Chapter 4

Cloud Extraction and Removal in Aerial and Satellite Images

4.1. Introduction

A common and complex aspect in aerial and satellite image application is encountered when image is captured from above the clouds. This causes signal attenuation of the image acquisition above the cloud cover and cloud-shadows modifies the ground local luminance. This will eventually affect the structural feature extraction process. Researchers in this field say that clouds and haze are the main source of noise in remote sensing and because of global warming an increased amount of water content could be found in the environment (Hau, C. Y. et al., 2008). Several methods were used to restore the cloud affected areas. But most of them are not suitable for high resolution satellite images affected by clouds (Chanda, B. & Majumder, D.D., 1991). Fusion techniques were also used to account for cloud and shadow defects (Abd-Elrahman, A. et al., 2008). These methods require cloud/shadow free images as reference images for processing. Therefore, the methods are not much reliable. Recent developments in the area include more efficient segmentation results but the performance is greatly influenced by the selection of the thresholds for various spectral tests (Reuter, M. et al., 2009). Borchartt, T. B. et al. (2011) suggested a method which works well but the algorithm
fails for the compensation of cloud-shadows and the scaling factors have to be obtained experimentally for each part of the image.

In this work, the cloud affected regions are detected and extracted by an adaptive segmentation algorithm. These cloudy regions, that were just extracted, are compensated for further processing. Then using a single program, later on, diminishes the effects of both clouds and cloud-shadows. The output hence obtained, is the input image with reduced or diminished effects of clouds and shadows.

4.2. Methodology

Many of the techniques developed to enhance cloud-associated regions ignore the information in the shadow regions. Fig. 4.1 presents the overall flow of our proposed system, considering both cloud and shadow regions which requires only a single image and single program for processing. The method can be applied for aerial/satellite RGB or gray scale images.

4.2.1. Extraction of Clouds

The clouds are detected by considering the hypothesis that, regions of the image covered by clouds present increased local luminance values (due to the direct reflection of the sunlight by the cloud). To automatically detect the presence of cloud in a region, the average of the local luminance (that is the mean image intensity) is used in the algorithm. For this the gray-scale image is divided to a number of small windows and finds the mean intensity $\mu^i$ of each window using the following equation (4.1). If the image is RGB, first we have to convert it into a gray scale image and is necessary to convert back after processing.

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

(4.1)

where $M$ is the number of pixels in $i^{th}$ window and $X^i_k$ denotes $k^{th}$ pixel in the $i^{th}$ window. For an RGB image, convert it to YIQ space and calculate the average intensity of Y channel alone. The window size can be varied depending on the cloud size. If clouds are of varied sizes and occupying only 1% of the larger image resolution, the best window size is 1.5% of image resolution.
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Figure 4.1. Flow Chart of the Proposed Method

- Input Aerial/Satellite Image
- RGB?
  - Yes
    - Convert to YIQ & Separate Y channel
    - Perform Windowing with the required window size & Find the Mean Intensity of each window $i$
    - Find $F = \frac{\text{Max. Mean Intensity}}{\text{Min. Mean Intensity}}$
    - Find $T_i = F \times \text{Min. Intensity value of window } i$
    - $Y(x, y) \geq T_i$?
  - No (Monochrome)

- Extracted Cloud Pixels
- Perform Cloud Processing
  - Create a binary shadow mask of the image
  - Obtain Shadow
    - Find Mean Intensity
  - Obtain Light Areas
    - Find Mean Intensity
  - Find Difference
    - Add difference to image pixel intensity
    - Aerial/Satellite Image of reduced effects of clouds & cloud-shadows
Next, cloud extraction is done by choosing a threshold depending on the statistical properties of the image. Here the threshold is depending on the parameter $F$ which is the ratio of maximum mean intensity $\mu_{\text{max}}$ and minimum mean intensity $\mu_{\text{min}}$ for adaptive segmentation (eqn.4.2).

$$ F = \frac{\mu_{\text{max}}}{\mu_{\text{min}}} $$

(4.2)

If $x'(i,j)$ represents minimum intensity value of the image in the $i^{th}$ region, the threshold $T^i$ is calculated by the following equation (4.3):

$$ T^i = F \times x'(i,j) $$

(4.3)

