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SHADOW DETECTION AND REMOVAL FROM URBAN HIGH RESOLUTION REMOTE SENSING IMAGES

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Розглянуто ідентифікацію та реконструкцію тіней на супутникових знімках надвисокого просторового розрізнення. У роботі використано знімки міської території, отримані супутником WorldView-2. Наявність тіней на знімках може привести до втрати значної частини корисної інформації. Задля відновлення освітленості та підвищення якості зображення в тіньових ділянках було розроблено ефективний алгоритм компенсації тіней. Для ідентифікації тіней використовували методи трансформації зображення та порогову бінаризацію. Модель тіні, що складається з прямого та розсіюваного світла, використовували для компенсації тіней.

Ключові слова: ідентифікація тіней; компенсація тіней; метод Отцу; модель тіні; NSVDI; супутникові знімки.

This work is devoted to shadow detection and removal from very high resolution (VHR) satellite images. As an example, a WorldView-2 satellite image of an urban area was processed. The presence of shadows can cause the loss of a significant part of useful information. To restore illumination in shadowed areas and increase image quality, we have developed an efficient shadow removal algorithm. In order to obtain a shadow mask, we used color transformation and thresholding. To remove shadows, a shadow formation model is used.

Key words: shadow removal; shadow detection; Otsu thresholding; shadow formation model, NSVDI, VHR images.

Introduction

In present time, data received from satellites and aircraft play a great role at Earth remote sensing. The necessity of useful information extraction from primary data calls for the development of new automated program complexes capable of processing a large amount of information. Shadow detection and removal is an important problem in the computer vision and image processing areas. Shadows appear in scenes when the light from a light source is completely or partially occluded by elevated objects. Shadows usually provide useful information about the object shape, height, and location, but they also can considerably reduce image quality. The presence of shadows can cause problems in pattern recognition and object identification and incorrect work of classification algorithms. Shadows cause object color and texture distortion. The aim of shadow removal is to obtain a shadow-free image. Shadow removal is an important preprocessing task for further image classification.

Very high resolution (VHR) satellite imagery is considered one of the highest quality currently available from remote sensing satellites. The VHR satellite imageries support a range of services, especially in urban areas, for city planning and monitoring, urban change detection, estimation of human activities/population, forest fires monitoring and urban object/feature detection [1, 2]. The problem of shadowing is important for VHR satellite images. For aerial images, the shadow size can be reduced by choosing the survey time, whereas a low-altitude satellite implements survey only during a fixed time period. Usually shooting is performed in the morning when the Earth atmosphere is most transparent. At that time the sun angle altitude is low, which results in wide shadowed areas in the image. The size of a shadowed area can be reduced by increasing the satellite viewing angle, but this causes object geometry distortions. In urban area images, high buildings can cause a great problem because their shadows cover a

significant part of the image. So the presence of shadows complicates the task of small object identification and interpretation. This problem is especially important for high resolution and very high resolution remote sensing images.

In Earth remote sensing, shadow removal is particularly important. The quality of satellite and aerial images can be significantly refined due to shadowed area processing. The objects located in the shadowed area become more visible. This makes easier a number of remote sensing tasks such as remote sensing data interpretation, thematic classification, mapping, change detection, etc.

The shadow removal process can be subdivided into three significant steps: shadow detection, restoring the illumination of the shadowed area, and removing the distortions that appear along the borders of shadowed and non-shadowed regions. Each of them can be investigated individually. In this work, particular attention is given to the first two.

Analysis of recent research

A great number of works have been devoted to shadow detection and removal. Many efficient algorithms have been developed for the processing of single images of natural scenes. Xiao and colleagues [3] proposed a shadow removal approach based on subregion matching illumination transfer. For shadow detection, they used a ratio map built on the HSI color model. Otsu's method was applied over the histogram of the ratio map for receiving a coarse shadow mask. Then the segmentation of the shadowed and lit regions and subregion matching based on the textural and space distance of each segment are performed.

Finlayson et al. [4] proposed a method to process a 3-band color image. First they find a single scalar function of image that is invariant to changes in light, color, and intensity and depends only on the reflectance. Then the invariant image is used together with the original image to locate shadow edges. By setting these shadow edges to zero in the original image and by a method paralleling lightness recovery, a color shadow-free image is obtained.

