SHADOW DETECTION OF URBAN COLOR AERIAL IMAGES BASED ON PARTIAL DIFFERENTIAL EQUATIONS

Yue Wang [a, *], Shugen Wang [a]

[a]School of Remote Sensing Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan 430079, China - Redflower_yue@126.com, wangsg@whu.edu.cn

Commission II, WG II/2

KEY WORDS: Shadow Detection, Urban Aerial Image, Partial Differential Equations, Image Understanding, Feature Detection

ABSTRACT:

Shadow detection plays an important role in digital aerial image processing. In this paper, shadow is treated as a special kind of image degradation. Shadow region commonly has lower brightness than non-shadow region. And, shadow region tends to have a slow gradient change in luminance value, or means to have some conformability. On the basis of these analyses, an edge detector is proposed firstly. Then, inspired by the general principle of the partial differential equations used in image restoration, a new shadow detection algorithm based on the PDES is presented, which uses the gradient values to be the parameter of edge detector. After the experiments with several urban color aerial images, it shows that the presented algorithm is effective for shadow detection, and no additional information is required except for the image itself.

1. INTRODUCTION

In many cases, aerial images are contaminated with shadow caused by buildings, trees and bridges, etc. As one of the features in aerial image, shadow can provide geometric and semantic clues about the shape and height of its casting object and the position of the light source. On the other hand, shadow can be treated as a special kind of image degradation. The poor visibility in shadow region directly influences computer operations such as object recognition, change detection, scene matching and true orthophoto generation. Therefore, the research of shadow detection on images is of great significance.

Robust shadow detection is considered as a difficult problem in computer vision and image understanding. Due to the reason that shadow usually holds some particular properties in different color spaces, many approaches for shadow detection and compensation based on invariant color models have been developed in recent years [1-3]. Tsai [1] presented a method which uses the spectral ratio image in HIS space to segment shadow, but dark blue objects and dark objects in images will be segmented mistakenly. Susuki et al. [2] presented a method that applies separation of spatial frequency components and probabilistic shadow segmentation in the RGB space and compensations of intensity and saturation values to improve the visibility of features in shadow region while retaining non-shadow region and the natural tint of shadow region. The parameters of above methods only fit into limited illumination conditions and cannot be applied to complex images. Some papers located shadow by image geometric information, such as detection edges of shadow regions, or complex projection computation, etc. Jiann-Yeou Rau [4] and Yan Li, etc [5] proposed a mathematical model to detect the occlusion and shadow by visibility analysis and photogrammetric engineering. But these approaches require lots of exact geometric information, such as the surface height information (DBM or DTM), the sun direction and so on. Shugen Wang and Junli Wang [6] presented an algorithm based on total variation theory to detect shadow region on the digital images automatically.

In this paper, we treat shadow on urban color aerial images as a special kind of image degradation. Based on the constraints that shadows possess in both intensity and geometry, we can obtain the important gradient values of shadow regions. Then, a new shadow detection algorithm based on the partial differential equations (PDES) is presented, which takes the gradient values as the parameter of edge detector. The experiment results indicate that the boundaries of segmented shadow regions are preserved well, and the information of non-shadow region remains unaffected.

2. SHADOW DETECTION

The theory of the partial differential equations is described in this section firstly, then, a shadow detection algorithm based on the PDES is presented. The parameters of concerned algorithm are determined by the gradient values, which are obtained by the convolution of the image with different filters.

2.1 Edge detector based on gradient

The luminance value of each image pixel is the product of illumination function and ground object illumination. Shadow region on the image is mainly caused by total or practical occlusion of the direct light source of illumination. As a result, shadow region commonly has low brightness than non-shadow region. And, shadow region tends to have a slow gradient change in luminance value, or means to have some conformability.

Thresholding is simply the method of binarizing an image by setting all pixels whose values are greater than some threshold level to “high”, and the remaining pixels to “low”. It’s also

* Corresponding author.

usually used to threshold shadow region. But considering the complex conditions in color aerial image, it is difficult to select the most suitable threshold level to best separate shadow region from non-shadow region.

In this paper, we presented a parameter function used for edge detection, which controls the speed of the diffusion of the PDES. Image will be adaptively segmented to detect shadow region with the computation of the PDES.

