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A robust mosaicking procedure for high spatial resolution remote sensing images

Xinghua Li [a,1], Nian Hui [b,1], Huanfeng Shen [a,c,*], Yunjie Fu [d], Liangpei Zhang [c,e]

[a] School of Resource and Environmental Sciences, Wuhan University, Wuhan, Hubei province, China
[b] Department of Navigation Data, Wuhan Kotei Informatics Co., Ltd., Wuhan, Hubei province, China
[c] Collaborative Innovation Center for Geospatial Information Technology, Wuhan University, China
[d] Chongqing Institute of Surveying and Mapping, NASM, Chongqing, China
[e] State Key Laboratory of Information Engineering in Surveying, Mapping, and Remote Sensing, Wuhan University, Wuhan, Hubei province, China

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ABSTRACT

With the rapid development of sensor manufacturing technology, high spatial resolution (HR) images are becoming more easily acquired and more widely used. However, it is common that a region of interest (ROI) cannot be completely acquired from a single image. Image mosaicking can resolve the problem by creating a new large-area image from multiple images with overlapping areas. A typical mosaicking procedure for HR remote sensing images includes three successive steps: tonal adjustment, seamline detection, and image blending. In this paper, we propose a robust mosaicking procedure featuring novel ideas in all three steps, which is aimed at processing HR remote sensing images of urban areas. Firstly, the tonal adjustment is realized by a local moment matching (LMM) algorithm, which solves the nonlinear photometric correlation problem between adjacent images. Secondly, an automatic piecewise dynamic program (APDP) algorithm for seamline detection is proposed to detect the optimal seamline on the overlapped area. Last but not least, we propose a cosine distance weighted blending (CDWB) method to ensure that the seamline is as invisible as possible. Compared to the state-of-the-art methods, the proposed method was proved to be effective in experiments with high resolution aerial and satellite images.

1. Introduction

In the last decades, high spatial resolution (HR) remote sensing images have become widely used to embody abundant geographic information. However, the narrow geographic range within a single image is one of the main factors which limits the further application of HR images. As we know, in terms of images with the same size, the higher the spatial resolution, the narrower the geographic range. As a result, the region of interest (ROI) often cannot be included in a single image. How to acquire a complete ROI from HR images has always been a hot topic. Accordingly, image mosaicking has been developed to solve the problem. In a nutshell, image mosaicking is the process of merging two or more images with overlapping areas into a single view with an indistinguishable seamline (Burt and Adelson, 1983).

Briefly speaking, there are two main reasons for the difficulties encountered in remote sensing image mosaicking. One is that the images are often taken at different times, and the other is that they are often taken from different angles. The former issue leads to different geographic features existing on the overlapped area, and a big tonal difference. The latter issue causes shape differences in the same geographic features on the overlapped area, especially for HR images. In other words, when the camera takes images from different angles, different objects will appear in the same position according to the geographic reference. To this end, the current mosaicking procedures for remote sensing images are structured as follows. Firstly, in order to make the mosaicked image a natural integrated image, tonal adjustment is necessary. A fusion process should then be undertaken. In general, the images to be mosaicked must have overlapping areas (shared areas). After the tonal adjustment, averaging the pixels of the overlapped area is the simplest way to mosaic the images. For low spatial resolution images, this

* Corresponding author at: School of Resource and Environmental Sciences, Wuhan University, Wuhan, Hubei province, China.
E-mail address: shenhf@whu.edu.cn (H. Shen).

[1] These authors contributed equally to this study and shared first authorship.

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method is very effective. However, when it comes to HR remote sensing images, this approach may cause ghosting. Researchers have therefore investigated how to find an appropriate seamline to weaken the ghosting effect (Chon and Kim, 2006). When an optimal seamline is detected, pixels of the mosaicked image approximately rely on only one image, based on which side of the seamline they lie on (Pan et al., 2009). A blending algorithm is also necessary to reduce the residual differences between the two neighboring images in a buffer along the seamline (Chon and Kim, 2006). To sum up, three successive steps are required to generate a satisfactory mosaicked image from HR images: tonal adjustment, seamline detection, and image blending.

In this study, we propose a robust mosaicking procedure for HR images, with the following improvements in tonal adjustment, seamline detection, and image blending. Note that the HR images to be mosaicked all have overlapping areas. In the first step, the tonal differences are corrected by local moment matching (LMM). An automatic piecewise dynamic program (APDP) seamline detection method then determines the location of the optimal seamline in the overlapped area. In the final step, the seamline is eliminated by a new method of cosine distance weighted blending (CDWB).

The rest of this paper is organized as follows. In Section 2, we survey the current approaches to image mosaicking. The algorithms we propose in this paper are discussed in Section 3, which is followed by the mosaicking experiments in Section 4. The conclusions and discussions are drawn in Section 5.

