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Segmentation of High-resolution Remote Sensing Image Based on Marker-based Watershed Algorithm

Ying Sun [1.2]
1. Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, Beijing 100086, P.R. China
2. Graduate University of Chinese Academy of Sciences ,Beijing 100049, P.R. China
yingsun@ceode.ac.cn

Guo-jin He [1]
1. Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, Beijing 100086, P.R. China
gjhe@ceode.ac.cn

Abstract

Because of the particularity of high resolution remote sensing image such as Quickbird, the segmentation methods used in common video or image are unsuitable for high-resolution remote sensing image. In order to overcome the shortcomings of over-segmentation existing in watershed algorithm, we bring in a new method which is an improvement to the Marker-based watershed algorithm. Firstly, the median filtering is carried out to the high-resolution remote sensing image to eliminate random noise in the image, and then gradients are obtained with mathematical morphology; finally, the Maker-based watershed algorithm is applied to the gradients to segment the image. Segmentation experiments carried out for the Quickbird images with different kinds of land cover types, show that the method is efficient and it can avoid over-segmentation when the image texture is homogeneous, but it also has some limitations when the image texture is relatively complex.

1. Introduction

In recent years, more and more high spatial resolution remote sensing images are available for earth observation. However, how to mine information from high resolution remote sensing images efficiently has always been one of the key issues for its application, in which image segmentation is a fundamental work. The initial region of the segmentation is the expression of the shapes of the image objects, therefore, segmentation quality has a direct influence on the following-up image analysis and understanding. Because of the complexity of remote sensing image and the uncertainty of the image segmentation of its own, getting high accuracy in remote sensing image segmentation is difficult and very important as well.

As far as image segmentation is concerned, several kinds of image segmentation approaches have been developed, such as edge-based image segmentation method, region-based image segmentation method and texture-based image segmentation method. The watershed algorithm is a region-based image segmentation approach, in which mathematical morphology algorithm is used. It can obtain the one-pixel width, consecutive and accurate boundary, thus it is widely applied to medical images, natural images and video images segmentation. However, since it is quite sensitive to the image noises [1,2], it may cause over-segmentation problems. Therefore, some new approaches were proposed to improve the watershed algorithm [3,4,5], of which the Marker-based watershed segmentation algorithm is approved to be capable of segmenting face and other scene images effectively[5]. In this paper, Marker-based watershed segmentation algorithm was used for high-resolution remote sensing image segmentation, and median filtering, as a method of preprocessing, was applied to the high-resolution remote sensing image to eliminate random noise in the image before image segmentation. Furthermore, discussion has been carried out on the basis of testing the Marker-based watershed algorithm using Quickbird images with different kinds of land cover types.

The rest of the paper is organized as follows: the method of Marker-based watershed image segmentation is presented in Section 2; Segmentation of high-resolution remote sensing image based on Marker-based watershed algorithm appears in Section 3; Section 4 is the experimental result and analysis; and the final section is the summary and expectations.

2. The method of Marker-based watershed image segmentation

Understanding the watershed algorithm requires that we think of the image as a geographical surface [6], where the grey values are interpreted as the elevation of the ground, and the water effuses from the bottom of the basin. Firstly, the water rushes into the lower basin, then rushes into the higher basin, when two basins' water converge, a dam is established to separate them and submerge the entire geography surface, dividing the whole surface into many regions. Actually it is one kind

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of region growth algorithm, the difference is that the watershed algorithm grows from the partial minimums which are detected from the image. Because of the influence of the dark noise and the dark texture, there are massive pseudo-local minimums, which may produce the pseudo-water basin in the image correspondingly. Therefore, each pseudo-local minimum will be taken with those true local minimums as an independent region to segment the image through watershed algorithm, and ultimately this leads to serious over-segmentation problems.

Marker-based watershed algorithm is an improvement [5] to the traditional watershed algorithm. It firstly extracts the regional minima locations which are relevant to the objects from the morphological gradient image and makes them constitute a binary marker image; then using minima imposition [7] to extract the partial minima of the original gradient image as the marker, reducing the segmentation areas produced by all the original partial minima in the gradient image; Finally the watershed algorithm divides the modified gradient image. This method produces good results in the face and other scenes experiments[5]. Is it also efficient for satellite images? We apply this method to segment Quickbird image, which is a kind of high-resolution remote sensing image. The segmentation result is shown in Figure 1.

