Cloud Automatic Detection in High-resolution Satellite Images Based on Morphological Features

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Abstract

Cloud cover is one of the main factors affecting the quality of remote sensing images, and cloud detection is the first problem to be solved in remote sensing data production. Therefore, cloud judgment becomes one of the primary tasks and key technologies of remote sensing image processing. The main detection objects include thin cloud, thick cloud and cloud shadow. The main interference factors include snow, gobi, desert, reflective buildings and other highlights. Firstly, the high reflectance characteristics of clouds are used to analyze the distribution of near-infrared and red bands in multispectral remote sensing images to realize preliminary cloud detection. And then using the detected suspected cloud region, different morphological features to distinguish between the cloud and other highlight features, realized the high score higher cloud detection accuracy of satellite images.

Keywords: Morphological Features, Cloud Automatic Detection, Satellite Images, Fractal Geometry

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1 Introduction

The cloud regions on remote sensing images not only cover the ground surface information, but also affect the inversion of atmospheric parameters, and determine the quality of remote sensing image to some extent. This not only increases the cost of resources and time of image transmission and processing, but also reduces the use value of remote sensing images. Therefore, cloud judgment becomes one of the primary tasks and key technologies of remote sensing image processing. The existing algorithms mainly use the spectrum, frequency and texture of cloud, combined with the threshold method, support vector machine method, clustering method and so on to do detection. The spectral binding threshold method mainly uses the strong reflection characteristics of cloud in the visible band, which is sensitive to threshold value. The detected threshold of the same satellite data will change greatly due to time, weather and other factors, thus increases the limitations of such methods. The frequency combined with threshold method mainly uses the low frequency characteristics of the cloud. Through wavelet analysis, Fourier transform and other methods, low-frequency data for cloud detection can be obtained. However, because of the low frequency information interference on the ground, multi-layer wavelet transform is usually adopted, which greatly reduces the cloud detection efficiency. Texture feature method uses the difference between cloud and ground texture features, dividing the image into block sub-graph, combining with the second moment, fractal dimension [17], grayscale symbiosis matrix and multiple bilateral filtering to calculate the texture features. This method needs to obtain reliable cloud feature interval in advance to ensure the accuracy of classification, thus has a low efficiency. Support vector machine and clustering method require a large number of training samples and have a strict requirement of the selection of classification characteristics. The need to reselect samples for different data leads to low efficiency.

This paper, by using high reflectance characteristics of cloud, firstly analyzes the distribution of near-infrared and RGB bands in high-resolution remote sensing images to realize preliminary cloud detection. And then, using the fuzzy boundary characteristics and geometric fractal dimension difference. of the suspected cloud regions detected, the cloud is separated from the image speckle noise and other highlighted objects. In this way, the high accuracy of cloud detection in high-resolution satellite images is achieved.

2 Algorithm principle

In this paper, the algorithm of automatic detection of high satellite image cloud based on morphological features can be divided into 5 steps: initial cloud judgment, morphological filtering, speckle noise removal and non-cloud target culling.

2.1 The principle of preliminary cloud detection

In this paper, the threshold method is used to detect the cloud-like region preliminarily. Its idea is to analyze the pixels of different channels (combination) of the brightness temperature, light temperature difference, reflectivity and set threshold value comparison, to determine whether the image is cloud pollution. The basic principle of cloud algorithm is as follows:

The mean and variance distributions of pixels in NIR (near infrared) band is used in the algorithm to determine whether it belongs to cloud region.

$$\mathrm{P}_{r1} = \frac{P_G}{P_{NIR}} \tag{1}$$

It is the attribute label of pixel P, P_G is the green band value of point P, P_{NIR} is the near infrared band value of point P. When the (2) formula is satisfied, it is considered that the mean value and variance of the band are valid.

$$\mathrm{P}_{r2} = \frac{P_R - P_{NIR}}{P_R + P_{NIR}} \tag{2}$$

It is a second attribute label of the pixel P, and the PR is the red band value of the point P. When each parameter satisfies the (4) formula, it is considered that the pixel is a cloud-judged result at near-infrared band.

$$P_{r1} > 1.05 \cup P_{r1} < 2.5 \cup |1 - P_{r1}| > 0.02 \cup P_{NIR} > T \cup P_{r2} < 0.2 \tag{3}$$

The above formula (1) ~ (3) uses the near-infrared band mean and the variance setting threshold to carry on the cloud judgment, namely is the preliminary cloud judgment result.

