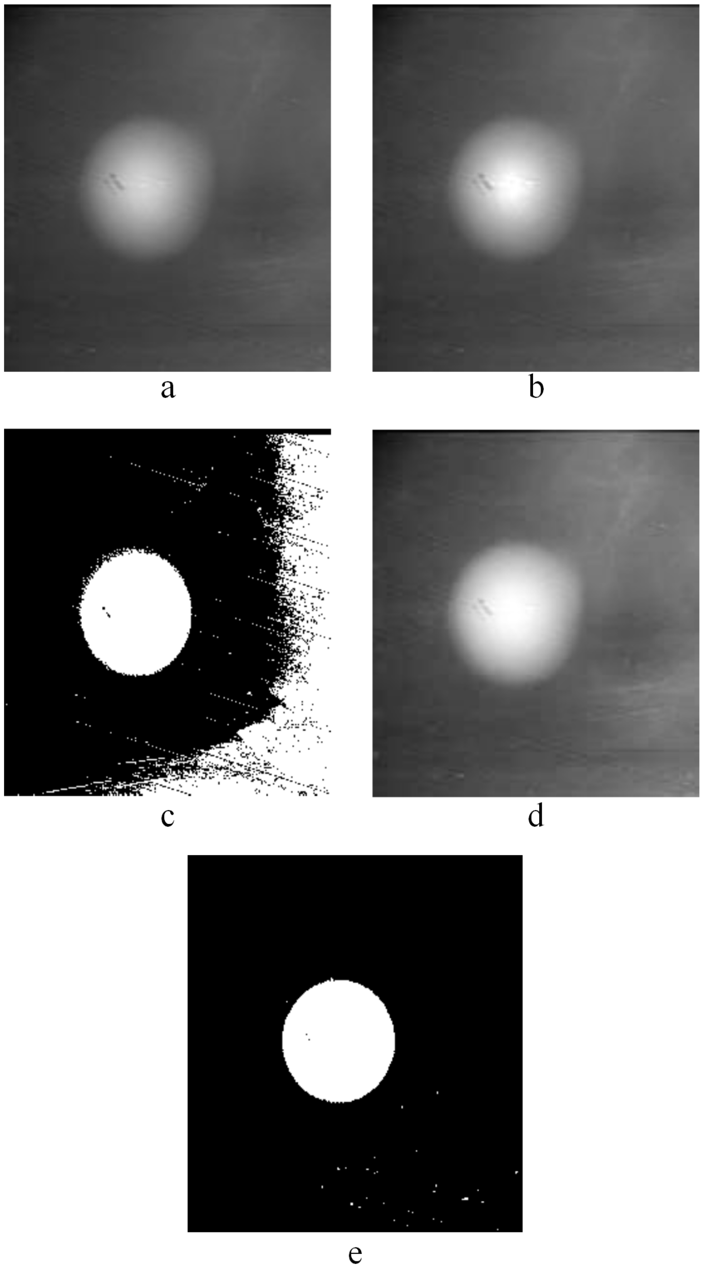

Fig. 3. Segmentation results of double spike method: a–original image of the red sphere in light, b–TNSC method, c–segmentation results of double spike method, d–improved grey progressing, e–segmentation results of double spike method

that the image contrast is enhanced, and the red sphere is completely segmented after threshold segmentation. What is more, the edge of the sphere is smooth, and the noise point is significantly reduced comparing to that of the diagram (c). At the same time, this paper uses segmentation evaluation indexes of FOM, UM and GC on the diagrams (c) and (e), and the performance evaluation results are shown in Table 1.

Table 1. The values of $f''(0)$ for various values of β

	Evaluation criterion		
Grey progressing method	FOM	UM	GC
NTSC method	0.0380	0.4738	0.1521
Method of improving the image grey progressing	0.1062	0.8643	0.7172

Analyzing the data in Table 1, the segmentation results show that three indicators FOM, UM and GC were significantly improved on the basis of the improved grey progressing method, illustrating that the improved grey progressing method is more suitable for underwater red light image segmentation than NSTC method.

