Research on Image Segmentation Algorithm Based on Component Tree

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Abstract. The key part of sea target recognition is to search for the possible ship targets in the image. For the problem that the standard segmentation of threshold algorithm is not effective in the complex sea condition, in this paper, a component tree image segmentation method based on minimum error threshold and ship area is proposed for ship target recognition. Firstly, area criterion is used to filter the image, then minimum error threshold method is used to construct the component tree and determine the filtering mechanism, finally, gray level criterion is used to filter the component tree. The simulation results show that proposed method is effective.

Keywords: Image segmentation; Minimum Error Threshold; Gray level criterion; Component tree.

1. Introduction

The goal of image segmentation is to divide an image into meaningful regions or parts, where each region has similar characteristics. The general development of image segmentation is as follows: the early classical segmentation techniques based on grayscale and gradient (such as threshold method, edge and region technique), the active contour model (such as parametric active contour model and geometric active contour model) in the 1980s, recent segmentation methods that combine prior knowledge (such as active shape model and active surface model). From the development of image segmentation, we can see that prior information is more used, more and more intelligentized and powerful segmentation ability.

Since the 1960s, many image segmentation algorithms have been proposed by domestic and foreign scholars to solve the problem of image processing. In view of the difference of the characteristic and information of image, image segmentation based on edge detection has been proposed in [2][3]; the method of artificial intelligence image segmentation use in [4]. Based on the analysis of the characteristics and performance of image segmentation methods, the image segmentation algorithm is roughly divided into clustering-based segmentation methods [5][6], the advantage of this kind of algorithm is that it does not need training set, and the disadvantage is that it needs to provide an initial cluster center. Based on region information image segmentation method [7], this kind of algorithm clusters the feature patterns of pixels based on the spatial continuity between the pixels of the image, however, it is easy to produce false segmentation region when segmenting the image with multi-pose and complex background, and the efficiency of the algorithm is low. The image segmentation method based on graph theory [8][9], this kind of method transforms the image segmentation problem into the graph partition problem, but the low efficiency and the slow speed is this kind of method most main restriction factor.
In this paper, a component tree image segmentation method based on minimum error threshold and ship area for ship target recognition is studied. The remainder of this letter is organized as follows. In Section 1, the background and significance of this paper are introduced, the current status of image segmentation algorithms and techniques are introduced, and the main work and content of this paper are listed. In Section 2, the minimum error threshold segmentation method is given. In Section 3, the segmentation algorithm is derived from the component tree combining the minimum error threshold and the area of the ship is described in detail. In Section 4, the false alarm caused by too many low gray values, the component tree is filtered by gray-level criterion. Finally, conclusions are summarized in Section 5.

2. Minimum Error Threshold Segmentation Method

The minimum error segmentation algorithm proposed by Kiteller and Llilngworth assumes that the gray distribution of the target and background follows the normal distribution.

Suppose there is a threshold value \( t \), \( 0 < t < L - 1 \), where \( L \) is the gray level series of the image, and the gray level histogram of the segmented image is \( h(z) \), and then

\[
P_i(t) = \sum_{i=0}^{L} h(z) P_i(t) = \sum_{i=1}^{L} h(z) \\
m_i(t) = \sum_{i=0}^{L} h(z) \times z P_i(t) \frac{m_z(t)}{P_i(t)} = \frac{\sum_{i=1}^{L} h(z) \times z}{P_i(t)} \\
s_i^2(t) = \frac{\sum_{i=0}^{L} [z - m_i(t)]^2 \times h(z)}{P_i(t)}, s_z^2(t) = \frac{\sum_{i=1}^{L} [z - m_z(t)]^2 \times h(z)}{P_i(t)}
\]

The conditional probability of the grayscale layer \( e(z,t) \) can be expressed as

\[
e(z,t) = h(z | i,t) P_i(t) / h(z) \quad i = \begin{cases} 1 & z \leq t \\ 2 & z > t \end{cases}
\]

Which, \( h(z) \) unrelated to \( i \) and \( t \) can be ignored. And then take the logarithms on both sides, and multiply -2 and then

\[
\xi(t) = \left[ \frac{(z - \mu_i)^2}{2\sigma_i^2} \right] + 2 \log \sigma_i - \log P_i(t) \quad i = \begin{cases} 1 & z \leq t \\ 2 & z > t \end{cases}
\]

