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Sonar Target Recognition Research Based on AUV

Jiamin Zhang[1], Qingjun Zeng[1], Zhiyu Zhu[1], Qiang Zhao[1], Jinyi Yao[1], Qirun Zhou[2]

1 School of Electronic and Information, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
2 School of Computer, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
E-mail:1584963971@qq.com

Abstract: In order to meet the requirements of underwater search and rescue, exploration, target detection and tracking, "T-SEA I" Autonomous Underwater Vehicle was developed. Based on the front-view sonar mounted at the Autonomous Underwater Vehicle, the target recognition experiment was carried out. Sonar target detection and identification research was carried out based on the selected images from moving target. In this paper, the system composition and principles of "T-SEA I" are described. We then propose a framework for a control system in which laptop and surface control box act as a surface monitor unit, While the PC104 industrial control board acts as the main control unit of the AUV's autopilot. The target recognition process includes three steps: image enhancement, target detection, feature extraction and identification. The three frame differential method is used to detected sonar target. A fast ellipse detection algorithm based on Hough transform is adopted in target characteristics extraction, this algorithm reduces the parameter dimension by using the geometry of the ellipse. The lake experiment shows that the AUV runs reliable and normally, it can meet the requirement of underwater work. Besides, the sonar target recognition is well. This Autonomous Underwater Vehicle's architecture and target recognition method have reference significance to the development of large-scale Autonomous Underwater Vehicle and the target identification of video and infrared.

Key words: AUV, control system, sonar, target detection, target recognition

1 Introduction

The ocean has a vast space on the earth, rich in resources. With the depletion of land resources and the continuous development of world economic and technology, human have accelerated the exploitation of ocean resources[1]. The rational development and utilization of ocean resources have great significance to the development and stability of mankind. Due to the complexity of the ocean environment, the way in which ocean exploited by manned detection is extremely dangerous. Underwater robots are appeared under this background.

Autonomous Underwater Vehicle (AUV) is a kind of cable-free autonomous underwater vehicle which can realize autonomous navigation through its own high-energy battery. Since AUV has strong environmental adaptability, large range of activities and flexibility, it is one of the best underwater operating tools for mankind[2-3]. As an important tool for mankind to explore, exploit and develop the sea, AUV has been widely used in fields such as scientific investigation, deep-sea operation, salvage and rescue, target detection[4]. The Ocean Seaver company's Iver2 AUV has been widely used in ocean exploration, environmental monitoring and some other fields. At the same time, sonar system acts as AUV's eyes, it has an irreplaceable role for AUV to reach the function of obstacle avoidance, navigation, information detection and etc.

Currently, the common algorithm in the detection of moving targets including background subtraction method, inter-frame difference method and optical flow method. The background subtraction method is simple and can extract the most complete moving target feature normally, but it has poor adaptability to environmental changes. The inter-frame difference method has low complexity and adaptability to the environment, but it is easy to detect incomplete image for slower moving targets. Although the optical flow method is suitable for the detection of moving target with static background and variable background, this method is complicated, has poor real-time performance and requires special hardware support at the same time[5]. There are mainly three types of algorithm in the elliptic feature extraction: the first is the random Hough transform method, which uses many to one mapping to avoid the huge amount of computation of traditional Hough transform[6]. The second uses the method of numerical analysis for ellipse fitting. The third method uses the ellipse geometry to reduce the dimension of the ellipse parameter and achieve the purpose of rapid detection as a result[7]. In this paper, we first introduce the developed "T-Sea I" AUV from it's system composition and control system. Then we introduce the principle and method of sonar target recognition. Finally we select the typical frames in the sonar target recognition experiment for target detection and recognition. The three-frame difference method is used to detect moving objects. This algorithm can extract moving objects more completely. A fast ellipse detection algorithm based on Hough transform is used to extract the moving target features. This detection algorithm reduces the dimension of the parameters by using the geometric properties of the ellipse. After this, Hough transform is used to obtain the whole ellipse features.

2 "T-SEA I" AUV's Constitute and Control System

2.1 "T-SEA I" AUV's System Composition

The developed "T-SEA I" AUV consists of water equ ipment and underwater equipment. The water equipment mainly composed of laptop,surface control box and opt ical fiber winch. The underwater equipment is AUV. It's technical specifications shown in Table 1, it's 3D structure shown in Fig.1.