3.2. Contrast experiment under uneven illumination

Turn to one of the two underwater lights with the same path to the camera. When collecting the image, move the support of the mobile camera and the underwater lamp to ensure that the illumination is not uniform. Taking the red sphere image as an example, Fig. 4 shows contrast experiments of red sphere segmentation under uneven illumination

As can be seen from the diagrams (b)–(d), the difference between the target and the background grey level of the improved grey progressing is larger than that of the NTSC method. Because of uneven illumination, the grey level of the red sphere region (target area) is close to that of the surrounding pixels, and it fails to segment by using double spike method. In the diagram (e), the target area of the image is processed by sliding window, reducing the segmentation error caused by the similar grey values, and the difference between the grey values around the target area can be obviously refined to segment the object. All of these indicate the effectiveness of the multi-threshold image segmentation method based on sliding window.

3.3. Contrast experiments of circle detection methodbefore and after improvement

In the experiment, the binary image after edge detection is processed, respectively, by the traditional point Hough transform and the improved method in this paper. The results of the experiment are depicted in Fig. 5.

In Fig. 5, there is partial deformation on the edge of the sphere in the diagram (a). As can be seen in the diagram (b), after the process of the traditional point

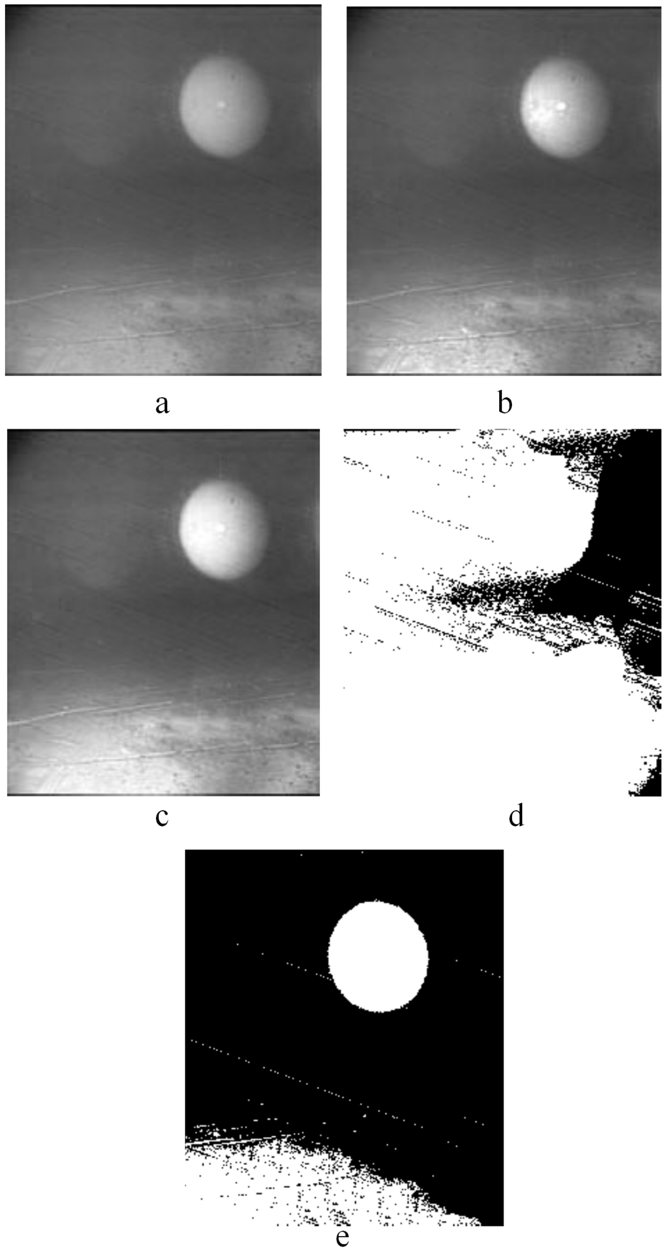

Fig. 4. Contrast experiment results of red sphere segmentation under uneven illumination: a–original image of the red sphere in underwater light, b–TNSC method, c–improved grey progressing, d–segmentation results of double spike method, e–results of multi-threshold segmentation based on sliding window

