Statistical Method of Bubble Distribution in Ship Wake Based on Digital Image

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Abstract. A large number of bubbles are formed in the wake of a ship when it is sailing. Statistical analysis of the wake bubbles can infer the important information of the ship such as draft, ship width and speed, which is of great significance in the military field. The experimental device is used to simulate the actual wake bubbles in this paper, and the detection method combining the sobel operator and the regionprop function is used to make effective statistics on the wake distribution. Experiments show that this paper can perform distribution statistics of wake bubbles in different situations and obtain better statistical results.

1. Introduction
When a ship is sailing on the water surface, due to the motion of the hull and propeller, a special area containing a large number of bubbles and vortices will be formed in the water area at the stern of the ship [1], which is the wake of the ship. The wake of a ship can’t be avoided or eliminated. The wake is still visible for a long time after the ship leaves, which provides a feasible way for ship detection and tracking. In addition, the characteristics of the wake can also be used to indirectly derive important information such as the ship’s type, tonnage, and speed. Bubbles are the most basic element in the wake, and the most important parameter that determines the shape of the wake. Therefore, the distribution statistics of bubbles in the wake are the premise and basis for studying the wake of a ship. The analysis and statistics of ship wake bubbles based on image processing can accurately, objectively and quickly reflect the number, size and distribution of bubbles in the image, so it has become a research hotspot in recent years.

References [2] use Euler's number to calculate the number of bubbles per unit area, and use the bwarea function to measure the average bubble radius. Reference [3] Improved on the basis of traditional Canny edge detection, proposed dynamic closed-value segmentation algorithm, adaptive filtering and smoothing technology, achieved the segmentation of wake area and sea background area by filtering. However, there is no statistical analysis of wake bubbles in the above methods, so a statistical method of bubble distribution in ship wake based on digital image is proposed.

2. Statistical Method of Bubble Distribution in Ship Wake Based on Digital Image
This paper focuses on the morphological information and distribution statistics of the bubbles in the wake of a ship. Firstly, based on a single bubble, the information such as the diameter and the centroid of mass of the bubble is extracted. Secondly, the morphological information and distribution of
bubbles under ideal conditions are counted. Finally, the statistical analysis of bubbles in the actual water is realized. Figure 1 shows the flow chart of the method.

![Flow chart of statistical method for bubble distribution in ship wake based on digital image](image)

Fig.1 Flow chart of statistical method for bubble distribution in ship wake based on digital image

2.1. Filtering and noise reduction
The median filter is used in this article as a simple nonlinear filter, which can overcome the shortcomings of edge blur caused by linear filtering. Its working process is:

1. The center of the sliding window coincides with the pixel to be processed.
2. Calculate the gray value of the corresponding pixels in the window, and arrange them from small to large.

2.2. Image binarization
Image binarization is to convert the gray value of the image pixels to 0 or 255, and the whole image has only two colors of black and white. First of all, set a threshold value. If the gray value of a pixel is greater than the threshold value, it will be set to 1, and other points will be 0. This is the process of binarization. It can be expressed by Formula 1, where \( f(x, y) \) represents the image to be processed, \( g(x, y) \) represents the result after binarization, \((x, y)\) represents the coordinates of pixels, and \( T \) represents the threshold value.

\[
g(x, y) = \begin{cases} 1 & f(x, y) \geq T \\ 0 & f(x, y) < T \end{cases}
\] (1)

2.3. Edge detection and extraction
The edge and contour of the image are the most basic features of the image. For the wake bubble image, the bubble shape information can be obtained by bubble edge detection and extraction. The edge is usually located in the position where the pixel value changes greatly, that is, the position where the derivative is larger. The most common classical edge extraction method is edge detection local operator method. Its main idea is to observe the change of gray level around each pixel, and detect the edge by using the change rule of the first or second derivative near the edge, which mainly includes gradient operator, Prewitt operator and Sobel operator [4-5]. Because the edge detected by the Sobel operator is wider and the influence of noise can be further suppressed, the Sobel operator is selected for edge extraction of the image.