It is a measurement that reflects the performance of the correct classification. On this basis, a criterion function can be defined \( J(t) \) to describe the average correct classification performance over the whole image

\[
J(t) = \sum_{z} h(z) \xi(z,t)
\]

For a given threshold \( t \), the criterion function indirectly shows that the overlap between the target and the background class distribution gauss model. Substitute in (3), then

\[
J(t) = \sum_{z=0}^{L} h(z) \left\{ \left[ \frac{(z - \mu_i)^2}{\sigma_i^2} \right] + \ln \sigma_i - 2 \ln P_i(t) \right\} + \sum_{i=1}^{L} h(z) \left\{ \left[ \frac{(z - \mu_z)^2}{\sigma_z^2} \right] + \ln \sigma_z^2(t) - 2 \ln P_z(t) \right\}
\]

Substituting formula (1) into formula (5)

\[
J(t) = 1 + 2 \left[ P_i(t) \ln \sigma_i(t) + P_z(t) \ln \sigma_z(t) \right] - 2 \left[ P_i(t) \ln P_i(t) + P_z(t) \ln P_z(t) \right]
\]
Make the gray value $t_0$ of the criterion function (6) take the minimum value, that is, the threshold value of the minimum error is

$$t_0 = \text{Arg} \left[ \min_{0 \leq t \leq L-1} J(t) \right] \quad (7)$$

3. Component Tree-based Segmentation Method Combining Minimum Error Threshold and Ship Area

3.1. Point-weighted Graph and Component Tree

3.1.1. Basic concepts of graphics. Let $V$ be a finite point set, $P(V)$ is a set of all subsets of $V$, and $E$ is a binary relation of $V$, that is, a subset of Descartes product $V \times V$, where $(x,y) \notin E$ and if $(y,x) \in E$ than $(x,y) \in E$. $(V,E)$ is called a figure, and the sector of $E$ are called edges. $\Gamma$ means a mapping from $V$ to $P(V)$, for all $x \in V$, $\Gamma(x) = \{y = V(x,y) \in E\}$. For every point $x$, the set $\Gamma(x)$ is defined the neighbor of $x$. If $y \in \Gamma(x)$, then $x$ is defined an adjacent point of $x$, where $x$ and $y$ are contiguous.

Make $X \subseteq V, x_0, x_n \in X$. The Path $\pi = (x_0, x_1, ..., x_n)$ from $x_0$ to $x_n$ in $X$ is a sequence of points where $x_0, x_1, ..., x_n$ is the point in $X$ and $x_{i+1} \in \Gamma(x_i), i = 0..n-1$. If there is a path from $x$ to $y$ in $X$, then $x$ and $y$ are connected for $X$. If $y$ and $x$ are connected, then $X$ is said to be connected. $Y \subseteq V$ is a connected component contained in $X$. If $Y \subseteq X$, than $Y$ is connected, and $Y$ satisfies the following properties: As long as there is connected $Z$ makes $Y \subseteq Z \subseteq X$, so $Y = Z$.

3.1.2. The basic concept of point-weighted graph. Record the set of all mappings from $V$ to $D$ as $F(V,D)$, where $k \in D$ can be an ordered arbitrary finite set. Such as a rational number set or a finite subset of an integer set. If there is a mapping $F \in F(V,D)$, then called $(V,E,F)$ point weighted graph, for point $p \in V$, $F(p)$ called point $P$ weight or level.

Let $F \in F(V,D)$, define $F_k = \{x \in V \mid F(x) \geq k\}$, where $k \in D$. $F_k$ is a cross section of $F$. $F_k$ connected component of the Cross section of $F$ is called a $k$ level component of $F$. $k$ level component is said to be a local maximum of $F$, if it does not contain an $k+1$ level component. Define $k_{\min} = \min \{F(x) \mid x \in V\}, k_{\max} = \max \{F(x) \mid x \in V\}$, which on behalf of the minimum level and the maximum level of mapping $F$.

Based on the above definition, select $V$ as a subset of $Z^2$, where $Z$ is the set of integers. Point $x \in V$ is called as two coordinates, and select $E$ as the four connected neighbor relationship, than $E = \{(x,y) \in V \times V; |x_1 - y_1| + |x_2 - y_2| = 1\}$.