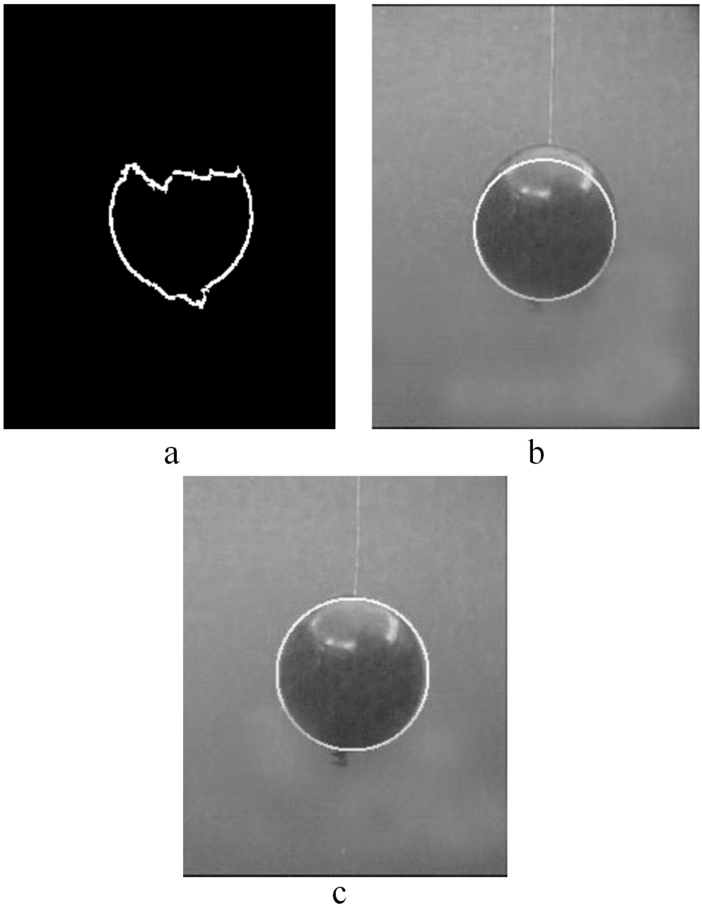

Fig. 5. Contrast experiment results of circle detection: a–partial deformation on the edge of the object , b–traditional point Hough transform , c–Improved method of circle detection

Hough transform circle detection, the results of the circle detection have obvious difference with the true value in the Y direction because of the irregular edge of the upper part of the sphere.

4. Conclusion

In this paper, it is studied the detection technology of underwater robot based on image segmentation. By improving the traditional technology, it is proposed that image segmentation method based on the improved grey progressing and multi-threshold segmentation method uses the sliding window. The traditional Hough transform circle detection method, and also three improvements of the feasibility and effectiveness of the method are verified by experiments. Finally, the following conclusions are drawn:

As to the problems of the threshold segmentation method based on the NTSC method, this paper proposed and verified an underwater image segmentation method on the basis of improving the grey progressing. The experimental results show that there is less interference and noise in the improved segmentation results, and the three evaluation indexes FOM, UM, GC have a certain degree of improvement. In the uneven illumination conditions in the water, this paper proposes multi-threshold image segmentation method based on sliding window, which is obvious for the existing problems such as incomplete target separation in the image segmentation results. And the experimental results show that the multi-threshold segmentation of sliding window method can effectively separate out the object. There are partial deformations of the target sphere image edge and other problems in image segmentation results, the traditional Hough transform circle detection method is improved and tested to solve the referring problems. Similarly, the underwater experiment results also show that the improved circle detection results has better accuracy than that of the tradition point Hough transform circle detection results. The experimental results show that the improved technology in this paper can make the work of underwater robots more smoothly, and provide convenience for the exploration of marine resources.

However, due to the limited time, the paper takes merely consideration of the conditions under uniform illumination and uneven illumination, which is not sufficient for the actual underwater working. And the experiment is too single, without taking into account the image color of this piece of content. Therefore, it is recommended that the light source structure can be taken as a breakthrough point, focusing on the process of the robot gradually closing to the target, and changing the color of the target, which makes the experiment more rigorous.

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