# CHARACTERISTICS OF SHADOW AND REMOVAL OF ITS EFFECTS FOR REMOTE SENSING IMAGERY

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## ABSTRACT

The effects of shadow in remote sensing imagery are investigated. The measurement of radiance in sunlit and shadowed areas was carried out to investigate the spectral characteristics of sunlight. Based on this observation, it is found that the radiance ratio (shadow/sunlit) increases as the sunlight gets weaker and the ratio is dependent on the wavelength of sunlight. The darkness of shadow is also found to vary depending on the surrounding condition. Thus the condition to restore a shadow-free image depends on the spectral bands and the location even in one image. A QuickBird image is then introduced and the spectral characteristics of sunlit and shadowed areas are investigated. Based on these observations, a method to detect shadowed areas and restore the shadow-free radiance for the multi-spectral bands is proposed. The effectiveness of the shadow correction method is demonstrated for the QuickBird image.

***Index Terms***— Shadow detection, radiance, shadow correction, multi-spectral bands, QuickBird

## 1. INTRODUCTION

Optical remote sensing sensors, in most cases, use sunlight as a source of illumination. Hence, remote sensing imagery is affected by shadows of clouds, trees, and buildings, etc. Especially for high-resolution satellite images and airborne images, shadow should be paid attention because shadow shares a significant portion of the imagery. If we conduct land-cover classification, shadow should be treated as one class in supervised classification (or automatically classified as a class in unsupervised classification) although such a class has no meaning as land-cover. Another problem of shadow is seasonal and time-dependence. Even though there is no change in the land-cover, a change in the shadow casting-condition gives a false change to the image.

Due to these reasons, it is very useful if the radiance of shadowed areas is corrected to the same radiance level of shadow-free areas. There have been several researches on the detection and correction of shadow [1, 2]. But these methods have not been tested for various cases and the characteristics of shadows are not so well investigated.

In this paper, the radiances of sunlit and shadowed areas are measured by a spectrometer and the spectral characteristics of shadow are investigated in visible to near-infrared regions. A QuickBird image of Bangkok, Thailand, is then introduced as an example and the spectral characteristics of sunlit and shadowed areas in the image are investigated. Based on these examinations, a method to identify shadow areas and to restore the shadow-free radiance for all the spectral bands is proposed. The effectiveness of the proposed method is tested for the QuickBird image.

## 2. MEASUREMENT OF RADIANCE FOR SUNLIT AND SHADOWED AREAS

To investigate general spectral characteristics of sunlight, the measurement of spectral reflectance of a white plate was conducted on December 4, 2008 at the rooftop of an eight-storied building of Chiba University, Japan. A hand-held spectrometer, MS-720 made by Eko Instruments Co., Ltd., Japan (http://www.eko.co.jp/eko/a/index.html), was used. The measurement was conducted every hour in the afternoon of the clear sunny day.

Figure 1 shows the radiance of the white plate in a sunlit area. It is observed that the irradiance of the sunlight gets weaker as the time goes from the noon to the late afternoon. The observation was also carried out in the nearby two shadowed areas. One area is in a dark shadow of a building wall, and another is in a light shadow of a parapet beam.

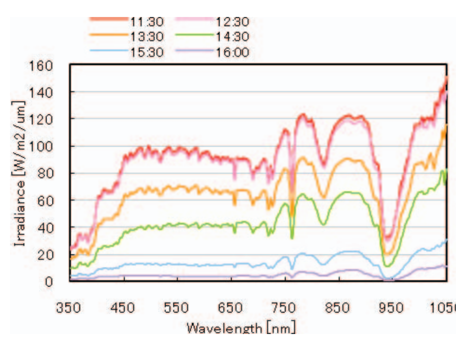


Fig. 1 The measured radiance of a white plate at the rooftop of Chiba University, Japan on Dec. 4, 2008.

The ratio of the radiance in the shadow and that in the sunlit area was calculated and shown in Fig. 2. The ratio increases as the sunlight gets weaker. It is also observed that the ratio shows a large difference between the dark and light shadows. Based on the figure, it is concluded that the effect of shadow is dependent on time (and season), and the casting condition of shadow. Another important issue is the ratio is dependent on the wavelength of sunlight. In the figure, the ranges of wavelength for each spectral band of QuickBird sensor is shown. It is observed that the radiance ratio gets smaller for the longer wavelength bands.

