Research on Image Segmentation Method Based on Consistency Theorem and Merging Criterion

Jia-min Lu¹, Hao-fei Li¹, Di Yuan¹,*, Ya-wen Miao¹ and Yi-fan Lei¹

¹College of Computer and Information, Hohai University, Nanjing, Jiangsu 211100, China

*Correspondence: 15651751235@163.com

Abstract. This paper takes Hongze lake as an example to explore a novel image segmentation method. We use the regional consistency theorem and the merging criteria to merge discrete pixels of similar features into smaller regions. Thereby, the lake area can be represented by a number of pixels, and the area's change trend can be measured by simply counting the pixel numbers before and after. By using this algorithm, it is possible to skip the cumbersome steps of calculating the area and obtain the area change trends rapidly, as it avoids a large number of duplicate calculations and reduces the situation of missing extreme pixel points. In addition, it saves the required time on manual processing and increases the processing efficiency greatly. Finally, the validity of the proposed algorithm is verified by comparing the lake area data with the yearbook.

1. Introduction

Due to changes in the natural environment and human factors such like urban developments, the lake shapes are changing on both time and space, all the time. Therefore, it is an important measure to update regional map and terrain data to automatically extract water edge and study its change trend of area. Through the area prediction, people can anticipate the flood disasters to avoid unnecessary losses and can better protect the water resources. Therefore, extracting the outline of the water and measuring its area have great influence on human development.

Automatically extracting the features from remote sensing images[1] has always been one of the important research issues in the field of the photogrammetry and remote sensing processing[2][3]. This paper takes Hongze lake as an example to study on the basis of the methods which current commonly used water body recognition and extraction. We use the regional consistency theorem and the merge criterion to combine the pixel points of similar feature, and then extract the lake contour. Our innovation is that we use the number of pixels occupied by the surface of the image to simulate the actual area of the lake. This method is faster and more accurate than previous method.

The rest of this article is organized as following. In section 2, image enhancement is made by histogram equalization. In the 3rd section, we use the consistency theorem to segment the image, and divide the part with big difference. In the 4th section, the consolidation criterion is used to establish regional consolidation and we also made the error analysis. The 5th section is the demonstration of our experimental results. We calculated the pixel points of Hongze lake from 2000 to 2003 and compared them with the actual area. Finally, in section 6, we briefly summarize our work and explain the potential problems.
2. Image enhancement
The pixels of some original images occupy many grayscale levels and are evenly distributed. They have high contrast and variable gray tone, resulting in low local contrast. In order to improve the visual effect of the image, the image should be enhanced. Enhancement processing refers to adding some information or transforming data to the original image by certain means. In this way, it can selectively highlight the features of interest in the image or suppress some unnecessary features in the image, so that the image can match the corresponding features of the vision. Commonly used image enhancement methods include Laplace sharpening and histogram equalization.

2.1. Laplacian Sharpening
Laplace sharpening[4] is an image domain enhancement algorithm based on the difference calculation of pixel grayscale in image neighborhood. This method means that when the pixel grayscale of the center of a neighborhood is lower than that of other surrounding values, the gray scale of the point will continue to be reduced. However, if the center pixel has a high grayscale, its grayscale will be further enhanced. A central value can be obtained by convolution of four directions of the domain center pixel. The sharpening process is realized by adding an attenuation factor to the processing result. Which will improve the image contrast and make the image clearer.

However, this method is too sensitive, and small noise points will appear. There is lossy compression because the object we are working with is a JPEG image transferred out of ENVI. After laplacizing, there will be grid noise interference, which will block the area of Hongze lake itself and greatly affect lake identification.

2.2. Histogram Equalization Method
After comparison, histogram equalization[5] is adopted in this paper. We use the cumulative distribution function to expand the gray level with more pixels in the image and compress the gray level with less pixels in the image. The uniform distribution of pixel values helps to complete the statistics of each grayscale number. The gray density and histogram distribution were calculated after the statistics were completed[6]. Finally, the cumulative distribution is rounded and the gray value is mapped to expand the dynamic range of pixel values. Figure 1 is the result of histogram equalization. This will improve the contrast and grayscale changes and make the image clearer.