An image $A$ having cloud infected pixels is obtained by eqn.4.4:

$$ A = \{(x,y) | (x,y) \subset X', X'(x,y) \geq T^i\} $$

(4.4)

### 4.2.2 Cloud Processing

In cloud processing, every independent regions with cloud and without cloud are processed. Thus the luminance content in cloud affected regions is reduced, this, in turn reduces the effect of clouds in the image. Processing of the cloud affected pixels is done using (eqn.4.5):

$$ I' = m_c + \frac{I - m_c}{\sigma_c} \cdot \sigma_s $$

(4.5)

where $I$ is pixel gray level value in cloud regions before processing, $I'$ is pixel grey level value after processing. $m_s$ and $\sigma_s$ are mean and variance of cloudy regions. $m_c$ and $\sigma_c$ are average value and variance of regions without cloud.

### 4.2.3 Shadow Segmentation and Compensation

The final step of the algorithm is the detection of cloud-shadows and its compensation. For detecting shadows, the method discussed in Chapter 3 can be used. The result of the shadow detection algorithm is a binary shadow mask, which will be the input to the shadow removal algorithm.

For shadow processing, we use the method suggested by Guo, R. et al. (2011), in which the RGB color space is first converted to YIQ space (refer section
According to Guo, R. et al. (2011) there are two types of light sources: direct and ambient light. Direct light comes directly from the source, while environment light is from reflections of surrounding surfaces. For shadow areas part or all of the direct light is occluded. The shadow model can be represented by the following equation (4.6):

\[ l_i = (t_i \cos \theta_i L_d + L_e) R_i \] (4.6)

\( l_i \) represents the value for the \( i \)-th pixel in RGB space

\( L_d \) and \( L_e \) represent the intensity of the direct light and environment light

\( R_i \) is the surface reflectance of that pixel

\( \theta_i \) is the angle between the direct lighting direction and the surface norm

\( t_i \) is the attenuation factor of the direct light

If \( k_i = t_i \cos \theta_i \) is the shadow coefficient for the \( i \)-th pixel and \( r \) denotes the ratio between direct light \( L_d \) and environment light \( L_e \), the shadow free pixel of I and Q channels are computed using eqn. 4.7:

\[ l_{i\text{shadow\_free}} = \frac{r + 1}{k_i r + 1} l_i \] (4.7)

For correcting the shadow infected pixel in the Y channel, find the average pixel intensities of shadow \( \mu_{\text{shadow}} \) and light areas \( \mu_{\text{lit}} \). Then the corrected pixel is obtained by (4.8):

\[ Y_{i\text{shadow\_free}} = Y_{i\text{Shadow\_infected}} + (\mu_{\text{shadow}} - \mu_{\text{lit}}) \] (4.8)

Converting the YIQ model back to RGB space we get the resultant image not having any of the cloud interferences and shadowing effects. For panchromatic images shadow compensation is done using eqn. 4.8 alone.

### 4.3. Study Area

The United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Centre identify and download aerial photographs and satellite imagery from USGS, NASA and NOAA. Earth Explorer is the search and ordering
website for all types of satellite data. Fig. 4.2 (a) and fig. 4.3 (a) are visible
(panchromatic) and infrared satellite images of south-east (SE) USA obtained
from AVHRR sensor downloaded from the USGS Earth Explorer
(http://earthexplorer.usgs.gov). Fig. 4.4 (a) is a high resolution (60cm) Digital Globe
Quickbird panchromatic imagery of Amazon rain forest distributed by Global Land
Cover Facility, Maryland, USA (http://glcf.umd.edu/data/quickbird) which is a
center for land cover science under NASA with a focus on research using remotely
sensed satellite data. Fig.4.5(a) is the aerial view of rainforest with clouds, Costa
Rica obtained from USGS Earth Explorer. Fig.4.6(a) is an RGB satellite image
obtained from Google Earth software (http://www.google.com/earth/download).
Fig.4.7(a) is an aerial image having cloud shadows obtained from USGS Earth
Explorer. Fig.4.8(a) shows a MODIS multispectral satellite image (refer
section 2.1.7.1).

