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Near real-time shadow detection and removal in aerial motion imagery application

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ABSTRACT

This work presents a method to automatically detect and remove shadows in urban aerial images and its application in an aerospace remote monitoring system requiring near real-time processing. Our detection method generates shadow masks and is accelerated by GPU programming. To obtain the shadow masks, we converted images from RGB to CIELCh model, calculated a modified Specthem ratio, and applied multilevel thresholding. Morphological operations were used to reduce shadow mask noise. The shadow masks are used in the process of removing shadows from the original images using the illumination ratio of the shadow/non-shadow regions. We obtained shadow detection accuracy of around 93% and shadow removal results comparable to the state-of-the-art while maintaining execution time under real-time constraints.

1. Introduction

A Wide-Area Motion Imagery (WAMI) System (Blasch et al., 2014), provides a big-picture of large areas of interest, which can increase the situation awareness, facilitating law-enforcement, tracking and mapping wildfires, borders control and military engagement by monitoring crowd behavior and tracking targets. We present a method to automatically detect and remove shadows in images captured by the WAMI System with local, on-line, near real-time image processing. Our main contributions are the use of a multilevel threshold determination technique to segment a modified Specthem Ratio image to detect shadows, as this ratio elicits shaded pixels. We also present how to effectively remove the shadows by using the statical information of the (unshaded) shadow boundary extracted by a proposed structuring mask. The illumination ratio of shaded/unshaded regions are used to enhance shaded pixels. We provide an implementation under near real-time constraints, *i.e.* processing each image before the system captures the next one.

In remote sensing applications, shadows are often considered as a nuisance, especially at low resolutions. They are known to modify the form and color of the regions of interest (ROI) (Pan et al., 2014), *e.g.* a green object may appear black if there's low luminance. The shadow effect can also lead to misidentification within regions where water is present due to the similarity of their spectral signatures. Moreover, the images captured from airspace are subject to change depending on the position of the light source and the movements performed by the acquisition hardware.

In color aerial images, color tone is a powerful descriptor that simplifies and dominates the identifying characteristics of visual interpretation applications. When humans perceive a color object, they describe it in terms of hue, saturation and brightness properties described by several similar color models such as HSL, HSI and HSV (hue-saturation-intensity/value). The amount of different HSL type color spaces across the literature and their device-dependence has caused many authors providing different equations for the same color space (Ford and Roberts, 1998). Although being very good for user interfaces, specially color selection, those HSL related color spaces provide a mere approximation of the illumination information in the image and often confound saturation and lightness or hue and lightness (Brewer, 1994). True lightness calculation requires an appropriate color space such as CIEL$*$a$*$b$*$ (CIELAB), or its polar counterpart CIELCh (Ford and Roberts, 1998). This color space describes mathematically all perceivable colors in the three dimensions *L* for lightness and *a* and *b* for the

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color opponents green–red and blue-yellow. In CIELCh, C is the module and h is the angle of the (a, b) coordinate.

The problems in identifying shadows include boundary ambiguity, color variability, variation of lighting, weather effects, and others. According to Jadhav and Jadhav (2016) shadows in aerial images have the following properties:

- Lower luminance (intensity) because the electromagnetic radiation from the sun is blocked (Tsai, 2006).
- Higher saturation with short blue-violet wavelength due to the Rayleigh effect of atmospheric scattering (Polidorio et al., 2003).
- Increased hue values, because the intensity change of a shaded area when compared to an unshaded area is proportional to the wavelength (Huang et al., 2004).
- Increased entropy, which denotes the randomness of the pixels in that region (Zhu et al., 2010).

The most popular approach for shadow detection is to use a variety of variant and invariant cues (features) to capture characteristics of shadows (Khan et al., 2016). A number of authors, Zhu et al. (2010), Lalonde et al. (2010), Guo et al. (2013) and Salvador et al. (2004) focused on the chromatic and textural properties of shadows to determine the illumination conditions in the scene. Another trend is to evaluate the illumination properties as did Xiaoyue Jiang and Wyatt (2011) and Panagopoulos et al. (2010). A blackbody radiator model has also been put forward to detect shadows (Makarau et al., 2011). Finlayson et al. (2006) applied an interactive diffusion process to fill in the derivatives in penumbra region, even though still causing texture loss. Later, Finlayson et al. (2009) have also used inpainting for shadow removal. Shadow invariant approaches attempt to retrieve the true color at each pixel as if there were no shadows in the image (Tian et al., 2009). As shadows are important to build 3D scenes, some authors detect and focus on them to estimate buildings heights as Liasis and Stavrou (2016). In video surveillance applications, techniques take advantage of multiple images (Finlayson et al., 2007) or time-lapse sequences to detect shadows (Joshi and Papanikolopoulos, 2008).