Among them, the mapping formula is:

\[
S_k = \sum_{j=0}^{\frac{n}{n}} k \quad k = 0, 1, 2, ..., G - 1
\]

(1)

In the formula, n represents the sum of pixels, while G represents the total number of possible grayscale levels. In processing with the cumulative distribution function, we need to ensure that the

Figure 1. Before and after image enhancement of remote sensing images
pixels are mapped. In this way, the original size relationship does not change, but only increases the ratio. The image will be clearer and easier to recognize later.

3. Use the consistency theorems for image segmentation

In the color image, if a certain area belongs to a nature of the area to be divided, such as land or water, then these areas will be consistent. This means that the expectations of these regions in probability statistics are consistent or similar[7]. That is, within the three channels of RGB, the pixels in the homogeneous region have the same expected value. But for non-homogeneous adjacent areas, at least one channel has a different expected value. If it is different, the consolidation criteria will be used to test it. If conformance is merged, otherwise the two regions will be split[8].

The characteristic values of RGB channels exist at each pixel point in the color image. In this paper, the different value of each pixel point in each channel is used to calculate, and then the homogeneous region is combined with the merge criterion. Because pixels in the homogeneous region within any RGB channel have the same expected value. But for non-homogeneous adjacent areas, there is at least one channel in which expectations are different. This requires a sampling function, \( f \), to sample the RGB of pixels in the original image, and obtain the independent random variable \( Q \in \{1, 2, \ldots, 255\} \), representing the independent random distribution of the original image. At this point, for the sampling of a pixel, we only need to pay attention to the difference between the value of the pixel itself within each channel and its four neighbors. In order to avoid a large number of repeated calculations, only a large difference is needed for calculation and comparison. If the large difference meets the merge criterion, the pixel values of other channels will also meet the criteria, and the color difference will be even smaller.

Its sampling formula \( f \) is as follows:

\[
    f(p, p') = \max_{a=\{R,G,B\}} \left( |P_a(x) - P_a(x')| \right)
\]

(2)

\( x \) is the pixel of the original image and \( x' \) is the pixel \( x \) neighborhood pixel (horizontal right and vertical down only), \( P_a(x) \in \{1,2,3,\ldots,255\} \) representing the pixel value of pixel \( x \) in any channel within the RGB three channels. After the calculation of the function \( f \), the pair of pixels \( (R, R') \) whose channel has the greatest difference in the neighborhood of RGB can be obtained, which are horizontally left and vertically downward, respectively. Figure 2 is the result of interest zone division.

Using this method, discrete pixels can be merged into small areas, and then the merge criterion can be used to calculate whether the pixel average of the area and the pixel values of other pixels can be merged. Random sampling results in discrete points. It is difficult to generate small areas. Only a large number of repeated calculations can find the boundary pixels to merge. Therefore, this method can avoid a large number of repeated calculations compared to random sampling, while avoiding the missing of extreme pixel points.

The most primitive operation is to consider each neighborhood pair as a small area, merge these areas according to the merging criteria, and then generate a larger area, further merge the larger area until it is close to land. There are significant differences in the eigenvalues of the three channels of RGB, so they cannot be merged.

