# Automatic Cloud Detection and Removal Algorithm for MODIS Remote Sensing Imagery

Lingjia Gu, Ruizhi Ren, Shuang Zhang

College of electronic science & engineering, JiLin University, Changchun, China gulingjia@jlu.edu.cn

Abstract— Cloud is one of the most common interferers in Moderate Resolution Imaging Spectrum-radiometer (MODIS) remote sensing imagery. Because of cloud interference, much important and useful information covered by cloud cannot be recovered well. How to detect and remove cloud from MODIS imagery is an important issue for wide application of remote sensing data. In general, cloud can be roughly divided into the two types, namely, thin cloud and thick cloud. In order to effectively detect and eliminate cloud, an automatic algorithm of cloud detection and removal is proposed in this paper. Firstly, several necessary preprocessing works need to be done for MODIS L1B data, including geometric precision correction, bowtie effect elimination and stripe noise removal. Furthermore, through analyzing the cloud spectral characters derived from the thirty-six bands of MODIS data, it can be found the spectral reflections of ground and cloud are different in various MODIS bands. Hence, cloud and ground can be respectively identified based on the analysis of multispectral characters derived from MODIS imagery. Cloud removal processing mainly aims at cloud region rather than whole image, which can improve processing efficiency. As for thin cloud and thick cloud regions, the corresponding cloud removal algorithms are proposed in this paper. Experimental results demonstrate that the proposed algorithms can effectively detect and remove cloud from MODIS imagery, which can meet the demands of postprocessing of remote sensing imagery.

*Index Terms* —MODIS data, Cloud detection, Thin cloud removal, Thick cloud removal, Multispectral image analysis

## I. INTRODUCTION

Cloud is one of the most common atmospheric interferers in MODIS remote sensing imagery. Because of cloud interference, abundant important information covered by cloud can not be obtained [1]. Cloud interference not only brings some difficulties for image post-processing, but also causes other image recognition and classification problems. How to effectively reduce or remove cloud interference is an important issue in remote sensing applications.

Commonly, cloud can be roughly divided into two types, including thin cloud and thick cloud. At present, many cloud removal methods are designed to process different cloud. Thin cloud can be removed based on the processing of spatial domain or frequency domain. For example, thin cloud can be removed by eliminating the band information which is sensitive to cloud based on data multiband analysis [2], or by homomorphism filtering method [3] based on the high-frequency component of image enhancement. However, thin cloud removal method based on frequency domain is only suitable for the processing of small cloud region. The reason is that data transformation processing from spatial to frequency domain would consume a large amount of memory, which causes a bottleneck in computation speed. At present, thick cloud removal methods mainly utilize the overlapping images derived from the same region and different acquisition time, or use fusion data collected by multiple sensors. The basic theory of thick cloud removal is to replace cloud region with sky data [4, 5].

Through research of cloud removal methods, we found it should adopt different processing methods based on cloud type. As for thin cloud-covered region, the spectral features of ground are partly remained. As a result, we may recover part ground information under thin cloudcovered region. However, as for thick cloud-covered image, ground scene information is almost completely covered, the only method is to replace cloud region with non-cloud-covered image of the same region at different time [6, 7]. However, it is difficult to find the replaced data and the cost is also higher, so the method has limitations in practical application. In additional, image rectification [8] needs to be realized in this method. Although there has abundant research on image rectification, manual rectification method is mainly used by remote sensing researchers, which is a waste of time and low precision. Many researchers seek for automatic or semi-automatic rectification method for remote sensing imagery [9, 10].

In order to effectively detect and eliminate cloud, an automatic cloud detection and removal algorithm is proposed in this paper. Firstly, several preprocessing works need to be done for MODIS L1B data, including geometric precision correction, bowtie effect elimination and stripe noise removal. Furthermore, through analyzing the cloud spectral characters derived from the thirty-six bands of MODIS data, it can be found spectral reflections of ground and cloud are different in various MODIS bands. Therefore, cloud and ground area can be respectively identified based on the analysis of multispectral characters derived from MODIS imagery. In general, most cloud regions including both thin and thick types can be detected by this method. Clouds removal processing mainly aims at cloud regions rather than whole image, which can improve processing efficiency. As for thin clouds and thick clouds removal, different removal algorithms are proposed in this paper. Experimental results demonstrate that these proposed methods can effectively detect and remove cloud from MODIS image, which can meet the demands of postprocessing for remote sensing imagery applications.