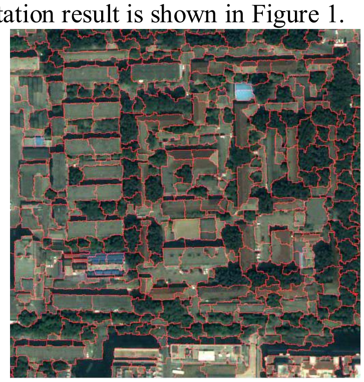


Figure 1.The segmentation result based on Marker-based watershed algorithm

It can be seen from Figure 1 that, there are many broken areas and the edge is inaccurate. The reason is that the high-resolution remote sensing image is far different from the general natural image and video image. Land covers in the remote sensing image are very complex, with clear details, and the slight differences are remarkably reflected. In order to eliminate random noise or smooth "the details" in the image, a preprocessing was carried out to the high-resolution remote sensing image before marker-based watershed algorithm was used.

3. Segmenting high-resolution remote sensing image using Marker-Based Watershed Algorithm

3.1. Median filtering to high-resolution remote sensing image

There are many methods which can be used to filter the image in the preprocess stage, such as Mean Filter、Median filter、Wiener filter and so on. Mean filter reduces the sharp changes of the image gray by replacing the pixel value with the neighborhood average value. However, it also has the negative effect of blurring the edge because the image edge is also constituted by the sharp changes of the grey level. The median filter is one kind of nonlinear filters that can effectively eliminate noises. This method removes those isolated pixels based on two criteria: 1, those isolated pixels are brighter or darker than their neighborhood; 2, the region of those isolated pixels are smaller than the half of the whole filter region, enabling pixels with different gray scales look closer to its neighborhood pixel .On the basis of eliminating random noises, this kind of filter effectively preserves the edges of the image, simple and fast. Therefore, in the paper the median filter is chosen to preprocess the high resolution remote sensing image.

3.2. The gradient information extraction by morphological method

Gradient image can better show the changing trend of the image, and a large number of experiments have proved that the watershed algorithm has great relations to gradient image, but has little relations to the image itself [5,8]. Thus gradient image is used to segment image through watershed algorithm. The differential operator is very sensitive to the noise, while edge extraction based on morphology is not so sensitive to the noise and the extracted edge is smooth relatively. Hence, we adopted morphological gradient operator to obtain gradient image.

The mathematical morphological gradient [8] image $I(x, y)$ is defined as follows:

$$\nabla(I)(x, y) = (\mathrm{I} \oplus \mathrm{M})(x,y) - (\mathrm{I}\Theta\mathrm{M})(x,y)$$

where I is the image and M is the structural element, $\mathrm{I} \oplus \mathrm{M}$ expresses that it carries the inflation to the input image, $\mathrm{I}\Theta\mathrm{M}$ expresses the corrosion to the input image.

In the high-resolution remote sensing image segmentation, color images are usually selected. In this case, the gradient image of color component is calculated in the RGB color space. If $\nabla(I)_c$ is the morphological gradient image containing the color information [10], in order to make better use of the three-band gradient information, the gradient image of the color image is calculated by averaging the values of the three-band gradients[9], shown as formula ,

$$\nabla(I)_c = ave\{\nabla(I_1), \nabla(I_2), \nabla(I_3)\}$$

where ave is denotes the averaging operation, I is a color image, $I_i (i = 1, 2, 3)$ respectively represents the three color components in the RGB color space. Results of the gradient image have a better display showing the difference between the basic contents of the image and noises, by enhancing the high-frequency of the image and weakening the region where the gray scale is relatively smoother, color images are also converted into grayscale one.

3.3. Low-pass filtering to the Gradient image

According to illuminance-reflectance model [5,8], we know that the low frequency corresponds to the main contents of the image, while the high frequency corresponds to the edge, texture and noises of the image. Therefore low-pass filter is given to gradient image to obtain low frequency of the image. The Butterworth low-pass filter, the Gaussian low-pass filter, the Wavelet low-pass filter are the commonly used low-pass filters. Note that, the Butterworth low-pass filter has effective low-pass filter function, and is capable of avoiding obvious ringing phenomenon. Thus we use the Butterworth low-pass filter to extract low frequency information of the gradient image, and to obtain the image $\nabla \mathrm{I}_c^{\mathrm{WPF}}$.

