Saranya M, International Journal of Computer Science and Mobile Computing, Vol.3 Issue.2, February- 2014, pg. 681-688

Available Online at www.ijcsmc.com

International Journal of Computer Science and Mobile Computing

A Monthly Journal of Computer Science and Information Technology

ISSN 2320–088X

IJCSMC, Vol. 3, Issue. 2, February 2014, pg.681 – 688

RESEARCH ARTICLE

Cloud Removal from Satellite Images Using Information Cloning

Saranya M[1]

[1]PG Scholar

Department of Computer Science

R.V.S College of Engineering and Technology

Coimbatore, TamilNadu, India

[1] m.saranya7591@gmail.com

Abstract— In recent years, on average about 35% of cloud covers are generally present in optical satellite images. To develop cloud-free satellite images for analyses of current land cover and land-cover change cloud removal approach based on information cloning is introduced. The approach removes cloud-contaminated portions of a satellite image and then clones information from cloud-free patches to their corresponding cloud-contaminated patches under the assumption that land covers change insignificantly over a short period of time. To identify exact location of cloud contaminated region, cloud detection based on window based thresholding approach is introduced. The proposed information cloning algorithm is used to reconstruct the missing data after removing the cloud-contaminated region. By replacing cloud contaminated target image with cloud- and shadow-free parts from the reference image, the information reconstruction is performed. This approach results in cloud removed images and is tested for various input images.

Keywords— Cloud detection; Window based thresholding approach; Cloud removal; Information cloning; Information reconstruction

I. INTRODUCTION

Clouds are common features of visible and infrared remotely-sensed images collected from many tropical, humid, mountainous, and coastal regions of the world. The Landsat cloud-free scenes for analyses of current land cover and land-cover change is developed using cloud removal approach. Landsat data has been used for high temporal resolution analyses of land-cover change related to urban expansion, regeneration of forests over abandoned agricultural land, estimation of forested

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area, identification of forests types and current land-cover classification, a key component for mapping habitats and biodiversity.

A simple and semi-automated method to detect clouds and shadows in Landsat imagery, and have developed a recent cloud-free composite of multitemporal images.

On average, about 35% cloud covered, indicating that cloud covers are generally present in optical satellite images[1]. This phenomenon limits the usage of optical images and increases the difficulty of image analysis. Thus the cloud removal approach is to ease the difficulties caused by cloud covers. If multitemporal images are acquired, the cloud-cover problem has a chance to be eased by reconstructing the information of cloud-contaminated pixels under the assumption that the land covers change insignificantly over a short period of time.

The principle is to identify clouds and shadows in a target image and replace them with cloud- and shadow-free parts from the reference images that are acquired at the different period of time. The aim of this study is to remove clouds and reconstruct information of missing data by taking advantage of the temporal correlation of multitemporal images.

The workflow of the proposed cloud removal method consists of the following processing steps: cloud detection, cloud shadow detection, cloud removal and information reconstruction. In the first step, a semiautomatic cloud detection approach[4] is adopted to detect clouds and cloud shadows for the input images. Then blob detection is used for labeling the detected regions and also provides the statistics of labeled region. In the last step, the proposed information cloning algorithm is performed to fill in the missing data after removing the cloud-contaminated pixels.