4.4. Results and Discussions
The proposed algorithm is evaluated with different types of images including visible
and infrared (VIS & IR) satellite images, RGB and monochrome aerial images, RGB
satellite images having considerable amount of clouds, and in some cases, shadows
in them. The experimental results are shown in below figures from fig.4.2 to fig.4.7.
The method first extracts shadows and clouds from the image and later on, reduce
the effects of both clouds and shadows. The output, hence obtained, is the input
image with reduced or diminished effects of clouds and shadows. All these processes
are based on the values of parameters that are calculated from within the image, and
so the algorithm is ‘adaptive’.

Figure 4.2: (a) Visible Satellite Image of SE USA (b) Cloud Processed Image
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Figure 4.3: (a) Infrared Satellite Image of SE USA (b) Cloud Processed Image

Figure 4.4: (a) Panchromatic Satellite Image of Amazon Rain Forest (b) Cloud Extracted Image (c) Cloud Processed Image

Figure 4.5: (a) RGB Aerial Image of Rainforest with Clouds, Costa Rica (b) Cloud Extracted Image (c) Cloud Processed Image

Figure 4.6: (a) RGB Satellite Image (b) Cloud Extracted Image (c) Cloud Processed Image
The results show that the algorithm works well for both cloud removal and shadow removal. Such cloud and shadow free images can be used as inputs for structural feature extraction processes. In the case of image segmentation programs, where regions like vegetation areas are to be extracted, the clouds or shadows if present, do not pose a problem and they provide an output much reliable and accurate, than the same from an image where the effect of clouds and shadows are present. The algorithm can also be used for cartographic purposes to an extent, as it can be used to find areas of same visual characteristics.

4.5 Comparison of the Proposed Method with Methods using Multispectral Images

As the method is intensity level processing, it fails for denser clouds. Though the cloud level is not thick but the entire scene is affected, then also the algorithm fails. That means each and every pixel is cloud infected and in spatial domain we have to consider a pixel as such; part of the pixel cannot be processed. So cloud detection will give good result but the processing part fails because even though only the part of the pixel is cloud affected then also the entire pixel is removed from the scene.

The algorithm used in Saunders, R.W. et al. (1988) is a standard scheme for cloud detection utilizing the spectral features of multispectral satellite images. Based on this criterion many algorithms are developed which include single channel and inter-channel threshold tests (Zaunick, E. et al., 2008; Gu, L. et al., 2011). Weather forecasting sensors like GOES, MODIS and AVHRR can be best suited for cloud detection in spectral domain. The algorithm developed in Gu, L. et al. (2011) uses MODIS bands for cloud processing in spectral domain.

Fig.4.8 shows a multispectral MODIS image having thick clouds and results obtained utilizing spatial features (our proposed method) and spectral features as the
method described in Gu, L. et al. (2011). It can be concluded that processing in spectral domain is necessary for the case of thick clouds.

![Image](image.png)

Figure 4.8: (a) Multispectral MODIS Satellite Image having Thick clouds (b) Cloud Processed Image using Proposed Method (c) Cloud Processed Image using Gu, L. et al. (2011)

But these types of dedicated cloud tests are used only for weather forecasting or to analyze the effect of global warming. For the case of structural feature extraction we have nothing to do with clouds; we only want to remove the clouds. So if the region has thick clouds better to discard that image and go for some other images of the same region. If the region has thin clouds, the algorithm described in our work is sufficient. But, if the region is near to north/ south poles or mountain areas most of the images taken at any time may have the effect of clouds and if we want to get the structural features of that region, there is a rare possibility to get a cloud free image or an image having thin clouds. For these types of regions, spatial domain processing fails and we have to go for spectral domain processing.

### 4.6 Summary

The solution for signal attenuation and the shadowing effect caused by the clouds is designed in this work. The system manages to diminish the effect of clouds and shadows and also estimate the region underlying it based on the pixel values of the surrounding regions. Unlike most previous methods which are suitable for image sequences, our method can extract and compensate clouds and shadows using only a single image. However, the algorithm can be modified to enhance the results for denser cloud images.