A SYSTEM OF THE SHADOW DETECTION AND SHADOW REMOVAL FOR HIGH RESOLUTION CITY AERIAL PHOTO

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KEY WORDS: Aerial, OrthoImage, High resolution, Surface, Integration, Photogrammetry, Extraction, Building

ABSTRACT:

This paper presents a methodology to automatically detect and remove the shadows in high-resolution urban aerial images for urban GIS applications. The system includes cast shadow computation, image shadow tracing and detection, and shadow removal. The cast shadow is computed from digital surface model (DSM) and the sun altitudes. Its projection in the pseudo orthogonal image is determined by ray tracing using ADS40 model, DSM and RGB image. In this step, all the cast shadows will be traced to determine if they are visible in the projection image. We used parameter plane transform (PPT) to accelerate the tracing speed. An iterative tracing scheme is proposed. Because of the under precision of the DSM, the fine shadow segmentation is taken on the base of the traced shadow. The DSM itself is short of the details, but the traced shadow gives the primarily correct location in the image. The statistics of the shadow area reflects the intensity distribution approximately. A reference segmentation threshold is obtained by the mean of the shadow area. In the fine segmentation, the segmentation threshold is derived from the histogram of the image and the reference threshold. The shadow removal includes shadow region and partner region labeling, the histogram processing, and intensity mapping. The adjacent shadows are labeled as a region. The corresponding bright region is selected and labeled as its partner. The bright region supplies the reference in the intensity mapping in the removal step.
Key Words: Shadow Detection, Shadow Removal, Aerial, Photogrammetry

1 INTRODUCTION

In image matching, change detection and other remote sensing applications, cast shadows caused by buildings will interfere the analysis and cause wrong results. The objective of our task is to detect the shadow area by image processing and photogrammetric engineering, and restore their color and intensities.

Shadow removal is a critical problem in image processing. In some literatures, binocular image computations have been used to remove the shadows (Chen and Rau, 1993), (Zhou, Qin, Kauffmann, and Rand, 2003). A mathematical model was proposed in literature (Zhou, Qin, Kauffmann, and Rand, 2003) to detect the occlusion by visibility analysis and photogrammetric engineering. When the building model is given it is projected to the image and the coordinates of the corners in the image are calculated. Shadow area is fulfilled by the same position of the slave image acquired in the meanwhile with the master one. Ray tracing is widely used in computer graphics as a kind of method to determine the intersection of a ray with a 3D surface. It is used in the visibility analysis to decide if the light between a pair of points is occluded (Paglierroni D. W. and Petersen S. M., 1994)(Paglieroni D. W., 1997)(Paglieroni D. W., 1999)(Bittner J.). In our work, it is used to decide the shadows in the projected image. Shadow restoration commonly is accomplished by histogram approaches, or homomorphologic filtering (Castleman K.R., 1998). These methods adjust the intensity for each pixel in the image, instead of local processing for the shadow area. A local processing is fulfilling the shadow area by another image. To do this a pair of images is needed. In our work digital image processing technique is used to remove the shadows in the original image directly.

The image used in our research is the aerial photo acquired by ADS40, which is a line scanning sensor. Another data is the digital surface model (DSM) of the same region. We developed a system to automatically detect, segment, and remove the shadows of the buildings. It first computes the space coordinate of a shadow from DSM by photogrammetriy and then projects it to the image plane. By integrated shadow detection, the shadow area in the image is segmented and labeled. At last the intensities of the shadow area are restored. In shadow computation and ray tracing, we proposed a building contour driven model. It is based on partial parameter plane transform (PPPT). In shadow removal we developed a method called companion area intensity mapping (CAIM). Experiments show that the system can precisely detect the shadow area and restore the brightness of the shadow to a natural visual effect.

2. SHADOW DETECTION AND SEGMENTATION

The photo scanned by ADS40 is rectified through level 0 and level 1 rectification to create the pseudo-orthoimage which is used in our research. We have studied three approaches to detect and segment the shadows in the image.