3.4. Extraction of the marker

In order to solve the over segmentation problems found in traditional watershed algorithm, we select the marker-based method to obtain the corresponding homogeneous areas that represent different land cover types. In this paper, the automatic marker algorithm - H-minima[5,7],which is simple and fast, is adopted. It is a morphological threshold operator, marking the majority irrelevant small areas as 0. The result of the gradient image by the extended minima transform whose height threshold is h is as follows

$$\nabla \mathrm{I}_c^{\mathrm{mark}} = HMIN(\nabla \mathrm{I}_c^{\mathrm{WPF}} \mid h)$$

Where $HMIN(.)$ is the morphological H-minima transform, it eliminates the partial minimum that the water basin is lower than the assumed height threshold h. The height threshold h has a direct influence on the numbers of segmentation results. The larger h is, the less the numbers of the areas are.

3.5. Segmentation of the image

After obtaining the marker images, image segmentation was conducted by the method introduced in paper [5,7]. The minima imposition technique modifies the gradient image so that regional minima occurs only in marked locations, other pixel values are "pushed up" as necessary to remove all other regional minima. $\nabla \mathrm{I}_c^{\mathrm{ws}}$ is the modified gradient image, having

$$\nabla \mathrm{I}_c^{\mathrm{ws}} = IMMIN(\nabla \mathrm{I}_c \mid \nabla \mathrm{I}_c^{\mathrm{mark}})$$

where, IMMIN (.) is morphological minimum calibration operation.

The watershed segmentation is conducted on the image $\nabla \mathrm{I}_c^{\mathrm{ws}}$, then

$$\mathrm{I}^{\mathrm{ws}} = WTS(\nabla \mathrm{I}_c^{\mathrm{ws}})$$

where, I^{ws} is the segmentation image, and WTS (.) is the watershed algorithm segmentation operator.

4. Experimental results and discussion

In order to verify the effect of this method, experiments were carried out with a Quickbird color image that has different land covers. The color image is the fusion result of the panchromatic image with the multi-spectral images. The experiment includes the effect of the median filter and its window size to the result, different morphological operators to the gradient image and different watershed algorithms to the segmentation result.

4.1. Effect of the median filter and its window size

Comparing Figure 2(a) and Figure 2(c) we can make the conclusion that: by the median filter, more accurate boundary of the object is obtained, and over-segmentation that caused by image noise is avoided. Simultaneously, size of the window also has influence on the result: a bigger filter window resulting to less number of segmentation areas. However, the boundary is not accurate enough because some useful information is filtered. As seen in Figure 2 (d), the boundary of the building shadow is not accurate and a red area in the result. On the contrary, the smaller the filter window, the more area of segmentation results that caused by the slight difference in homogeneous area of the image, and the boundary is also inaccurate too, In Figure 2(b), the forest on the right side of the image is divided into many regions. Based on a large number of experiments to the high-resolution remote sensing images, median filter with a 5*5 window size was proved to give the best result.

4.2. Effect of different morphological operator to the gradient image

As the gradient image is obtained through mathematical morphology, the size of the structural element has impact on the results. Comparing Figure 3(a) with figure 3 (b), we can find that some boundary in Figure 3(a) is inaccurate just like the arrow pointing, so the structural element of 5*5 was selected to get the gradient image.

4.3. Segmentation with improved watershed algorithm

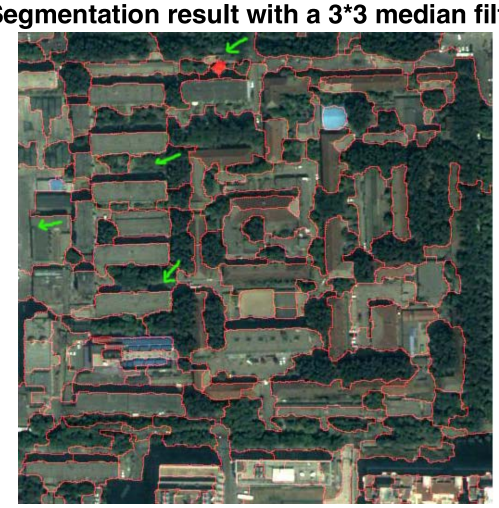
From Figure 4(a), we know that: using original watershed algorithm on the image preprocessed by median filter will cause a very serious over-segmentation problem, Furthermore, there is a great relationship between height threshold and segmentation results, the smaller the threshold, the more areas, On the contrary, the bigger the threshold, the fewer the segmentation areas. Experiments show that a satisfying segmentation result is expected when the height threshold is set to be 12 in minima imposition stage, median filter window size is 5*5 and morphological structural element is 5*5.

