

QUANTITATIVE ANALYSIS OF SHADOW EFFECTS IN HIGH-RESOLUTION IMAGES OF URBAN AREAS

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ABSTRACT:

Shadow effects have drawn much attention by researchers with increasing use of high-resolution remote sensing images of urban areas. For correction or compensation to pixels that falling in shadow areas due to the existence of vertically standing objects such as buildings and trees, quantitative analysis of shadow effects is essential. In this paper, we proposed an object-based approach for predicting, identifying shadow areas and their corresponding surrounding areas based on airborne laser scanner (ALS) data. Quantitative analysis of shadow effects is followed based on high-resolution multi-spectral (MS) images. In the case study, we use 4 m-resolution multi-spectral IKONOS image and 1 m-resolution digital surface model (DSM), which is derived from airborne laser scanning data. We predict shadow areas of a multi-spectral image by using the hillshade algorithm based on meta data of the image (sun angle azimuth and sun angle elevation) and the DSM data of the same area. Building relief displacement caused by slightly oblique viewing in imaging is derived too, based on the DSM, nominal collection azimuth and nominal collection elevation to avoid mixture of predicted shadow areas and displaced areas of buildings. An object-based approach has been applied to identify shadow areas as objects instead of pixels so that adjacency relationships with surrounding areas can be derived. The differences of spectral values between shadow areas and their surrounding areas are quantitatively measured and compared. Per-object comparison between shadow areas and their corresponding surroundings is considered much more robust as compared with per-pixel approach. A shadow correction model is proposed that is based on quantitative comparison of different sites with different configurations. The experimental results show that local setting and configuration have to play an important role in shadow correction due to complexity of shadow effects. The detailed descriptions of methods, experimental results are presented in this paper, as well as the proposed shadow correction model.

1. INTRODUCTION

Shadow removal is a critical problem in image processing. It is an important issue too for use of high-resolution remote sensing images in urban areas where many high-rise objects cast shadows that may have impacts to many applications.

1.1 Shadow effects

Shadow effects may be ignored when using coarse resolution space images i.e. coarser than 20 m. They have impacts on classification accuracy when using high resolution data such as resolution of 1 to 4 m. Therefore quantitative analysis of such impacts is needed before proposing methods for shadow correction or improvement.

1.2 Existing methods

Researchers have been worked on the shadow effects for some time and a number of correction methods have been proposed too (Li et al., 2004; Madhavan et al., 2004; Massalabi et al., 2004; Nakajima et al., 2002). Panchromatic (PAN) aerial images with grey scale had been the focus of shadow correction to generate large-scale true ortho-photo in an early stage. To

correct the illumination differences around shadow areas, image enhancement technique was applied. Around the building areas, characteristics of ground features are often dominated by human activities and are usually quite different from place to place. Hence, local enhancement is preferred. Surrounding the shadow area, a buffer zone is first constructed using dilation operator. If presented, rooftops are further excluded from both the shadow area and the buffer zone. This is to keep the similarity of image contents in the shadow area and those in the buffer zone. The histograms for particular pair of buffer zone and shadow area are calculated accordingly. Considering the formal one as the reference histogram, the grey value transformation table for the shadow area is then constructed with histogram matching method. Thereafter, the shadow enhancement was accomplished area by area (Rau et al., 2000). In our case, we have to deal with shadow effects with multi-spectral satellite images in which shadow correction have to be made for each spectral band or each colour channel. The spatial resolution (1 to 4 m) in our cases is much coarser than that of aerial images (0.1 to 0.4 m).