The first one is to detect and segment shadows only using image analysis. The results are correct in most cases. However, because of the complicity of the urban circumstance, there may be some factors effecting the detection of the shadow. For example, the high reflectivity ground, the glass wall of the building, make shadow somewhere bright, and cause their intensities close to the non-shadow area. These shadows may not be detected by image analysis technology. Besides, the threshold of the segmentation is difficult to decide. Thus, the segmentation of the shadow is not reliable. The second one is to compute the shadow location in the RGB image by photogrammetric engineering, using camera model and digital surface model (DSM). If the DSM had been as precise as the image, the result would have been perfect. However, for the time being, this is not practice. The basic locations of the buildings in DSM have no problem, but the resolution is lower than the image. In addition, DSM is short of details of the buildings. From our experiments, using this method singly, the shadows detected in the image have some errors. Based on the above factors, the last one is to integrate the above two methods to adopt their advantages and abundant their shortcomings. In detail, since the locating of method 2 is reliable, the cast shadows are first computed by method 2, and based on it the shadow area and its corresponding bright area are segmented and labeled by image analysis. This strategy ensures correct shadow locating, and no false shadow or losing shadow happens. Meanwhile, the details of the shadow area shape persist.

2.1 Coordinate Of The Shadow In 3D Space

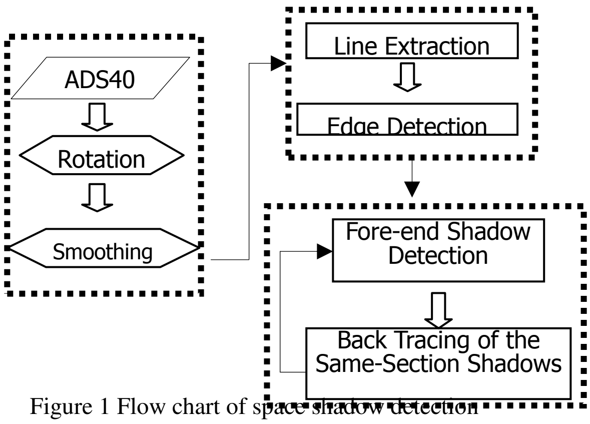


Figure 1 Flow chart of space shadow detection

The ADS40 model, DSM are used in this stage to figure out the space coordinate of a shadow. The shadow we care refers to that casts by a building. After all shadows are computed, they have to be decided if they are visible or not in the image. The algorithm of shadow coordinate in local space rectangular (LSR) system(ADS40 Information Kit) can be described by the flow chart in Figure 1. The LSR system is the object space under WGS84 used for photogrammetric processing.

The altitudes of the sun can be represented by the zenith angle and the altitude angle. The two angles are independent obviously. We first rotate the DSM by an angle equal to the zenith, making the zenith angle is equivalent to point from the left to the right horizontally for the rotated DSM. Then we can compute the shadow in 1D condition. Consider a row of the rotated DSM. It is a 1D height field now. One point in this row, if possible, will cast a shadow point, called fore-end shadow, along the equivalent zenith angle. The points between these two points must be shadow points too, called same-section shadows (when no other models supplied besides of DSM).

2.2 Shadow Traced In Image

A shadow in space computed by photogrammetry is traced to obtain its projection in level 1 image. This procedure need ADS40 camera model, DSM, and shadow coordinate in LSR. Figure 2 shows the scheme of the procedure.