Let $u(x, y)$ be an intensity image and the most common method of obtaining a gradient image is to compute local derivative at each pixel:

$$\nabla u = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial u}{\partial y} \end{bmatrix} \tag{1}$$

and the gradient magnitude is:

$$\left|\nabla u\right| = \left[G_x^2 \quad G_y^2\right]^{\frac{1}{2}} \tag{2}$$

The edge detector $g\left(\left|\nabla u\right|\right)$ can be defined as

$$g\left(\left|\nabla u\right|\right) = \frac{1}{1 + k\left|\nabla M * u\right|^2} \tag{3}$$

where $\nabla M * u$, a smoother version of u, is the convolution of the image u with different two-dimensional filter M. And k is a constant depended on I.

The edge detector $g\left(\left|\nabla u\right|\right)$ is strictly positive in homogenous regions and near zeros on the edges. It is used for edge detection and controls the diffusion speed of the PDES. if ∇u has a small mean in a neighbourhood of a point (x, y), the point (x, y) will be treated as an interior point of a smooth region of the image, and the diffusion will be strong; on the other hand, that is, if ∇u has a large mean value in the neighbourhood of a point (x, y), then this point will be treated as an edge point, and the diffusion will be lowered, since assumes $g\left(\left|\nabla u\right|\right)$ considerably smaller values for large values of $\left|\nabla u\right|$. The balance between the forcing term and the diffusion term is made by $1 - g$, which works as a moderated selector of the diffusion process.

Until present, there are no rigorous choices for the values of k. In practice the k constant was chosen in the manner in which allows the function $g\left(\left|\nabla u\right|\right)$ to carry out its role. Because we want to detect the interior points of shadow region, in this paper, we think k should be $0 \le k \le 0.001$. Although shadow is dark, it is colourful in different images, so k increases with the increase of contrast between shadow region and the whole image.

2.2 Description of the proposed algorithm based on the PDES

The partial differential equations have been extensively used and studied in image processing in the past decade because of their flexibility in modelling and various advantages in the numerical implementation. In this paper, shadow on urban color aerial images is treated as a special kind of image degradation, so a shadow detection algorithm based on the PDES is proposed.

The basic idea of PDES is to represent an image as a $\Re^2$ function. Let I be an observed image and u be the representation of the reconstructed image. These functions can be defined as functions of $\Omega \subset \Re^2 \to \Re$ that associate the pixel $(x, y) \in \Re^2$ to its greyscale levels $I(x, y)$ or $u(x, y)$; Ω is the image support.

The edges are defined as being the curves where the gradient obtains its local maximum. Early edge-based segmentation approaches such as Canny's edge detector use local filtering techniques. These approaches have light computational cost and stable under noise, but have difficulty in establishing the connected edge.

Malik and Perona were pioneers in sacle space image processing [7].The Perona-Malik flow can be used for both edge detection purposes and image de-noising purposes. They substituted the heat equation by the following anisotropic diffusion equation:

$$u_t = div\left(g\left|\nabla u\right|\nabla u\right), \quad \text{in } \Omega \times \mathbb{R}_+ \tag{4}$$

$$u(x, y, 0) = I(x, y) \tag{5}$$

Where g is a non-increasing and smooth function, such that $g(0) = 1$, $g(s) \ge 0$, and $g(s) \to 0$ when $s \to \infty$. The idea is that if $\left|\nabla u\right|$ is large, then the diffusion will be low, and therefore the exact localization of the edges will be preserved.

Nordström [8] introduced the forcing term $u - I$ in the Malik-perona (4, 5) resulting in the model

$$\frac{\partial u}{\partial t} - div\left(g\left|\nabla u\right|\nabla u\right) = I - u \tag{6}$$

This new term has the property of preserving $u(x, y, t)$ close to the initial $I(x, y)$. It has the advantage of possessing a nontrivial stationary state eliminating, in this way, the necessity of a selection process for stop time.

Our work is inspired by the algorithms of Nordström [8] and Shugen Wang [6]. We propose the following algorithm based on the PDES model for shadow detection:

$$u_t = g\,div(\frac{\nabla u}{|\nabla u|}) - (1-g)(u-I)\,,\quad x\in\Omega\,,\quad t>0 \qquad (7)$$

$$u(x,y,0) = I(x,y)\,,\quad x\in\Omega\,, \qquad (8)$$

$$\frac{\partial u}{\partial n} = 0\,,\quad x\in\partial\Omega\,,\quad t>0 \qquad (9)$$

where g is the edge detector calculated in equation (3) , $I(x,y)$ is an image to be processed, $u(x,y,t)$ is its smoothed version in the scale " t ".

