Real-Time Image Processing and Mapping Algorithm for Forward-looking Sonar of AUV

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***Abstract*—The key of autonomous underwater vehicle to perform a variety of missions in complex sea environment was to accurately distinguish obstacle and mapping in real time. In this paper, the information of obstacle was segmented from sonar image by image filter, image enhancement, fuzzy clustering algorithm and morphology method. Then the coordinate system was established, the barrier information of each frame was projected onto the entire barrier map. Finally, the experiment on the lake proves that the methods of the image processing and mapping algorithm are feasibility.**

Keywords—Autonomous underwater vehicle; forward-looking sonar; sonar image processing; mapping

I. INTRODUCTION

Autonomous Underwater Vehicle (AUV) is an intelligent robot that completes a variety of missions in complicated sea environment by itself. It maybe collide the obstacle which is uncharted such as: oil drilling platform, uncharted island, reefs and so on during the voyage. Therefore, the AUV needs the ability of acquiring information of barrier and mapping the obstacle map in real-time. The paper tried to solve the problem that how to rely on the sensors of AUV to fast and accurately distinguish the obstacle and mapping the obstacle map in real-time in complicated sea environment.

In recent years, the applications of image sonar are more and more widely in the field of ocean development by the development of sonar technology. The decision-making of collision avoidance and mapping has become an important research direction in image processing field by the sonar image processing. Sonar image processing includes filter image enhancement and segmentation in the field of optical image processing [1]. But there is essentially different between sonar image and optical image in principle and mechanism of imaging. But the sonar image relative to the optical image has the characteristics of low image resolution, noise interference, multi-path phenomenon, Doppler effect, etc [2]. Even if the digital image processing and recognition has been relatively mature, but many methods can be used for optical image processing which is not feasible in the sonar image processing.

At present, there are a lot of achievements about the map building technology of ground mobile robot. But the dynamic underwater environment map building technical achievements are very small [3]. This is because that the there are many essential differences between the underwater environment and the general ground environment [4]. First of all, ground mobile robot can not consider air current effect on the robot motion, but the AUV must consider the influence of the currents in underwater environment, which is dynamic and time-varying; Secondly, the ground mobile robot path planning can be applied to a variety of sensors for target detection and recognition, but because of the limit of load and deep-sea work environment, the sensor for AUV is less, which will inevitably affect the AUV to acquire the information of the obstacles; Finally, compared with the ground environment, the noise interference is more frequent, more serious under the underwater environment. All these make the map building more complex and difficult than the ground environment. In order to achieve security obstacle avoidance and map building under the dynamic underwater environment, two problems need to be solved: one is direct to process the information of the sonar collection, and extract the information of obstacle. Two is to fuse the AUV navigation data to mapping two-dimensional local environment map.

II. SONAR IMAGE PROCESSING

A. Image filtering and image enhancement

Image preprocessing is an important part of the building map, which needs accord the requirement of sonar image features to extract the information of the barriers. The noise of sonar image is random disturbance, and it can be formed the salt noise, Gauss noise, pepper noise and the speckle noise with the difference in transducer sensitivity, temperature fluctuations, the marine environment and the multipath interference. And in order to improve the signal-to-noise ratio of the sonar image, and still need enhance the image after filtering for projecting the useful information. Forward looking sonar is very sensitive to the noise, so image filtering and image enhancement must be carried out after the building map. In this paper image filtering and image enhancement method based on the software development kit of the image sonar, and we set the threshold by dynamic maximum and minimum value of the sonar image. The original sonar image of the test pool is shown in Figure 1. The processing result of the Software Development Kit (SDK) is shown in Figure 2.

Supported by the Key Research Program of the Chinese Academy of Sciences, Grant NO.KGFZD-125-014.