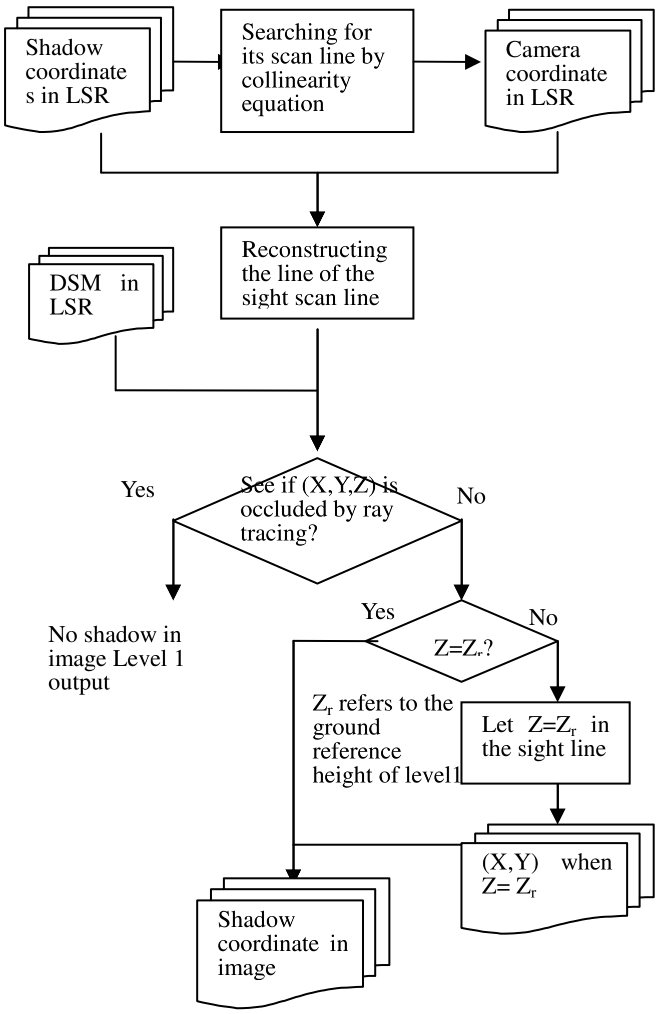


Figure 2 Flow chart of shadow tracing

The objective of ray tracing here is to decide if a cast shadow is visible by a scan line. In ray tracing, a cast shadow in space is first determined to be scanned by a certain scan line, supposing not blocked by any object, which is carried out by the camera model. Then it is traced to decide if it is visible or blocked. If visible, its position in the project image is computed by colinearity function.

Ray tracing is a computationally expensive procedure. The height field preprocessing is used to boost the efficiency by parameterizing the empty space above the height field surface, or DSM (Paglieroni, 1999). We improved the ray tracing algorithm for further boosting. Only the contours of buildings need to perform the parameter transform. In tracing, when the intersection of the ray with the cone corresponds to the current contour locates at a point before the current contour, the shadow is occluded and invisible, and the iterate procedure stops. Otherwise, the tracing goes on to the next contour. Figure 3 illustrates the tracing steps as an example. Each contour corresponds to a cone and the associated parameter. In a 1D height field starting from the current camera position and stopping with the shadow point, tracing begins with contour c1. The ray intersects with the cone of c1 at point s1. Because s1 is after c1, tracing goes on to the next contour c2. The ray intersects with the cone of c2 and c3 at s2 ad s3 respectively. Since s3 is before c3, tracing stops, and the shadow is known as occluded.

If a shadow is visible its projection in the average ground height is then computed according to the colinearity equation(ADS40 Information Kit). The image of level 1 is the projected image of the average ground height. Therefore, the projection of a shadow in the image can be obtained by translation, scaling, and rotation.

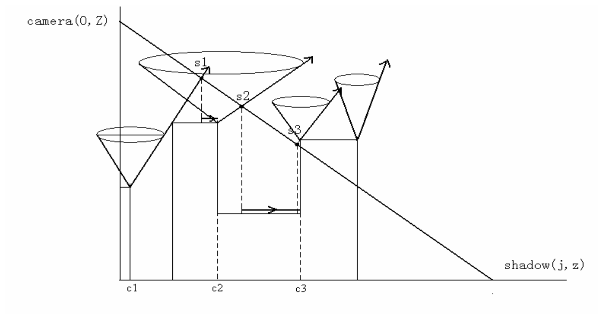


Figure 3 Steps of height field ray tracing

2.3 Integrated Shadow Detection and Location

The shadows derived from the last stage do not entirely fit with what we observe from the image. Because DSM itself is short of the details, such as the fine structure of the building, it is not practice to obtain the precise result singly by DSM. However, the shadow area now contain most true shadows and only little false shadows, the statistics of the shadow area reflects the distribution of the intensities of the shadow approximately. Therefore, a reference segmentation threshold is obtained from the mean of the intensities of the shadow area computed in last stage. In the image histogram the local minimum value which is most close to the reference threshold is taken as the threshold for the fine segmentation. Thus, a fine segmentation will give a more precise shadow result. The procedure is described as in Figure 4.