For shadow correction of high-resolution IKONOS PAN images, airborne laser scanner data were used to predict shadow areas at first. Shadow compensation was followed by using different

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values between shadow pixels and their surrounding pixels. Two methods were proposed for shadow correction: the gamma correction and the amount conversion of statistics as described in equation (1) and equation (2) respectively (Nakajima et al., 2002).

$$OutPixel = 2047 \times (InPixel \div 2047)^{1/\gamma} \quad (1)$$

Where $OutPixel$ = Output pixel value
 $InPixel$ = Input pixel value

The gamma value has to be determined for each image.

$$y = \frac{S_y}{S_x} (x - x_m) + y_m \quad (2)$$

Where x = input pixel value
 y = output pixel value
 x_m = average of input density
 y_m = average of output density
 S_x = standard deviation of input density
 S_y = standard deviation of output density

The average of input/output density and standard deviation of input/output density were obtained based on 4 categories: building, tree, road and ground. Shadow correction was made by using parameters derived from one of four categories accordingly. Therefore, it is a category-based correction.

We consider that with the gamma correction approach, it uses only one parameter: gamma for all shadow pixels, thus it ignores the existence of different background of shadow areas. With the amount conversion of statistics, it has been limited to 4 categories when using the average of input/output density and standard deviation of input/output density as parameters for shadow correction. It is also time-consuming to manually determine to which category a shadow area belonging.

In this research, the objective of this research to find a shadow correction method that uses local setting and configuration. In other words, model parameters have to be derived locally or from an adjacent region of corresponding shadow area. We are looking for an automatic and adaptive approach for shadow correction of multi-spectral IKONOS images with the assistance of ALS data. Based on experiences and limitations of conventional per-pixel approaches, an object-based approach is proposed to deal predicted shadow areas, find surrounding areas and shadow correction. In section 2, the outline of the object-based approach is presented. Results of a case study are presented in section 3 to examine and illustrate shadow effects effectiveness of the proposed shadow correction method. Conclusions and remarks are given in section 4.

2. THE OBJECT-BASED APPROACH

In this research, we use term object to represent an image region in terms of 4-connection (a pixel is considered to be connected to its up and down, and left and right neighbors only). A labeled image is created and used to represent image objects where pixels that are determined to be parts of an object will have the same object identification (ID) number (Zhan, 2003). In this case, an object represents a shadow area or a surrounding region that usual contains pixels that are connected as image region based on 4-connection. Image objects are used as index

too to link object IDs to object locations as indicated by labeled pixels and object attributes derived from MS images and DSM. Therefore, they play a central role in analyzing shadow effects and implementing of the proposed shadow correction method. The diagram of the object-based approach can be found in Figure 1. The detailed description of procedure and steps of the proposed method is presented in the following subsections.

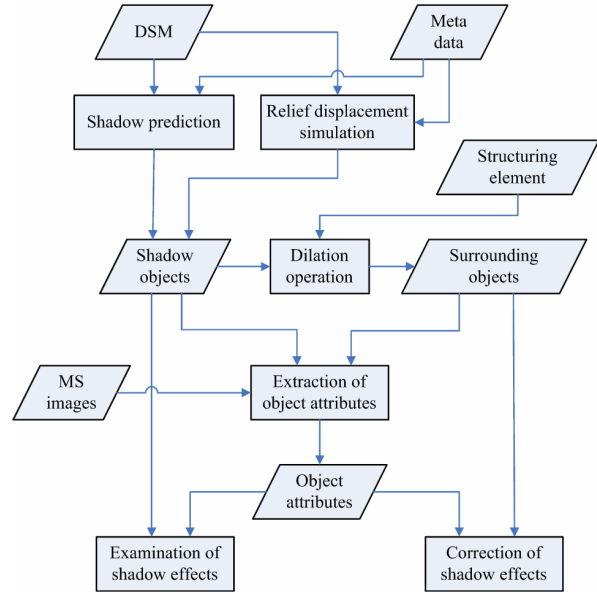


Figure 1. Predicted shadow pixels (white dots), surrounding pixels (green crosses) superimposed with IKONOS MS image (small portion).

2.1 Prediction of shadow areas

With the assistance of DSM obtained by ALS and meta data of image acquisition (sun angle azimuth and sun angle elevation), shadow areas can be predicted by using the hillshade algorithm. Displacement of high objects such as buildings can be predicted too by using the same methods, based on the DSM, nominal collection azimuth and nominal collection elevation to avoid mixture of predicted shadow areas and displaced areas of buildings.

