Research of Ship Wake Tracking Based on Image Sonar

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***Abstract*—A long "V" shaped linear wake with lots of bubbles is formed behind a sailing ship, which provides a target feature of the ship. Ship wake acoustic detection is one of the most effective ways for the Autonomous Underwater Vehicle to automatically search, track and attack surface targets. In this paper, we processed the sonar image data of ship wake in the lake test, using the sonar image sequence of multiple features fusion method and Kalman filter method, matching the acoustic scattering strength characteristic and geometric characteristics to realize the detection and tracking of ship wake.**

Keywords—ship wake; sonar image; wake tracking;

I. INTRODUCTION

The ship inevitably formed the "V" linear wake by the propeller to stir seawater during the voyage, and its wake can be extended to several kilometers behind the ship. The wake which has been generated by the surface ship during the voyage has many features such as acoustic characteristics, optical characteristics, electrical characteristics, magnetic characteristics and thermal characteristics[1]。 Ship wake acoustic detection is one of the most effective ways for autonomous underwater vehicle to detect, track and attack surface targets. The reflection characteristic of ship wake bubbles is the key to detect and track the ship wake. At present, the traditional method of wake detection is the top view sonar detection under the wake method, so the AUV need to sail under the ship wake, sending sound pulse signal to the top and receiving the acoustic signal echoes. Reflective waves are obviously different in the wake region and non wake region. According to the processing of the received signal we can judge whether the AUV is in the wake region, and the AUV can detect and track the surface ship wakes [2]. But this method has low detection rate and high false alarm rate with a lot of noise interference.

This paper mainly studies the sonar image of ship wake, and the use of image processing method to identify the ship wake. The AUV can detect the existence of wake, wherever it is outside or inside the ship wake region. It determines the characteristic parameters of ship such as the ship heading. Finally, it can be realized that the AUV is able to detect and track of the ship. However, the image sonar on the AUV has many advantages to detect the ship wake, mainly: (1) the surface ship will engender the wake during the voyage, and the wake will not disappear. The life of bubble in the wake generally was considered in 15~45 min, so detection probability is very high with the wake of bubbles; (2) The geometrical size of the wake relate to the width of the ship and waterline, so it is difficult to use small sailing or aerosol bomb which simulate of the ship wake to implement trick. So AUV can resist general acoustic interference, when it detected the ship wake; (3) Although the AUV can closely detect and track the ship wake, but it can be hidden very well; (4) When the AUV detected and tracked the wake that could be not affected by the self noise, therefore, it could be allowed to further improve its speed; (5) Sonar recognition system is simple, reliable and easy to use. Therefore, image sonar has been prayed more and more attention and widely adopted in the world, as an effective means of ship detection.

II. THE CHARACTERISTIC OF SHIP WAKE

A lot of acoustic characteristics of the ship wake can be described, such as: the geometric characteristic, acoustic characteristics, optical characteristics and magnetic characteristics, etc. The geometric characteristic includes the length, depth, width and linear feature of wake. This paper focuses on the geometric characteristic and acoustic scattering strength characteristic of ship wake.

A. The geometric characteristic of ship wake

Geometric characteristic of ship wake depends on factors such as the type, the speed of ship, and the sea state, but the linear characteristic of ship wake is the most obvious. The surface ships generate the surface wave ship wake, which can be divided into the narrow V ship wake and typical Kelvin ship wake. It is shown in Figure.1.

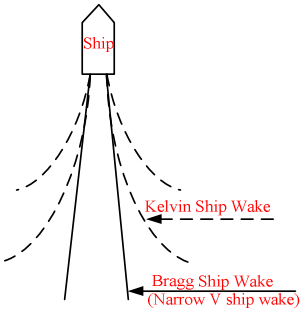

Fig. 1. Surface wave ship wake

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It can be seen clearly that the narrow V ship wake has obvious linear feature. So we only detect the two wake straights which outstrip the threshold value of the length and angle. In this paper, the wake detection was based on the geometric characteristics.

B. The characteristic of acoustic scattering strength

The change of acoustic scattering characteristic is mainly caused by the change in the physical characteristic of the bubble, so the acoustic scattering strength characteristic varies with time which is significantly statistical characteristics. Acoustic scattering characteristic of the ship wake is equal to the life of the ship wake. It is related with the speed change of the ship, the sea state, the characteristic of wake and the ability of the wake detection device.

The traditional method of wake detection is using the single beam sonar, which can only collect acoustic scattering strength of the wake for small region, so it can not reflect the acoustic scattering strength changes of the whole area wake. In this paper, we adopted the high resolution multi-beam image sonar to measure the acoustic scattering strength of wake. Dalian Key Laboratory for Underwater Test and Control Technology carried out ship wake experimental researches on the acoustic scattering strength and geometric characteristics of the ship wake. For example, the experimental study on the acoustic scattering of the ships' wakes using imaging sonar[b] and sound scattering and geometric characteristics of ship wakes[a], and the studies had obtained the acoustic scattering strength of ship wake varying with time. It is shown in Figure.2. It can be seen from the figure that the acoustic scattering strength of ship wake varying with time gradually decay after the wake forming within a period of time. In this paper, we adopted the sonar image sequence of multiple features fusion method, matching the intensity of the wake acoustic scattering characteristic and geometric characteristic, to detect the surface ship wake.