Table 1 "T-SEA I" AUV's technical specification

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Parameter	Content
Diameter(mm)	220
Length(mm)	210
Weight(kg)	65
Maximum speed(kn)	2.5
Battery life(hour)	6
Working depth(m)	60
Drive equipment	one main push, two lateral push, two vertical push
Navigation equipment	Fiber optic inertia, GPS, DVL
Observation equipment	Sonar, lights, Camera

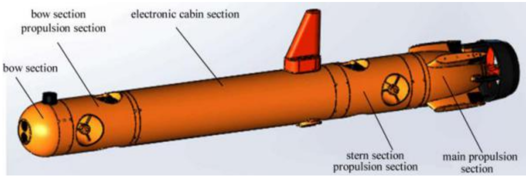

Fig.1: "T-SEA I" AUV's 3D structure

The water equipment consists of bow section, bow propulsion sction, electronic cabin section, stern propulsion section and main propulsion section. The bow section includes underwater camera, lighting and sonar; The bow propulsion section is mainly composed of the bow lateral thruster and bow vertical thruster; the stern propulsion section is mainly composed of stern lateral thruster and stern vertical thruster; the main propulsion section mainly consists of the main thruster, safety throwing mechanism and rudder.

The electronic cabin section acts as the core of "T-SEA I" AUV, it is mainly composed of the seal end plate, DVL, antenna and instrument compartment. The instrument compartment is installed in the interior of the electronic cabin, it is mainly composed of fiber optic inertia, battery pack, network switch, optical transceiver, autopilot, motor controller, camera PC104 board, image acquisition card and wireless data transmission equipment. "T-SEA I" AUV's physical figure shown in Fig.2.

Fig.2: "T-SEA I" AUV's physical figure

2.2 "T-SEA I" AUV's Control System

"T-SEA I" AUV's control system includes water control unit and underwater control unit. The water control unit is mainly responsible for the release of controlling commands and the monitor of AUV's running state. The underwater control unit executives the control commands and return information about AUV's navigational status. There are two typical communication modes between water control unit and underwater control units: optical fiber communication and wireless communication. Underwater control unit using PC104 industrial control board as the main control board. At the same time, this AUV equips with a separate camera PC104 board to process camera data. The whole control system block diagram shown in Fig 3.

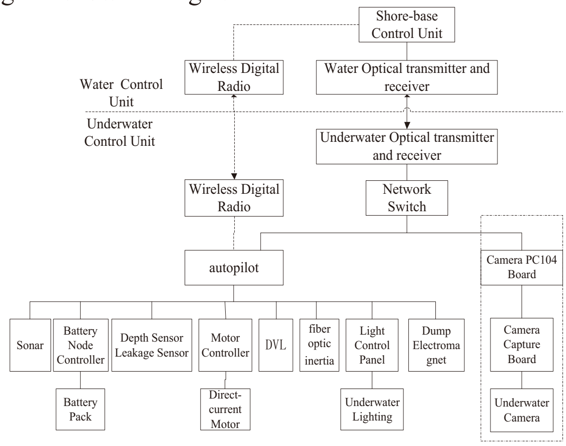

Fig 3: "T-SEA I" AUV's control system diagram

"T-SEA I" AUV uses distributed control system. The "T-SEA I" AUV can be divided into five parts from the control structure: water control unit, automatic pilot unit, motion control unit, information measuring unit and navigation unit. "T-SEA I" AUV's electronic cabin adopts the communication backplane to route the whole AUV control system, and connects the control units and the sensing devices through the communication backplane. Each of the AUV's sensing devices and control boards is connected to automatic pilot's PC104 main control board via the communications backplane.

3 Research on Sonar Target Recognition

3.1 Sonar Image Enhancement

Firstly, the original pseudo-color images collected by sonar is converted into grayscale images, and then the converted grayscale images are enhanced. This involves two steps: grayscale transformation and median filtering. First, the contrast of the images are enlarged by the grayscale transformation, this making the images visible and the corresponding features more obvious. Then, the median filter is used to relief the image noise[8]. This experiment uses the linear grayscale transformation and 5*5 square filter template's median filtering method to enhance the sonar images.

3.2 Sonar Target Detection

The function of target detection is to separate the target from the background in order to facilitate the subsequent target recognition[9]. In this paper, three-frame difference method is used to detect the target. Since the sonar remains relatively still under water and the background area changes little, the three-frame difference method can achieve good target detection effect. The specific steps of using the three-frame difference method for sonar target detection are as follow.