2.2 Formation of shadow objects

The binary image of shadow image is labeled by checking 4-connection to create the object identification image in which pixel values represent object IDs. In this stage, small objects, e.g. containing less than 10 pixels, will be removed in order to eliminate small and noisy objects and pay more attention to the main shadow objects.

2.3 Determining surrounding areas of shadow objects

To determine the surrounding areas of the corresponding shadow objects and use them as reference data for comparison of shadow and nearby non-shadow areas, and for shadow correction. A dilation operation is applied to obtain adjacent objects to their shadow objects. The structuring element is designed by considering the shadow direction, width of adjacent objects (buffer regions), etc. The adjacent areas in the shadow-cast direction are expected to be extracted by applying the dilation operation to each shadow object one by one. The surrounding areas are used as reference data for comparison and

for correction of their corresponding shadow areas. Thus the same identification numbers are used to label each pair of shadow object and reference object.

2.4 Comparison of shadow objects and their surrounding areas

To examine the differences between shadow objects and their surrounding areas, mean density, standard deviation of each object are derived accordingly, based on spectral values of pixels with the same object IDs. The mean density, standard deviation can be explained as darkness and contrast of a shadow object as well as its surrounding object for each specific shadow area. In this research, shadow effects are quantitative measured pair wise for each shadow object. All pixels of a shadow object are used for the measurement of this particular object so as to its surrounding object. In cases that a small object may contain only few pixels, using the statistical method (mean density, standard deviation) is considered much robust than using the histogram method (minimum, maximum) when small number of pixels are involved for small objects.

2.5 Shadow correction based on shadow objects and their surrounding areas

In this research, we make shadow correction in two aspects: to level grey values of shadow pixels and to enhance contrast of these pixels. The leveling of grey values of shadow pixels can be determined by mean density of pixels in a shadow object and its surrounding object. Contrast enhancement can be controlled by standard deviation of pixels in a shadow object and its surrounding object. Thus we use formula 2 for shadow correction for each shadow object. We consider that the statistical approach as presented by formula 2 takes into account of frequencies of grey values of pixels inside an object. This implies that pixels with high frequency values are more likely to be located in the central part of grey value range due to the nature of the normal distribution. Thus they have higher opportunities to be leveled in density and enhanced in contrast as compared with the histogram approach. Applying the histogram approach on the other hand, only the ranges of grey value (max. - min.) are considered and used for shadow correction. The frequency information (concerning the majority of pixels) is ignored. As a consequence, one or two pixels with extreme value will have large effects on the result of shadow correction.

3. CASE STUDY

To examine shadow effects on high-resolution multi-spectral images, IKONOS MS images of the study area – Southeast of Amsterdam - are used in the case study. DSM data of the same site are chosen too, which are obtained by ALS. The study area covers 3 km×3 km where large high-rise buildings cast large shadows on relatively flat terrain. Thus it is considered as an idea site for this research.

3.1 Data preparation

IKONOS MS images of the study area were geo-referenced based on large scale (1:2,000) base map. 1 m resolution DSM was used for shadow prediction and displacement simulation.

3.2 Extraction of shadow areas in IKONOS images

To extract shadow areas in IKONOS images, shadow areas were predicted in ArcView by using the hillshade algorithm

based on DSM and meta data of IKONOS images - sun angle azimuth and sun angle elevation. Displacement of high objects had been simulated too by using the same methods, based on the DSM, nominal collection azimuth and nominal collection elevation to avoid mixture of predicted shadow areas and displaced areas of buildings. In this case study, only predicted shadow pixels that are not in the simulated displaced areas are considered as shadow areas, and used for the remaining examination and shadow correction. Shadow pixels that are located inside the displaced areas are considered as parts of high objects (non-shadow). To this end, a binary image (1 m) that represents shadow areas was obtained. To make this image with the same resolution as IKONOS MS images (4 m), a resampling operation was applied that a 4-m pixel would be decided as a shadow pixel in 4 m resolution image only if more than 12 pixels out of a total 16 pixels (3/4 majority) of 1-m image are shadow pixels, in order to find relatively pure shadow pixels.