Thus, in order to restore the shadow-free radiance for a shadowed area, the sunlight condition and the shadow casting condition should be known. In other words, the condition to obtain a shadow-free image is depending on time, season and location.

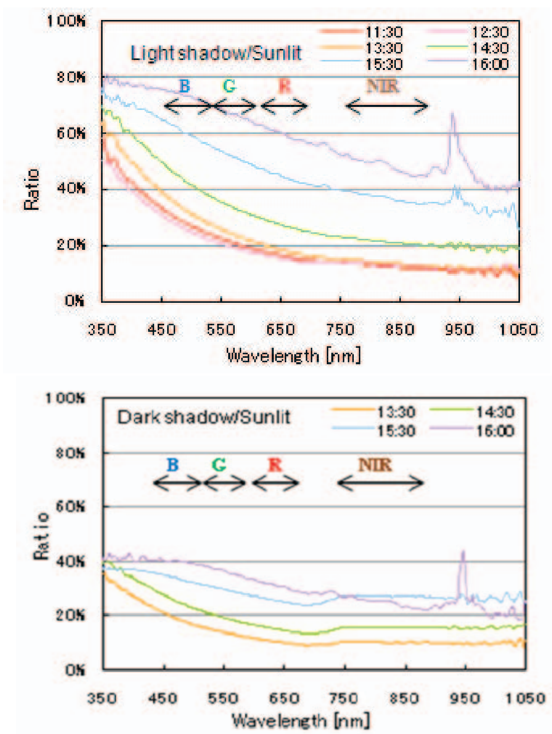


Fig. 2 The radiance ratio of the white plate placed in the two shadow areas and the sunlit area.

## 3. QUICKBIRD IMAGE AND SHADOW EFFECTS

To examine the effects of shadow in optical remote sensing imagery, a QuickBird (QB) image of Bangkok, Thailand, acquired on November 7, 2002, is selected as an example. Figure 3 shows a false color composite of the study area. There are several tall buildings and the large shadows of these buildings are casted on the ground. There are also many mid- to low-rise buildings and trees in the area and thus, the shadows due to these standing objects share a large portion of the image. If a standard land-cover classification method is applied, the shadow areas should be treated as one class due to their low intensity values for all the spectral bands. Figure 4 shows the result of the unsupervised classification by K-means method. In the figure, the most of shadow areas are seen to be classified into two classes.

Fig. 3 False color composite of the QuickBird Image of Bangkok acquired at 10:53 (GMT 3:53) on Nov. 7, 2002.

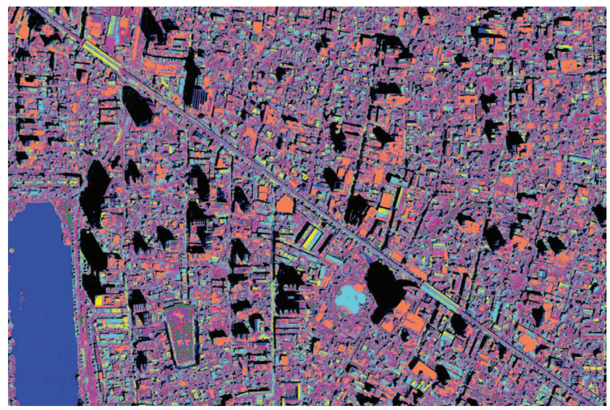

Fig. 4 The result of unsupervised classification of the QB image by K-means with 10 classes. The pixels showing in black color (19.6% of the total area) represent two classes.

This kind of result is, in most cases, unsatisfactory, because the objective is to obtain the land-cover classification, not to extract shadow areas. Hence, a method to extract shadowed areas and then to restore the shadow-free spectral values is sought in this study.