2.4. Morphological information extraction and distribution statistics
Hough transform is a method for effectively identifying geometric shapes in image processing [6]. Its basic idea is to transform the spatial domain of the image into a parameter space. The points on the same circle of the original image are mapped to the same point in the parameter space. Therefore, it can be judged whether there is an approximate circle in the original image according to the degree of aggregation of the points in the parameter space. Since the bubble shape is not completely circular, the Hough transform method will be limited, so the regionprops function is used to detect the centroid and equivalent radius of irregularly shaped bubbles.
3. Experiment and analysis

3.1. Experimental setup
Perform the experiment according to the process shown in Figure 1. First select a single bubble for experiment, then experiment on the bubble under ideal conditions, and finally simulate the actual bubble through the experimental device for statistical analysis. The experimental device is shown in Figure 2. The experimental device is mainly composed of a high pressure cylinder, a water tank, and a pressure control device. By adjusting the air pressure in the airway, different types of simulated wake bubbles can be obtained, and then the images are collected by a high-speed camera.

3.2. Statistical experiment and result analysis of bubble distribution
According to the experiment setting and experiment process, first experiment with a single bubble image. The experiment uses a 3*3 median filter to filter and denoise the image, the binarization threshold is [0.5 0.7], the Sobel operator is used for edge detection, and the Hough transform is used for morphological information extraction. The experimental results are shown in Figure 3. As can be seen in Figure 3(e), this method can effectively extract the centroid and radius information of a single bubble. (113,65) is the centroid of the bubble and 13.88 is the radius of the bubble.

![Experimental results of the single bubble](image)

Use the same method to experiment with wake bubbles under ideal conditions. The experimental results are shown in Figure 4 and Figure 5.
Fig. 4 The experimental results of the ideal ship wake bubbles

(a) Histogram of bubble radius distribution (b) Histogram of bubble centroid location distribution

Fig. 5 Distribution statistics of the ideal ship wake bubbles

The image is divided into 12 regions as shown in the figure, and the region numbers are marked, and the position of the bubble centroid is calculated according to the distribution of the region. The results are shown in table 1. Comparing the experimental results, it is not difficult to find that the bubble radius in the image is mostly concentrated between [0.5], and the position of the bubble centroid is mostly concentrated in the area ① and ⑦.

| Area number | ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ | ⑨ | ⑩ | ⑪ | ⑫ |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|
| Number of bubbles | 72 | 31 | 0  | 38 | 13 | 32 | 64 | 16 | 9  | 38 | 28 | 2  |

In this experiment, the Hough transform can accurately identify most of the bubbles and extract the corresponding information, but the bubbles with larger depth of field in the image still can’t be accurately identified. Unlike ideal bubbles, actual bubbles are mostly irregular in water. Due to conditions, the bubble generating device shown in Figure 2 is used to simulate the ship wake bubbles. If the same method as the above experiment is used, it can be obtained as shown in Figure 6.
As can be seen in the figure, for bubbles with an approximate circular shape, the shape information can be completely detected, but for most bubbles with irregular shapes, a circle is automatically fitted according to the bubble contour, so this does not reflect the true information of the bubble. In addition, there are still bubbles whose shape information can’t be detected in the figure. The regionprops function is a powerful function in image processing. It is short for get the properties of region, which is a function used to measure the properties of the image region. Therefore, the regionprops function can be used instead of the Hough transform to obtain the morphological information of the wake bubble. The experimental results are shown in Figure 7.

The red rectangle in the figure represents the smallest bounding rectangle of the bubble in the image, to estimate the length and width of the bubble, the red "*" represents the center of mass of the bubble, and indicates the diameter and center of mass coordinates of the bubble.

4. Conclusion
In the experiment, an ideal wake bubble image is selected as the research object. The outline of this bubble is the standard circle in our cognition. After image preprocessing, the Hough transform is used to successfully extract the bubble shape information. In order to approach the actual wake bubble shape of the ship, the simulated bubble is obtained through the laboratory bubble simulation device, and the regionprops function is used to overcome the shortcomings of the Hough transform and effectively obtain the bubble shape information. The experimental results show that this method can
accurately obtain the shape information and distribution statistics of the ship wake bubbles, which lays a theoretical foundation for further research on the wake.

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