2.2 Morphological feature Extraction

Mathematical morphology is a mathematical method of analyzing geometrical shape and structure, which is based on set algebra and quantitatively describes the geometry structure with set theory. Mathematical morphology consists of a group of morphological algebraic operators, the most basic of which are: corrosion, expansion, opening and closing. These operators and their combinations are used to analyze and process the image shape and structure.

The expansion operator is $\oplus$, A is used to inflate by B can be written as $A \oplus B$, B is the structural element, where A and B are first considered as all pixel sets with a value of 1. It is defined as:

$$A \oplus B = \{(\hat{B})_Z \mid \cap A \neq \varphi\} \tag{4}$$

Corrosion is an operation of "shrinking" or "refining" objects in binary images. The corrosion operator is $\ominus$, A is corroded by B can be written as $A \ominus B$, defined as:

$$A \ominus B = \{z | (\hat{B})_z \cap A \neq \varphi\} \tag{5}$$

Use B to open the operation of A, recorded as $A \circ B$, this operation is the A by B corrosion and then use B to expand the corrosion results:

$$A \circ B = (A-B) \oplus B \tag{6}$$

The mathematical formula for closed operations is:

$$A \bullet B = \{x | x \in (\hat{B})_Z \Rightarrow (\hat{B})_Z \cap A \neq \varphi\} \tag{7}$$

The upper formula shows that the result of A being closed by B includes all points satisfying the following conditions, that is, when the point can be covered by the structural elements of the mapping and displacement, the intersection of A and B mapped and displaced structure elements is not 0.

Both operations and closed operations can remove specific image details that are smaller than structural elements, and guarantees that global geometric distortion is not generated. The results of morphological filtering were used to filter the patches below the area threshold to achieve speckle noise removal.

2.3 Texture Feature Analysis

The results of preliminary cloud judgment can be extracted from thick clouds and thin clouds, but there are some high brightness artificial buildings and other noises. These noises can be effectively removed by using the weak texture characteristics of the clouds. Generally speaking, the gray distribution of the cloud on the image is uniform and the texture is coarse. On the contrary, the texture complexity and the degree of gray-scale jump are larger. In order to eliminate the effect of noise effectively, the combination of histogram equalization and bilateral filtering can effectively overcome this problem.

The luminance component I of the image is balanced by the histogram equalization, and the luminance figure IE can be changed to highlight the hidden texture information in the image.

Bilateral filtering can effectively maintain image edge characteristics while smoothing the image. For satellite images, the texture is usually extracted by a number of bilateral filters, which has high requirements for computer memory and computing power. In this paper, histogram equalization is an effective way to enhance the texture of ground objects, which can be effectively extracted by only one bilateral filter. The filter image IE′ is obtained by the transformation of the equalization luminance graph IE by the formula (8).

$$IE'(i,j)=\frac{\sum_{(i,j)\in\Omega x,y} w(i,j)IE(i,j)}{\sum_{(i,j)\in\Omega x,y} w(i,j)} \tag{8}$$

In the formula, a window with a (i, j) centered M×M (odd M) size is represented. For each pixel point (i, j) in the window, its weight w (i, j) is composed of two parts,

$$w(i,j)=W_s(i,j)\times W_r(i,j) \tag{9}$$

$$W_s(i,j)=e^{\frac{-\|(i,j)-(i',j')\|^2}{2\sigma_s^2}} \tag{10}$$

$$W_r(i,j)=e^{\frac{-\|IE(i,j)-IE(i',j')\|^2}{2\sigma_r^2}} \tag{11}$$

In the formula, $w(i, j)$ is the calculation weight. $w_s(i, j)$ is the spatial distance factor. $w_r(i, j)$ is the brightness similarity factor. σ_s and σ_r represent the standard deviation of the Gaussian function, and the σ_s value is 2. σ_r value for the $IE_{\max}/10$, $IE_{\max}$ represents the maximum of equilibrium brightness. the e is the mathematical constant, and the i, j is the center pixel coordinate of the filter (i', j'). For other pixel coordinates in the window, $IE'(i, j)$ is the center pixel brightness value after the bilateral filtering. Construct detail Graph by formula (12), I'_D the pixel gray value in detail graph.

$$I'_D=|IE-IE'| \tag{12}$$

2.4 Characteristic analysis of fractal dimension

Fractal dimension is a mathematical method, which is mainly used to study the complex geometrical form of nature. The core feature of Fractal is self-similarity, which is similar to one part of itself. Box dimension algorithms are often used in grayscale images, which are defined as below.