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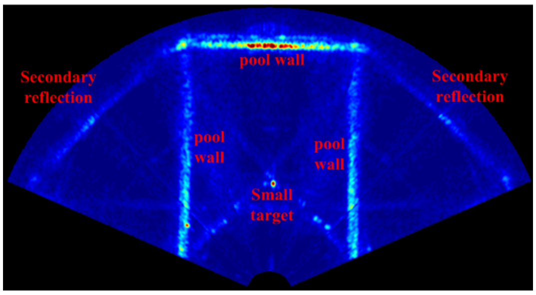

Fig. 1. The original sonar image of the test pool

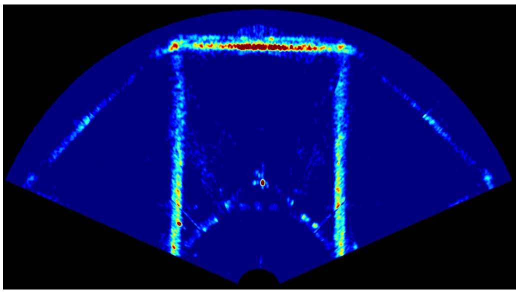

Fig. 2. The processing result of the SDK

The results show that a lot of noise and speckle noise is removed and the signal-to-noise ratio is greatly improved and the contour information of target has also been enhanced by filtering method of the software development kit. The filtering method by the software development kit is almost not time-consuming.

B. Fuzzy clustering algorithm

Image segmentation is a technique and process with similar pixel of image to be classified and extracted [5]. In this paper we adopted K-means clustering method to deal with the sonar image. Firstly, an accurate number of K was determined as the initial cluster center. Then we assigned the remaining objects to the nearest class according to the distance form the center. And a new cluster center was formed by recalculating each class object.

Fig. 3. The result of K-median fuzzy clustering algorithm

This process was repeated again and again until each cluster center was convergent. The K-means clustering algorithm is more suitable in the complicated marine environment. The result of K-median fuzzy clustering algorithm is shown in figure 3.

C. morphological processing

Morphology is a nonlinear filtering method; erosion and dilation are the basis of morphology. Erosion can eliminate boundary points and filter out the noise which is small and meaningless pixel [6]. Dilation can smooth the outline of the image and fill the gap on the contour. In this paper, we adopted the erosion treatment before the dilation treatment, because the sonar image is the most difficult to get rid of big spots which have the highly echo intensity. This treatment can remove the bright spot, clear image edge burr and isolated points and fill the holes in the image, while it can retain the large target area. The result of morphology method is shown in Figure 4. The result proved that the major noise was removed, and the useful data was recovered.

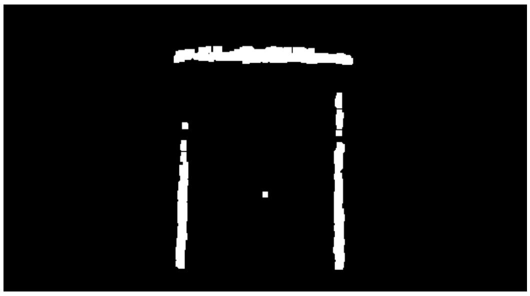

Fig. 4. The result of morphology method

III. THE SENSOR MODEL AND COORDINATE TRANSFORMATION

Building a map of the environment is an important research area of AUV, AUV use the information to automatically build a map of the perception of the environment. Representation of the map can be broadly divided into three categories: raster maps, geometric map, topology maps. This paper used the raster map method, and the environment was divided into a number of the same size as the grid, each grid point out the existence of an obstacle. This method has the advantage to create and maintain easily, keeping the information of various obstacles environment as a whole. It is useful for the collision avoidance and path planning.

In this paper, the Sonar sensor was the multi-beam imaging sonar which acquired the original data was the discrete data points, and a grid cell area represented by the distance with γ and the angle with β. Obviously, we need to convert the polar coordinate system of the AUV to the earth coordinate system. According to the characteristics of two-dimensional image sonar, we only consider the AUV motion in the horizontal XY plane, without considering float, dive and tilt, swing, etc. Five degrees of freedom of the AUV were reduced to two degrees of freedom plane motion, and therefore it greatly accelerated the computing speed and map building speed. The coordinate transformation model of the AUV is shown in Figure 5. In the figure, X is corresponding to the geographical north direction; the black bold lines are the robot coordinate system and origin of coordinate is the initial position of the robot. And x_1, y_1 represent the next position of the robot; x_2, y_2 represent the position of a point of the barrier.