This paper is organized as follows: Section II introduces several necessary preprocessing for MODIS data. Section III describes an effective cloud detection algorithm. The algorithms of thin and thick cloud removal are respectively proposed in Section IV and Section V. Section VI is a summarization and conclusion of this research.

## II. MODIS DATA PREPROCESSING

MODIS [11] is the main information data acquisition instrument in Earth Observing System (EOS) series of satellites, its goal is to research and forecast the earth changes which are influenced by nature and human being. The development and application of MODIS can advance the global environment research to a higher level. MODIS instrument includes 36 spectral bands at three different spatial resolutions with nominal ground fields of view of 250 m, 500 m and 1 km. Its spectrum distributes between 0.14 µm to 14 µm, which covers visible light, near-infrared and infrared bands. MODIS loads on Terra and Aqua satellites and can observe the global change one time each day, it can obtained 6.1 M bits data per second from atmosphere, sea and land on the earth. Now, MODIS has become the basic detector for observing the earth and supply ecology development data.

In order to provide high precision imagery for MODIS application, it needs to do some preprocessings, including geometric precision correction, bowtie effect elimination and strip noise removal. In the process of geometric precision correction [12], because there are much useful latitude and longitude information in MODIS data, these geographic data can be used as GCP to realize geometric precision correction.

Bowtie effect mainly represents that some data are overlapped in neighbor scan rows. Moreover, the more near to image edge, the more it can be seen. In the procedure of bowtie effect elimination, we use the previous proposed algorithm [13]. It firstly detects the rough positions of overlapping data. In additional, consider influences of the instrument characters and earth's curvature, the positions of overlapping data need to be further rectified to obtain more precise results. At last, the optimal rectification method is used to obtain rectified MODIS data. As seen in Fig.1, the used algorithm can effectively eliminate bowtie effect.



(b) Rectified image

Figure 1. Result of bowtie effect elimination

Stripe noise is the most common noise in MODIS data which is caused by slight errors in the internal calibration system, variation in the response of the detectors and random noise. In MODIS imagery, stripe noise seriously affects image interpretation and information application. Here, the previous proposed destriping algorithm [14] is used to resolve this problem. From Fig.2, it can be seen that the proposed destriping algorithm can achieve fine effect.



(a) Original image

(b) Rectified image

Figure 2. Result of stripe noise removal

#### **III. AUTOMATIC CLOUD DETECTION ALGORITHM**

The 36 distinct spectral bands of MODIS data are divided into four separate Focal Plane Assemblies (FPA): Visible (VIS), Near Infrared (NIR), Short- and Mid-Wave Infrared (SWIR/MWIR), and Long-Wave Infrared (LWIR). Cloud detection algorithm is mainly based on the multispectral analysis of cloud. Considering reflectance and radiation of cloud are different from earth's surface in Visible and Infrared band spectrum, we may utilize cloud spectral features to detect cloud region.

In view of cloud spectrum characters in Visible /Near Infrared and thermal infrared band are complementary [15, 16], we select the following five bands: band CH1 (0. 620-0.670 µ m), CH2 (0.841-0.876 µ m), CH26 (1.360-1.390 µ m), CH29 (8.400-8.700 µ m) and CH31  $(10.780-11.280 \,\mu$  m). We combine the cloud reflectance of Visible /Near Infrared with its brightness temperature of thermal infrared to detect cloud region. The region meets all of the following four conditions is regarded as cloud:

Condition 1: In Visible band CH1, the sky data has lower reflectance, its value is  $0 < \rho$  sky <0.3; while cloud has higher reflectance, its value often is  $\rho_{cloud} > 0.3$ ; at the same time, this band can enhance the contrast of cloud and ground, so CH1 is the first choice for cloud detection.