In practical applications, the high-resolution remote sensing images are normally from different sources, and contain varieties of land cover types in a image. In this paper five areas of Quickbird images with different land cover types were selected to conduct the experiment. Overall the results are acceptable, but some problems occur in some areas, particularly in the texture images, where the segmentation boundary of the object is inaccurate. For example, in Figure 5(e) the forest with similar texture was segmented into many broken areas.

(a) Segmentation result without median filter

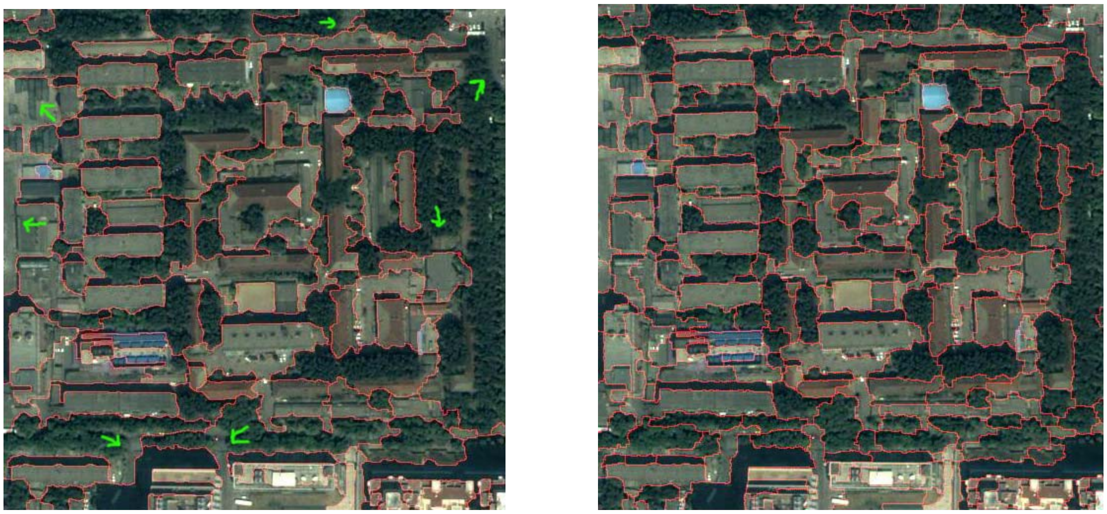
(b) Segmentation result with a 3*3 median filter

(c) Segmentation result with a 5*5 median filter



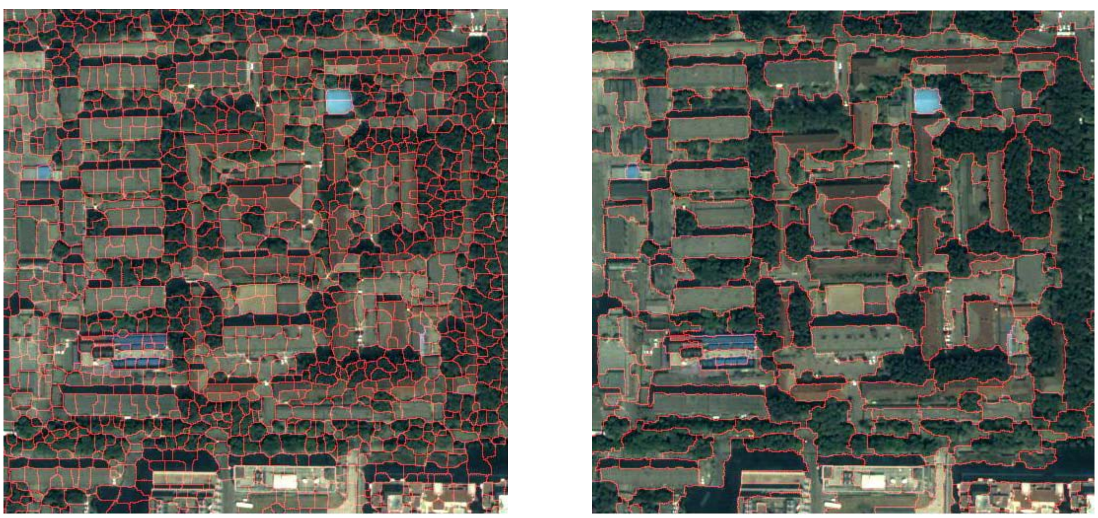
(d) Segmentation result with a 7*7 median filter