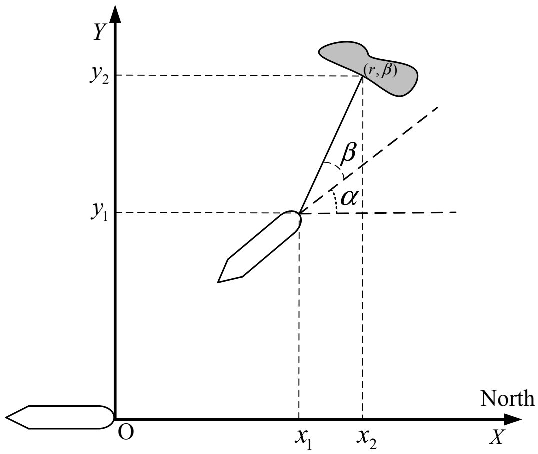

Fig. 5. coordinate transformation model of the AUV

The formula of coordinate transformation is as follows:

$$x_2 = x_1 + r \bullet \cos(\alpha + \beta) \quad (1)$$

$$y_2 = y_1 + r \bullet \sin(\alpha + \beta) \quad (2)$$

IV. Lake Test

The sonar image real-time processing method and mapping algorithm were proved that the methods were feasible and accurately provided real-time obstacle map for AUV by the lake test. In the test, the invisible reefs were as the collision avoidance obstacle. While the AUV was near close to the island, we acquired each frame image data by the forward-looking sonar with navigation date of AUV. And the image processing method and mapping method can offer the real-time multi-obstacles information of each frame and the barrier map for the AUV. Several original sonar images of the lake test in different locations are shown in Figure 6, and the results of image processing method are shown in Figure 7. The obstacle map is shown in Figure 8. It can be seen from the result of the obstacle map that the mapping method can accurately and fast mosaic obstacle information of each frame.

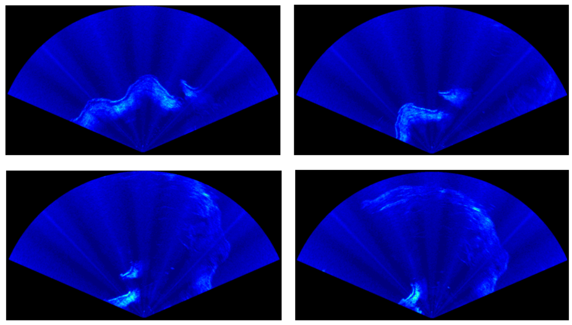

Fig. 6. Several original sonar images of the lake test in different locations

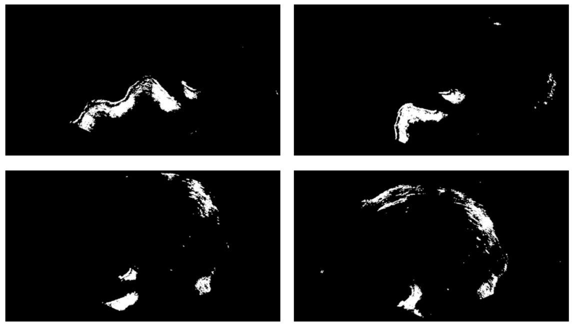

Fig. 7. The result of image processing method

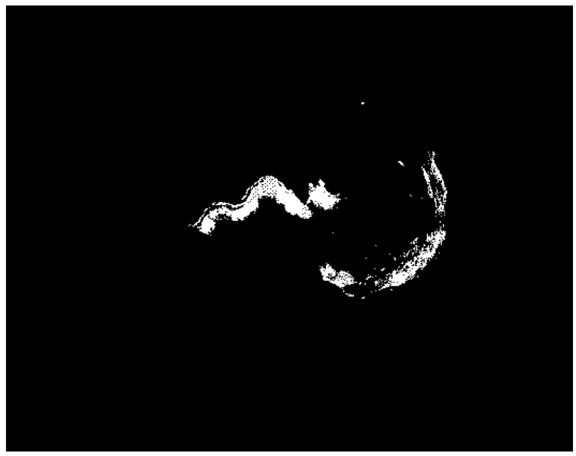

Fig. 8. The obstacle map

V. Conclusion

This paper proposes a real-time image processing and mapping methods which are suitable for forward-looking obstacle avoidance sonar of AUV. The image processing method is able to correctly offer the azimuth and distance information of the obstacle in real-time. The mapping method can accurately and fast mosaic the result of image processing method for each frame. These methods are proved to be feasible and effective by the lake test.

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