Condition 2: In Near Infrared band CH2, although cloud has high reflectance, the reflectance of barren land and green are similar to cloud, so it is difficult to identify cloud. Through research, although cloud reflectances of Visible /Near Infrared band are similar, the reflectances of other surface type have obvious difference in the two bands. Therefore, the pixels which  $\rho_{CH2}/\rho_{CH1}$  lie in the range between 0.8 and 1.6 are regarded as cloud region.

Condition 3: As for high-level cloud detection, for example cirrus, CH26 band is very suitable. Because CH26 band has strong capability of water vapor absorption, ground radiation is difficult to reach the bottom of radiation sensor, while the upper water vapor features of cloud are very significant. As a result, this band is very useful to detect thin cloud.

Condition 4: Base on the error values of bright temperature between CH29 and CH31 band, cloud region can be effectively determined.

#### IV. THIN CLOUD REMOVAL ALOGRITHM

#### A. Test Data Selection

MODIS L1B 1KM data on April 1, 2009 at 05:30 am (U.S. Time) is selected as test data, because the whole image is very large, here, we show one part of the image. Fig.3 (a) shows original CH1 image, Fig.3 (b) shows original CH2 image, Fig.3 (c) shows original CH26 image, Fig.3 (d) shows original CH29 image, Fig.3 (e) shows original CH31 image Fig.3 (f) shows thin cloud detection results using the proposed algorithm.



(a)Original CH1 image



(c) Original CH26 image

(b) Original CH2 image



(d) Original CH29 image



Figure 3. Original band images and thin cloud regions

## B. Thin Clouds Removal Algorithm

Thin cloud has some special features, such as high brightness, low contrast and low frequency. In order to reduce thin cloud interference, one effective method is to enhance ground information covered by cloud.

(1) Ground information enhancement

Image enhancement techniques can be divided into two broad categories: spatial domain methods, which operate directly on pixels, and frequency domain methods, which operate on the Fourier transform of an image. High-pass Butterworth filter is used to enhance the high frequence components of cloud region, namely, ground information.

(2) Cloud brightness processing

Through image enhancement processing, ground information becomes obvious. In additional, it needs to decrease brightness of cloud region for better image effect. Because cloud has uneven thickness, the processing result is not good when whole cloud regions decrease same brightness value. If brightness decreases less, image edge between thin part and non-cloud region is smooth, but brightness of thick part is high; if brightness decrease sharp, thick part can achieve good result, but it will cause obvious boundary effect between thin part and non-cloud region. Aim at the situation, a proper strategy [17] is designed to decrease different brightness.

Step1: Compute the center of gravity for each thin cloud region. The center of gravity is usually located in the thicker part of thin cloud region.

Step2: For each cloud region, it is divided into several layers from center of gravity to boundary position.

Step3: cloud brightness of each layer is decreased different levels according to its position.

#### C. Thin Clouds Removal Results

Fig.4 (a) shows the original image covered with thin clouds, Fig.4 (b) shows the result of thin cloud removal. From Fig.4, it can be seen that part ground information covered by thin clouds can be recovered well.



(a) Original image with thin clouds



(b) Image without thin clouds

Figure 4. Result of thin clouds removal

# V. AUTOMATIC THICK CLOUD REMOVAL METHOD

Fig.5 (a) shows the first band of thin cloud removal image which can be regarded as less cloud region. Fig.5 (b) shows the first band of thick cloud image derived from the same observation region and different data acquisition time, which acquisition date is on April 17, 2009 at 05:30 am (U.S. Time).



(a) Less cloud regions



(1)

Figure 5. Less cloud image and thick cloud image

The goal of thick cloud removal is to remove thick cloud and recover ground information under it. The processing procedure of thick cloud removal is shown in Fig.6.



