A novel method of extracting geometric features of ships based on GrabCut algorithm

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Abstract. Using remote sensing images to accurately identify ships is of great significance in both military reconnaissance and civil surveillance. This paper presents a method of extracting geometric features of ships based on GrabCut image segmentation. Firstly, by establishing gaussian mixture model of image area, the problem of segmentation of suspected target area is transformed into graph minimum cut, then the suspected target is segmented by iteration energy minimization, and the moment method is used to extract the minimum enclosing rectangle of ship target, so as to obtain the geometric features of ship target. Experimental data analysis shows that compared with the traditional algorithms, the proposed method can quickly extract the geometric features of ships in different directions in remote sensing images, and has strong robustness, which can meet the requirements of target detection engineering.

1. Introduction
Remote sensing image is of great significance in maritime search and rescue, fishing vessel surveillance, and military reconnaissance[1,2]. Target image feature extraction is the key technology of target recognition, which directly affects the accuracy of target recognition detection. With the continuous improvement of the resolution of remote sensing satellites with wide coverage range, geometric features of target objects are often taken as an important initial basis to determine the type of ships due to their advantages such as simple and intuitive[3,4], as one of the important research issues in remote sensing image analysis.

Most of the existing ship detection algorithms adopt the strategy of "from rough to fine": firstly, the suspected target area is extracted, and then the possible target area is quickly extracted from the image by using some features with small computation and obvious characterization. Then the target discrimination is confirmed, that is, combined with more accurate features, the suspected target area is confirmed, a false alarm is removed, and the real ship target is extracted. In 2013, Yang[5] removed the target-free area through the analysis of the sea surface, to obtain the candidate target area. In 2016, Li[3] first obtained the target contour through level set segmentation and then used the region elimination method to filter out clutter. Secondly, the long axis and rotation angle of the target slice is obtained by fitting the target with the minimum enclosing rectangle. The least-square ellipse is used to fit the short axis of the ship target. Thus, the feature information of the ships including length, width and angle is obtained. In 2016, Wang[6] extracted the binary image of the target based on the graph similarity segmentation method, combined with the affine invariant moment and geometric parameter
characteristics of the ship target, and carried out rough identification of the target. In 2018, Xiong[7] selected the ship area based on the maximum entropy algorithm for high-resolution SAR images based on visual salient images, and obtained the external rectangle that best represented the geometric outline of the ship through azimuth estimation and rotation. In 2018, Wang[8] completed the extraction of the initial target candidate region based on the maximum symmetric surround significance detection and proposed a new edge-to-direction gradient histogram feature to characterize the ship characteristics to describe the ship target.

There are still two main difficulties in optical remote sensing image ship detection, which are rapid extraction of suspected targets and description and identification of targets. To solve the above problems, an optical remote sensing ship geometric feature extraction method based on GrabCut is proposed. The main research work of this paper includes two parts. In the first part, the gaussian mixture model of the remote sensing image background and the target area is established, and the suspected target area is segmented into the minimum cut of the graph. On this basis, the iterative energy minimization algorithm is used to segment the target area. In the second part, the moment method is used to obtain the minimum enclosing rectangle fitted to the target center and principal axis, and the geometric features of the ship are extracted.

2. Basic theory of GraphCut image segmentation

GrabCut is an upgraded version of traditional image segmentation GraphCut, or an interactive image segmentation technology using GraphCut and maximum flow technology[9].

GraphCut is a popular energy optimization algorithm, which is applied in front background segmentation, stereo vision, image matting, etc. This method associates the image segmentation problem with the minimum cut problem of the graph, as shown in Figure1 below.

A graph consists of vertices and edges, both of which have weights. There are two types of vertices, two types of edges and two types of weights in Figure 1. The normal vertex consists of each pixel of the image, and then there is an edge between each of the two neighborhood pixels, whose weight is determined by the "boundary energy term". There are two terminal vertex target S and background T, and each normal vertex and S are connected. The edge weight is determined by the "regional energy term" Rp(1), and the edge weight of each normal vertex and T is determined by the "regional energy term" Rp(0). At this point, the weights of all edges are determined, and the graph is determined accordingly. Therefore, the minimum cut is the set of the minimum weight edges, the disconnection of which can exactly cause the target and background to be separated, and the minimum cut corresponds to the minimization of energy.
3. GrabCut image segmentation and feature extraction

3.1 Gaussian mixture model for regional segmentation
GrabCut adopts RGB color space, gathers pixels into K classes through K-means clustering, and uses the full covariance GMM (Gaussian mixture model) of K Gaussian components to model the target and background. The energy of the graph is expressed as formula (1), which is composed of regional term and boundary term.

\[ E(\alpha, k, \theta, z) = U(\alpha, k, \theta, z) + V(\alpha, z), \]
\[ U(\alpha, k, \theta, z) = \sum_n D(\alpha_n, k_n, \theta_n, z_n), \]

