Shadow Detection and Compensation for Color Aerial Images

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1 Introduction

Due to the special requirements for the weather condition during the aerial photography, the appearance of shadow on the images caused by ground objects with certain height is unavoidable. The shadow on the aerial images has dual characteristics. On the one hand, the shadow can be used to determine the height of ground objects or to help for the building recognition and shape extraction. On the other hand, the existence of the shadow on the images will not only affect the recognition of objects in the shadowed regions, but also influence the success of algorithms for edge detection, ground cover classification and image matching. Therefore, it is necessary to identify and compensate the shadowed regions on aerial images.

The shadow processing on the images consists of two main aspects: the shadow detection and the shadow elimination or compensation. Actually, the intensity values or color components of image pixels are the products of illumination function and ground object reflection, and it is nearly impossible to completely remove shadows from images due to the complication of the above-mentioned compound functions. However, there still exists the intensity and color information in the shadowed regions, which makes it possible to compensate the information of the shadowed regions. However, one of the key problems is how to improve the visibility of features in shadowed regions with retaining the information of non-shadowed regions unaffected. Although the traditional image processing algorithms, such as the histogram...
transformation and homomorphic filtering\(^1\), are helpful for the enhancement of shadowed regions, they will simultaneously affect the information of non-shadowed regions. In recent years, several algorithms for the shadow detection and compensation have been proposed\(^2\), but there is not a generally acknowledged efficient approach.

2 Principle of shadow compensation

From the mechanism of aerial photography, we know that the intensity of an image is composed of two parts: one is the amount of available light to illuminate the ground objects; the other is the ability of ground objects to reflect light. It is well known that the intensity of image at any point \((x, y)\) can be modeled as

\[
I(x, y) = L(x, y) \times I(x, y)
\]

(1)

where \(L(x, y)\) is the illumination function of the sun, and \(I(x, y)\) is the reflectivity function of ground objects. The illumination function and the ground reflective function are quite different in the aspect of spectrum characters. Usually, the former is corresponding to the low frequency component of image intensity because of the even illumination for the ground scene, while the latter is corresponding to the high frequency component of image intensity due to the ground details, edges and textures. For the shadowed image regions, the intensity values are usually small and the color information is poor due to the short of illumination. The intensity of shadowed image regions can be modeled as

\[
I(x, y) = a(x, y) \times L(x, y) \times I(x, y)
\]

(2)

where \(a(x, y)\) stands for the intensity attenuation function of the shadow. It seems that, in order to compensate the shadow information, we only need to adjust the illumination function for the shadowed regions as well as take account of the color information.

On the basis of the above analysis, the procedure of the shadow detection and compensation for color aerial images may comprise the following four steps: ① transforming the digital color image from RGB space to HSI space, which contains the information value \(I\), ② performing the morphological opening operation and closing operation to intensity value \(I\) in order to obtain the low frequency component \(I_L\) of intensity value, ③ performing the threshold processing and conditioned morphological erosion operation to \(I_L\) in order to separate the shadowed regions from the non-shadowed regions, ④ adjusting the color components to the original image in the RGB color space in order to compensate the shadowed regions.

3 Method of shadow compensation

3.1 Low frequency separation

From section 2 we know that the image intensity values corresponding to the illumination are mainly concentrated on low frequency part, therefore, we can use the low frequency component of image intensity to substitute for the illumination function of whole image. Actually, the image intensity values also contain the reflection information of ground objects. In order to separate the illumination component from the image intensity, an algorithm based on the gray-morphological smoothing filter is used for obtaining the low frequency component:

\[
I_L(x, y) = f_s(f_c(I_c(x, y), g), g)
\]

(3)

where \(I(x, y)\) is the intensity function of the original image; \(I_L(x, y)\) is the low frequency component of image intensity; \(f_s\) stands for the closing operation; \(f_c\) stands for the opening operation; \(g\) is a structuring element which represents the morphological smoothing filter and it is usually a 3×3 or 5×5 matrix. Fig. 1 shows an example of the separation of low frequency component.

3.2 Shadowed region separation

In order to separate the shadowed regions
from the whole image, we can perform the
threshold processing of the low frequency
component $I_L(x, y)$ as follows

$$I'_L(x, y) = \begin{cases} 
\text{low,} & I_L(x, y) < \text{low} \\
I_L(x, y), & \text{low} \leq I_L(x, y) \leq \text{high} \\
\text{high,} & I_L(x, y) > \text{high}
\end{cases}$$

(4)

where $\text{high}$ and $\text{low}$ are two thresholds ($\text{high} > \text{low}$), which stand for the mean intensity of non-shadowed regions and shadowed regions, respectively, and their values can be obtained through the analysis of image gray histogram.