2. Related works

As was previously mentioned, there are three key aspects in image mosaicking: tonal adjustment, seamline detection, and image blending. In this section, we introduce some of the existing methods for these three aspects.

2.1. Tonal adjustment

Tonal adjustment plays an important role in making a mosaicked image appear to be a natural single image. The current approaches to tonal adjustment are based on the premise that the reflection conditions in the overlapped region remain constant. The average luminance condition of the reference image in the overlapped area is computed, and the other image is normalized into uniformity (Du et al., 2001). The mean value denotes the average of the image intensity, and the variance or standard deviation represents the volatility of the intensity. These are the most basic indicators for image tone. Yi et al. (2003) detailed three common tonal adjustment methods: (1) the approaches based on image entropy; (2) the methods using mean variance; and (3) histogram matching. The approaches based on entropy are based on the principle that the overlapping areas of the adjacent images represent the same area, so the entropy should also be the same. The color difference is then eliminated by entropy mapping. The methods based on mean variance adjust the tone using the mapping relationship between the image mean and variance (Zhang et al., 2003). Histogram matching stretches the histogram of all the bands in one image to be similar to the shape of the reference image, to adjust the tone (Du et al., 2001; Gonzalez and Woods, 2007). Mills and Dudek (2009) used a linear approximation model to adjust the tone generally. These kinds of methods compute a pair of gain and bias values based on the overlapped area, and build a linear correlation of the image before and after adjustment (Zhang et al., 2003; Gonzalez and Woods, 2007). This sort of adjustment has the common shortcoming that the image may appear dark or bright in the overall view. In this case, some local features in the tone may be ignored. To avoid the overall luminance difference and to allow better consideration of the local features, we propose the LMM algorithm in the step of tonal adjustment.

2.2. Seamline detection

As to the detection of the seamline, this has always been the focus of HR image mosaicking (Zagroub et al., 2009). Seamline detection aims at finding the optimal seamline where the images share the most similarity. When detecting the seamline in an urban area with clusters of buildings, if the seamline can go through a flat area, or go along the natural edges of the buildings, instead of crossing the buildings, it will be hidden among these complex geographic entities (Duplaquet, 1998).

Based on the snake model (Kass et al., 1988), Wang et al. proposed the improved snake model (Wang et al., 2010). In their work, the sum of the mismatched values on the line is considered as the energy. The line with the lowest energy is then the optimal seamline. This model solves the local optimum problem existing in the snake model, to some extent, but not completely. Kerschner (2001, 2000) proposed the twin snake algorithm. In this approach, the two lines of the twin snake start from opposite borders of the overlapped area, and are forced to be attracted to each other. The optimal seamline is determined if the two lines are merged. However, this algorithm cannot overcome the local minima problem completely, and it requires a high computational cost (Chon and Kim, 2006).

Dijkstra (1959) proposed Dijkstra's algorithm to solve the problem of the shortest path, and Davis (1998) used this algorithm to choose the optimal seamline for images with moving objects. In this approach, the seamline is placed by creating a difference image for the two neighboring images, with pixels given higher values if they have greater intensity differences. The optimal seamline is then the minimum cost path from one edge of the overlapped area to the other. Unfortunately, the algorithm has two shortcomings: it is only useful for carefully controlled source images, and its traversal efficiency is a little low for remote sensing images.

Pan et al. (2009) proposed large-area Voronoi diagrams to generate a seamline network for mosaicking over a large geographic area. This algorithm, which can easily obtain a seamline network, especially for multi-image mosaicking, is suitable for common industrial production. However, for high-accuracy mosaicking, this method cannot fulfill the requirements.

Duplaquet (1998) developed a dynamic program (DP) based algorithm combining the color and gradient similarity to trace the optimal seamline. The DP algorithm (Agrawal and Horgan, 1990) is also an algorithm that can obtain the shortest path. However, compared with Dijkstra's algorithm, the time consumption is much less. The most significant superiority of the DP algorithm is the rapid operation, which is very important for HR remote sensing image mosaicking. However, the accuracy of the seamline location by the use of the DP algorithm still has room for improvement. Xing et al. (2010) used an algorithm modified from the DP algorithm, which showed a slight improvement over the original DP algorithm. Nevertheless, the detected seamline still easily goes through buildings, which causes obvious discontinuity. To avoid such discontinuity, we propose the APDP algorithm in this paper.

2.3. Image blending

The third step—image blending, also called feathering (Levin et al., 2004)—provides a smooth transition near the seamline. In this field, hard correction (HC) (Zhu and Qian, 2002; Shmuel, 1981), weighted stacking on overlapped areas (Chon and Kim, 2006; Gonzalez and Woods, 2007; Uyttendaele et al., 2001), and