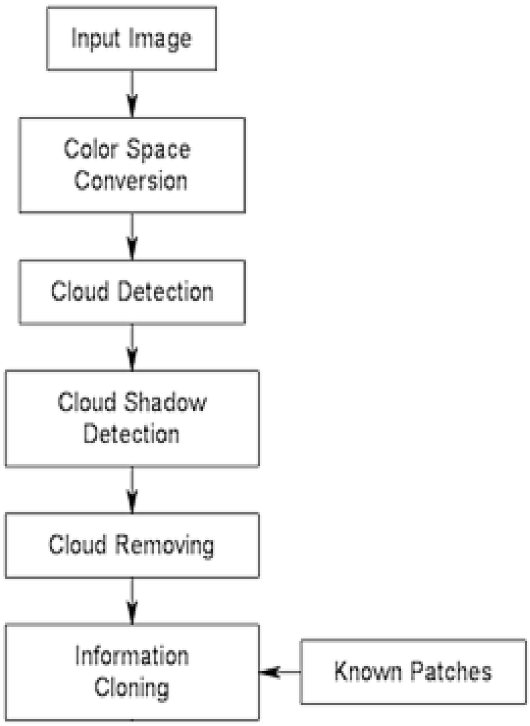

Fig.1 Workflow of our proposed Technique

The information cloning algorithm is introduced to reconstruct the information of cloud-contaminated region using several high similarity and cloud-free patches acquired at different times. The gradient of the selected patches is used to guide the reconstruction process to optimize the pixel intensities in the cloud-contaminated regions. To find an accurate and optimized reconstruction result the problem is formulated as an optimization equation with the boundary condition.

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With the aid of patch-based reconstruction and global optimization [2], satisfactory cloud-free results can be obtained even though the amount of cloud cover is large.

The sequences of images acquired by the Landsat sensor demonstrate the feasibility of this approach to process clouds in a heterogeneous landscape, and demonstrate the robustness of this approach to process images with a large amount of clouds.

II. PROPOSED CLOUD REMOVAL APPROACH

In this section, the proposed cloud removal approach is described. It consists of the following steps: cloud and shadow detection, blob detection, cloud removal, information reconstruction. The workflow of the proposed technique is shown in Fig.1.

A. Cloud and Shadow Detection

Given a cloud-contaminated image, called target image, and its corresponding images captured at the same position but different times, called reference images.

(a)

(b)

Fig.2 (a) Target Image; (b) Reference Image

A semiautomatic window based thresholding approach is adopted to detect clouds and cloud shadows in both the target and reference images. In the thresholding-based approach the cloud

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boundaries in the cloud contaminated images are defined. The cloud detection based on window based thresholding approach is by considering hypothesis that, regions of the image covered by clouds present increased local luminance values to automatically detect the presence of cloud in a region. The window size can be varied depending on cloud size, if clouds are of varied sizes and occupying only 1% of larger resolution. Choose the threshold value depending on the statistical properties of the image.

Once the cloud pixels are identified, their shadows are roughly predicted according to the cloud location. The dark and connected components within the neighborhood of the predicted shadows are identified as the shadow components. This approach is simple and can detect most clouds and cloud shadows.

B. Blob detection

The blob detection[7] must be performed after cloud and shadow detection. The blob detection block supports variable size signals at the input and output. The aim is to remove the cloud and shadows according to the statistics that are computed during blob detection. The blob analysis will return the labeled region and its statistics such as pixel location, number of pixels and blob count.

C. Information Reconstruction

The details of selected blobs are used to reconstruct the information of corresponding cloud-contaminated regions using information cloning algorithm[6]. The reconstruction problem is mathematically formulated as a Poisson equation[6] and solved using a global optimization process

The cloud contaminated region in the target image is denoted as Γ, and its boundary is denoted as $\partial\Gamma$. Let f be an unknown image intensity function defined over the cloud-contaminated region Γ (i.e., the unknown that is to be calculated). Let f be the image intensity function defined over the target image minus the cloud-contaminated region Γ, and let **V** be a guidance vector field defined over the cloud-contaminated region Γ. The vector field **V** is defined as the gradient of the selected patches and is used to guide the reconstruction process[8] to optimize the pixel intensities in the cloud-contaminated regions.

Thus, the information of cloud-contaminated region is reconstructed by several different blobs in a reference image. When the cloud-contaminated region Γ contains pixels on the border of the target image, these pixels are calculated to remove the boundary values.

III. IMPLEMENTATION OF CLOUD REMOVAL APPROACH

A. Color Space Conversion

To detect the clouds in the image, the intensity is to be calculated first. For the given RGB input image, it must be converted into any of the color space for further processing .Here the YIQ color space conversion is performed where the Y component represents the luma information I and Q represent the chrominance information. The Y channel alone is used to find the average intensity.