In the energy formula, \( U \) is the region term, which represents the penalty for a pixel being classified as a target or background, and is represented as the negative log of the probability that a pixel belongs to the target or background. Where the calculation formula in the Gaussian mixture probability model is as follows:

\[ D(x) = \sum_{i=1}^{K} \pi_i g_i(x; \mu_i, \Sigma_i), \]

Among them \( \sum_{i=1}^{K} \pi_i = 1 \) and \( 0 \leq \pi_i \leq 1 \).

\[ g(x; \mu, \Sigma) = \frac{1}{\sqrt{(2\pi)^d|\Sigma|}} \exp \left[ -\frac{1}{2} (x - \mu)^T \Sigma^{-1} (x - \mu) \right] \]

\[ V(\alpha, z) = \gamma \sum_{(m,n) \in C} [\alpha_m \neq \alpha_n] \exp(-\beta \|z_m - z_n\|^2) \]

\( V \) is the boundary term in the energy formula, reflecting the difference between neighborhood pixels \( m \) and \( n \). In RGB space, Euclidean distance is used to describe the similarity of two pixels.

3.2 Iterative energy minimization algorithm
GrabCut algorithm is one-time energy minimization, while GrabCut algorithm makes GMM parameters better in each iteration process, thus making image segmentation better[10]. The main flow of the algorithm is as follows:

3.2.1. Initialize
First, an initial Trimap \( T \) is obtained by selecting the target in the box, that is, the pixels outside the box are all the background pixels \( T_B \), and the pixels inside the box are all the "possible target" pixels.

Then for each pixel \( n \) in \( T_B \), initialize the label of pixel \( \alpha_n = 0 \), that is the background pixel. For each pixel \( n \) in \( T_U \), the label \( \alpha_n = 1 \) of pixel \( N \) is initialized as the pixel that may be the target.

By k-means algorithm respectively belong to the target and background pixel clustering into k classes, each gaussian model has some pixels in the GMM sample set, as its mean and covariance parameters can be obtained by RGB values estimated, and the weights of the gaussian component can through belongs to the gaussian component of the pixel number and the ratio of the total number of pixels to determine.

3.2.2. Iteration minimization
The Gaussian component in GMM is assigned to each pixel:

\[ k_n := \arg\min_k p_n(\alpha_n, k_n, \theta, z_n), \]

For the given image data, learn to optimize GMM parameters:

\[ \theta := \arg\min_{\theta} \sum_{n \in T_U} D(\alpha_n, k_n, \theta_n, z_n), \]

Segmentation estimation:

\[ \hat{\alpha} := \arg\min_{\alpha_n} \sum_{n \in T_U} E(\alpha_n, k_n, \theta, z_n). \]
Repeat the above process to convergence and conduct post-processing such as boundary smoothing.

3.3 Target aspect ratio feature extraction based on a minimum enclosing rectangle

Firstly, the remote sensing image after image segmentation is binarized, and the connected region which may be the target object is obtained through region growth. For an image \( f(x, y) \), calculate the center and principal axis according to the moment method, and the main theoretical formula is as follows:

The \( p + q \) moment of \( f(x, y) \) is:

\[
m_{pq} = \sum_x \sum_y x^p y^q f(x, y)
\] (9)

The corresponding barycenter coordinates are:

\[
\begin{align*}
\bar{x} &= \frac{m_{10}}{m_{00}}, \\
\bar{y} &= \frac{m_{01}}{m_{00}}
\end{align*}
\] (10)

The central moment of order \( p + q \) of \( f(x, y) \) is:

\[
M_{pq} = \sum_x \sum_y (x - \bar{x})^p (y - \bar{y})^q f(x, y)
\] (11)

Normalized central moment:

\[
\mu_{pq} = \frac{M_{pq}}{M_{00}}, r = \frac{p + q}{2} + 1
\] (12)

Find the spindle direction:

\[
tan2\theta' = \frac{\mu_{11}}{\mu_{20} - \mu_{02}} = \frac{M_{11}}{M_{20} - M_{02}}
\] (13)

\[
\theta' = \frac{atan2(M_{11}, M_{20} - M_{02})}{2}
\] (14)

After obtaining the center position and principal axis direction, all enclosing rectangles of the ship target in the angle interval \([0^\circ, 90^\circ]\) are calculated to find the minimum enclosing rectangle according to the decision criteria. The maximum signal-to-noise ratio (target background pixel area ratio) criterion has strong applicability and can obtain a higher estimation accuracy[11]. This paper completes the minimum enclosing rectangle fitting based on it. After that, the length and width pixels of the ship targets are extracted and the aspect ratio characteristics are calculated.