Figure 6. The processing procedure of thick cloud removal

# A. Overlapping Region Detection

First of all, we should detect the overlapping region of the two images. The traditional methods used to detect overlapping regions are usually based on image processing, and detection procedures are relative complex. In this paper, we may simply and quickly detect the overlapping regions of the two images by utilizing MODIS data. Through analysis of MODIS data, it includes the corresponding geographical coordinates besides image data. As for MODIS L1B 1KM data, its image size is  $2030 \times 1354$  pixels, while the size of latitude and longitude data is  $406 \times 271$  pixels, namely, the image data is 25 times the size of the geographical data. Through the interpolation algorithm, we can obtain the new geographical data which size is the same with image data. Therefore, the overlapping region is confirmed according to the data ranges of longitude and latitude.

#### B. Matching Point Pair's Detection

# (1) SIFT algorithm and feature matching

SIFT algorithm [18] was published by David Lowe. SIFT features are local and based on the appearance of the object at particular interest points, and are invariant to image scale and rotation. They are also robust to changes in illumination, noise, and minor changes in viewpoint. Based on SIFT algorithm, we can obtain all descriptor vectors for keypoints such that the descriptors are highly distinctive and partially invariant to the remaining variations. Then, feature matching is done through a Euclidean-distance based nearest neighbor approach. In order to increase robustness, matches are rejected for those keypoints for which the ratio of the nearest neighbor distance to the second nearest neighbor distance is greater than 0.8. This discards many of the false matches arising from background clutter. Fig.7 shows the image of matching point pair's based on SIFT algorithm and the nearest neighbor approach.



Figure 7. The matching pair's image based on SIFT algorithm and the nearest neighbor approach

# (2)The strategy of extracting exact matching points

As shown in Fig.7, there are still some false matching pairs after the above processing. In order to obtain exact matching pairs in further, we put forward an effective strategy to extract exact matching pairs based on consistency theory [19].

This strategy is designed as follows:

Step1: Use the feature points of the first image as the reference points, then seek for corresponding matching points in the second image by SIFT algorithm and nearest neighbor approach, we can obtain K pairs of matching points, including false matching point pairs.

Step2: Given  $A(x_A, y_A)$  and  $A'(x_{A'}, y_{A'})$  is a pair of matching point, then compute (1):

$$dx = x_{A'} - x_A \tag{1}$$

Where dx is x-coordinate distance of the two matching points, compute the x-coordinate distances of all matching points, record them as dx(n) {n = 1,2...K}; Compute the number sum of different dx(n), and find  $dx(s) \{s \in n\}$  whose value is greater than given threshold.

Similarly, compute (2) :

$$dy = y_{A'} - y_{A} \tag{2}$$

Here, dy refers y-coordinate distance of the two matching points, compute the y-coordinate distances of all matching points, and then record them as  $dy(n) \{n = 1, 2...K\}$ ; Statistics the number of different dy(n), and find  $dy(t) \{t \in n\}$  whose value is greater than given threshold. Extract the matching point pairs whose x-coordinate distance is dx(s), meanwhile, y-coordinate distance is dy(t).

Step3: Use the feature points of the second image as the reference points, adopt Step1 to seek matching points in the first image, and then repeat Step2.

Step4: Find the matching point pairs which are identical in Step2 and Step3, then obtain final matching point pairs.

Table.1 shows the matching results using the proposed strategy, and Fig.8 shows the result of exact matching point pairs.

TABLE I. THE MATCHING RESULTS OF THE PROPOSED STRATEG	Y
---	---

Reference Image	Initial matching pairs	True matching pairs	False matching pairs	Percentage of accuracy	
Less cloud	117 pairs	87 pairs	30 pairs	74.36 %	
Thick cloud	140 pairs	88 pairs	52 pairs	62.86%	
Exact matching point pairs, 77 Paris					



Figure 8. The result of exact matching point pairs

#### C.Image Rectification

Because the two images were acquired from different date and angle, we use these matching point pairs (also called control points) to realize image rectification. Image rectification is a transformation process; it is used to correct a distorted image into a standard coordinate system. In this paper, we adopt the quadratic polynomial model as transform model.