3.3 Extraction of shadow objects in IKONOS images

The binary image of shadow image is then labeled according to 4-connection to create the object identification image where pixel values represent object ID. In the meanwhile, objects that are smaller than 10 pixels were removed to eliminate small and noisy objects. Up to this stage, pixels that have been labeled with the same ID belong to the same object. The object ID image was used as masks or location indexes to derive attribute information from IKONOS MS images.

3.4 Extraction of surrounding objects in IKONOS images

To find surrounding object of a shadow object, we applied a dilation operation to each shadow object to determine surrounding pixels of a corresponding shadow object, which was labeled with same object ID with the corresponding object to record the 1 to 1 corresponding relationships between shadow object and reference objects. The structuring element (*se*) used here was specifically designed according to the direction of sun light so that high-rise objects themselves would not be considered as parts of reference objects. The *se* is designed as follows according to the fact that sun light was approximately from the southeast direction.

$$se = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Predicted shadow pixels, surrounding pixels that had been superimposed with IKONOS MS image are shown in Figure 2.

3.5 Examination of shadow effects in IKONOS MS images

To examine shadow effects in IKONOS MS images, we use 57 pairs of shadow objects and their surrounding objects, derived using the proposed method as described earlier. The average density of shadow objects (mean value of pixels covered by a shadow object) and their surrounding objects (mean value of pixels covered by the surrounding object) was derived for each shadow object and for each spectral band of IKONOS MS images as shown in Figure 3. Linear equations were obtained by

using the linear regression method based on 57 shadow objects of the test site. The test results show that the average contrast of surrounding objects are approximately 3 to 4 times larger than their corresponding shadow objects for all 4 spectral bands as indicated by the linear equations in Figure 3. Such linear relationships are considered significant based on 57 test samples.

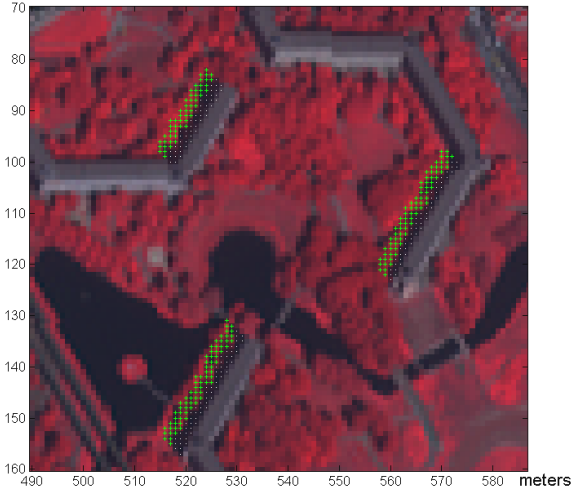


Figure 2. Predicted shadow pixels (white dots), surrounding pixels (green crosses) superimposed with IKONOS MS image (small portion).

3.6 Correction of shadow effects in IKONOS MS images

Correction of shadow effects in IKONOS MS images was implemented by applying formula 2 to 57 pairs of shadow/surrounding objects one by one. To make the corrected image smoother, a smooth operation was applied to shadow areas using the following filter.

$$\begin{bmatrix} 0 & 0.2 & 0 \\ 0.2 & 0.2 & 0.2 \\ 0 & 0.2 & 0 \end{bmatrix}$$

To have close examination on the relationships between shadow object, adjacent object, result of shadow correction as well as result of smoothing operation, we present figures obtained from a pair of shadow object and its reference object. This is considered as a typical example of shadow object indicated by the lowest circle as shown in Figure 5. Derived parameters from this sample case, average densities and standard deviation values from different spectral bands are present Table 1 and Table 2 respectively. Histograms of this particular shadowobject, its surrounding object, result of shadow correction, and result after smoothing operation for different spectral bands are illustrate in Figure 4. Accompanied curves are the estimated normal distributions based on sample pixels of this sample object as shown in Figure 4.

