Detection and Compensation of Shadows based on ICA Algorithm in Remote Sensing Image

Chengfan LI, Jingyuan YIN*, Junjuan ZHAO, Feiyue YE
School of Computer Engineering and Science, Shanghai University, Shanghai 200072, P.R. China, E-mail:david-0904@163.com
doi: 10.4156/ijact.vol3.issue7.7

Abstract

The shadow is one of the basic features of remote sensing images, especially high resolution remote sensing images, and greatly reduces the information of earth targets. The detection and compensation of shadow is important hotspot and difficulty of remote sensing image processing. In view of the present shadow detection and compensation characteristics of remote sensing image, this paper puts forward a new method by using independent component analysis (ICA) algorithm, grayscale histogram, RGB channels, HIS space transformation and multi-threshold retinex to achieve the shadow detection and compensation. The shadow detection and compensation were verified by the QuickBird remote sensing image, the shadow correct detection rate reached to 80%. The results show that this proposed method with high precision, easy operation, avoided the complex mathematical morphological operation and has good effect of shadow detection and compensation.

Keywords: Remote Sensing Image, Shadow, ICA, Detection, Compensation

1. Introduction

The high resolution remote sensing images have the characteristics of details clearer and more rich information [1-4]. The shadow is one of the basic features of remote sensing image, it makes obstruction of information of target reflect. Shadow is an ubiquitous image features in high resolution satellite image, the buildings and trees keep out the light led to reflected light intensity regional abate, optical sensor receiving signals is reduced, and the corresponding place area formation of the image darker gray than other areas. The exist shadow has brought great difficulty to subsequent image processing, for example, image segmentation, feature extraction and image classification, it is necessary to handle the shadow areas of high resolution remote sensing images [5-10].

In recent years, many domestic and foreign scholars have proposed variety methods of shadow detection for remote sensing image, and have achieved the certain effect. There are two classes of shadow detection in remote sensing image. One is calculation of the shaded area in terms of the geometry of the object shape, the height of the sun and azimuth Angle, it need a lot of auxiliary data, and has large amount of calculation method and big limitation [11]. The other is image common features based on the shaded area; it can direct calculate the shadow area. The image features include image texture, color, gray and edge, are all based on histogram [12], homeomorphisms system to eliminate shadows technologies [13], normalized method, texture analysis [14], whole variational model method [15] and multiband shadow detection method [16], and so on.

Though these methods can detect the shadow, it also has some shortcomings. Such as histogram method, it is statistical image data according to the two-apex method of gray histogram, then use the histogram test shadow tensile technique remove shadows, for water, the processing results low as shadow is considered as shadow, high reflectivity in shadows area was are considered as the non-shadow, obviously it has much error in large area, and it is not apply to the complex terrain image. And some shadow detection methods and involve in mathematical morphology methods including corrosion and expansion algorithm, it is more complex and not easy control. Generally speaking, a common eliminate shadow method contains the image processing and shadow region information compensation. Compensation shadow region information can compensate for shadow areas only processed, and helps keep and improve overall quality image. Due to the complexity of remote sensing images and its influence shadow numerous factors. Theoretically, totally obliterate the shadow is almost impossible.
Domestic and foreign scholars recently also proposed some shadow detection and compensation algorithms, but so far no one is known effective method [17].

Independent component analysis (ICA) is a statistical method that deals with observations vector to extract linear components as independent as possible. This simple idea has proved very fruitful for signal processing and images analysis. More generally, it is used in all cases where a system of multiple sensors, listens to a discrete set of sources with consistent signals, the source signals may be assumed to be mutually statistically independent. However, the idea of seeking independent components was not just a method for signal and image processing. The ICA is really an extension of a well-known statistical method, for example, the principal component analysis (PCA) method. In recent years, it has found widespread use in the medical image processing, signal unmixing and wireless communication, and so on.