4. Use consolidation criteria for zone consolidation

4.1. Homogeneous area consolidation

The formula is as follows:
In the formula, $g=255$, $\delta=6$ the two values given here are empirical values, $(R, R')$ represents the neighborhood, represents the mean in the $R$ region, and $|R|$ represents the number of pixels in the $R$ region, $S$ is called a scale, Control the size of $b(R)$ to control the size of the merge zone. When the two regions are merged, the average value is used as a criterion for the judgment. Then, when the region and the pixel and the pixel and the pixel are merged, the merger criteria of the mean value of the pixels of the region and the pixels value of the pixel can be determined. In figure 3 we mark the edge of the segmented region.

\[
p(R, R') = \begin{cases} 
  \text{true} & \text{if } |\overline{R} - \overline{R'}| < \sqrt{b^2(R) + b^2(R')} \\
  \text{false} & \text{otherwise}
\end{cases}
\]

(3)

\[
b(R) = g \sqrt{\frac{1}{2s|R|} \left( \ln \frac{|R|}{\delta} \right)}
\]

(4)

In the formula, $g=255$, $\delta=6$ the two values given here are empirical values, $(R, R')$ represents the neighborhood, represents the mean in the $R$ region, and $|R|$ represents the number of pixels in the $R$ region, $S$ is called a scale, Control the size of $b(R)$ to control the size of the merge zone. When the two regions are merged, the average value is used as a criterion for the judgment. Then, when the region and the pixel and the pixel and the pixel are merged, the merger criteria of the mean value of the pixels of the region and the pixels value of the pixel can be determined. In figure 3 we mark the edge of the segmented region.

![Figure 2. Segmentation based on statistical consistency](image)

![Figure 3. Mark the segmentation area edge](image)

The pixels in the homogenous region should have similar mathematical expectation. The expectation also approximates the average of the pixels in the region. $b(R)$ gives the confidence of the region, which in turn creates a confidence interval around the pixel values in the region. The pixel value under any channel is within the confidence interval of the mean value of the pixel in the area, then it meets the merging criterion and can be merged, otherwise it needs to be segmented.

Since the size of $b(R)$ is inversely proportional to the segmentation scale, it is inversely proportional to the number of pixels in the region. Therefore, the value of $b(R)$ also influences the criterion of the merging criterion, and thus affects the segmentation effect. In the process of segmenting the image by using the algorithm, the optimum segmentation scale suitable for the image searching.

4.2. Analysis of Regional Consolidation Errors

The error of this algorithm is mainly caused by over-segmentation. This error mainly comes from the judgment of the merge criterion and other signal errors in the image segmentation process. According to the merge criterion, the segmentation scale will relax the condition of neighborhood merge. When the mean difference of the neighborhood is large, it can also be combined into a region to form a large continuous region. On the contrary, when the segmentation scale is small, the merging conditions of the adjacent areas will be tightened. You can only merge if the mean of the adjacent region is similar. In the process of image segmentation, noise will also be affected. For these broken areas, the error can be reduced by setting the image segmentation threshold. Figure 4 shows the main water body around Hongze lake. The figure 5 is our final processing result, which is the contour of Hongze lake.
5. Experimental results

First, we use different eigenvalues to segment the image based on the consistency criterion, and mark the different regions with color. On the basis of different colors, the edges of the segmented regions are further marked. After the parameters were set, the main waters in the image were extracted, and finally the Hongze lake area was identified and its pixels were calculated. The method is used to complete the above steps, which saves a lot of time compared with the previous method of ENVI. It can quickly obtain data results and lake outlines.

Shown in Figure 6 and Figure 7. Figure 6 is the Actual area variation trend, while Figure 7 is the variation trend of pixel points measured by this method. As we can see, the two curves are basically similar, which means our algorithm is accurate.

6. Conclusion

This paper proposes a novel image segmentation algorithm. Based on the histogram equalization and region consistency, it uses JPEG format images to directly detect and calculate pixels having the same feature, like water, forests, wetlands, etc.

In the view of the fact that there are many fragmented waters around the Hongze lake, we process the images and use the pixels having similar features to simulate the real water areas in Hongze lake. This method's feasibility is validated by comparing the pixels' areas with the real water data in the yearbook.

In the future, we will further improve this method's accuracy by optimizing the parameters, and expand its usage to wetlands or deserts. However, there is no doubt that this method provides great efficiency on measuring the lake trend. Using Matlab, a more intuitive interface and result image can be generated.
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