Guo et al. [5] segment the image using the mean shift algorithm. Then, using a trained classifier, they estimate the confidence that each region is in shadow. Classification results are used to build a graph of segments, and graph-cut is used to solve the labeling of shadow and non-shadow regions. The shadow removal approach is based on a simple shadow model where lighting consists of directed light and environment light.

Shor and Lischinski [6] proposed a new method for removing shadows from a single image, based on the affine shadow formation model. The parameters of the model are estimated by a mask of shadowed and lit regions. Then a pyramid-based restoration process is applied to produce a shadow-free image.

In recent years, shadow removal algorithms have been applied to remote sensing data received from different spacecraft. Singh [7] proposed an approach based on HSV color model to shadow removal in complex color remote sensing images of urban areas. Shadows are detected using a normalized difference index and subsequent thresholding based on Otsu's method. The mean and variance of these buffer areas are used to compensate the shadow regions.

Kotur and Kiran [8] proposed an inner-outer outline profile line (IOOPL) matching algorithm to remove shadows from satellite images. The shadow features are evaluated through image segmentation.

Tiwari and colleagues [9] proposed the following algorithm to obtain a shadow-free aerial image. First they determine a coarse shadow map using the ratio of hue over intensity. Then enhanced transformation is applied to obtain a precise shadow mask. The shadow is eliminated from the image by the pixel-wise product of each image pixel by a scaling factor.

The purposes of article

The aim of our research is to obtain a shadow-free satellite image. Many works have been devoted to shadow removal for single nature images. Our goal is to apply existing methods and create an efficient automatic shadow removal algorithm for VHR satellite images. Thus our algorithm implementation makes easier further image processing and interpretation.

The main material

We propose an efficient algorithm for shadow removal from VHR satellite images. A WorldView-2 image of an urban area is used as a test image (Fig. 1). Shadow detection is a key step of the algorithm. To detect shadow regions, we perform a shadow segmentation algorithm to obtain a binary shadow mask. First the image is transformed from the RGB color space to the HSV color model. A shadow detection index is calculated to obtain the grayscale ratio image $r(x)$. To determine an optimal threshold for shadow segmentation, we apply Otsu's thresholding method over the $r(x)$ histogram.

To remove shadows from the image, we apply a simple shadow model, which assumes that each pixel in the illuminated region is lit by direct light and reflected light. To estimate the shadow recovery parameters for each shadowed region, we use the lit regions adjacent thereto.

Shadow detection

A shadow occurs when an object partially or totally occludes direct light from a source of illumination. If the light energy is fallen less, that area is represented as shadow region whereas if the light energy is emitted more, this area is represented as non-shadow region. Shadow can be classified into two groups: cast shadow and self-shadow. Cast shadow is caused by the projection of the light source in the direction of the object. Self-shadow is still a shadow but represents the part of the object that is not illuminated directly by the light source. Again cast shadow can be classified into two parts: umbra and penumbra. The part of a cast shadow where direct light is completely blocked by its object is called umbra, while the part where direct light is partially blocked is called penumbra. Both cast and self-shadow has different brightness value [10].

Shadow detection is a wide area for research. A great number of works are devoted to this problem. Depending on the data type and the data processing aim, different approaches can be used. The main complexity of shadow detection methods is to separate shadows from the background and to correct the identification of objects of dark color. There are several approaches to shadow detection. Thresholding is the most widely used method. In [11,12], image thresholding is based on the value of intensity and different spectral indices. Border improvement techniques are widely used for shadow border improvement and noise suppression, for example, differential edge detection operators [13] and morphological operators [11].

The luminance and chromaticity properties of shadows can be used by means of the transformation of a 3-channel color image from the RGB space to the HSV(Hue Saturation Value), HSI (Hue Saturation Intensity), YIQ (luma, inphase, quadrature) and YCbCr models [14, 15]. Then the spectral ratio is calculated. Pixels in shadowed regions have higher values in the ratio image than pixels in non-shadowed regions. Otsu's method is then applied over the histogram of the ratio image to automatically determine the threshold for segmenting the regions in shadow into a binary shadow mask. Tsai [15] studied the application of the spectral ratio to different color models. He also used the following spectral ratio:

$$r(x) = (H + 1) / (I + 1), \quad (1)$$

where H is the hue image component, and I is the intensity.