Shadow is an important feature of high resolution remote sensing image, it has severely restricts remote sensing automatic interpretation and thematic information extraction. How to detect and compensate the shadow accurately also has become a hotspot and difficulty of the high resolution remote sensing research field. In view of the present characteristic of shadow detection and compensation in high resolution remote sensing image, this paper first analyzes the shadows internal gray distribution of remote sensing image based on ICA algorithm, through to the RGB channel analysis of the shadow and the non-shaded region are analyzed to distinguish shadow and the non-shadow region; secondly is distinctions between shadow and water features, shadow areas detection and compensation realized by Retinex multi-threshold method; finally is the shadow detection precision assessment. The proposed method has high accuracy of shadow detection, simple operation and convenient features, it avoids complex mathematical morphological operation, and has good shadow compensation effect and better potential application.

2. ICA theory

The assumptions ICA are the source variable s is statistical independent. Meanwhile, the source variable is also a non-Gaussian distribution. Obviously, the distribution in the basic model is unknown. The mixed matrix A is calculated and can further calculate the inverse matrix of A. That is to say to separation the matrix $X = A^{-1}$, thus has gotten the estimate $y$ of dependent component $S$. Let $m$ be the number of sensors, which provides $m$ linear combinations of the original source signals to produce the observed $X = (x_1, x_2, \ldots, x_n)^T$, $n$ is the number of measured signals. We then have

$$x_i = a_{i1}S_1 + a_{i2}S_2 + \cdots + a_{in}S_n, \quad i = 1, 2, \ldots, m$$

(1)

The formula (1) can also be expressed as follows:

$$X = AS = \sum_{j=1}^{n} a_jS_j$$

(2)

where $A= [a_1, a_2, \ldots, a_n]$ is mixed matrix, $a_i$ is the base vector of mixed matrix. The source signal was estimated by observation $X$ and mixed matrix $A$. In the remote sensing images, we will get the different ICA components by ICA processing.

3. Shadow region characteristics analysis

Shadow features mainly displays in the following aspects: the shadow of the surface appears represents the dark due to lack of light; shadows shape and size are decided by the sun rises geometry angle, height and shape and the position of object and the sensors; shadow pixel in all visible bands are low value pixels. The original high resolution satellite images are gray image, the traditional shadow identifying method will produce a different shaded area to discrimination based on different gray threshold with gray size. In urban areas there has a similar shadow the features with the images of gray
including water, characteristics of the roof of the building, some part of objects, boundaries etc. A pixel gray can only partly reflect the characteristics of shadow, and do not represent the existing shadow.

3.1. Gray level distribution of shadow internal region

Because the shadow areas commonly has brightness characteristics, so at present the most of the algorithm put forward mainly based on these features. For shadow area with strong reflex terrain, its brightness values increase, and may even more than some of the non-shadow dark area. If detecting the characteristic only uses low brightness, the shadow areas of the earth objects including strong reflex terrain will be leaked out detection.

The difference values of RGB channel between shadow region and non-shadow region according to the object illumination model analysis as shown below [18]. The hue of objects is determined by weight of contain different color, shadow region R, G, B value equivalent weight reduction, red changes caused by increased blue components, tonal value tall. Each object has more pixels in the high resolution remote sensing image, and has a corresponding strong statistical characteristic. The Figure 1(a) is grayscale histogram of shadow region in high resolution remote sensing image. From the Figure 1(a), there have low brightness values in shadow region.

![Figure 1. Gray graphs ((a) shadow; (b) water)](image)

3.2. Color characteristics distribution of water

Research shows that the grayscale histogram characteristics of the shadow and water is very similar, it is difficult to distinguish. But in fact water can be observed with more uniform variation characteristics. Extracting shaded area and water, Figure 1(b) distribution histogram was established by the grayscale area statistical analysis. From the Figure 1(b), the grey distribution of water has the characteristics of sharp and single-peak gray distribution, and more diverse area in shadow region, Compared to its projection place, the basic representation have wider distribution and multi-peak characteristics.