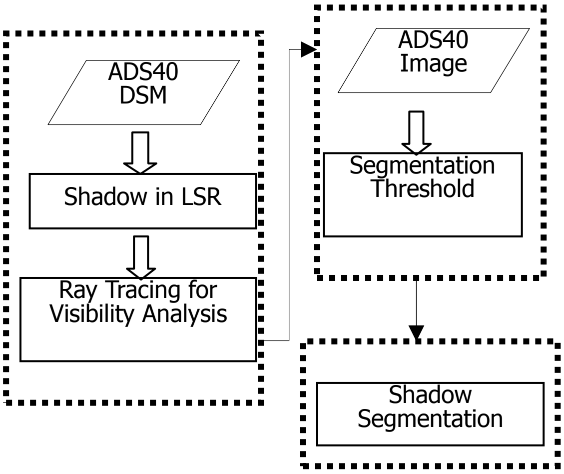


Figure 4 Integrated shadow detection in image

3. SHADOW REMOVAL

As we experienced, simply adjust the brightness and contrast of the image can not remove the shadow effect, not even some filtering techniques. Further more, these methods change the intensities of the whole image, not only the shadow pixels. There are methods restoring the shadows in satellite images using illuminating model. However it can not be copied to aerial images, because camera height for aerial imagery is much lower than satellite imagery, the material feature of the ground object affects to its intensity in the image. Digital image processing techniques are used in our work to resolve this question. The intensities of the shadow pixels can be restored by mapping them to the bright pixels refer to the same objects, which is called companion area intensity mapping (CAIM). So the shadow removal module contains two stages. The first stage is deciding the companion area to the shadow area. The second stage is computing the statistics of the two regions and mapping shadow intensities to their companion intensities.

3.1 Companion Area

It is difficult to decide the area containing exactly the same objects with those in a shadow area automatically. Here we give a simple but effective way for this purpose. A companion area should satisfy the following criteria. 1) It must not include any shadow pixels. 2) It is the neighbor to the relevant shadow area. 3) It has a rational area. According to these conditions, we trace the companion area forward along the direction of shadow casting. The shadow direction is defined as the sun zenith. From the edge of the shadow area, pixels along the shadow direction within a certain distance are taken as the companion area pixels, as illustrated by the light gray area in Figure 5.

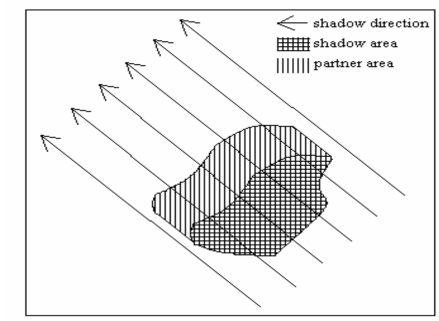


Figure 5 Shadow area and its companion area

3.2 Intensity Mapping

Intensity mapping is implemented to the shadow pixels based on the histogram analysis to the shadow area and the corresponding companion area. Both of the histograms of the two areas contain a head and a tail parts. They cover a certain ranges but contain fewer pixels. To acquire better performance of our algorithm, we limit these two parts in mapping by setting an upper cutoff and a lower cutoff to the histogram. Those intensities within the head and tail are replaced by the upper cutoff and the lower cutoff respectively in mapping. The mapping is a gamma control.

$$M = \left(\frac{m-l}{h-l}\right)^{gamma} (H-L)+L \qquad (1)$$

Where

m = intensity of a pixels before mapping

M = intensity of a pixels after mapping

h = upper cutoff of the shadow area

l = lower cutoff of the shadow area

H = upper cutoff of the companion area

L = lower cutoff of the companion area

Gamma = the control parameter

CAIM maps the upper and lower cutoffs of the shadow area to the upper and lower cutoffs of the companion area respectively, and so for the means of the shadow and companion areas. Thus, the gamma parameter can be decided by the averages of the two areas.

