Water-shore-line Detection for Complex Inland River Background

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Abstract. Water-shore-line (WSL) detection in complex inland river background plays an important role for detection of water surface targets and the security of vessels. However, because of the blurred image and water ripple caused by the environmental factors such as rain, snow, fog, wind and sunlight, it is very difficult to detect and recognize the WSL. In order to deal with these problems, the WSL detection method is designed and implemented in the paper. First of all, a gradient detection operator based on distance is proposed to improve the sensitivity of the edge detection to the noise. Secondly, the edge image is processed by the line shape filter operator because of the characteristics of the water ripple. And then the WSL is obtained by straight line fitting using the optimized ransac algorithm. Finally, the results of field experiments show that the method is effective and timeliness in a variety of complex environments.

1. Introduction
This paper is a sub-topic of attitude estimation of unmanned surface vessels (USVs) during the autonomous berthing process in the inland river area. WSL detection from the shoreline images captured by boat-mounted camera is an important part of the research. After acquiring the shoreline, it can not only reduce the detection area, reduce the calculation time, improve the accuracy of target detection in the shoreline area, but also estimate the distance between ship and shoreline by visual algorithm. However, there are many difficulties in the WSL detection under complex background, such as rain, snow, fog and wind in the natural environment, which bring great disturbance. Especially, the water ripple caused by the strong wind is similar to the WSL. And it is easy to lead to misjudgement in actual projects.

In this paper, the iNav-I multifunctional USV is used as the experimental platform, and the shoreline images acquired are used as the research object. The difference between ripple and shoreline is analyzed and studied, and a WSL detection method suitable for complex background is proposed. Algorithm framework is shown as Figure.1. Firstly, the edge image can be obtained by improved Canny algorithm which improve the sensitivity of the edge detection to the noise using a gradient operator based on distance. Secondly, the edge image is processed by the line shape filter operator which can eliminate most of the water ripples. Finally, the WSL is extracted by straight line fitting using the optimized ransac algorithm.
The reminder of this paper is organized as follows. In section II, WSL detection research status is firstly presented and WSL characteristics are analyzed. Then, The WSL detection method is proposed in section III and The experiments and results analysis are shown in section IV.

![WSL detection algorithm framework](image)

Figure.1 WSL detection algorithm framework

2. WSL DETECTION RESEARCH STATUS AND CHARACTERISTICS ANALYSIS

2.1 WSL detection research status

Regarding the WSL detection, the essence is similar to that of sea-sky-line detection. The sea-sky-line is the connection line between the sky area and the water area. The WSL is the connection line between the shore area and the water area. For the sea-sky-line detection algorithm, a large number of scholars have done related research.

Sun et al [1] first calculated the gradient in the vertical direction of the image, and binarized the gradient image, and then extracted the sea-sky-line with linear fitting.

Literature [2] is improved slightly. And they use firstly texture features to reduce sea-sky-line area, then the candidate points are obtained in this area, finally the line parameters are calculated by using the improved linear fitting method.

Ma et al. [3] analyzed the adverse effects of waves, clouds and reflected light in the shoreline image, and proposed that the candidate points should be detected by line segment firstly, and then the shoreline should be fitted by the least squares method. This method has played a certain role in suppressing the noise such as waves.

Gui et al. [4] proposed to get the candidate points of the sea-sky-line in the image search area by using the black-and-white template correlation method, then used the ransac algorithm to remove the outliers, and finally carried out the least square linear fitting of all the inliers.

Wang et al [5] put forward gradient based saliency and regional growth methods. Firstly, the gradient saliency image and its histogram were calculated, and then the supporting region was obtained by region growing method. Finally, the detection of sea-sky-line was completed by considering the contrast, line length and direction characteristics in the region.

Gershikov et al [6] compared five commonly sea-sky-line detection methods, analyzed them and puts forward the improvement measures of these methods. From the experimental comparison, it can be seen that the combination method of canny and Hough has better precision and time-consuming performance.

Wei et al [7] proposed an automatic water line detection method which combines optical shadow processing and energy optimization. In similar inland river areas, it was validated with a practical USV system.

Since the selection of shoreline candidate points and straight line fitting is relatively simple and suitable for engineering applications. Combination scheme of canny and straight line fitting is adopted here, but the Hough transform is time-consuming, so the ransac algorithm is used to extract the straight line.