Shadow detection can be broadly classified into model-based methods, property-based methods or even machine learning methods (Adeline et al., 2013). Model-based methods use geometric modeling (Fang et al., 2008; Zhan et al., 2005), for previously known scenes. It has many limitations as the necessity of a point light source, a flat background and different orientations of the object and the cast shadow. Property-based methods involve classification and segmentation (Leone and Distante, 2007; Ying-Li Tian and Hampapur, 2005), which usually involve a slow pixel-per-pixel process, comparing a candidate shadow region's texture to a background reference frame, and histogram thresholding (Tsai, 2006; Chung et al., 2009; Nandini et al., 2014; Chen et al., 2007; Dare, 2005). Different applications make use of different methods. For instance, when we have no prior knowledge of the image, geometric modeling cannot be used.

Histogram thresholding is one of the most used methodology among authors for shadow detection. Based on the properties of shadow pixels, it preserves the pixels that have low luminosity over the pixels with high luminosity. Also, it pursues the color constancy concept, where the color properties of objects do not change with low luminance. Tsai (2006) proposed an efficient shadow detection algorithm to identify shadows converting the RGB color space into several color spaces (as HSI, HSV, HCV, YIQ) and applied threshold on the hue over intensity ratio. The work by Tsai (2006) has poor accuracy on complex high-resolution images. Chung et al. (2009) modified Tsai's method by performing successive local thresholding on shadow candidate pixels, increasing the shadow detection accuracy but increasing processing time as well. Furthermore, there was the necessity of empirically setting some parameters, which depends on the content of the image, impairing automation. Thresholding is the most efficient methodology in terms of computational resources and the one this paper builds upon, focusing on automation, and real-time implementation, while maintaining values of shadow detection accuracy comparable to the state of the art.

It seems clear that the hue, saturation and intensity characteristics provide relevant information on the shadows of an image. Therefore, this work presents the implementation of a computational method to detect shadows in urban aerial images based on the image representation in the CIELAB color space. Additionally, we use the power that lies in the Graphics Processing Unit (GPU) in order to accelerate complex (or time/resource demanding) calculations. The level of parallelism that can be achieved by GPUs implies several pixels being processed at the same time, causing a reduction in execution time compared to sequential implementation.

To improve the performance in terms of faster responses in the processing of images, we implemented the method making use of *CUDA*®, or *Compute Unified Device Architecture*, a parallel computing platform and programming model idealized and provided by NVIDIA™.

In the next section, we discuss our shadow detection methodology in details, going over each step to obtain a final shadow mask. In Section 3, we describe our removal method. Section 4 describes the proposed methodology, discuss CUDA and GPU, and the application for which the method is mainly designed for. The assessment strategy is presented in Section 5. Section 6 shows the computed images and the final shadow masks for each of the three input color aerial urban images as well as the shadow-removed images. We also evaluate the speed improvement and performance regarding correctness and precision of the implemented method using CUDA. Finally, we draw conclusions in Section 7.

Table 1
Shadow detection algorithm.

	$Mask = Shadow(original)$
1	$L, C, h \leftarrow$ RGB conversion to CIELCh
2	$h_e, L_e \leftarrow$ Mean filter h and L channels
3	Specthem $\leftarrow$ Specthem Ratio $\frac{h_e+1}{L_e+1}$ (Eq. 8)
4	modSpecthem $\leftarrow$ Preprocessing of Specthem
5	Hist $\leftarrow$ Calculate histogram of modSpecthem image
6	Level $\{1,2,3\} \leftarrow$ Multilevel Otsu's on Hist
7	ShadowBW $\leftarrow$ Threshold Specthem with Level 3
8	Mask $\leftarrow$ Morphological Closing operation on ShadowBW
9	Return Mask

Table 2
Shadow removal algorithm.

	$Enhanced = Removal(Mask)$
1	*subMask* $\leftarrow$ Separate *Mask* into labelled connected regions
2	For each *subMask* in *Mask*
3	Get shaded region from *subMask*
4	*borderMask* $\leftarrow$ Subtract *subMask* from dilated *subMask*
5	Get unshaded borders from *borderMask*
6	*Ratio* $\leftarrow$ Calculate illumination ratio between border and shadow region
7	Relight pixels based in *Ratio*
8	Return Enhanced

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