Due to the effect of light diffraction, the intensity change from the shadowed regions to the non-shadowed regions is usually not abrupt, but smooth. We can call this border area as intermediate area, just as shown in Fig. 2. The shadow processing of these areas should be taken individually, and their intensity thresholds can be determined according to $\text{low} \leq I_L(x, y) \leq \text{high}$ in Eq. (4).

**3.3 Conditioned erosion operation**

The morphological erosion operation is defined as follows:

$$I - g(x, y) = \min_{i, j} (I - g(i, j))$$

(5)

where $(x, y)$ are the image coordinates; $(i, j)$ are the structuring element coordinates; $I$ stands for the intensity of image; $g$ stands for the intensity of structuring element. The procedures of morphological erosion operation are: taking $g(i, j)$ as a template and then searching the minimum image gray difference within the scope of structuring element.

The conditioned erosion operation can be defined as

$$I(x, y) - k > (I - g)(x, y)$$

(6)

where $k$ is a constant, $0 < k < 1$; in our experiment, $k = 0.1$; the value of $g(x, y)$ is usually equal to zero.

There are two purposes of the conditioned erosion operation for $I'_L(x, y)$; one is to further smooth the low frequency component of intensity so as to eliminate the reflection information of ground objects from image; the other is to further separate the shadowed regions and non-shadowed regions. Fig. 3 is an example of
conditioned erosion operation. If you view the processing results carefully, you will find that the line with arrow highlighted in Fig. 3(b) will disappear after the erosion operation as shown in Fig. 3(c), which exactly indicates the fact that the shadow is a closed area.

![Fig. 3 Result of conditioned erosion operation](image)

### 3.4 Shadow compensation

The shadowed region on the color image looks dark, and the blue component usually takes dominant position slightly. This is because the received illumination of shadowed regions is mainly from the scattering of the blue sky. When we compensate the intensity and color information for the shadowed region, the blue component of shadowed region should be restrained properly. In the following, the RGB color space is used for the adjustment of intensity and color component of shadowed regions on the original image:

\[
RGB'(x,y) = \begin{cases} 
R(x,y) \times k^a \\
G(x,y) \times k^b \\
B(x,y) \times k^b 
\end{cases}
\]

where \(R(x, y), G(x, y)\) and \(B(x, y)\) stand for the red, green and blue component respectively; \(a\) and \(b\) are the adjustment parameters of color, and their values are usually close to 1, and \(a > b\) (in our experiment, \(a = 1.0\) and \(b = 0.8\), for restraining the blue component).

For the non-shadowed regions, because of the fact that \(I'(x,y) = \text{high}\), i.e. \(k = 1\), it means that only the intensity and color components of shadowed region will be adjusted based on Eq. (7), the non-shadowed region will retain unaffected.

### 4 Experimental results and analysis

On the basis of the approach introduced above, an experiment of shadow compensation is taken by using several color images, and the experimental results are shown in Fig. 4.

Fig. 4(a) is a typical color aerial image of urban area. After separating low frequency component of intensity and shadowed regions from non-shadowed regions, we can obtain Fig. 4(d). In Fig. 4(d), you will find that even though the white car is in the shadowed region, it is still identified as the part of non-shadowed region because its intensity is greater than the threshold \(I'_{\text{low}}\). After the conditioned erosion operation, the white mark of the car disappears in Fig. 4(e). The final result of shadow compensation is shown as Fig. 4(f).

Fig. 5 is an example of shadow compensation for the trees. From Fig. 5 you will find that the result image looks lack of stereo feeling compared with the original image. This is because the tree crown is undulated, when the cast-shadow of tree on the ground is compensated, the self-shadow of the tree leaves will be compensated simultaneously, which will influence the stereo visual effect of the trees.

### 5 Conclusions

It is very meaningful for the shadow detection and compensation of color aerial images
Fig. 4 Result of shadow compensation

of urban area with large scale. The shadow compensation can not only improve the visibility of features in shadowed regions caused by buildings or trees, but also improve the success rate of algorithms for edge detection and object recognition. Experimental results indicate that the proposed method is efficient for the shadow detection and compensation while retaining the information of non-shadowed regions unaffected.

References

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