The water in the shadow region usually takes the dark because of its image of reflection coefficient is lesser, its brightness values and shadow regional brightness values was close. If only tested using brightness low value characteristic will appear mistake that water is divided into shadow. Due to blue band has good penetration ability to water, but blue band gets atmosphere scattering, green bands severely affected by the strongest of water penetration ability. Therefore, the brightness difference value of green channel and blue channel for water is a markedly different, namely \( \triangle I_G = I_G - I_B \). While general shadow area are not have such characteristics, blue channel and green channel have similar brightness values, its brightness difference value is smaller than water \( \triangle I_I \), namely \( \triangle I_I < I_G \).
Figure 2. The grayscale histogram of component G and B ((a). G component of water; (b). B component of water; (c). G component of shadow; (d). B component of shadow)

Figure 2 (a) and 2 (b) is the grayscale histogram of G and B component of water in high resolution remote sensing image, Figure 2 (c) and 2 (d) is the grayscale histogram of G and B component of water in shadow region. Through the comparison of Figure 2, the brightness value the B and G channel in water is bigger than brightness difference value in a shadow area. The grey value of image was transformed by these features. The grey value of low value part can effectively detect the characteristics of water and the mass, and grass and shaded area road gray value characteristics clearly different from water and the shadows, it is very easy to apart the shadows of different kinds of earth objects.

4. Shadow detection of high resolution remote sensing image

According to above analysis, the realization process of shadow detection of high resolution remote sensing images mainly includes all shadow detection and discrimination between shadow and water.

4.1. All shadow detection

The general shadow region detection is in HSI (Hue, Saturation, Intensity) space due to strong correlation of the three components in RGB space. Commonly color remote sensing image often represented by RGB color, so it needs to undertake color space transformation before image processing. The transformation formula from RGB to HIS expressed as follows:

\[
I = \frac{R + G + B}{3} \\
S = 1 - \frac{3}{R + G + B} \cdot \min(R, G, B) \\
H = \cos\left(\frac{0.5 \cdot ((R - G) + (R - B))}{\sqrt{(R - G)^2 + (R - G) \cdot (G - B)}}\right)
\]

The shadow areas statistics in remote sensing image show that the gray variance of shadow area less than other general shadow region. Different between shadow region grey values of strong consistency, the surface properties influence of shadow areas by the mean and variance and gray cast shadow is not very obvious. Accordingly, this paper use I component covariance threshold generally improved shadow detection threshold value method. Namely, combined with human recognition ability and computer operation ability, determine covariance threshold and brightness threshold, this method overcomes the problem of repeated trying calculating threshold.

Firstly, selecting two blocks shadow areas have representative using human ability. One is the brightest area in shadow, the other is the darkest area in shadow, and separately calculated the maximum: \(I_{\text{max1}} = \max\{I(x_i, y_i), I_{\text{min1}} = \min\{I(x_i, y_i), I_{\text{max2}} = \max\{I(x_j, y_j), I_{\text{min2}} = \min\{I(x_j, y_j)\} \).
\[ I(x, y) \] is the brightness value of the selected shadow region. \((x_1, y_1)\) and \((x_2, y_2)\) represent
the brightness scale of the selected shadow region, respectively. Compared to these two groups of extreme,
if \(I_{\text{max}1} > I_{\text{max}2}\) and \(I_{\text{min}2} < I_{\text{min}1}\), then sure, \(I_{\text{max}1}\) and \(I_{\text{min}2}\) is brightness segmentation threshold.

The covariance value of the selected shadow region is below following:

\[
\text{cov} = \sqrt{\sum_{m=-1}^{1} \sum_{n=-1}^{1} (I(i+m, j+n)-p)^2}
\] (6)

where \(P\) is average brightness value between any pixels and its eight constituency domain neighborhood pixels brightness, \(I(i, j)\) is center pixel luminance values of any selected eight neighborhood pixels in shadow region. Calculation the \(\max(\text{cov})\) of covariance choose regional, make sure that \(\max(\text{cov})\) is covariance segmentation threshold.

Calculating the covariance value of luminance values in the image range from the \(I_{\text{max}1}\) to \(I_{\text{min}2}\), between its pixels eight neighborhood pixel luminance values, if \(\text{cov} \leq \max(\text{cov})\), the calibration \(\max(\text{cov})\) is shadows.

