Prediction and Compensation of Building Shadows Using High-Resolution Aerial Imagery and Airborne Laser Scanning Data

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Keywords: building shadows, aerial imagery, airborne laser scanning data, parallel projection.

SUMMARY

In this paper is presented a methodology for prediction and compensation of building shadows cast on high-resolution aerial imagery taken from complex urban scenes. Shadowed areas are very common, mainly in high-resolution images and cause negative effects that disturb conventional techniques of image analysis. The proposed methodology consists in four sequential steps. First, the building roof contours are manually extracted from a grey level image generated by the normalization of a digital elevation model (DEM), which is derived from airborne laser scanning data. Second, the building roof contours are projected onto a local mean plane by using orthogonal and parallel projection. The height of the local mean plane is computed from the DEM data. The direction of the parallel straight lines is derived from the solar ray attitudes (azimuth and elevation), which are computed for the acquisition time of the aerial image. The results of this step are two polygons: one representing the building bottom and another one representing the projected building roof. Then, these two polygons are combined to give a region containing the shadow cast by a particular building. Finally, this region is registered onto the image plane (3rd step), in which a procedure for compensation of shadowing effects is applied (4th step). This procedure includes threshold, shadow area and companion area (bright areas neighboring shadow regions) labeling, histogram analysis and intensity mapping. Companion areas supply information used in the intensity mapping for compensating shadow areas. The results obtained in the experimental evaluation of the proposed methodology showed that it works properly, since the method allowed the prediction and compensation of shadow areas in high-resolution aerial imagery.

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1. INTRODUCTION

The main reason for shadow occurrence on high-resolution imagery is the direct blocking of the sunlight by high objects as buildings and trees. Surfaces affected by shadows are weakly illuminated and usually appear dark on imagery. In geometric sense, shape and size of a shadow depend on the azimuth and elevation of the sun, besides other parameters as shape and size of shadowing object, as well as the spatial position and orientation of the acquisition image sensor (MASSALABI et al., 2004).

Negative effects caused by shadows increase with the spatial resolution of the image. Shadows modify spectral response of the objects and affect the performance of image analysis tasks due to the partial or total obstruction of image objects. In some applications like image matching and change detection, shadows caused by high objects as buildings and trees interfere in image analysis and produce wrong results (MASSALABI et al., 2004).

In the literature is possible to find two main groups of methods for shadow detection and/or compensation of shadow areas in remote sensing imagery. The first one uses basically image data and conventional techniques of image analysis (e.g., thresholding, segmentation etc.) for detecting shadows. The second one employs multisource data (for example, image data combined with solar and object elevation information) for predicting shadow occurrences in imagery and compensates their negative effects.

In this paper, a method for prediction and compensation of shadow areas cast by buildings on high-resolution aerial imagery is presented. The proposed methodology uses airborne laser scanning data and solar ephemeris information combined with data derived from the imagery for solving the mentioned problem.

2. METHODOLOGY

The proposed method for prediction and compensation of building shadows cast on high-resolution aerial imagery is based upon four sequential steps:

– **Derivation of building roof contours:** This step consists of a visual identification and a manual extraction of building roof contours from a normalized image, which is obtained by a transformation procedure applied to a digital elevation model (DEM). As this DEM is derived from an airborne laser scanning data set, from now on we will refer to it as DEM-laser;

- **Prediction of building shadow:** In this step a set of image shadow polygons is obtained, whose three-dimensional vertexes are referred to a local coordinate system. At the beginning, each building is assumed to be a regular solid. The intersection between this solid and a horizontal mean plane (HMP) representing the local surface defines a polygon representing the building bottom contour. Next, the building roof contour is projected onto the HMP using the parallel projection, whose projecting parallel lines orientation is computed in function of the solar azimuth and elevation, both estimated at the image acquisition time. For each building, the building shadow polygon is derived by combining the projected building roof and the building bottom.

- **Shadow registering on the aerial image:** This step consists in projecting onto the aerial image the polygons obtained in the previous step. Therefore, the interior and exterior orientation parameters of the image must be available;

- **Shadow compensation on the aerial image:** In this step a companion area intensity mapping is performed with the goal to restore the intensity of shadowed pixels and, consequently, to compensate the area affected by a building shadow.