Let F be any non-empty bounded subset of RN, the smallest number of sets that can cover F with the largest diameter δ, then the upper and lower box dimensions of F are respectively defined as:

$$\overline{Dim_B}F=\lim_{\delta\to 0}\frac{\log N_\delta(F)}{\log(1/\delta)} \tag{13}$$

$$\underline{Dim_B}F=\lim_{\delta\to 0}\frac{\log N_\delta(F)}{\log(1/\delta)} \tag{14}$$

If the formula (13) is equal to the formula (14), it is said that the two box dimensions with the same value F are

$$\underline{Dim}_B F = \lim_{\delta \to 0} \frac{\log N_\delta(F)}{\log(1/\delta)} \tag{15}$$

In this paper, the fractal Geometry method is used to judge whether the object is a cloud by using the texture feature and the geometrical fractal dimension feature. Cloud image Segmentation of the two-value map has a lot of problems, including noise points and burrs, large clouds inside a small hole, fine pieces of cloud, and so on, which will bring inconvenience to feature extraction, the solution is denoising and extraction can better represent the image content of a number of major cloud blocks. Firstly, the mathematical morphology operation is used as an auxiliary tool to partially eliminate the problems of noise and burr by using both open and closed operations. Open operation is to the image first corrosion after expansion, can eliminate burrs, remove finely cloud block, closed operation is to the image first expansion after corrosion, can fill a small hole, connect the slit. Then, remove the finely-grained cloud blocks and small holes. In fact, the morphological structure of cloud images is sufficient to characterize some clouds with larger area and dominant position, which is meaningless and time-consuming to extract features of too small cloud blocks. Some large cloud blocks exist in some small black holes, can be used as noise removal, more can highlight large cloud block. For the above consideration, set an area threshold value A1, the area is less than A1 of cloud block and small hole are removed, the remaining cloud block as the main cloud block.

Due to the brightness of the cloud threshold in different seasons need to adjust, too cumbersome, so in the algorithm does not use the bright temperature band for cloud detection. In order to reduce the cloud residue as far as possible, this study is based on the spatial differences of clouds, through the morphological characteristics of the cloud to detect. The complex surface cover types and various types of clouds and cirrus in the image pose a great obstacle to cloud detection, especially the presence of large areas of snow and cloud spectral characteristics are very similar, cloud detection will often be removed with snow and clouds. A multi-band cloud-based algorithm does not consider snow, removes the cloud and removes snow, but there are still more snow residues, which may interfere with subsequent research. This paper presents a method based on cloud morphological features to obtain better cloud detection results.

3 Processing flow

Cloud detection algorithm flow chart of this paper based on high resolution multi-spectral images is shown as figure 1.

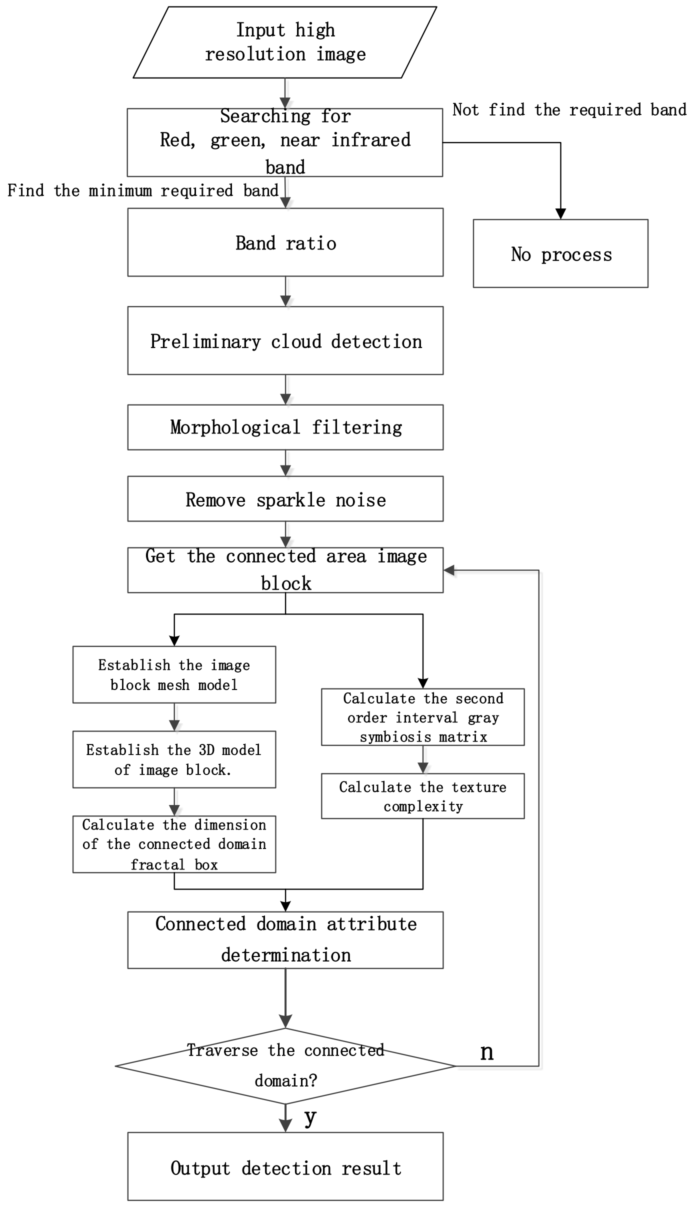

Figure 1: The flowchart of cloud detection algorithm for high-resolution images.