1) Extract three consecutive images from H frame consecutive enhanced images collected by sonar, recorded as I_{k-1}, I_k, I_{k+1}. Make differential processing between the two adjacent frames of sonar images respectively. The

differential results recorded as D_k, D_{k+1} ,As shown in equation 1 and equation 2.

$$D_k = |I_k - I_{k-1}| \tag{1}$$

$$D_{k+1} = |I_{k+1} - I_k| \tag{2}$$

2) Select the appropriate threshold and do binary processing for the two sonar images D_k, D_{k+1}, the binary images are recorded as d_k, d_{k+1}.

3) Perform and operation on d_k, d_{k+1}, finally we obtain the target's binary image L_k.

Due to the existence of noise interference, the interior of the target detected by the three-frame difference method is likely to be hollow. The mathematical morphology "open operation" is used to process the target image obtained by the three-frame difference method, this method can smooth the target boundary as well as fill small holes in the interior of the target.

3.3 Sonar Target Recognition

3.3.1 Sonar Target Edge Feature Extraction

The corresponding information of the target contour can be obtained by the edge feature extraction. This is prepare for extracting the elliptical feature of the target. In this paper, Sobel edge operator is used to extract the edge features of the target object. This method can also enhance the weight of pixels in the four directions: up, down, left and right. The computational formulas are as follow.

$$\begin{aligned} f'_x(x,y) &= f(x-1,y+1) + 2f(x,y+1) \\ &\quad + f(x+1,y+1) - (x-1,y-1) \\ &\quad - 2f(x,y-1) - f(x+1,y-1) \end{aligned} \tag{3}$$

$$\begin{aligned} f'_y(x,y) &= f(x-1,y-1) + 2f(x-1,y) \\ &\quad + f(x-1,y+1) - f(x+1,y-1) \\ &\quad - 2f(x+1,y) - f(x+1,y+1) \end{aligned} \tag{4}$$

$$G[f(x,y)] = |f'_x(x,y)| + |f'_y(x,y)| \tag{5}$$

Among them $f'_x(x,y)$ represents x direction's first-order differential, $f'_y(x,y)$ represents y direction's first-order differential. $G[f(x,y)]$ represent s Sobel operator's gradient. After determining the grad ient, set a constant T, when $G[f(x,y)]$ greater than the constant T, this point is marked as the boundary po int, it's pixel value is set to 0 and other points' pixe l value are set to 255.

3.3.2 Rapid Elliptical Feature Extraction Based on Hough Transform

The basic idea of Hough transform is to use the duality of point and line in the image space and parameter space to calculate the parameter values of pixel space in the image space corresponding to parameter space, then search for local peak in parameter space, the peak corresponding to the linear parameter is the test result. Hough transform is widely used in feature extraction due to its insensitivity to noise and good robustness, which allows small defects and deformations in the curve when detecting targets[10].

The geometry equation of a typical ellipse is given by formula 6. In this equation, a represents the long half axis of the ellipse, b represents the short half axis of the ellipse, (p,q) represents the center of the ellipse, θ represents the angle between the ellipse's long half axis and x axis, (x,y) is one point on the ellipse.

$$\frac{[(x-p)\cos\theta+(y-q)\sin\theta]^2}{a^2} + \frac{[(y-q)\cos\theta-(x-p)\sin\theta]^2}{b^2} = 1 \tag{6}$$

Due to a straight line like $y = ax + b$ only need to use two parameters like a, b to define,the mapping form from the image space to the parameter space is simple, which only need to calculate in two-dimensional parameter space, the amount of computation is not big as well[11]. However, an ellipse has up to five parameters, the conventional method required the accumulation of five dimensions in the parameter space, the calculation is too large. In this paper, a fast ellipse feature extraction method based on Hough transform is adopted. This method reduces the parameter dimension by using the geometric features of the ellipse so as to achieve the purpose of fast ellipse detection. The key idea of this feature extraction method is to use the following geometric features of the ellipse: In the whole target image which will be detected, the center coordinate of the ellipse is the point with the minimum maximum distance from the edge of the ellipse at all points on plane. Feature extraction steps are as follow:

1) Building array M , saving the target's edge coordinate information to M , calculating the maximum distance from all points in the whole image, the point corresponding to the minimum maximum distance is ellipse's center coordinate (p,q), this maximum distance is ellipse's long half axis a.

2) Bring the center of the ellipse (p,q) and the ellipse's long half axis a into elliptic equation to get the equation of ellipse for two unknowns b and θ.

3) Conversion from image space to two-dimensional Hough parameter space. During this period, accumulating b 's value and θ 's value. The maximum cumulative values' position coordinates in Hough parameter space are b 's and θ 's true values.