The RGB to YIQ color space conversion is based on the following formula.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.229 & 0.587 & 0.114 \\ 0.595716 & -0.274453 & -0.321263 \\ 0.211456 & -0.522591 & 0.311135 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The major advantage of YIQ is the grayscale information is separated from color data. So the same signal can be used for both color and black and white sets.

B. Window Based Thresholding Approach

The cloud and shadow detection is done using window based thresholding approach [5] by considering hypothesis that, regions of the image covered by clouds present increased local luminance values to automatically detect the presence of cloud in a region, the average of the local luminance is used in the algorithm.

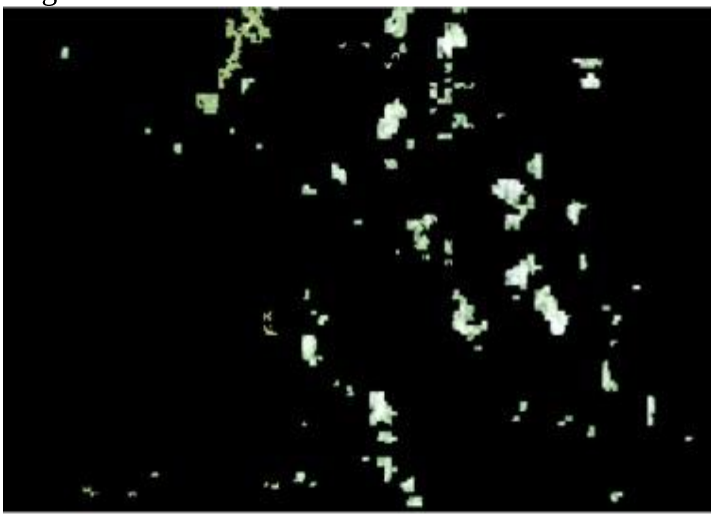

Fig.3 Cloud detection

For this grayscale image is divided to a number of small windows and finds the mean intensity μ^i of each window using the following equation,

$$\mu^i = \frac{1}{M} \sum_{k \in X^i}^{k=1...M} Xi$$

Where M is the number of pixel in the i^{th} window and X^i_k is the k^{th} pixel in the i^{th} window.

The window size can be varied depending on cloud size. The best window size is 1.5%[5] of image resolution. Choosing thresholding depending on the statistical properties of the image .

C. Blob Analysis block

After the detection of clouds and shadows in the target image, the blobs are detected using blob analysis. For every blob, the pixel intensity values of labeled region in the target image are calculated. The same process will be done for the corresponding reference image.

Then average pixel intensity value for cloud pixel and its surrounding pixel is taken. According to that average pixel intensity value the cloud pixels are removed and then reconstruction is performed.

D. Information Cloning Algorithm

The information cloning algorithm[6] is proposed to reconstruct the information of cloud-contaminated region. The algorithm is as follows.

- The gradient images are created from the original image generally by convolving with a filter.
- The filter involved in gradient images is imfilter. The imfilter performs multidimensional filteri according to the specified boundary options. The boundary option used here is ‘replicate’ which inputs array values outside the bounds of the array are assumed to equal the nearest array border value.