Figure 2.The segmentation results with median filter and different size of window



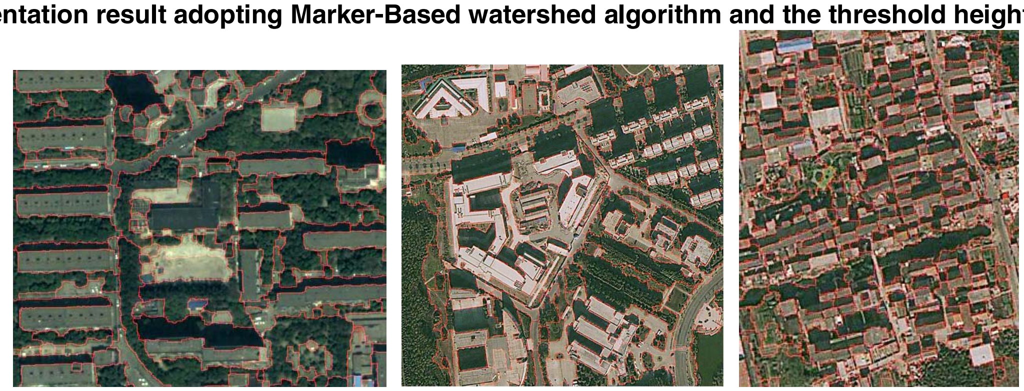
(a) (b)

Figure 3. **The segmentation results with different morphological operators to the gradient image, (a) is the result using a square structure element of width 3, (b) is the result using a square structure element of width 5.**

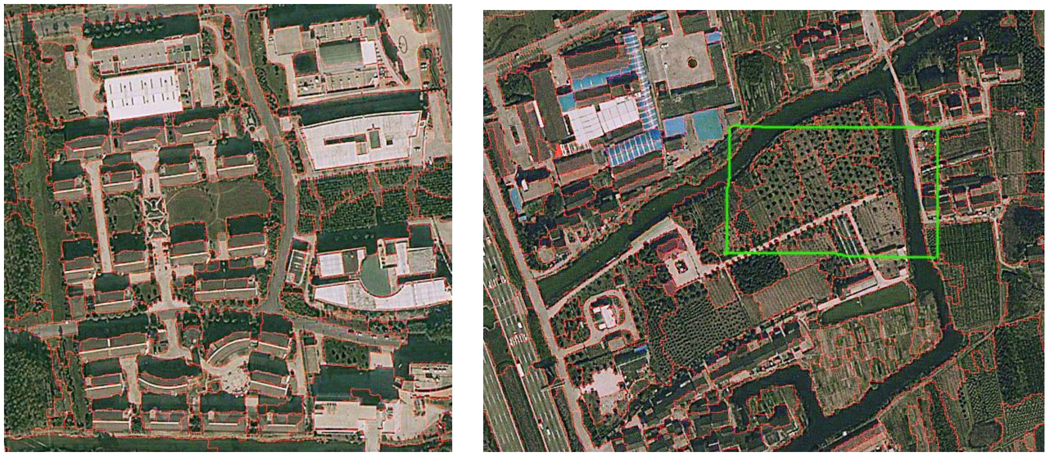


(a) (b)

Figure 4. **(a) is the segmentation result not adopting Marker-Based watershed algorithm, (b) is the segmentation result adopting Marker-Based watershed algorithm and the threshold height is 12**



(a) (b) (c)



(d) (e)

Figure 5.**the Quickbird images segmented by marker-based watershed algorithm**

5. Conclusion and expectations

The experiment proves that the marker-based watershed segmentation algorithm works well for segmenting the high-resolution remote sensing images, although some problems occur in some texture-detailed images. Experiment also shows that, when we preprocess the remote sensing images, extract the gradient information and get the marked minimums, selection of the structural elements and threshold have great effect on the results. In this paper, these values are empirical, which are totally got from experiments. An intelligent self-adaptive approach for choosing these values should be taken into account in the future.

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