2.1. Derivation of building contours

2.1.1. <u>Derivation of the normalized image</u>

For the visual identification and the manual extraction of building roof contours from a DEM-laser, first it is necessary to transform the DEM into a normalized image, in which the digital numbers are proportional to the DEM-laser elevations. This is a normalization process applied to the DEM-laser point coordinates.
This step is carried out in two stages. First, the image dimensions (width and height) are computed using the equations

$$w = (E_{\max} - E_{\min})/GSD, \tag{2.1}$$
$$h = (N_{\max} - N_{\min})/GSD, \tag{2.2}$$

where:

- $(E_{\min}, N_{\min})$ are the DEM-laser lower left corner coordinates;

- $(E_{\min}, N_{\min})$ are the DEM-laser upper right corner coordinates;

- *GSD* is the DEM-laser ground sample distance;

In the second stage, the DEM-laser planimetric coordinates (E_k, N_k) are mapped into a corresponding pixel position given by (C_k, L_k) coordinates in the normalized image. This is performed by using the equations

$$C_k = (E_k - E_{\min})/GSD, \tag{2.3}$$

$$L_k = (N_{max} - N_k)/GSD, \tag{2.4}$$

where (E_{min}, N_{max}) are the DEM-laser upper left corner coordinates.

The digital number ND_k to be assigned to the position is calculated by using the equation

$$ND_k = \frac{255}{h_{max} - h_{min}} \cdot (h_k - h_{min})$$

where, h_{min} and h_{max} are, respectively, the lowest and highest DEM-laser altitude values;

The foregoing process produces a grey-level digital image with 8-bit radiometric resolution, in which gray values are scaled over [0, 255]. The darkest gray value corresponds to the DEM-laser site with altitude equals h_{min} and the brightest gray value is assigned to pixels corresponding to the DEM-laser site with altitude equals to h_{max}.

One advantage of the grey-level digital image generation process is the possibility of obtaining the (E, N, h) coordinates from the (C, L, ND) pixel coordinates observed on the normalized image. This can be carried out using the DEM-laser–to–normalized image inverse transformation. Section 2.1.2 gives additional details.

2.1.2. Manual extraction of building roof contours

After the DEM-laser–to–normalized image transformation, it is possible to extract building roof contours from the resulting image. This is carried out by measuring the coordinates of roof contour points from the normalized image. This procedure is depicted by **Figure 2-1**.

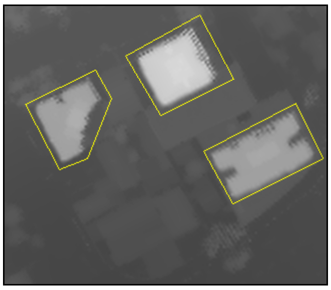

Figure 2-1: Building roof contours extraction.

The roof contour point coordinates (C, L, ND) must be transformed into a Local Cartesian Coordinate System (LCCS) before performing the prediction and the compensation of shadow areas. **Figure 2-2** depicts the transformation sequence to be applied to the (C, L, ND) coordinates for obtaining the LCCS coordinates (X_L, Y_L, Z_L).

$$\left(C, L, ND\right) \rightarrow \left(E, N, h\right) \rightarrow \left(\phi, \lambda, h\right) \rightarrow \left(X, Y, Z\right) \rightarrow \left(X_L, Y_L, Z_L\right)$$

Figure 2-2: Transformation sequence applied on building roof contours points.

The $\left(E, N, h\right) \rightarrow \left(\phi, \lambda, h\right) \rightarrow \left(X, Y, Z\right) \rightarrow \left(X_L, Y_L, Z_L\right)$ coordinate transformations are well-known and as such will not be presented here. Details for these transformations can be found in FAZAN (2007). The $\left(C, L, ND\right) \rightarrow \left(E, N, h\right)$ transformation is given by the equations

$$E = E_{\min} + C \cdot GSD \,, \tag{2.5}$$

$$N = N_{\max} - L \cdot GSD \,, \tag{2.6}$$

$$h = h_{\min} + ND\left[\frac{h_{\max} - h_{\min}}{255}\right], \tag{2.7}$$

which corresponds to the DEM-laser–to–normalized image inverse transformation.