### 4.2. Difference between water and shadow

Firstly, the difference between G and B channel of water in shadow region was calculated. From the above analysis, the brightness difference of water in G, B channel than shadow region in value the B channel G. through to the characteristics of comparative analysis of difference value to determine the threshold value \(TG - B\). Secondly, using this threshold value to detect the former two paces the shadow areas and need to further process, remove \(\Delta I\) part that the greater than \(TG - B\), that is to say the water in the shadows will be removed.

### 5. The compensation of shadow in high resolution remote sensing image

#### 5.1. Multi-threshold Retinex method

Retinex theory is proposed first by Land [19] as the human eye perception brightness and color visual model. Let assumption the ideal image \(f(x, y)\) is: \(f(x, y) = r(x, y) \times i(x, y)\). The image \(f(x, y)\) is represent by environment brightness function \(i(x, y)\) and the reflectivity function \(r(x, y)\). Environment brightness function \(i(x, y)\) is described the brightness of the environment, it relies on objects, expression is object's reflection ability and light intensity, including scene the detail information. Environment brightness function based on model is a small change of low-frequency information images. Jobson [20] and other researchers defined single threshold function Retinex algorithm. Multi-threshold Retinex algorithm is an improved method of single threshold function Retinex algorithm. Such an approach is often used to eliminate shadows. Specific algorithm process as follows [21]:

\[
R_{\text{MSR}}(x, y) = \sum_{k=1}^{k} W_k (\log I_i(x, y) - \log[F_k(x, y) * I(x, y)]) \quad i=1, 2, 3.
\] (7)

\(R_{\text{MSR}}(x, y)\) is the last result, \(W_k\) is the relational weight coefficient of \(F_k\), and \(k\) is the number of environment brightness function. \(I_i(x, y)\) represent the i-th color channel of original remote sensing image. It represent the color image when \(I = 3\), \(*\) is the convolution operators, \(F_k(x, y)\) is convolution kernels, and it is a Gaussian function. The specific function is:

\[
F_k(x, y) = Ae^{-r^2/\sigma^2} \quad (r^2 = x^2 + y^2); A = 1/\int \int F(x, y) dx dy
\] (8)

where \(A\) is a constant, the environment brightness function \(F_k(x, y)\) choose the standard deviation \(\sigma\) to control the scale and range of environment brightness function [22].
The selection of standard deviation $\sigma$ is very important to enhance the image, and it determines the information quantity of retained. When choosing smaller standard deviation, it can finish color dynamic range compression. But color perception need better consistency, so it needs to seek a balance between color dynamic range compression and color perception consistency [23]. The image after such processed not only keeps the details, but also got good color restoring effect. The segmentation parameters of multi-threshold Retinex algorithm are shown in Table 1 below.

| Table 1. The segmentation parameters of multi-threshold Retinex algorithm |
|---------------------------------|-----------------|-----------------|-----------------|
| Dimension 1 | Dimension 2 | Dimension 3 |
| Size | 5 | 100 | 200 |
| Characteristics | Retain more Detail information | Good color Restored effect | Computing faster, can quickly browse shadow compensation |

5.2. Smooth shadow boundary

The shadow of object becomes clearer area by the Retinex threshold method for the enhanced shadow region, meanwhile another problem produced is the shadow boundaries became more apparent, so we need shadow on the border fuzzed. Use $3 \times 3$ window to suits the shaded area, $3 \times 3$ window center for shadow boundary pixel, pixels within mark out the window first and last pixel, according to this two sure a straight line $L_1$, calculates the slope $K$. Through the window in vertical pixels and center of linear $L_2$, draw another linear $L_1$ and $L_2$ in straight line near the window center select the most three pixel, pixels and computational that is to say this value instead of center pixels. Every pixels of the shadow boundary will be treated according to the pixels order to move the $3 \times 3$ window.