The intensities at the edges of the shadow area are higher than those in the inner, because the illuminating condition is a little different at the edge from in the inner. They generally belong to or close to the upper cutoff of the shadow area, and become very bright after restoring. This edge effect is reduced by smudging.

4. THE RESULT AND DISCUSSIONEA

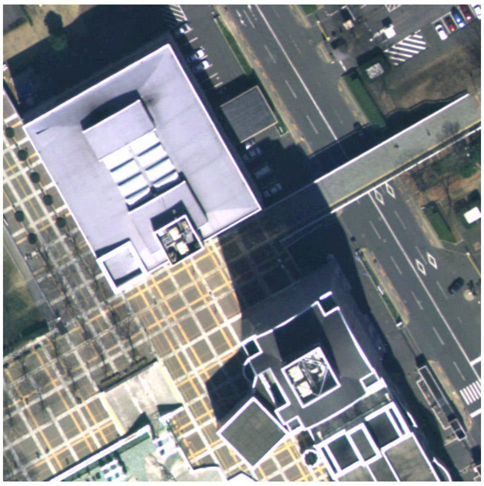
We made experiments using ADS40 image of level 1 and the associated data to test our shadow detection and shadow removal method. The study field is in Tsukuba, Japan. The resolution of image and DSM is 20cm and 1m respectively. Figure 6 shows some patches of the image and the effects of

(a)

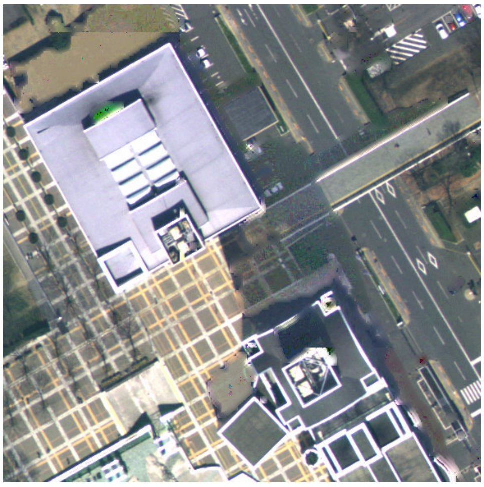
(b)

(c)

(d)



(e)



(f)

Figure 6 Image patches before and after shadow removal

shadow detection. (a), (c) and (e) are some patches of the original image. (b), (d) and (f) are the restored image by CAIM to (a), (c) and (e) respectively.

From the experiment images we can see, that most shadow areas have been restored successfully. Somewhere the color and brightness differ from their surroundings. One reason is the chosen of the companion area. It is selected as a neighboring region along the shadow direction. If it covers just as same as what the shadow area contains, the restoring will be perfect. This can be obtained roughly by DSM data. However the companion is chosen now by computation on the image without the height information, thus companion area may cover some objects not existing in the shadow area, and vice versa. But the chosen of companion area based on DSM is unpractical for the time being because it will bring in much more computation.

As conclusion, our research makes several main achievements as following. 1. Developed several shadow detection method. a) Directly detect and segment the shadow region from the image, not using DSM and photogrammetry. b) Compute the cast shadow by DSM and the sun altitudes, and trace the shadow to the image plane. c) Considering the advantages and shortcomings of the two method, proposed an integrate method. 2. Proposed a set of techniques to remove the shadow region by image analysis. a) Companion area to a shadow area is chosen. b) Pre-processing of the histograms of the shadow area and its companion reduces the impact to the mapping result of the lowest intensities and the highest intensities. c) Seamless mosaic to smooth the edges of the shadow area after intensity mapping.

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