2.2. Prediction of the regions affected by building shadows

In this step the regions shaded by buildings are obtained. First, all the points representing a building roof contour are projected onto the HMP using the orthogonal projection, to obtain the corresponding building bottom contour. In order to perform this projection, it is necessary to know the building height, whose value is obtained through the difference between the building roof contour height (Z_L^R) and the HMP height (Z_L^P).

Next, the points representing a building roof contour are projected onto HMP, but now by using the parallel projection. The main reason for using the parallel projection is the fact that the projection center is related to the sun position and, as such, it can be considered to be located at the infinite distance. The parallel projection straight lines are defined in function of the building height and the LCCS position of the sun. In order to obtain this position, the sun position is firstly established in the astronomical horizontal coordinate system, which requests the solar azimuth (A_s) and solar elevation (h_s) coordinates. Several astronomical reference system transformations are necessary for obtaining these astronomical coordinates. Details of this procedure are given by FAZAN (2007). The projection of each roof contour point onto the HMP is given as follows

$$X_L^P = X_L^R - BH \frac{\cos\left(A_s\right)}{\tan\left(h_s\right)}, \tag{2.8}$$

$$Y_L^P = Y_L^R - BH \frac{\sin\left(A_s\right)}{\tan\left(h_s\right)}, \tag{2.9}$$

where:

– $\left(A_s, h_s\right)$ are the solar azimuth and elevation, respectively;

– $\left(X_L^P, Y_L^P\right)$ are the LCCS planimetric coordinates of a building roof contour point projected onto HML;

– $\left(X_L^R, Y_L^R\right)$ are the LCCS planimetric coordinates of a building roof contour point;

– BH is the building height, given by the equation

$$BH = Z_L^R - Z_L^P \, . \qquad (2.10)$$

Equations 2.8 and 2.9 are not defined for $h_s = 0^o$ (at the sunrise and sunset) and $h_s = 90^o$ (when the sun passes through the local upper meridian). One can interpret that for this cases do not occur or make sense the presence of shadow projections.

The projection of the building roof contour onto the HMP results in a polygon, but it is necessary to combine it with the building bottom polygon to obtain the region affected by a particular building shadow. **Figure 2-3** illustrates a simple case.

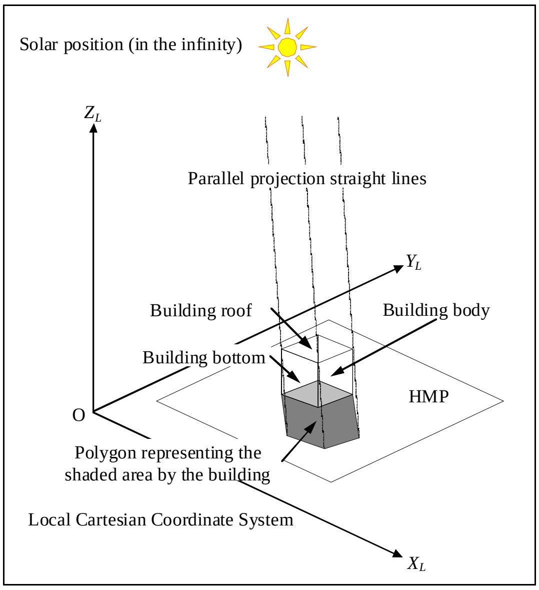

Figure 2-3: Prediction of the shadow area cast by a building.

2.3. Registering of shadow regions on the aerial image

After the prediction of the regions affected by shadows, the polygons representing them are registered onto the aerial image. For this purpose, it is necessary to know the interior and exterior orientation parameters of that image.

The interior orientation parameters, for example, can be getting from the camera calibration report and the exterior orientation parameters can be estimated by performing a space resection by the collinearity equations (WOLF & DEWITT, 2000; MIKHAIL et al., 2001).

The results of this step are regions of interest (RoI) in the image containing affected pixels by shading (shadow pixels) and surrounding regions. Based upon these pixels, a process for compensation of shadow pixels is applied.

2.4. Compensation of shadow regions in the aerial image

The RoI determined previously allows a shadow compensation to be applied to the image in order to reduce or even eliminate the effect of shadow in the image. For this purpose, digital image processing techniques are used.