The normalized saturation-intensity difference index (NSVDI) is widely used to identify shadows [7, 11, 12]:

$$NSVDI = \frac{S - V}{S + V}, \quad (2)$$

where S is the saturation image component, and V is the value component.

Spectral information from different channels of satellite images is widely used [16]. Shahi et al. [17] proposed a novel spectral index, SDI, which can be applied to multispectral Word View-2 images:

$$SDI = \frac{Band8 - Band2}{Band8 + Band2} - Band7, \quad (3)$$

where band8, band2, and band7 are WorldView-2 spectral bands.

To determine the best approach for our purposes, we tested three different methods: spectral ratio and NSVDI calculation with further optimal threshold finding and supervised classification. To evaluate the results of detection procedures, we used the statistical metrics that allow the validation of the process. Completeness, correctness and quality metrics were adopted in this work to verify which approach was best able to improve shadow detection and to avoid misclassification. The process consists of comparing the detected result with a reference shadow mask, also called ground-truth (GT), pixel by pixel. The first quality metric, called completeness, is defined by (4) and represents the percentage of shadow pixels in the GT image that have been properly detected by the approach. The value can vary in the interval [0:1], where the value 1 is considered ideal and shows how complete the approach is.

$$cor = \frac{TP}{TP + FP} . \quad (4)$$

The correctness metric, shown in (5), represents the percentage of shadow pixels correctly identified by the method, in accordance with GT, 1 being the ideal value

$$com = \frac{TP}{TP + FN} , \quad (5)$$

where TP, FP, and FN are the numbers of shadow pixels identified correctly, non-shadow pixels identified as a shadow, and shadow pixels identified as non-shadow, respectively.

The last metric is the quality, shown by (6), and it combines both previous measures showing how good the approach is, 1 being the ideal value to be achieved.

$$qua = \frac{TP}{TP + FP + FN} . \quad (6)$$

Metrics evaluation shows that the binary mask received by NSVDI thresholding (Fig. 3) gives the best results. It was used for shadow detection.

In our work, we started with transforming the original RGB image to the HSV color space:

$$\begin{aligned} R' &= \frac{R}{255}, \quad G' = \frac{G}{255}, \quad B' = \frac{B}{255}, \\ S &= \begin{cases} 0, MAX = 0 \\ 1 - \frac{MIN}{MAX}, MAX \neq 0 \end{cases}, \\ V &= MAX, \\ H &= \begin{cases} 0, MAX = MIN \\ 60 \left(\frac{G' - B'}{MAX - MIN} \bmod 6 \right), MAX = R' \\ 60 \left(\frac{B' - R'}{MAX - MIN} + 2 \right), MAX = G' \\ 60 \left(\frac{R' - G'}{MAX - MIN} + 4 \right), MAX = B' \end{cases} \end{aligned} \quad (7)$$

where

$$\begin{aligned} MAX &= MAX(R', G', B'), \\ MIN &= MIN(R', G', B'). \end{aligned} \quad (8)$$

As a result, we obtain three components of the image: a hue (H), a saturation (S), and a value (V).

Shadows have a high saturation and a low value, thus the V and S components are used in the NSVDI. For each image pixel x , the NSVDI is calculated. As a result, we obtain a grayscale image $r(x)$ (Fig. 2). Applying Otsu's method over the $r(x)$ histogram we find the optimal threshold T that maximizes the function [3, 7, 9, 15]:

$$F(T) = \frac{(\bar{\mu} \cdot w(T) - \mu(T))^2}{w(T) \cdot \mu(T)},$$

$$w(T) = \sum_{i=0}^T p_i,$$

$$\mu(T) = \sum_{i=T+1}^{255} p_i,$$

$$\bar{\mu} = \sum_{i=0}^{255} i \cdot p_i$$
(9)

where p_i is the probability of pixels with gray level i .

To obtain a shadow binary mask, we apply Otsu's thresholding over the NSVDI histogram. Then all pixels of the image are divided into shadow ones ($r(x) > T$) and non-shadow ones ($r(x) < T$).

Shadow removal

In order to restore the illumination of the shadowed regions, we applied a shadow formation model [6, 18]. It shows how much direct light each pixel of the image receives. Our shadow model includes two types of illuminance: direct light, when rays from a light source are incident on the object, and reflected illuminance, when the object is lit by rays reflected from surrounding surfaces. Non-shadowed regions are lit by both types of illuminance, but shadowed regions are lit only by reflected light. The shadow model can be represented by the formula:

$$I(x) = R(x) \cdot L(x),$$
(10)

where $I(x)$ is the value of the pixel x , $L(x)$ is the pixel illuminance, and $R(x)$ is the pixel reflection.