6. Empirical study

6.1. Research data

This study takes the QuickBird high resolution remote sensing image inner city somewhere as the research objects. The research areas includes road, water, buildings, tall trees, shadow with buildings shadow, trees shadow, terrain shadows and automobile, etc, this study mainly focus on crushing shadow in buildings shadow, and neglected for other shadow. QuickBird satellite image has a pan band and red, green, blue, near infrared multispectral bands, the pan band spatial resolution is 0. 61 m, multispectral spectrum resolution is 2.44 m.

6.2. Shadow detection and compensation

The result of shadow detection and compensation in QuickBird high resolution remote sensing image is shown in Figure 3. The Figure 3(d) is the composition image of three ICA components of QuickBird image.
Figure 3. The shadow detection and compensation images ((a). the first component of QuickBird image; (b). the second component of QuickBird image; (c). the third component of QuickBird image; (d). the false composite image of the three components; (e). the detection of shadow; (f). the compensation of shadow)

Figure 4. The comparison of grayscale histogram ((a). shadow detection; (b). shadow compensation)

From the Figure 3(e), the shadow region was detected perfectly. Figure 3(f) is the compensation results after the multi-threshold Retinex method and smooth shadow boundary process, the shadow compensation has good effect. In addition, from the Figure 4, in the shadow region of two pieces of remote sensing image before and after the compensation, this paper proposed compensation method based on gray-level histogram the shadow can better expand the brightness of the shadow areas after the scope of shadow region, rebuilding terrain clearer, and it greatly improves the image visual effect.

6.3. Accuracy evaluation of shadow detection

The existing accuracy evaluation standard of shadow detection involves two aspects, one is the correction detection rate:

\[
N_{DR} = \frac{N_{TP}}{N_{TP} + N_{FP} + N_{FN}} \times 100\% \]

the other is loss rate:

\[
N_{FR} = \frac{N_{FN}}{N_{TP} + N_{FP} + N_{FN}} \times 100\%
\]

Where \(N_{TP}\) (true positive) is the correct number of identified shadow region from the all shadow region, \(N_{FN}\) (false negative) is the number of leak detection in shadow region, \(N_{FP}\) (false positive) is the mistaken number of shadow region. The accuracy evaluation table of this paper proposed shadow detection method is shown in Table 2 below.

Table 2. Shadow detection accuracy evaluation

<table>
<thead>
<tr>
<th></th>
<th>(N_{TP})</th>
<th>(N_{FN})</th>
<th>(N_{FP})</th>
<th>(N_{DR})%</th>
<th>(N_{FR})%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>80.00</td>
<td>13.33</td>
</tr>
</tbody>
</table>
From the Table 2, the correction detection rate $N_{DR}$ is 80%, the leak detection rate $N_{LR}$ is 13.33%, it have been achieved a good effect. Because of the shadow compensation effect is restrict first by shadow detection accuracy of the regional characteristics and its coessential characteristics, so comparing two period before and after shadow compensation of high resolution remote sensing image histogram to obtain the compensation shadow.

7. Conclusions and discussions

The shadow is an important feature of high resolution remote sensing image, and it serious interferes with the reflectance information of earth target and restricts the thermal information extraction accuracy, and also has become the hotspot and difficulty in high resolution remote sensing image. This paper using ICA algorithm, gray statistic histogram and RGB channel distinguish shadow, the shadow and water information, realized the shaded area detection on the basis of analysis of internal gray distribution in the high resolution remote sensing image of shadows. Secondly, shadow areas detection and compensation was achieved by Retinex method multi-threshold method, and a shadow detection accuracy evaluation was conducted. The results show that this method has the characteristics of high precision, simple operation, good shadow compensation effect and potential application.

In addition, the objects cause shadows varied including the object of trees and tall buildings, landslides. Due to the length of article, the shadow detection and compensation method proposed is appropriate or not for different shadow type, the high reflection object shadow region whether can consider as shadows and how to cope with, this paper is not involves in these aspects. But in fact this will depend on further discussions and need to be solved.

8. Acknowledgements

We thank the vital comments made by the reviewers and the editorial team. This work was supported by the Key Project of Shanghai Leading Academic Disciplines of China (No.J50103).

9. References