2.3 Numerical approximation of the model

Let u_{ij} denote the value of the intensity of the image u at the pixel $(x=i\Delta t, y=j\Delta t)$. $u(i,j,t_n)$ is denoted by u_{ij}^n . The time derivative u_t at (i,j,t_n) is approximated by the forward difference $\frac{u_{ij}^{n+1}-u_{ij}^n}{\Delta t}$, where Δt should be not more than 0.25.

Using Neumann boundary conditions, we compute $u_{ij}^{n+1}, n=0,1,...,N$, by

$$u_{ij}^{n+1} = u_{ij}^n + \Delta t g\,div(\frac{\nabla u}{|\nabla u|}) - (1-g)(u-I) \qquad (10)$$

where $u_{ij}^0 = I(x_i, y_i)$.

The term $div(\frac{\nabla u}{|\nabla u|})$ is the local curvature of the iso-intensity contour. Both the central difference and the central difference with half grid are used to approximate the term $div(\frac{\nabla u}{|\nabla u|})$ in our experiments. To take full advantage of the character that there is obvious different variance between shadow region and non-shadow region, and taking into account the results of central differences with half grid operator is superior to the results of direct difference operator in shadow detection, we apply central difference with half grid steps to approximated the term $div(\frac{\nabla u}{|\nabla u|})$ (future details see [6]). The term $|\nabla u|$ is approximated from the smallest two values among eight one-sided difference that can be obtained from the eight neighbouring values of the given point.

The effect of each different diffusion filter is different in shadow detection. $\nabla M * u$ is the gradient of a Gaussian-smoothed version of u given in [7] and [8]. The Gaussian filter is isotropic and therefore smoothes the image in all directions blurring sharp boundaries. The Sobel filter is also applied in our experiments. The compared results are presented in section 3.

Shadow detection is an iterative calculation process. In the calculation process, the algorithm suppresses changing pixels' values of the non-shadow region to stand out the shadow region.

3. EXPERIMENTAL RESULTS

The proposed shadow detection algorithm is implemented in MATLAB programs under Microsoft Windows XP environment. We apply the algorithm in several actual urban color aerial images, and the image is operated band by band in original RGB color space. Experimental results show that our method is effective to detect shadow. We also have conducted an experiment to evaluate and compare our algorithm with the method based on invariant color models given in [1].

In the first experiment, we apply the rotationally symmetric Gaussian lowpass filter of size 5 with standardard deviation sigma 0.8 to obtain the image's gradient values. The test image is a color aerial image, and the filter and the equation (10) are operated band by band in original RGB color space. As we have seen, shadow regions appear a high contrast with the whole image, so we let $k = 0.0008$. The discretization of the equation (10) was run for 20 iterations with $\Delta t = 0.05,\ k = 0.0008$. The original image shown in figure 1(a) is segmented by the proposed shadow detection method and shown in figure 1(b). The segmentation result is compared with that of the methods given in [1]. The figure1(c) and (d) shows the detected results by Tsai's method. From the compared result, we can see the information of non-shadowed regions remains unaffected using our method.

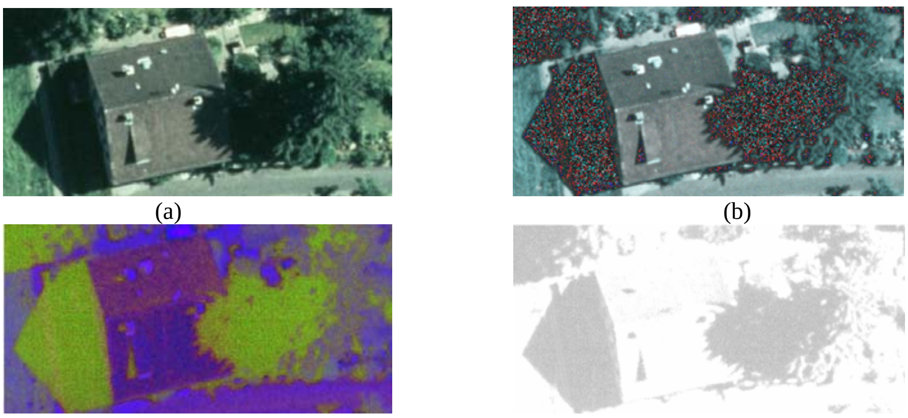
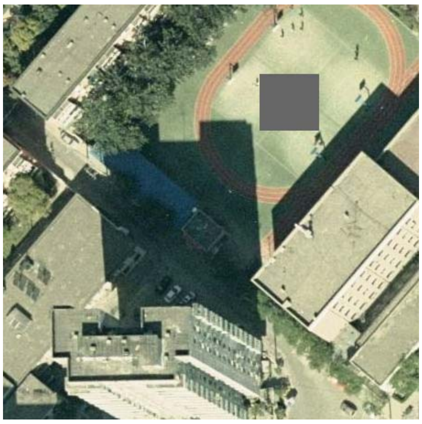
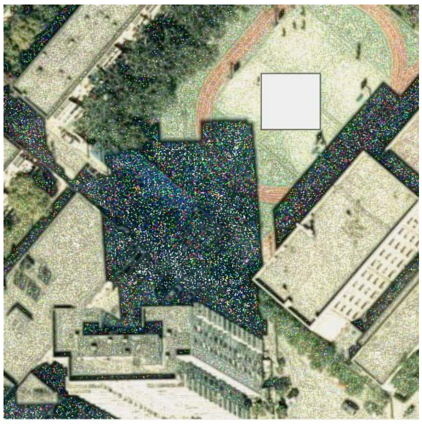