The important steps are as the following steps:

1. Required bands: red, green and near-infrared.
2. Calculate the ratio-red band to near-infrared band and green band to near-infrared band in two forms.
3. Calculate the mean, variance, maximum and minimum of near-infrared band of the two ratio results.
4. Automatically compute the cloud threshold, divided into situations such as whole cloud. if

(maxWhole / mean < 2) {TCloud = mean - 0.5 * var; }; According to the above two ratios and the statistical results of near-infrared bands, the preliminary cloud results are obtained. The acquirement of threshold is obtained mainly according to the spectral curve of the cloud obtained by the scientific literature and the actual statistical results.

5. Morphological filtering and speckle noise filtering.
6. Adopt a method combining histogram equalization and bilateral filtering. Using the weak texture feature of cloud, the noise of high brightness artificial building is eliminated effectively.
7. Use fractal geometry method to remove mountains and highlight snow and gobi; Use the feature of the connected domain to remove the highlighted path.

4 Experiment and validation

We selected some representative remote sensing data for testing (218 images in total). We mainly choose three kinds of remote sensing data from MSS1 sensor, which are multi-cloud, little cloud and no cloud. Here, multi-cloud data refers to large cloud cover in the image, with a small amount of highlighter interference, such as desert, gobi desert, snow, salt mine, highlighting buildings, roads, glaciers etc.. Little-cloud data refers to little cloud cover in the image, with several highlighter interference. None- cloud data refers to no cloud cover in the image with large amount of highlighter interface. This kind of data is mainly used to test the distinguish ability between cloud and highlighted objects in high-resolution data images in cloud detection program. Some test results are shown in the figures below.

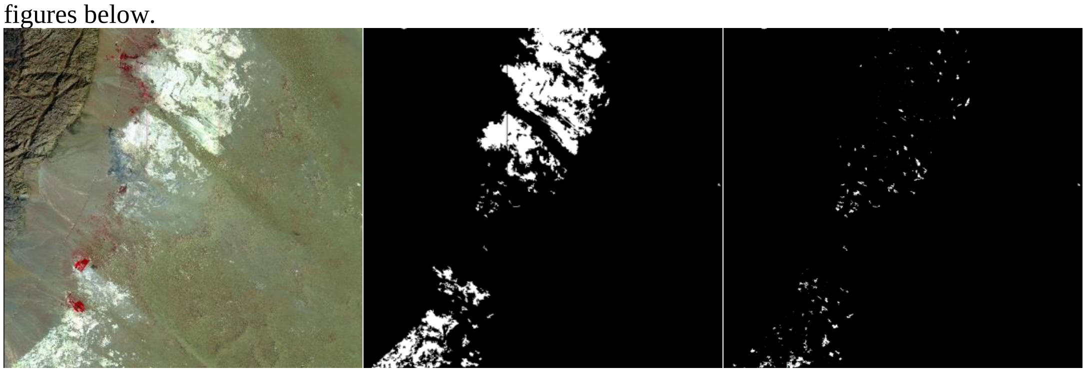

Figure 2: because of edge linear features of big regions, it can effectively eliminate the cloud-like target area by means of geometric fractal dimension. (Figure 2~5 from left to right: Left: cloud area image under detection. Mid: preliminary cloud test results. Right: results after morphological features judgment.)