Given a point coordination of reference image is (X, Y), its corresponding point coordination of target image is (x, y), then:

$$\begin{cases} x = a_0 + a_1 X + a_2 Y + a_3 X Y + a_4 X^2 + a_5 Y^2 \\ y = b_0 + b_1 X + b_2 Y + b_3 X Y + b_4 X^2 + b_5 Y^2 \end{cases}$$
(3)

Input six matching point pairs to (3) and solve the quadratic polynomial equation, we can obtain the coefficients  $a_i$ ,  $b_i$  (i = 0,1..5) and build the polynomial rectification model between the two images. Compute the new coordination for the target image by using the rectification model, and then use the bilinear interpolation algorithm to acquire the rectified image which has the same coordination system with the reference image.

#### D.Thick Cloud Detection Results

Fig.9 (a)-(e) shows the thick cloud images derived from the different bands of MODIS data. For the thick cloud image, the thick cloud regions can be detected using the propose cloud detection algorithm. Fig.9 (f) shows the thick cloud regions where clouds are labeled with white color.





(c) CH26 image





Figure 9. Original band images and thick cloud regions

As seen in Fig.9 (f), some clouds points cannot be detected due to the influences of cloud shadow, which decrease the image quality of thick clouds removal. As a

result, we use morphological dilation method to process thick cloud regions. Fig.10 shows the rectified result of thick cloud regions.



Figure 10. The rectified image of thick cloud regions

#### E. Image Fusion Processing

In order to recover the ground information, thick cloud regions should be replaced with the corresponding regions from the rectified image. However, the image gray of the replaced region is not identical with that of its surrounding region, which decreases the whole image quality. The following image fusion processing is used to resolve the problem:

Step1: Compute the gray mean of the replaced region and that of the surrounding regions of thick cloud image.

Step2: Compute the error value between the two gray means, and then adjust pixel gray of the replaced region according to the error value.

Step3: As for the edges of the replaced image, the fade in-out blending approach [20] is adopted to realize image smooth effect.

Step4: Repeat above Steps, realize data fusion based on the two images.

## F. Experimental Results

Fig.11 shows the color images of less cloud, thick cloud and thick cloud removal. As shown in Fig.11(c), thick cloud can be effectively removed with the proposed method. Through the processing of thick cloud removal, we can clearly observe the important ground information under thick cloud-covered region.



(a) Less cloud image



(b)Thick cloud image



(c) Result of thick cloud removal

Figure 11. Original color images and thick cloud removal image

#### VI. CONCLUSIONS

Because of climate influences, most remote sensing images include thin or thick clouds, which severely affect data post-processing and application. Therefore, it is very necessary to remove cloud interferences from original image. An effective cloud detection algorithm is proposed in this paper, which can detect most thin or thick cloud regions based on the analysis of the multispectral information from MODIS data. Cloud removal processing mainly focuses on the cloud detection regions rather than the whole image, which can improve processing efficiency. As for cloud removal, we designed the corresponding algorithms for thin or thick cloud type processing. Using the proposed methods, cloud can be automatically detected and removed without manual interference. Experimental results demonstrate that the proposed methods can effectively remove clouds from MODIS image, which can meet the demands of postprocessing for remote sensing imagery applications.

#### ACKNOWLEDGMENT

This work was supported by a grant from the JiLin University –Research on detection method of single-layer cloud height for plain area based on MODIS satellite remote sensing data (421031011419).