3.1.3. Component tree. As shown in table 1, you can see that because of the inclusion relationship, the connected components of different cross sections can form a tree structure. For any component in $F$, remember $h(c) = \max(k)$, the $c$ is the $k$-level component of $F$. According to the above definition, also has $h(c) = \min(F(x) \mid x \in c)$. The $C(F)$ is defined as a collection of all $[k,c]$, the $k, c$ elements in $C(F)$ are called nodes, where $c$ is a part of $F$, and $k = h(c)$. Defines the height of $[k,c]$ as $k$, if $[k_1,c_1] \in C(F)F \in F(V,D)[k_2,c_2]$ and $[k_2,c_2] \in C(F)$, then $k_1 = k_2$.

Let $F \in F(V,D), [k_1,c_1],[k_2,c_2]$ be the different elements in $C(F)$. If $c_2 \subset c_1$, and $C(F)$ does not exist, makes $c_2 \subset c_2 \subset c_1$, then $[k_1,c_1]$ is called the sire node of $[k_2,c_2]$, and $[k_2,c_2]$ is called the child node of $[k_1,c_1]$. Through the “sire node” relationship, $C(F)$ forms a tree, called $F$ component tree. An element in $C(F)$ that has no sub-children is called a leaf node, and a node that has no sire is defined an original node.
Table 1. Weighted graph and its cross-sectional area at different levels.

|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

Figure 1 shows the component tree of image components.
3.2. Image Segmentation Based on Component tree Combining Minimum Error Threshold and Ship Area

3.2.1. Concept of component tree filtering. One of the main applications of component tree is image filtering, which involves removing the unconcerned parts and preserving the interested parts. The filtering of component tree is a process of decision. The nodes are divided into active and inactive nodes. The nodes that are not saved after filtering are defined as inactive nodes, and the remaining nodes are defined as active nodes. The decision criterion $T$ of filtering is based on one attribute or combination of attributes of a component. This article only uses the component’s area attribute in the preliminary segmentation. The process of filtering can be defined by the following formula. By calculating the properties of the components corresponding to each regular node and filtering out the components corresponding to the non-conforming property values, the image filtering can be easily realized.

Definition 1: If $X \subseteq \mathbb{R}^2$ is a binary set, $T$ is some filter criteria, define the filter $\Phi_T$ as follows:

$$\Phi_T(X) = \bigcup \{ C \subseteq X \}$$  \hspace{1cm} (8)

Definition 2: If $f$ is a gray image, $\chi_s(f)$ is the gray level $s \in \Pi$ the threshold set, where $\Pi$ is a series of integer gray levels, $\Phi_T$ is a binary connected filter, so the definition of gray level connected filter $\Phi_T$ is

$$\Phi_T(f)(x,y) = \max \left\{ t : (x,y) \in \Phi_T(f), \chi_s(f) = t \right\}$$  \hspace{1cm} (9)

In the process of image filtering, area criterion is used, if $[k,c] \in C(f)$, then $\text{area}([k,c]) = \text{card}(c)$, among which $C(f)$ is the component tree of the image $f$, $c$ is the $f$ component, $[k,c]$ is the $f$ and $k$ horizontal component, $\text{card}(c)$ represents the number of pixels contained in the component. The component whose area attribute is within a certain range is selected as the filtered result. The final filtered image is reconstructed by a partial stack of connected components corresponding to the reserved nodes. In ship target recognition, the purpose of filtering is to distinguish the pixels belonging to and not belonging to ship target.

3.2.2. Component tree filter based on minimum error threshold and Ship area. The core of ship target recognition is to search for possible ship targets in images. Several classical segmentation algorithms are not ideal, such as adaptive threshold determination is very difficult in complex sea conditions, the standard threshold algorithm segmentation is not good. In this paper, we use an image segmentation algorithm evolved from the mathematical morphology method. The region of interest is retained after image data is filtered, and the rest of the image is filtered.
In the filtering algorithm used in this paper, the image is regarded as a three-dimensional landform. The first step is to build an image of the component tree, the component tree can represent a gray-scale image, which contains the information of each component of the image and the image of the next layer of the relationship between the components. The nodes of the component tree represent the connected components of the original image after threshold segmentation of all possible gray values. The leaf nodes of the component tree correspond to the local maximum of the image. Connections between nodes describe how connected components fuse together. The structure of the tree is determined by the absolute gray level of the connected component. Finally, the root node corresponds to the lowest gray value of the image.