A small portion of the original IKONOS MS image, the result of shadow correction, shadow correction after smoothing operation on shadow areas, and aerial photograph of the same area are presented in Figure 5. The experimental results demonstrate that shadow areas have been significantly improved in both brightness and contrast

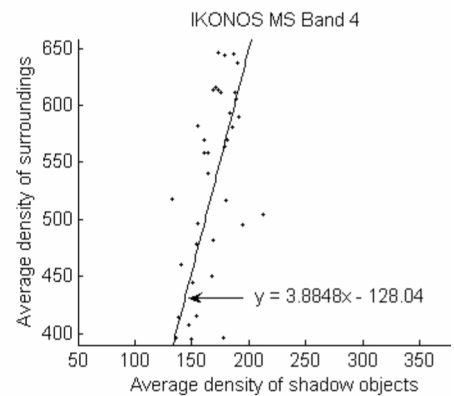
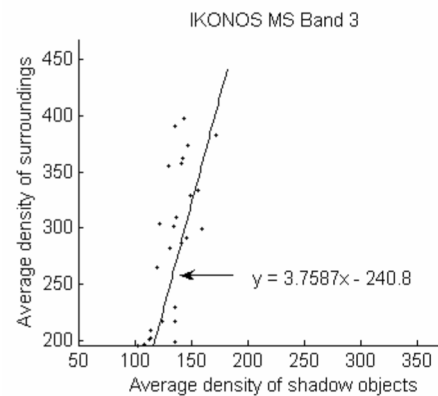
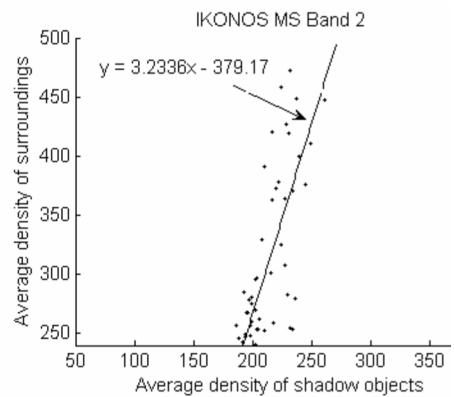
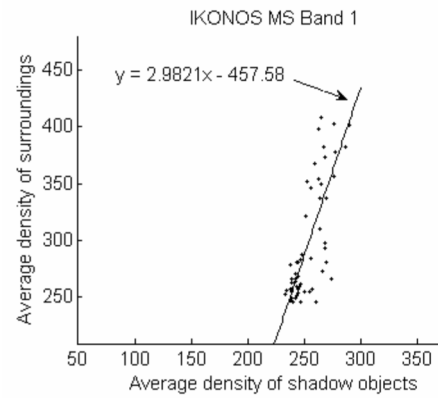


Figure 3. The relationship between average density of shadow objects and their surrounding objects, based on 57 shadow objects of the test site.

Table 1. Comparison of average density of a shadow object between original, surrounding, corrected, and smoothed

	Band 1	Band 2	Band 3	Band 4
Shadow object	237.6	190.7	100.8	160.7
Surrounding object	246.7	229.3	131.4	540.4
Corrected object	255.9	240.3	143.0	499.1
After smoothing	255.9	240.3	143.0	499.1

Table 2. Comparison of standard deviation of a shadow object between original, surrounding, corrected, and smoothed

	Band 1	Band 2	Band 3	Band 4
Shadow object	11.4	18.3	16.4	63.4
Surrounding object	9.4	28.4	24.2	204.7
Corrected object	16.8	26.7	25.5	89.8
After smoothing	16.8	26.7	25.5	89.8