According to LI et al. (2004), the intensity of shadow pixel can be restored by mapping them to the bright pixels refer to same objects, which is called companion area intensity mapping (CAIM). Hence, the shadow compensation procedure comprises two main stages. The first one is the identification of the companion area for a particular shadow region. The second one is the computation of the statistics of two regions and the mapping of the shadow intensities into their companion intensities.

2.4.1. Companion area

The pixels inside a registered shadow on the aerial image define a region of interest (RoI) that contains shaded pixels and neighbor pixels not affected by building shading.

The companion area required for an intensity mapping is set as the neighbor area. The set of pixels defining a companion area is separated from the set of pixels defining the shadow area by performing a threshold procedure.

2.4.2. Intensity mapping

Intensity mapping process for shadow pixel compensation used in this approach is based upon the histogram analysis for a particular shadow region and its corresponding companion area. For improvement of the intensity mapping performance, a lower cutoff and an upper cutoff are set up for both histograms.

Thus, in the mapping procedure the intensities within a histogram range are replaced by the corresponding lower and upper cutoffs. The intensity mapping process is performed by using a gamma control equation (LI et al., 2004)

$$M = \left(\frac{m-l}{u-l}\right)^{gamma} \cdot (U-L) + L \,, \qquad (2.11)$$

where:

– m is the intensity of a shadow pixel before mapping;

– M is the intensity of a shadow pixel after mapping;

– u and l are, respectively, the upper and lower cutoffs of the shadow area histogram;

– U and L are, respectively, the upper and lower cutoffs of the companion area histogram.

CAIM procedure works by mapping the upper and lower cutoffs of the shadow area into the upper and lower cutoffs of the companion area.

3. EXPERIMENTAL EVALUATION AND RESULTS

For the experimental evaluation of the proposed methodology, one high-resolution aerial imagery and associated interior orientation parameters were used. Additionally, a set of control points with (E, N, h) coordinates was employed for image exterior orientation parameters estimation. For this purpose, a space resection by collinearity equations was performed. Airborne laser scanning data used for the experimental evaluation comprise an irregular point mesh, from which a regular grid (the so-called DEM-laser) was generated by performing an interpolation procedure. Finally, solar ephemeris data were used for computing the solar azimuth and elevation at the image acquisition time. For checking the performance of the method discussed in this paper, two experiments were carried out, which are described below.

Figure 3-1 depicts the result obtained in the first experiment. The image patch in (a) shows the shadowed area cast by a high building. The result obtained by using CAIM for shadow compensation is depicted by the image patch in (b), where is possible to check that shadow area has been restored with reasonable quality.

(a)  (b) 

Figure 3-1: (a) Part of the original aerial image showing a shadowed area cast by a building (a); Shadowed area compensated by CAIM (b).

Figure 3-2 depicts the result obtained in the second experiment. Such as in the experiment 1, the image patch depicted in (a) shows the shadowed area cast by a high building, and the image patch showed in (b) contains the result for shadow compensation performed by CAIM procedure. The result obtained here is worse than that one obtained in the experiment 1, but in some areas (e.g., the house roof indicated in image patch (b)) the compensation procedure seems work properly, enhancing the information existing under the shadowed area.

(a)  (b) 

Figure 3-2: (a) Part of the original aerial image showing a shadowed area cast by a building (a); Shadowed area compensated by CAIM (b).

4. CONCLUSIONS

It can be concluded from the observation of the experimental results that the combination of the method proposed by FAZAN (2007) for prediction of building shadows on high-resolution aerial imagery with that one proposed by LI et al. (2004) for shadow compensation by CAIM procedure seems to work properly.

Also it was possible to see that the CAIM procedure is affected by the chosen of the companion area used as reference for performing the shadow compensation, as well as the quality of the evaluated aerial image, according to show the experimental results.

One main suggestion for quality improvement of the results given by the proposed method is to adopt a more sophisticated procedure for derivation of the companion area, which is used as reference in the CAIM for shadow compensation. In this paper, only a simple thresholding was employed and this fact may have contributed to reduce the quality of the experimental results.

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BIOGRAPHICAL NOTES

Antonio Juliano Fazan has received his Dipl. Eng. from the São Paulo State University (Brazil) in 2004, and his M. Sc. degree from São Paulo State University in 2007. Currently, he is working on to obtain his Ph.D. degree in Cartographic Sciences at the São Paulo State University.

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