4 "T-SEA I" AUV's Sonar Target Recognition Experiment

4.1 Sonar Target Recognition Experiment

The sonar target recognition experiment site selected in one lake in Suzhou. In the experiment, the AUV remained relatively stationary, driving the target through rowing. The target object identified was a round iron lid. The recognition experiment is divided into two stages. During the first stage, the target is closer to AUV, sonar's scanning distance is set to 10 meters and sonar's scanning mode is set to 180 degrees normal scan, During the second stage, the target is far away from AUV, sonar's scanning distance is set to 20 meters and sonar's scan mode is set to 90 degrees fast scan. The experimental site and the target object are shown in Fig. 4 respectively.

Fig. 4: The experiment site and the target object

Two typical sonar original images of the first phase of the recognition experiment and two typical sonar original images of the second phase of the experiment are respectively selected for target recognition. The original sonar images are shown in Fig. 5.

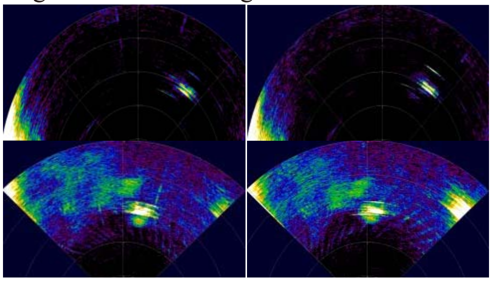

Fig. 5: Original sonar images

4.2 Sonar Image Enhancement Result

The enhanced images are shown in Fig. 6.

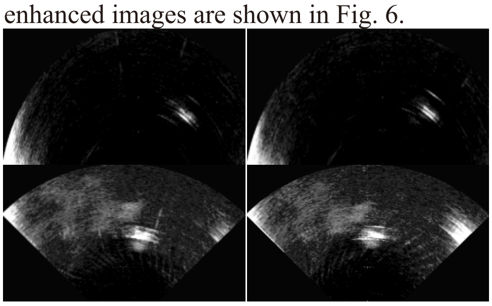

Fig. 6 Enhanced sonar images

4.3 Sonar Target Detection Result

The result of the target detection on the four enhanced images are shown in Fig. 7.

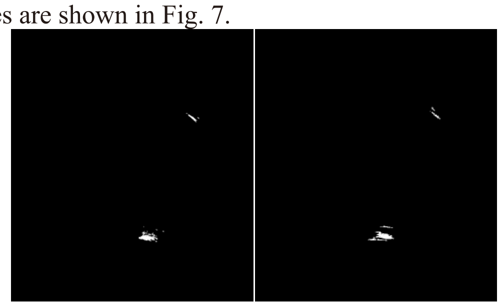

Fig. 7: Result images of target detection

4.4 Sonar Target Recognition Result

Firstly, we extract the sonar target's edge. After edge feature extraction, the elliptic feature extraction algorithm is used to extract target' elliptic character. The feature extraction results are shown in figure. 8. Due to the existence of noise interference, some noise point features around and inside the target are extracted together.

In this experiment, the target object is a round iron lid. Due to the influence of water flow and the target object making irregular movement under water, the target object obtained by sonar is actually oval. From the results of target detection and feature extraction, we can see that the target of recognition is approximately an elliptical feature, which is consistent with the characteristics of the target object used in this experiment, this proves the success of the sonar target recognition experiment.

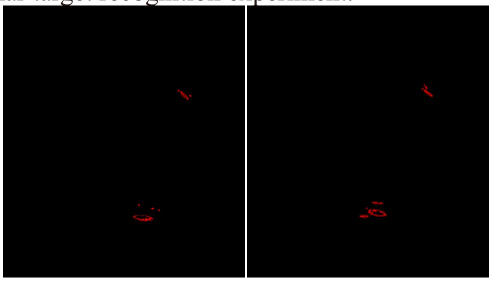

Fig. 8: Result images of elliptic feature extraction

5 Conclusion

This paper introduces the system composition and control system of "T-SEA I" AUV, and uses Micron DST sonar equipped with this AUV to perform target recognition experiments in one lake in Suzhou. The three-frame difference method is used to detect the obtained typical sonar images. A fast ellipse detection algorithm based on Hough transform is used to extract features. Firstly, the number of parameters are dimensionally reduced by geometric features of the ellipse. After the parameters were reduced to two dimensions, the ellipse feature was extracted by Hough transform. The results show that the autonomous underwater robot operates normally and reliably, and the sonar target recognition effect is good. The identified target features are consistent with the characteristics of the target object used in the experiment. The sonar target recognition methods used in this experiment have laid a solid foundation for the sonar target tracking research of the autonomous underwater robot.

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