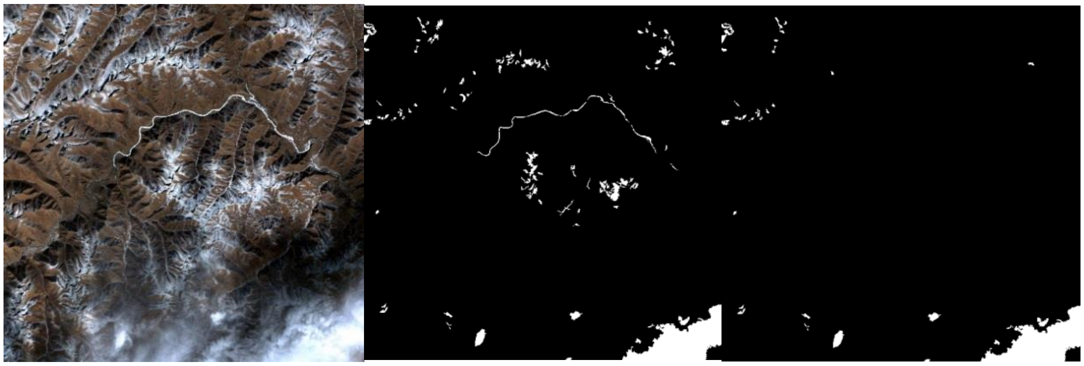

Figure 3: because of complex edge features of regions for cloud-like areas-snow and long length shape for road, judgments are very accurate. Simultaneously the cloud area can be reserved.

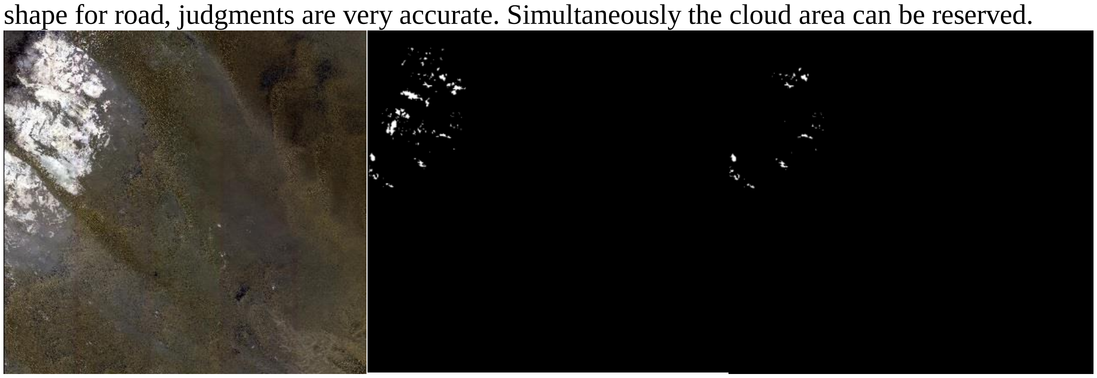

Figure 4: the same as figure 2, there is a certain inhibition effect on the judgment of the highlighted strata, but it is not completely eliminated.

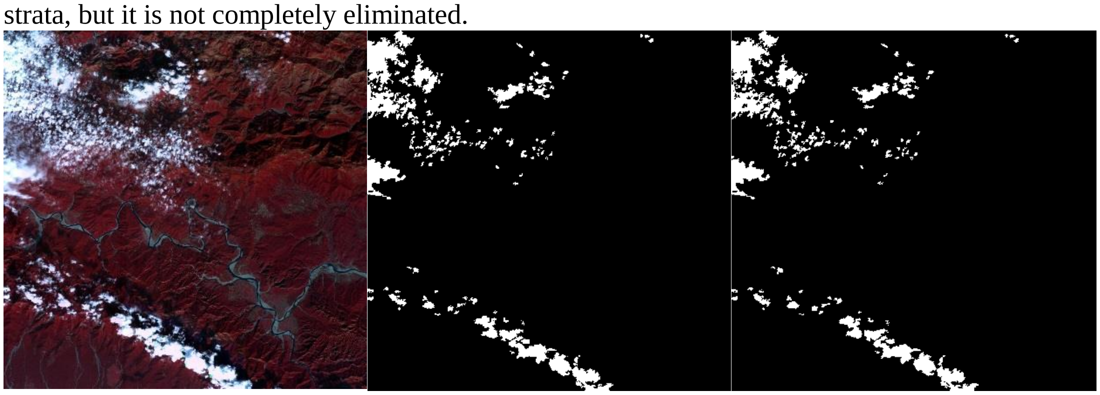

Figure 5: because of smooth edge features of cloud regions, there is little impact on the judgment of the whole cloud area.

5 Conclusion

In this paper, a series of morphological feature extraction and multiple threshold joint judgment methods were used to optimize the cloud detection results of remote sensing images of the threshold method. In the case of the interference of the highlighted objects such as snow, this method can effectively remove the jamming objects, so that the correct rate of cloud detection was improved to some extent, but there were still some false alarm and leak alarm case. In order to improve the accuracy rate furtherer, we can judge the target object's Fourier descriptor, target edge gradient and target fine length. There are many characteristics of the differences between the cloud and the ground, which need to be excavated.

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