#### References

- Kathleen Strabala, "MODIS Cloud Mask User's Guide," Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, 1998.
- [2] Gao B C, Kaufman YJ, Han W, et al, "Correction of thin cirrus path radiance in the 0.4-1.0 mm spectral region using the sensitive 1. 375 mm cirrus detecting channel," Journal of Geophysical Research, vol.103, 1998, pp.32169-32176.
- [3] Feng C, Ma J W, D Q, "An Improved Method for Removal of Thin Cloud in Remote Sensing Images," Remote Sensing for Land & Resources, vol.4, 2004, pp.1-4 (in Chinese).
- [4] Wang H, Tan B, Shen Z Y, "The Processing Technology of Removing Clouds Images Based on the Multi-Resource RS Image," Journal of Institute of Surveying and Mapping, vol. 18 (3), 2001, pp.41-44(in Chinese).
- [5] Fang Y, Chang B Y, "The Research of Removing the Affect of Clouds Cover by Combining the Multi-Sensor Images," Journal of Image and Graphics, vol. 6(2), 2001, pp.139-141(in Chinese).
- [6] Song M, Civco D L, "A Knowledge-based Approach for Reducing Cloud and Shadow," Proc. of 2002 ASPRS-ACSM Annual Conference and FIG22 Congress, 2002, pp.22-26.
- [7] FU Xiaoshan, "Removing Cloud from Remote Sensing Image Based on Gray Gradient," Bulletin of Surveying and Mapping, vol.10, 2008, pp. 41-61 (in Chinese).
- [8] ZHANG Jixian, LI Guosheng, ZENG Yu, "The study on automatic and high-precision rectification and registration of multi-source remote sensing imagery," Journal of Remote Sensing, vol. 9 (1), 2005, pp.73 (in Chinese).
- [9] JIAN Jianfeng, Lin Yi, ZHOU Lihua, "Optimized High-Precision Registration Method of Multi-source Remote Sensing Images,"Journal of TongJi University (Natural science), vol. 36(10), 2008, pp.1427-1432 (in Chinese).
- [10] Tian Yue, Zhang Yongmei, Li Bo, "Fast remote sensing image registration algorithm," Journal of Beijing University of Aeronautics and Astronautics, vol.34(11), 2008, pp.1356-1359(in Chinese).
- [11] Justice, C.O., et al, "The Moderate Resolution Imaging Spectroradiometer (MODIS): land remote sensing for global change research," IEEE Trans. on Geosci. and Rem. Sens., vol.36(4),1998, pp.1228-1249.
- [12] Van A, Nakazawa M, Aoki Y., "Highly accurate geometric correction for NOAA AVHRR data considering the feature of elevation and the feature of coastline,".Proceedings of the IEEE International Geoscience and Remote Sensing Symposium(IGARSS'08), vol.2,2008, pp.1060–1063.
- [13] Ren R Z, Guo S X, Gu L J, "Fast bowtie effect elimination for MODIS L1B data," The Journal of China Universities of Posts and Telecommunications, vol.17(1), 2010, pp.120–126.
- [14] Ruizhi Ren, Shuxu Guo, Lingjia Gu, "Stripe Noise Removal Method for MODIS Remote Sensing Imagery," The 2nd International Conference on Computer Engineering and Technology (ICCET 2010). vol.1, 2010, pp.565-569.

- [15] Song X N, Zhao Y S, "Cloud Detection and Analysis of MODIS Image," Geoscience and Remote Sensing Symposium, vol.4, 2004, pp.2764-2767.
- [16] Steven Platnick, Michael D King, Steven A Ackerman, et al, "The MODIS cloud products: algorithms and examples from Terra," IEEEE Transactions on Geosciences and Remote Sensing, vol.41 (2), 2003, pp.459 – 473.
- [17] Ruizhi Ren, Shuxu Guo, Lingjia Gu, "An Effective Method For the Detection and Removal of Thin Clouds from MODIS Image," SPIE Optical Engineering + Applications Satellite Data Compression, Communication, and Processing, vol.74550Z, 2009, pp.7455.
- [18] David G. Lowe, "Distinctive image features from scaleinvariant key points. International Journal of Computer Vision," vol. 60, 2004, pp.91-110.
- Vision," vol. 60, 2004, pp.91-110. [19] Lingjia Gu, "An Automatic Target Image Mosaic Algorithm," The IEEE Region 8 Eurocon 2007 Conference, 2007, pp.369-374.
- [20] Lingjia Gu, Shuxu Guo, Ruizhi Ren and Shuang Zhang, "Target Image Mosaic Algorithm Based on Interest Points,"International Conference on Communications, Circuits and Systems, vol. II, 2007, pp. 755-759.