Using the panchromatic (PAN) QB image and its histogram shown in Fig. 5, the threshold value to extract shadowed areas is determined by visual inspection. Then the pixels whose brightness values are smaller than the threshold are considered as in shadow. By this method, some black surface materials in a sunlit area may be considered as in shadow. On the contrary, a light-color surface in a light-shadow area may be classified as not in shadow. A more sophisticated method considering a 3D city model and the darkness of shadow may be necessary if more accurate shadow extraction is required.

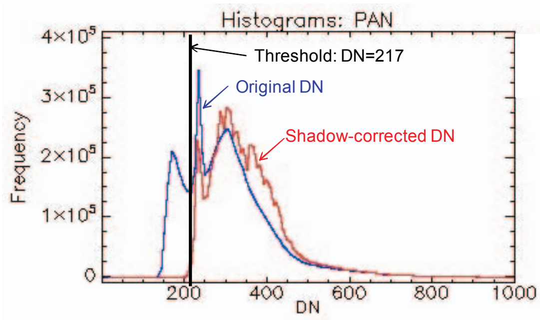


Fig. 5 The original and shadow-corrected histograms of the PAN band intensity for the QB image.

Fig. 6 Extracted pixels (gray and white) as in shadow.

Figure 6 plots the pixels extracted as in shadow in this threshold value, which correspond to 21.4 % of the whole image (3,000*2,000 pixels) and the ratio is close to the two classes in Fig. 4. This ratio of shadowed areas shows that even in a tropical region (the sun angle is generally high), shadow shares a significant portion of satellite images.

## 4. SHADOW CORRECTION METHOD

Several shadow correction methods have already been proposed. Kouchi and Yamazaki [2] employed a simple ratioing method to increase the pixel values of each spectral band. In the study, the land cover classification is performed first, and then the average intensity ratio of the shadow class and another class is used to restore the brightness of the shadowed pixels. The method was applied to Terra/ASTER images (15m resolution) including the shadows due to clouds. This method considers one brightness ratio between shadow and another land-cover class. However, the darkness of shadow in a dense urban area depends on the object to interfere direct sunlight. The brightness of the shadowed pixels is also affected by the surface material (color). Thus, a new shadow correction method is proposed in this study to consider these characteristics of shadow in high-resolution optical images.

Figure 7 compares the digital numbers (DNs) of the same surface material under sunlight and in shadow for the 4 spectral bands. The ratio of the DNs is not the constant value for each spectral band because the darkness of shadow has some variation, as demonstrated in our spectrometer measurement. Thus, 11 pairs (in sunlight and in shadow) of small areas with the same surface material were selected and the linear regression analysis was carried out. The obtained relationships in Fig.7 were used to restore the brightness of the pixels in shadow. It is observed that the relationship is different for each spectral band and the regression line does not go through the origin, which means the ratio to restore the brightness is dependent on the DN value of a shadowed pixel. The similar relationship was developed for the PAN image and the shadow-correction was also conducted for the band as shown in Fig. 5.

Finally, using the corrected multi-spectral bands (2.4m resolution) and the corrected PAN band (0.6m), the corrected pan-sharpen image (0.6m) was produced.

Figure 8 compares a part of the original image (left) and the shadow-corrected image (right). Three small area pairs (red, blue, yellow) used to develop the relationship in Fig.7 are also shown in the figure. It is seen that after the shadow correction, the surface condition could be clearly recognized.

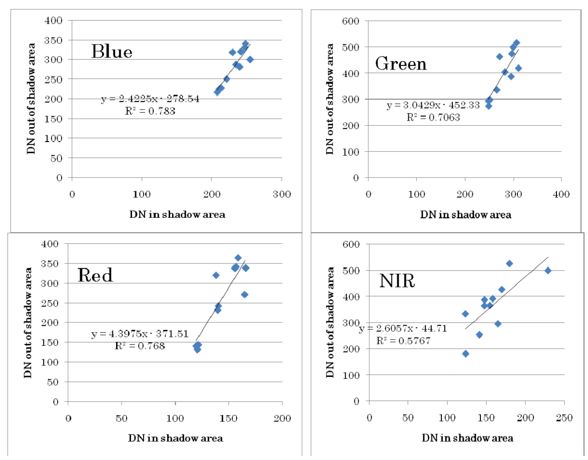


Fig. 7 Relationship between DNs in sunlit and shadowed areas with the same surface materials.

