A Real-time Image Processing Method for Multi-beam Forward-looking Sonar of AUV

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Abstract. The key of real-time obstacle avoidance for AUV is to accurately and fast identify underwater obstacle. In this paper, according to the characteristics of the multi-beam forward-looking sonar of AUV, we extracted the obstacle information from sonar image with the image filtering, fuzzy clustering and morphological methods. Finally, it can be proved that the real-time image processing method is feasible and effective by the lake trial.

Introduction

When the autonomous underwater vehicle (AUV) executes all kinds of missions in the complicated environment, it maybe encounter the obstacle which are uncharted such as: reefs, oil drilling platform, uncharted island and so on during the voyage. Therefore, AUV needs the ability of real-time obstacle avoidance. The multi-beam forward-looking imaging sonar is the eye of AUV to make real-time obstacle avoidance decision and complete the missions, and the image processing method is the soul of AUV avoidance decision and missions.

In recent years, with the development of sonar technology, image sonar applications is more and more widely in the field of ocean development, the sonar image processing is an important research directions in the field of underwater robots. Sonar image processing includes filter image and segmentation in the field of optical image processing. 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 [1]. 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. In the aspect of image denoising, Jia Jian, Jiao Licheng et al. based on the Bresenham theory to improve the conversion efficiency and applied to the image denoising, compression and other applications [2]. Zhao Chunhui, Shang Zhengguo et al. proposed multi-resolution domain HMT image denoise and enhancement algorithm which based on Hidden Markov model and verified by experiments to obtain higher signal-to-noise ratio [3]. In the aspect of Image segmentation, R.Callaghan proposed image segmentation method which based on Nonsubsampled Contourlet transform and watershed algorithm. This method can obtain better segmentation results and effectively reduce the over-segmentation of the watershed algorithm [4].

In this paper, a real-time image processing method is proposed for the multi-beam forward-looking obstacle avoidance sonar of AUV. The image processing method is demonstrated by comparing with different processing methods in this paper. The image processing method is demonstrated by the trial on the lake.

Multi-beam Forward-looking Sonar

The sonar in our project is a P450-130S produced by the Teledyne BlueView in United States, which is very suitable for forward-looking obstacle avoidance sonar of AUV with the advantages of low price, small size, and low power consumption. Therefore, it is very suitable for collision avoidance and target recognition applications. The following is the main performance index: The
frequency of 450KHz, horizontal angle of 130°, vertical angle of 15°, a maximum range of 250m, the number of beams is 768, beam spacing of 0.18°, resolution of 5cm. The sonar is shown in figure 1.

Fig 1. Multi-beam forward-looking sonar

Sonar Image Processing Method

Image preprocessing is an important part of the target detection, which is not immutable and frozen, and it needs to analyze the features of sonar image and barrier. In this paper, the image preprocessing process is shown in figure 2.

Fig 2. The process of image processing

Image Filter. The noise of sonar image is random disturbance, and it can be formed the Gauss noise, salt noise, pepper noise and the speckle noise with the difference in transducer sensitivity, temperature fluctuations, the marine environment, multi-path interference. Forward looking sonar is very sensitive to the noise, so filtering process must be carried out after the image processing. Median filtering, mean filtering, Wiener filtering, wavelet analysis [5] are common methods of image filtering.

Fig 3. The original sonar image of the test pool

In this paper, the image filtering method based on the software development kit of the image sonar, and we set the dynamic threshold by the maximum and minimum value of sonar image. Then, the result compares with the median filtering by performing the same frame image of the test pool which is shown in Figure 3. The processing result of median filtering is shown on the left in Figure 4, and the processing result of the dynamic threshold method is shown on the right. The results show that both of the two methods can achieve the filtering of the sonar image, although the median filter can remove
the impulse noise, but it makes the image fuzzy, the speckle noise and signal aliasing. But a lot of noise and speckle noise is removed by the dynamic threshold method. And the median filtering consumes more time to deal with a sonar image which takes about 100 milliseconds, while the dynamic threshold method by the software development kit is almost not time-consuming. It can be seen from the results that the filtering method in the paper is better than the traditional method of filtering on the processing time and the effect of image filtering.

Fig 4. The result of median filtering and the dynamic threshold filtering method

**Fuzzy Clustering Algorithm.** Image segmentation is a technique and process with similar pixel of image to be classified and extracted, and can not form a unified and recognized segmentation algorithm so far. The classic fuzzy clustering segmentation method is sensitive to noise, operation cost and poor edge data. The disadvantages affect the application [6,7]. In this paper we adopted K-means clustering method to deal with the sonar image, which based on the traditional fuzzy C-means algorithm. Threshold iterative method and fuzzy K-means clustering algorithm respectively process the image of figure 5. The result of iterative threshold algorithm is shown on the left in figure 6 and the result of K-median fuzzy clustering algorithm is on the right. The results show that although the two algorithms are separated from the noise out of the pool wall, the fuzzy K-means clustering algorithm is better in the aspect of continuity. The reason is the fuzzy K-means clustering algorithm image is divided into four categories, and iteration threshold simply divides the image into foreground and background. For the complexity of the marine environment, the fuzzy K-means clustering algorithm is more suitable. So it can be proved that fuzzy clustering algorithm is more suitable for the image segmentation algorithm of AUV by comparing the traditional threshold iterative method with K-means clustering algorithm.

Fig 5. The result of iterative threshold and K-median fuzzy clustering algorithm

**Image 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 that is small and meaningless pixels. After the data of the erosion treatment, image can filter out most of the noise, but also corroded the boundary of the valid data. So it must carry out the dilation treatment [8], after the erosion treatment. 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 6, which the noise is removed, and the useful data is recovered out.

![Fig 6. The result of morphology method](image6)

**Lake Trial**

The real-time sonar image processing method was proved that it was feasible, and it can accurately provide real-time obstacle information for AUV by the lake trial. The trial adopted the fixed-depth underwater towed-vehicle that manufactured by Shenyang institute of automation Chinese academy of sciences. It can simulate underwater navigation process of the AUV, and as the platform of image sonar. The towed-vehicle is shown in figure 7.

![Fig 7. The fixed-depth underwater towed-vehicle](image7)

In the lake trial, the visible island was as the collision avoidance obstacle, while the towed-vehicle was near close to the island, and maintained the direction of the image sonar has been facing the island. An original sonar image of the test is shown on the left in figure 8, and the result of filtering a, K-means fuzzy clustering algorithm and morphological processing result is shown on the right. It can be seen from the results that the most of the noise is filtered out, and the island target is extracted.

![Fig 8. The original sonar image of the island](image8)

This paper contrasted the time consumptions of each frame image processing with the time consumptions of each frame acquisition by sonar (as shown in Figure 9). The time consumptions of image processing was between 150ms and 250ms, and the time consumptions of acquisition by sonar
was between 300ms to 400ms, which indicated that the image processing method can guarantee the requirements of real-time obstacle information for the AUV.

![Graph showing time consumptions](image)

**Fig 9.** The comparison of time consumptions

**Conclusion**

This paper proposes a real-time image processing method which is suitable for multi-beam forward-looking obstacle avoidance sonar of AUV. This method is able to correctly determine the outline and the distance information of the obstacle in real-time. Sonar image processing method is feasible and effective by the lake trial.

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