4. Test Results and Discussions

In this study, the VHR-10 dataset was used for experimental verification. The images were culled from Google earth and Vaihingen data sets. We took a total of 44 images numbered from 266 to 310 containing multiple ship class targets.

In this paper, a proper amount of data is expanded through rotation and scaling, and finally, 300 remote sensing images containing ship targets are obtained. On this basis, verification tests shall be carried out. Some of the experimental results are shown in Figure 2.
In the actual experiment, when the multi-target and the single target are fitted with the minimum external rectangle, some minimal point-like suspected targets (red dots in the figure) will appear, and the aspect ratio of length and width is usually 1:0. By setting the length-width ratio threshold, false targets can be automatically removed. To compare the accuracy of geometric feature extraction, on the one hand, the minimum external rectangle is manually marked as the truth value of the length-width ratio. On the other hand, take the method of reference [3] as an example to carry out multi-group experiments of traditional methods to extract geometric features. After removing the false alarm targets, some experimental results were counted as shown in Table 1.

| Target | Length-our | Length-[3] | Length-rea | Width-our | Width-[3] | Width-rea | Ratio-our | Ratio-[3] | Ratio-rea |
|--------|------------|------------|------------|-----------|-----------|-----------|-----------|-----------|-----------|
| d(1)   | 59.0023    | 63.2409    | 59         | 20.0102   | 19.9978   | 22        | 2.9486    | 3.1624    | 2.6818    |
| d(2)   | 63.0818    | 65.8462    | 64         | 10.8939   | 9.3764    | 13        | 5.7906    | 7.0225    | 4.9231    |
| d(3)   | 64.0039    | 55.1063    | 63         | 19.0014   | 19.5832   | 19        | 3.684     | 2.8140    | 3.3158    |
| d(4)   | 69.0288    | 73.1638    | 69         | 15.7736   | 13.6601   | 15        | 4.3762    | 5.3560    | 4.6000    |
| d(5)   | 77.4654    | 82.5331    | 68         | 15.7300   | 15.6235   | 13        | 4.9247    | 5.2826    | 5.2308    |
| d(6)   | 66.6840    | 73.6461    | 67         | 15.1454   | 13.5648   | 15        | 4.4029    | 5.4290    | 4.4667    |
| d(7)   | 66.9985    | 71.5829    | 70         | 13.5871   | 13.5029   | 14        | 4.9310    | 5.3013    | 5.0000    |
| d(8)   | 61.1045    | 63.7263    | 63         | 10.9779   | 9.8093    | 13        | 5.5560    | 6.4965    | 4.8462    |
| d(9)   | 71.0630    | 74.0109    | 70         | 12.8504   | 11.4786   | 13        | 5.5300    | 6.4477    | 5.3846    |

The geometric feature data obtained by different methods are drawn into line graphs, as shown in Figure 3, where -rea series is the actual geometric feature data for reference, -our series is the geometric feature data extracted by this method, and -3 series is the geometric feature data extracted by the reference [3] method. The Figure 3 shows that the length of the characteristics, the method of reference [3] the results with the actual data differences (the average absolute error is 5.0715 pixels), the method results with the actual data is relatively close to (the average absolute error is 1.9656 pixels), only the target d(5) are greatly influenced by target segmentation result is not ideal error absolute value (9.4654), lead to quite a different length value and actual value. In terms of width characteristics, the methods in this paper and reference [3] differ little from the actual data. Therefore, the characteristic results of the length-width
ratio of the method in this paper are better than the method in reference [3], which is closer to the actual data.

![Figure 3. Comparison of geometric feature extraction results by different methods](image)

(a) Contrast of length and width  
(b) Contrast of the ratio of length to width

A large number of accurate experiments show that the detection accuracy of the proposed method is up to 96.8%, which is superior to the traditional method on the whole. According to the comparison between the geometric parameters of each target and the actual ship target feature library, the type of ship target can be judged directly.

5. Conclusion

Based on the GrabCut algorithm interactive image segmentation technology, this paper makes full use of the texture color information and boundary contrast information in the image to accurately extract effective ship targets and suppress the jamming effect of remote sensing images. In the feature extraction process, by using the moment method of image processing, the minimum external rectangle is fitted by its direction angle and center, the long axis and the short axis of the ship target are further obtained, and the length-width ratio of the ship is calculated as the effective discrimination basis.

Based on the results of several experiments, it can be seen that the method proposed in this paper has a great advantage over the traditional method in the reference [3] in the result accuracy, and has good extraction effect and performance. Based on the length and width feature extraction results in this paper, combined with practical experience and ship target related data, the type of ship can be determined quickly and intuitively.

Acknowledgments

This work was financially supported by National Defense Advance Research Project (No.315025102), Major Science and Technology Special Project of Sichuan Province (N0.20-18GZDZX0017).

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