2.2 WSL CHARACTERISTICS ANALYSIS

According to the actual image captured by the camera in the USV, the results are as follows:

Above the image is the sky background, which is mainly cloud information, its gray level change is relatively flat, the sky is the most reflective, and the brightness is the highest;

Below the image is the water surface background, the gray mean value is significantly smaller than the gray mean value of the sky background, and the water surface texture is affected by wind, current and light, showing obvious unevenness;
In the middle of the image is the shore area, mainly the onshore building information, which has the lowest gray value. The boundary line between the shore area and the sky background is called the skyline, which is the line connecting the points with large gray differences. However, due to the diversity of the contours of the objects on the shore, the curve of the skyline presented in the image is irregular.

The boundary line between the shore area and the water surface is called the WSL. It is also the line connecting the points with large gray gradient. Because of the horizontal characteristics of the water surface and the height of the camera, the WSL appears as a straight line in the image. Usually the shoreline is horizontal or inclined, and the angle is related to the direction of the camera and the motion of the UAV.

The WSL in the image is usually the longest straight line through the whole image, and the water surface ripple is often a short line segment, which is also the original intention of the line shape filter operator.

3. WSL DETECTION METHOD
The proposed WSL detection method consists of three steps. Firstly, the improved Canny algorithm is used for edge detection of images, then line shape filter is used to remove water ripple, and finally the ransac algorithm is used to fit straight line.

3.1 Improved Canny algorithm
In the Canny algorithm, the traditional gradient operator does not solve the problem of the change of the rotation of the gradient amplitude which is called the gradient magnitude does not have rotation invariance. Aiming at this problem, some scholars have proposed adjusting the weights of horizontal and vertical directions so that they have 45 degree rotation invariance [8] [9]. Here, we propose a distance based gradient operator, of which the size is \((2n+1) \times (2n+1)\), and the coefficients are the reciprocal of the distance from the point to the center point. The operator \(S\) is as follow, and \(R_{i,j} \) denote the distance between the image pixel \(I_{i,j}\) in the template and the template center \(I[i,j]\), such as \(R_{i,j} = 1/\sqrt{n} \).

\[
S = \begin{bmatrix}
1/R_{i,j+1} & \ldots & 1/R_{i,j+n} & \ldots & 1/R_{i,j-n} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
1/R_{i+1,j} & \ldots & 1/R_{i+n,j} & \ldots & 1/R_{i-n,j} \\
1/R_{i-j+1} & \ldots & 1/R_{i-j+n} & \ldots & 1/R_{i-j-n}
\end{bmatrix}
\]

(1)

(2)

3.2 Line shape filter
Through the analysis of the edge image, the water ripples are intermittently presented in the image, which have strong inhomogeneity and irregularity. However, the WSL need to detect is a straight line, so we ingeniously propose a line shape filter to reduce the impact of water ripple. The operation rules of the line shape filter are as follows: such as binary edge image \(A\) and line shape filter operator \(B\) whose length is \(n\).

(1) if \(n\) pixels in the image \(A\) corresponding to \(B\) are all 1, then the pixel value of the generated image is 1, otherwise it is 0.

(2) if pixel value 1 is obtained, the length of the generated image pixel value 1 is at least \(n\), until the next 0 appears in the image \(A\), so that the pixel value of the generated image is 0.

For clearer representation, formula (2) is an operation example and symbol \(\ast\) represents the filter operation.
3.3 Straight line fitting
For the filtered binary edge image, the random sample consensus (ransac) algorithm is used for straight line fitting to extract WSL. The process is as follows [10]: (1) Selecting randomly two points from filtered image to determine a straight line. (2) Finding the inliers of the line through a certain threshold. (3) Repeating the above steps and finding the sample with the largest number of inliers. (4) The straight line obtained through this sample calculation is the best estimate.

For straight line fitting, the number of iterations of ransac is as follows: 

$$ k = \frac{\log(1/\varepsilon)}{\log(1 - P)} $$

P represents the correct probability, and W indicates the probability of selecting a inliers from the data set each time.

In order to ensure the effectiveness and reliability of engineering applications, the ransac algorithm is modified in detail [11]. The rules of selection of samples as follows: (1) The selection of the first point is closer to the image center and the higher the priority is. (2) The selection of the second points takes the first point as the origin and moves horizontally at a distance to get the center point, and the closer the center is, the higher the priority is.