The pixel illuminance can be written as the sum of the direct light intensity vector and the reflected light intensity vector:

$$L(x) = L_D(x) + L_R(x).$$
(11)

Hence we obtain the expressions for the shadowed and non-shadowed regions:

$$I_{lit}(x) = R(x) \cdot L_D(x) + R(x) \cdot L_R(x),$$

$$I_{shd}(x) = \eta(x) \cdot L_R(x) \cdot R(x),$$
(12)

where $\eta(x)$ is a spatially variant factor that accounts for reflected light attenuation.

Using (9), we obtain new values of the shadowed regions:

$$I_C(x) = R(x) \cdot L_D(x) + \frac{1}{\eta(x)} \cdot I_{shd}(x),$$

$$I_C(x) = A(x) + \gamma(x) \cdot I_{shd}(x),$$
(13)

$$A(x) = \mu(B) - \gamma \cdot \mu(S),$$

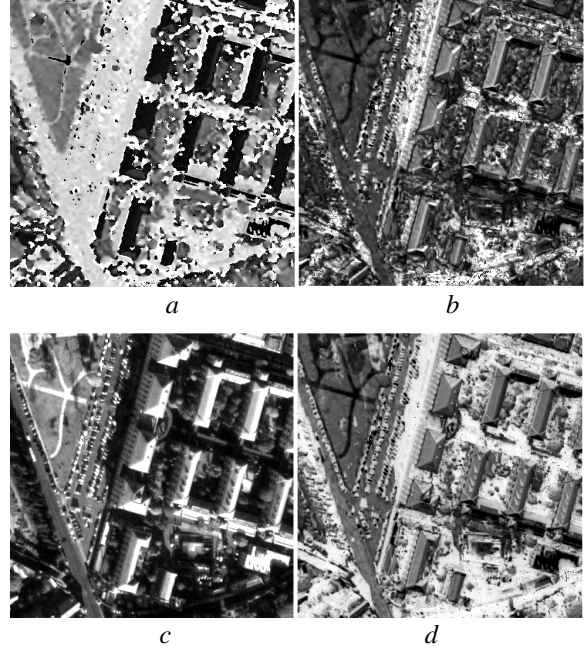
$$\gamma(x) = \frac{1}{\eta(x)} = \frac{\sigma(B)}{\sigma(S)},$$
(14)

where $\mu(L)$ and $\mu(S)$ are the mean values of the lit region and the shadowed region, respectively, $\sigma(S)$ and $\sigma(L)$ are the standard deviations of the shadowed and the lit region. $I_C(x)$ is the new value of the pixel x in the shadowed area. To estimate a new mean value and standard deviation for each shadowed segment, we use the lit regions adjacent thereto.

In Fig. 5, the normalized histograms of the shadowed and non-shadowed regions are presented. The first and the second diagram show the pixel distribution before and after the shadow removal, respectively. The red diagrams correspond to the shadowed regions, and the blue ones correspond to the non-shadowed regions. As can be seen, after the application of our restoring algorithm the pixel distribution in the shadowed regions approaches the pixel distribution in the illuminated areas. Figure 6 shows the histograms of the whole image before and after the removal algorithm application.



Fig. 1. Original satellite image



*Fig. 2. HSV model components: a – hue component;
b – saturation component; c – value component;
d – NSVDI grayscale image*



Fig. 3. Shadow binary mask



Fig. 4. Resulting shadow-free image

Conclusions and recommendation for further research

In this work, an efficient algorithm for shadow removal from a satellite image is proposed. We are the first to apply a shadow formation model to shadow removal from a WorldView-2 satellite image. For shadow detection a threshold based method was applied. For our image the best result was obtained by NSVDI index and optimal threshold finding. The illumination of the test image is restored using a shadow formation model. As a result, we have obtained a shadow-free WorldView-2 satellite image. The test results confirm the efficiency of the proposed algorithm. There are, however, a number of artifacts introduced into the resulting images. These artifacts are due to the fact that the shadows are illuminated nonuniformly and the determination of the shadow border is imperfect. Further research will be devoted to removing artifacts along the shadow borders and processing images from other spacecraft.