Fig. 8 True color composite of the original image (left) and the shadow-corrected image (right) for area A

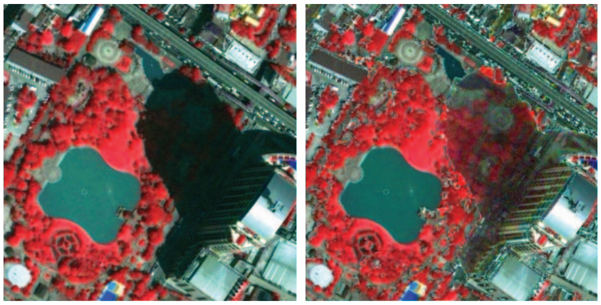

Fig. 9 False color composite of the original image (left) and the shadow-corrected image (right) for area A

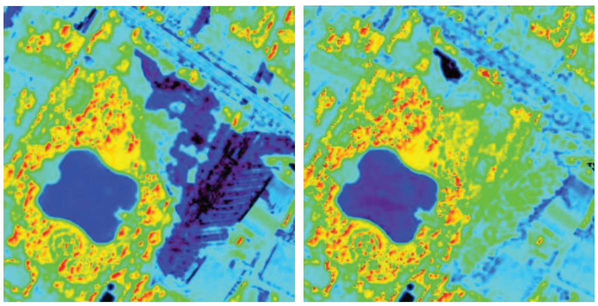

Fig. 10 NDVI of the original image (left) and the shadow-corrected image (right) for area A

Fig. 11 False color composite for the shadow-corrected QuickBird Image

Figures 9 and 10 shows the comparison of the original and corrected images in false color composite and in the normalized difference vegetation index (NDVI). The radiance of the vegetation in the large building shadow has been successfully restored and it can be recognized as vegetation, red in false color and with high NDVI value. This example highlights the fact that the NDVI value becomes small in shadow because the reduction of radiance is more for a longer wavelength as shown in Fig. 2.

Figure 11 shows the shadow-corrected image for the whole area. Comparing with Fig. 3, the large building shadows were mostly eliminated although some of them are still remain. Finally, the unsupervised classification was conducted for the shadow-corrected image and the result is shown in Fig. 12. It is seen that no shadow class exists.

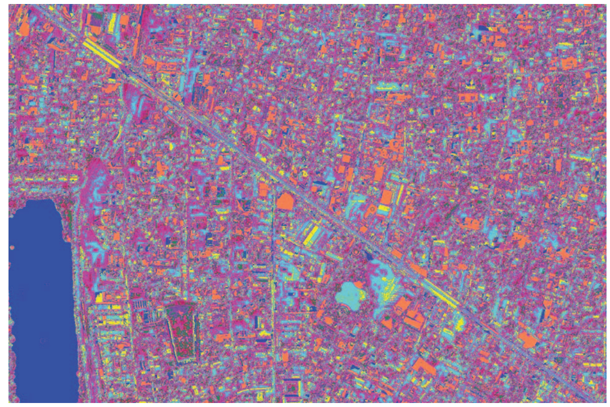

Fig. 12 The result of unsupervised classification of the corrected QB image by K-means method with 8 classes

The proposed shadow correction method is applicable to other optical remote sensing imagery, such as digital aerial images [3] and medium-resolution satellite images [2]. Such examples will be shown elsewhere,

## 5. CONCLUSIONS

The measurement of radiance in sunlit and shadowed areas was carried out to investigate the spectral characteristics of sunlight. The result showed that the radiance ratio (shadow/sunlit) increases as the sunlight gets weaker and the ratio becomes smaller as the wavelength gets longer. The darkness of shadow is also found to vary depending on the shadow-casting condition. A QuickBird image of Bangkok was then introduced and the spectral characteristics of sunlit and shadowed areas were investigated. Based on the inspection, a method to detect shadowed areas and to restore the shadow-free radiance for the multi-spectral bands was proposed. The effectiveness of the shadow correction method was demonstrated by visual inspection and by land-cover classification.

## REFERENCES


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