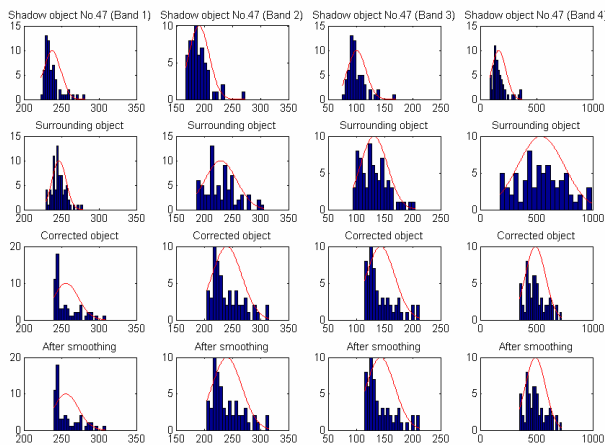


Figure 4. Comparison between histograms of a shadow object, its surrounding object, result of shadow correction, and result after smoothing operation in each band.

4. CONCLUSIONS

In this paper, we proposed an object-based approach for predicting, identifying shadow areas and their corresponding surrounding areas, based on airborne laser scanning data and relevant meta data. Quantitative analysis of shadow effects is followed based on high-resolution multi-spectral images.

A shadow correction model is proposed that is considered adaptive because it uses parameters that are derived locally, using automatically determined adjacent region. Thus local settings and configurations can play an important role in shadow correction. Such local information is considered crucial form shadow correction due to complexity of shadow effects. However, additional examination is needed on how shadow correction effort benefits to accuracy improvement of land-use/cover classification.

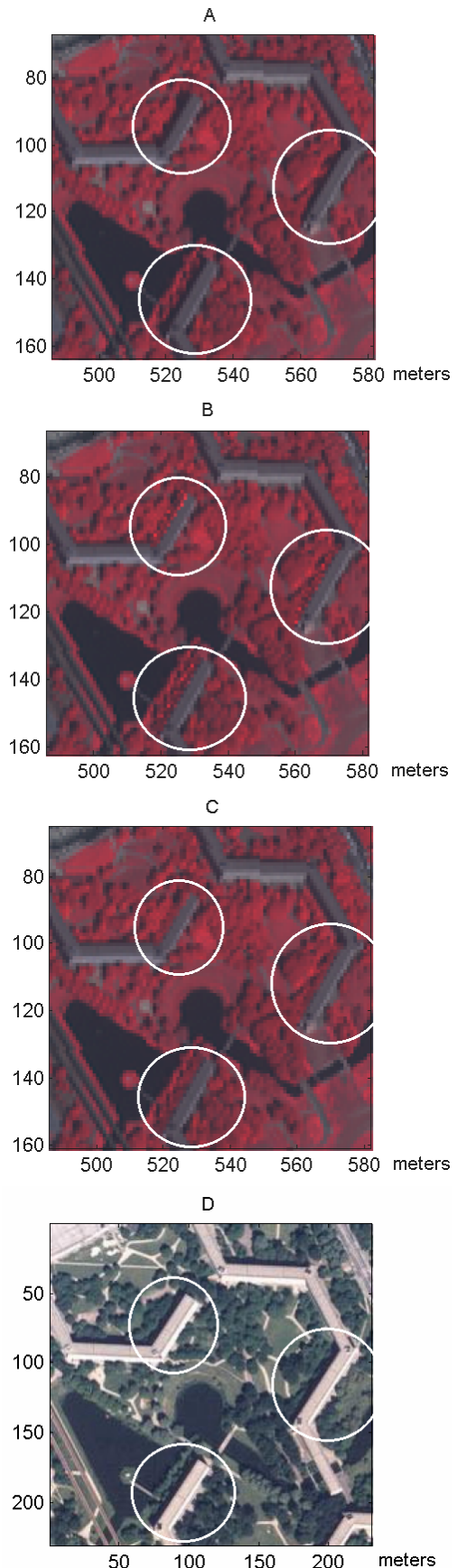


Figure 5. Original IKONOS MS image (A), result of shadow correction (B), result after smooth operation (C) and aerial photograph (D) (small portion).

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