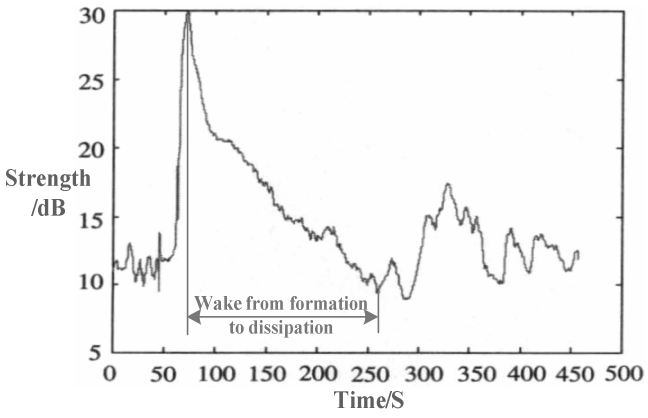

Fig. 2. acoustic scattering strength of ship wake varying with time

III. SONAR IMAGE PROCESSING

Building Image preprocessing is an important part of the ship wake detecting and tracking, which extracts the information of the wake on the basis of the sonar image features. Imaging sonar is very sensitive to the noise, so image preprocessing must be carried out after detecting and tracking. 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[5]. So we acquired the original sonar image data of the ship wake by the lake test. In the lake test, the speedboat crossed through the field of sonar monitoring at high speed. The one of original sonar images is shown in Figure.3. It can be seen clearly the ship and the "V" linear ship wake after the ship with lots of noise.

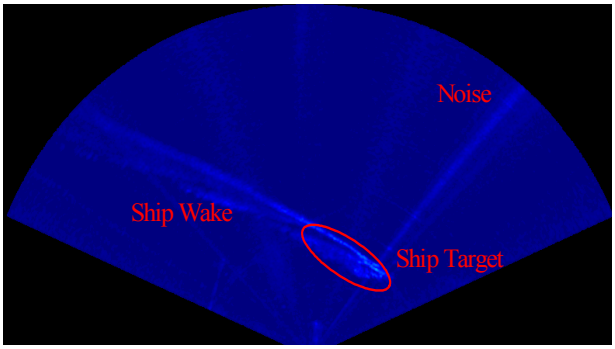

Fig. 3. the original sonar image of the ship and ship wake

When the speedboat appeared in the visual field of sonar, it was easy to track the moving speedboat by the sonar image sequences. But we considered the wake tracking method that only ship wake appeared in the sonar image without speedboat in this paper. So we selected two frames of sonar images, when the speedboat left the sonar field three seconds and fifteen seconds respectively. The original sonar images of the ship wake are shown in Figure.4.

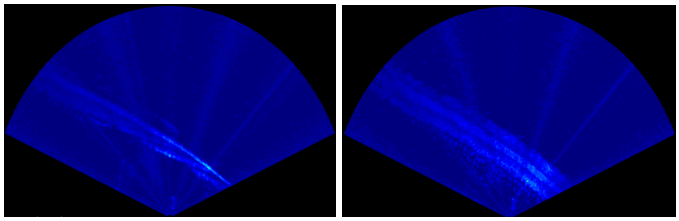

Fig. 4. the original sonar images of the ship wake without speedboat

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 results of image filtering and image enhancement are shown in Figure.5. 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.

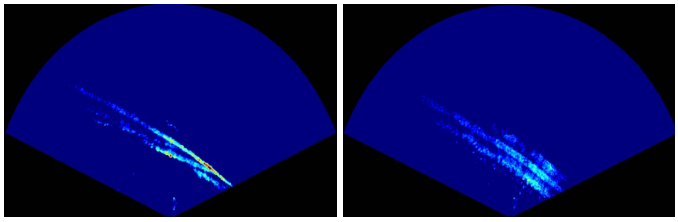

Fig. 5. the result of the image filtering and enhancement algorithm

Then, according to the characteristics of ship wake, using the k-means clustering and morphological algorithm[6], and so on, removed the bright spot, clear image edge burr, isolated points and fill the holes in the image. The results are shown in Figure .6. It can be seen from the result that the noise is removed and the ship wake is separated from the noise. 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.

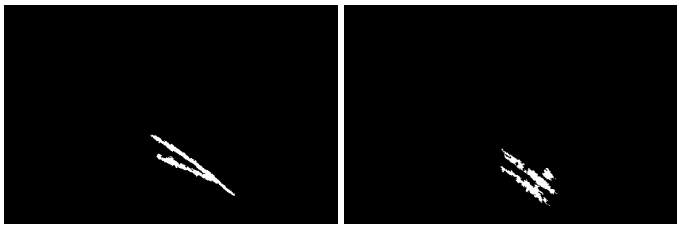

Fig. 6. the result of the k-means clustering and morphological algorithm

IV. SHIP WAKE DETECTING AND TRACKING

In this paper，the ship wake detection method based on recursive modified Hough transform field method[7]. This method can detect the obvious wake using the biggest peak value in Hough transform field firstly. Secondly, the biggest peak value was gotten rid of from the Hough transform field so as to give prominence to the hypo-peak value for the second wake. So recursively modifying the multi-peak structure of Hough transform field is going on till all linear wakes that their peak values and lengths in modified Hough transform field are higher and longer than the threshold value are detected.