Once the component tree is built, the next step is to determine the filtering mechanism for the component tree. The area of the ship target in the image, that is, the number of pixels of the ship target has a certain range. Therefore, area can be chosen as the filtering criterion. The resolution of the image used in this paper is 1 m and 0.61 m, and the complexity of the image is indicated by the difference of the information content of different kinds of images, for images with flat or monotonous background, such as those with calm sea background or sea clutter background, the information content is lower, for images with more clouds, such as images with ships or images with large ships, it’s got a lot of information. As mentioned in the previous chapter on ocean characteristics, this paper adopts different area criterion for images with different amount of information. For those images with more than 0.08 bits of information, the reserved area is between [20,500], components with a reserved area of [20,100] for image classes with information less than 0.08 bits.

3.2.3. Component tree filtering based on gray-level criterion. The component tree based image segmentation only depends on the ship area, and there are too many false alarms with low gray values. Therefore, the component tree is filtered by the gray level criterion. The determination of the gray level criterion is determined by the minimum error threshold mentioned above, because we know from the experience of image segmentation using the minimum error threshold method for several types of images in this paper, the minimum error threshold segmentation has certain segmentation effect on several kinds of experimental data, that is, at least some pixels of the ship target can be segmented, the connectivity between the segmented pixels does not ensure that the ship is correctly identified in subsequent ship identification. In this paper, the minimum error threshold is used to determine the gray-level criterion, and the gray-level criterion is, there are at least 3 points in the reserved component whose gray value is greater than minimum error threshold, which is the result of considering the influence of image noise and using minimum error threshold to segment experimental data.

4. Simulation Experiment
According to the difference of the information entropy of the image, the range of the area set is determined when the image is segmented. If the information entropy of the image is large and the information of the image is rich, there may be large ships, so the image segmentation area set a wider range. When the entropy of the image is small, the information of the image is not abundant, which means that there is no large ship, so the area of the image is set narrow.

According to the calculation and analysis of the information entropy of QuickBird and Orbview panchromatic images, when the information entropy is greater than 0.08 bit, the area range of the segmentation is set to [20, 500] (in the sense of Pixel). When the information entropy of the image is less than 0.08 bit, the area of the image is set to [20,100]. And the minimum error threshold method is used to segment the optical remote sensing image containing the ship target, results as shown in figure 2 and figure 3 below, the original image in figure 2 is an Orbview panchromatic image with severe sea clutter, and the original image in figure 3 is a QuickBird panchromatic image with a flat ocean background, figure 4 shows an Orbview panchromatic image with a cloud background, the images are 256×256.
Figure 2. Cloudless OrbView panchromatic remote sensing image processing effect.
Figure 3. Cloudless QuickBird panchromatic remote sensing image processing effect.

The experimental results show that the proposed segmentation method based on component tree threshold is more ideal than the minimum error segmentation method when applied to two kinds of cloudless panchromatic remote sensing images, the validity of the algorithm is verified.

Figure 4. Orbview panchromatic image with cloud background.

Figure 4 shows the segmentation of Orbview Panchromatic Image with cloud background. As can be seen from (b) and (c), the results obtained by using the segmentation algorithm presented in this paper are better than those by using minimum error threshold, it can be seen that the algorithm can segment the ship target successfully in the complex background of the image, thus laying a foundation for the improvement of the ship recognition rate.
5. Conclusion

In order to solve the problem that the traditional threshold algorithm is not effective in the complex sea condition, this paper proposes a component tree image segmentation method which combines the minimum error threshold with the area of the ship. Firstly, area criterion is used to filter the image. Then minimum error threshold method is used to construct the component tree and determine the filtering mechanism. Finally, gray level criterion is used to filter the component tree. The experimental results shows that the proposed method is superior to the minimum error threshold method in both cloud-free and cloud-free conditions. The following research will continue in-depth analysis in the quantitative evaluation of segmentation effect.

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