Figure1. (a) Original RGB image; (b) results of shadow detection by our method; (c) HSV image; (d) results of shadow detection by Tsai's method



(a)



(b)

Figure2. (a) Original RGB image; (b) results of shadow detection by our method

In the second experiment, we made a pseudo shadow region with a certain gray in true color image. We apply sobel horizontal edge-emphasizing filter to smooth the image. The discretization of the equation (10) was run for 10 iterations with $\Delta t = 0.05,\ k = 0.0003$. The original image is shown in figure 2 (a) and the result is shown in figure 2 (b). The result indicates the proposed shadow detection method can suppress pseudo shadow region.

Compare the results of two experiments, we also find it's important to choose the two-dimensional filter M . The sobel filter has better result in finding edges of shadow regions than the Gaussian filter, but it also generates noise in non-shadow regions. The edges of shadow regions need to be further refinement.

4. CONCLUSIONS

In this paper, we analyze the PDES model for image restoration, and present a new algorithm for shadow detection in urban color aerial images. On the basis of this algorithm, different filters are used to smooth the image and obtained the gradient vector to detect shadow with edge-preserving. The balanced smoothing and the use of the little time concept to stop the evolution of the PDES produces good results. The whole algorithm is simple to apply, and additional information except the image itself is not required.

The implementation and experimental results indicate that the automatic approach based on partial differential equations for shadow detection is successful and effective. This proposed method is a new and significative attempt, it can segment shadow region while suppressing the change of non- shadow region and suppress pseudo shadow region.

REFERENCE

[1]Victor J.D.Tsai, 2006. A comparative study on shadow compensation of color aerial images in invariant color models. IEEE transactions on geoscience and remote sensing, 44(6), pp.1661-1667.

[2]A.Susuki, A.Shio, H.Arai, and S.ohtsuka, 2000. Dynamic shadow compensation of aerial images based on color and spatial analysis. In: Proceedings of the 15th International Conference on Patten Recognition, Barcelona, Catalonia, Spain, Vol. Ⅰ, pp.317-32.

[3]Su.J, Lin.X and Liu.D, 2006. An automatic shadow detection and compensation for remote sensed color images. In: The 8th International Conference on Signal Processing, Vol.Ⅱ,

[4]Jiann-Yeou Rau, Nai-Yu Chen and Liang-Chien Chen, 2000. Hidden compensation and shadow enhancement for true orthophoto generation. In: Proceedings of Asian Conference on Remote Sensing. pp.112-118

[5]Yan Li, T.Sasagawa and Peng Gong, 2004. A system of the shadow detection and shadow removal for high resolution city aerial photo. International Archives of Photogrammetry and Remote Sensing, 35(B3), pp.802-807.

[6]Shugen Wang, Junli Wang, Aiping Wang, 2006. Shadow detection and extraction from imagery based on total variation. Geomatics and information Science of Wuhan University, 31(8), pp.663-666.

[7]P.perona, J.Malik, 1990. Scale-space and edge detection using anisotropic diffusion, IEEE Transactions on Pattern Analysis and Machine Intelligence, 12(7), pp.802-807.

[8]K.N. Nordström, 1990. Biased anisotropic diffusion: a unified regularization and diffusion approach to edge detection, IEEE Transactions on Visualization and Computer Graphics, 8(3), pp.318-327.