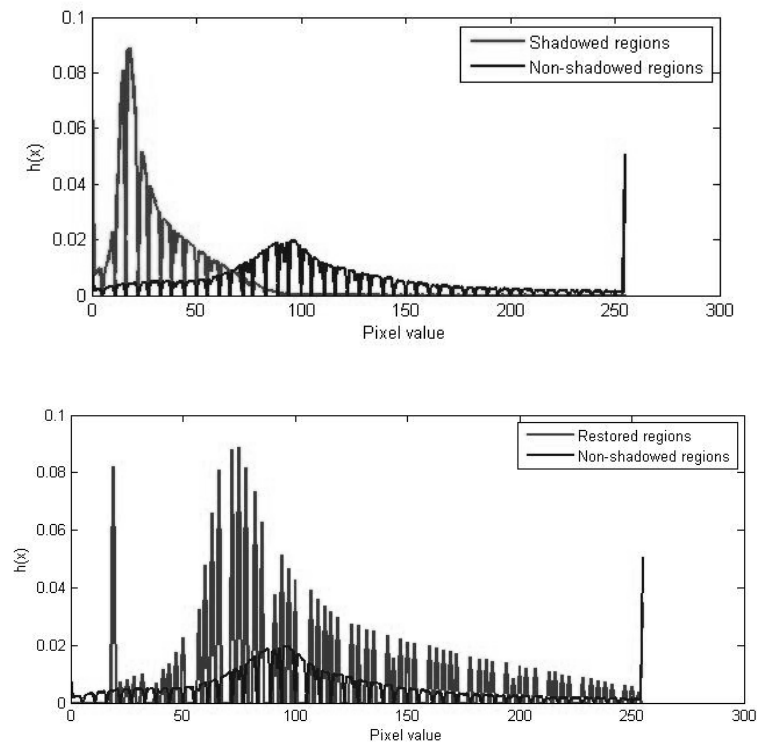


Fig. 5. Normalized histograms of shadowed and non-shadowed pixels

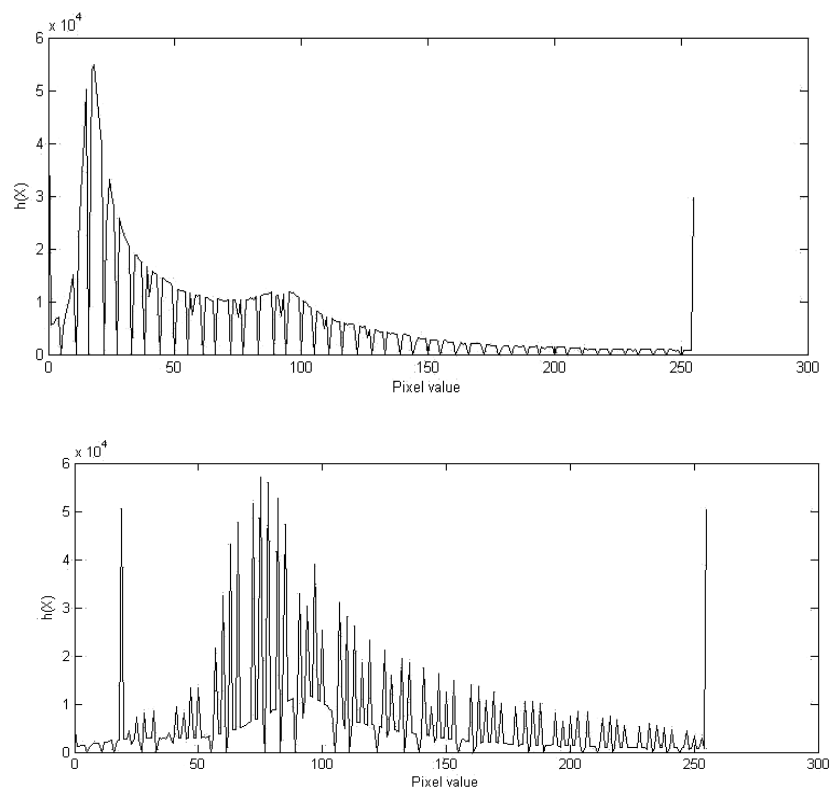


Fig. 6. Normalized histograms of shadowed and non-shadowed pixels

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