4. EXPERIMENTS AND RESULTS ANALYSIS
In order to verify the validity of the WSL detection method proposed in this paper, the different background images was collected from the ship “Huang Helou” in the field of the Yangtze River inland. The test platform is Intel Core i5-3470CPU, 4G memory, Win7 system and Visual C++ editor.

4.1 Edge detection experiments
The experimental results had been shown, the graph (a), (b), (c) is the original image, under the framework of Canny algorithm, graph (d), (e), (f) are obtained by distance gradient operator, and (o), (p), (q) graphs are obtained by the default Gaussian gradient operator of Canny.

As can be seen from Figure.2, the distance gradient operator is superior to Gauss gradient operator when the number of pseudo-boundary is taken as the evaluation criterion.

4.2 WSL detection experiments
The experimental results had been shown, the graph (a), (b), (c) is the original image, under the framework of Canny algorithm, graph (d), (e), (f) are obtained by distance gradient operator, and (o), (p), (q) graphs are obtained by the default Gaussian gradient operator of Canny.

On the basis of the above-mentioned edge detection, the edge image are processed by using line shape filter, and then the ransac algorithm is used for line fitting. In order to verify the validity and practicability of the method, Hough, Radon and direct ransac algorithm are used for experiments respectively. And line shape filtering is not carried out in the direct ransac algorithm, which directly fit the line.

The experimental results are shown in Figure. 3, graph (a), (b), (c) are obtained by Hough algorithm and the longest straight line is selected to fit the result; graph (d), (e), (f) are obtained by Radon algorithm; graph (g), (h), (i) are obtained directly by ransac algorithm.
4.3 Experimental results comparison

In this paper, three sets of data are collected for each complex background, and each group has 100 images (A, B, and C in Table 1 indicate daytime, rain and night background, respectively), and the recognition rate and time are calculated: The absolute error (sum on the left and right borders of the image with the real WSL and detected WSL) is less than 10 pixels are defined as identifiable and the real WSL is manually labeled. The time-consuming is the average of 100 images. The default gradient operator is adopted in the Canny method.

| A  | recognition rate | time-consuming(ms) | Hough | Radon | ransac | Canny | proposed |
|----|------------------|---------------------|-------|-------|--------|-------|----------|
|    | recognition rate | time-consuming(ms) | 77%   | 80%   | 91%    | 95%   | 95%      |
| B  | recognition rate | time-consuming(ms) | 50%   | 46%   | 77%    | 78%   | 90%      |
|    | recognition rate | time-consuming(ms) | 13%   | 22%   | 45%    | 70%   | 81%      |

It can be seen from the table: (1) the recognition rate of Hough and Radon algorithm is lower than other algorithms; (2) the direct ransac algorithm takes too much time due to more detection points; (3) the Canny method adopts linear filtering. Regardless of the recognition rate or time-consuming, there is a certain improvement; (4) Compared with the Canny algorithm, the proposed method removes the Gaussian smoothing step, and the time is slightly reduced, which is consistent with the theory.

4.4 Field experiments

The purpose of this paper is to detection the WSL from boat-mounted camera images in a complex background. In order to achieve this goal, and to verify the validity and practicability of the proposed algorithm, the field experiments were carried out. The iNav-I multi-functional USV (Figure 4) was...
used to obtain the shoreline image in the East Lake and the Yangtze River respectively. In the experiment, the camera sensor was placed on the USV, and its direction was consistent with the USV, which is controlled by a shore-based remote control.

The experimental results are shown in Figure 5. The left side is the image collected in the East Lake, the middle side is the image collected near Wuhan Yangtze River Bridge, and the right side is the image collected near The Second Yangtze River Bridge of Wuhan. From the image results, the proposed algorithm had completed the detection of the WSL well.

![Figure 4. The iNav-I multifunctional USV](image1.png)

![Figure 5. Field experiment result images](image2.png)

5. CONCLUSION
In this paper, based on the actual demand of the WSL detection of the boat-mounted camera, the WSL is detected by a complete set of methods. A distance-based gradient operator is proposed for the defect of the gradient amplitude in Canny algorithm. The surface ripple characteristics are studied and the line shape filter method is skillfully used. The experimental results show that the proposed algorithm can achieve ideal results in WSL detection.

Acknowledgments
This work is supported by the school-level research project through Grant No. 2016XJZD008

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