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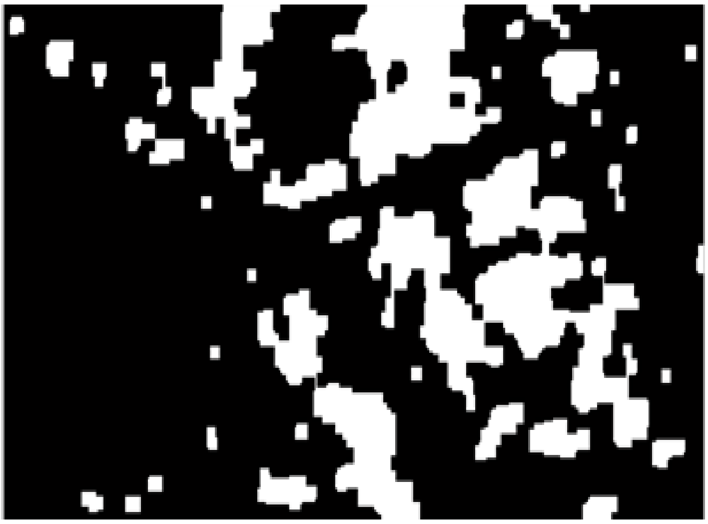

Fig.4 Blob detection

- The gradient of an image is given by the formula:

$$\nabla f = \frac{\partial f}{\partial x}\hat{x} + \frac{\partial f}{\partial y}\hat{y}$$

Where,

$\frac{\partial f}{\partial x}$ is the gradient in the x direction.

$\frac{\partial f}{\partial y}$ is the gradient in the y direction.

The cloud contaminated region in the target image is denoted as Γ, and its boundary is denoted as ∂Γ. Let *f* be an unknown image intensity function defined over the cloud-contaminated region Γ (i.e., the unknown that is to be calculated).

- Let *f* be the image intensity function defined over the target image minus the cloud-contaminated region Γ, and let **V** be a guidance vector field defined over the cloud-contaminated region Γ.
- To find an accurate and optimized reconstruction result the problem is formulated as an optimization equation[1] with the boundary condition $f|\partial\Gamma = f^*|\partial\Gamma$ as follows.
  $\min \iint |\nabla f - \mathbf{V}|2$ with $f|\partial\Gamma = f^*|\partial\Gamma$
  Where,
  $\nabla = ((\partial/\partial x), (\partial/\partial y))$ is the gradient operator.
- The solution to the above equation is of the following Poisson equation with Dirichlet boundary conditions.
  $\Delta f = div\ \mathbf{V}$ over Γ, with $f|\partial\Gamma = f^*|\partial\Gamma$
  Where,
  $\Delta = (\partial 2/\partial x2) + (\partial 2/\partial y2)$ is the Laplacian operator,
  $div\mathbf{V} = (\partial v1/\partial x) + (\partial v2/\partial y)$ is the divergence of the vector field $\mathbf{V} = (v1, v2)$

The minimization indicates that the gradient of the unknown function *f** is close, in *L*2-norm, to the gradient field **V** of the selected patches. The physical meaning is to interpolate inward while enforcing the spatial variations of the unknown function *f** to the guidance field **V** as close as possible.

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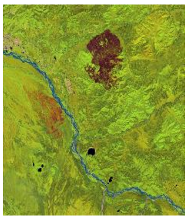
Therefore, the minimization has a good probability of inconsistently cloning the details of selected patches to the cloud-contaminated regions, thereby resulting in a cloud-free image with the reconstructed information.

IV. RESULTS AND DISCUSSION

This cloud removal approach using information cloning has been tested on the following satellite images and the results are shown as follows.

Target image	Reference image	Cloud removed image
		
		
		
		

In this paper, the cloud cover images with different types of landscapes are used to test the proposed approach. The cloud-free patches in the reference image with the highest rank are utilized to reconstruct the information of cloud-contaminated regions. A sequence of images that contains several different landscapes, simulates clouds by partly obscuring a cloud-free image of the sequence, and then compares the reconstructed image with the original cloud-free image. To demonstrate the advantage of utilizing multitemporal images, information reconstruction is done using single reference image and multiple reference images.

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V. CONCLUSION

In this paper, an information cloning algorithm for cloud removal has been introduced. The cloud-contaminated portions of a satellite images are detected based on window based thresholding approach. The detected clouds are removed and then the information of missing data is reconstructed with a single reference image. This approach is based on the patch-based information reconstruction strategy with the global optimization process. This approach results in cloud removed images and is tested for various input images.

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