The step of recursive modified Hough transform field method is as follows:

1) First of all, we transform the original image to the binary image, and acquire the set of pixels which are equal to parameter space of R_0. Find the maximum point of the i th line, and (ρ, θ) as corresponding parameter space of the first wake straight L_1; And define the pixels set of wake ω_1, acquiring the difference set $\Omega_1 = \Omega_0 - \omega_1$ which is equal to parameter space of R_1.

2) Find the maximum value of R_1, and the point set parameter is equal to the second wake straight L_2; And determine the set of pixels ω_2 by the same method of L_1. Finally, we acquire the difference set $\Omega_2 = \Omega_1 - \omega_2$ which is equal to parameter space of R_2.

3) So we can determine wake straight L_3, L_4, L_5, etc, by the same method.

In the above algorithm, the parameter space could be continually modified by the pixels of the detected wake straight corresponding to the parameter space, so we can eliminate the interference of wake straight has been detected. The result of recursive modified Hough transform field method is shown in Figure.7.

According to the sonar image characteristics of ship wake, the acoustic scattering strength of Narrow V ship wake is the most intensive, so we only detect the two wake straights under the detection conditions of the length, angle and the peak of the largest and most obvious. It can be seen from the figure that the two wake straights are detected by the recursive modified Hough transform field method. And we can also acquire the slope and length of the two wake straights.

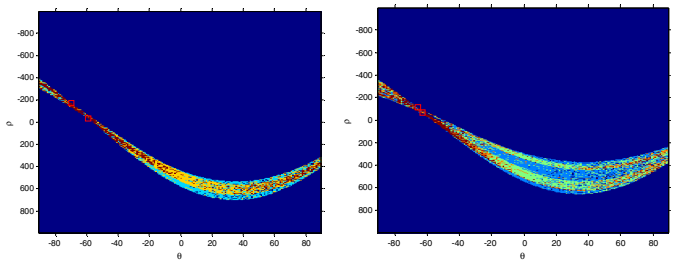

Fig. 7. The result of recursive modified Hough transform field method

Then, we adopted the sonar image sequence of multiple features fusion method, matching the intensity of the wake acoustic scattering characteristic and geometric characteristic, to detect the surface ship wake. Once the surface ships target has been detected, according to the geometric characteristics of the ship wake, we got the heading of the ship at this moment.

But the wake detection and tracking process took very short time, when the image sonar continuously acquired two images. So we can calculate the heading of surface ship by the of sonar image sequence which might be a frame or several frames. According to the previous frames information of detected wake and the correlation of dynamic sonar image sequence, this paper adopted the Kalman filter method to estimate the ship wake of possible location and region. Comparing with image ergodic search, this method reduces the complexity of computation, and also improves the accuracy of the detection and continuity. The results are shown in Figure.8. It can be seen clearly the shape of ship wake, and the results of recursive modified Hough transform field were shown in green lines and the heading of the speedboat was shown in red line.

Fig. 8. The result of the Hough transform and the heading of the speedboat

Finally, we compared the result of the ship wake detection and tracking method with the actual track of the speedboat which can prove that the ship wake detection and tracking method is feasible. The results are shown in Figure.9. The actual track of speedboat was shown in green lines and the heading of the speedboat was shown in red line at the moment. The direction of the two lines was almost identical. So the

sonar image processing method was proved that it was feasible and it could accurately provide the heading of the surface ship.

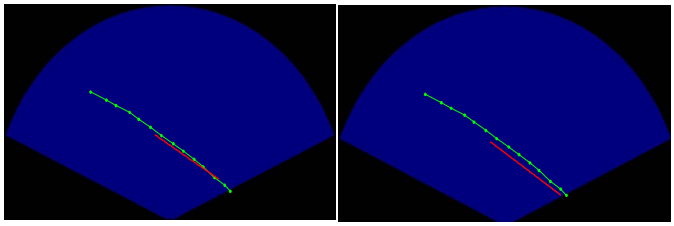

Fig. 9. Compared ship wake tracking method with the track of speedboat

V. CONCLUSION

This paper proposes the real-time wake detection and tracking methods which apply to the high resolution multi-beam image sonar of AUV. This paper adopted the sonar image sequence of multiple features fusion method and Kalman filter method, matching the intensity of the wake acoustic scattering characteristic and geometric characteristic, to detect and track the surface ship wake. The method is proved to be feasible and effective by the lake test data. The research results could be the important foundation for the development of the new wake tracking technique and the effective surface target tracking and attacking for underwater vehicles. They are useful and significant for practical engineering applications.

VI. REFERENCES

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