ISPRS Journal of Photogrammetry and Remote Sensing 117 (2016) 149–160

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Registration of multitemporal aerial optical images using line features

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form 31 March 2016
Accepted 1 April 2016
Available online 22 April 2016

Keywords:
Image registration
Aerial optical images
Multitemporal images
Line features
Change detection

ABSTRACT

Registration of multitemporal images is generally considered difficult because scene changes can occur between the times the images are obtained. Since the changes are mostly radiometric in nature, features are needed that are insensitive to radiometric differences between the images. Lines are geometric features that represent straight edges of rigid man-made structures. Because such structures rarely change over time, lines represent stable geometric features that can be used to register multitemporal remote sensing images. An algorithm to establish correspondence between lines in two images of a planar scene is introduced and formulas to relate the parameters of a homography transformation to the parameters of corresponding lines in images are derived. Results of the proposed image registration on various multitemporal images are presented and discussed.

1. Introduction

Aerial optical images of urban scenes are rich in line features. Lines are geometric features that are stable under changes in camera view-angle. They represent straight segments along boundaries between regions of different properties. Even when the properties of individual regions change over time, as long as adjacent regions exhibit differing properties, boundaries between the regions and, therefore, the straight segments along the boundaries remain unchanged.

The problem to be addressed in this paper is as follows: Given two aerial optical images of a planar scene taken at different times, we would like to register the images using line features in the images. A planar scene is one in which change in scene elevation within the viewing area is negligible compared to the distance of the camera to the scene.

The images to be registered are assumed to be from a man-made scene where line features are abundant. Moreover, the scene is assumed to be flat so that the relation between the images can be described by a single homography transformation. It is understood that some lines detected in one image may be missed in the other, and corresponding lines in the images may not have corresponding endpoints.

An example of the kind of images to be registered is given in Fig. 1. Fig. 1a shows a Landsat 5 image of an area in Western Australia taken on January 8, 1990; and Fig. 1b shows another Landsat 5 image of the same area taken on January 2, 2011. These images are courtesy of the U.S. Geological Survey. Land-cover changes occurring during this period are significant; however, there are region boundaries with straight segments that have been preserved over time. Line segments in the images detected by a least-squares line fitting method (Pavlidis and Horowitz, 1974) are also shown in Fig. 1. The coefficients/parameters of these lines will be used to find a homography transformation to register the images.

In the following sections, after reviewing multitemporal image registration methods and methods that use line features to register images, details of the proposed image registration are provided. Then, experimental results of the proposed method on various multitemporal images are presented and discussed.

2. Related work

Due to radiometric differences between multitemporal images, from very early on, raw image intensities were not used to register such images. Anuta (1970) used intensity gradients, Dai and Khorram (1997) used zero-crossing edges representing region boundaries, and Eugenio et al. (2002) used coastlines detected by a gradient energy function to register multitemporal images. By matching boundaries of land cover patches, Cao et al. (2014) and Han et al. (2015) found correspondence between the boundaries. The centroids of corresponding closed boundaries were then used as corresponding control points to register multitemporal images.

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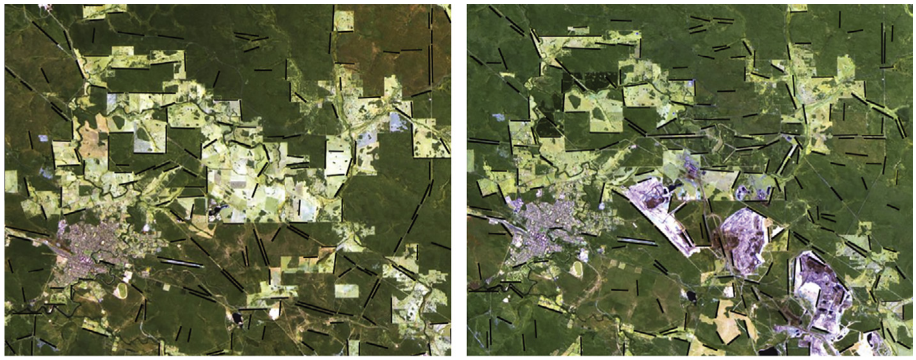
http://dx.doi.org/10.1016/j.isprsjprs.2016.04.002



(a) (b)

Fig. 1. (a), (b) Landsat 5 images of an area in Western Australia taken on January 8, 1990 and on January 2, 2011, respectively. These images are courtesy of the US Geological Survey. 113 lines are detected in image (a) and 101 lines are detected in image (b). These lines will be used to determine the parameters of a homography transformation to register the images.

The need for geometric features in order to avoid radiometric differences between the images being registered was recognized by Li and Davis (2001) and Hu et al. (2015). They suggested using feature points to register multitemporal images. Correspondence was established between points in two images using the descriptors associated with the points. A descriptor for a point characterizes the gradient properties of the neighborhood of the point. In addition to points, Coulter et al. (2003) used information from the global positioning system to capture an image that had the same center as an image captured earlier in order to reduce the geometric difference between the images.

Chen et al. (2003) and Moorthi et al. (2011) showed that radiometric differences between multitemporal images can be dampened by using mutual information as the similarity measure when registering the images.

Most recently, Murphy and Le Moigne (2015) demonstrated use of shearlet features in registration of multitemporal images. To register two images by a rigid transformation function, a distance measure was used to relate corresponding features in the images. Then, by minimizing the distance measure through an iterative process determined the rigid transformation parameters.

The effectiveness of line features in the registration of remote sensing images has been demonstrated before (Habib and Alruzouq, 2004; Li and Shi, 2014; Shi and Shekar, 2006). The main difficulty in the use of line features in image registration is in determining the correspondence between the lines.

In a matching paradigm known as Random Sample and Consensus or RANSAC (Fischler and Bolles, 1981), Coiras et al. (2000) found the affine parameters for registering two images by selecting three random lines in each image, finding the intersections of the lines, and using the intersections as corresponding points. If the randomly selected lines in the images truly correspond, the obtained affine transformation will align many lines in the images. The process of randomly selecting lines and verifying their correspondence is repeated until an affine transformation is found that can align a sufficiently large number of lines in the images. After being transformed by an affine transformation, a line in the sensed image is considered to align with a line in the reference image if the distance between their midpoints falls below a prespecified threshold distance.

To speed up computation of the affine transformation by RANSAC, Li et al. (2008) determined the parameters in two steps. In the first step, an initial correspondence was established between lines in the images by using the angular difference and the distance between midpoints of nearest lines in the images. When the images have small translational and rotational differences, some of the initial correspondences will be correct. In the second step, three lines were randomly selected from the reference image, and from the initial correspondences the three corresponding lines were identified in the sensed image. Using the intersections of line triples in the images as corresponding points, affine parameters were computed and the match rating between remaining lines in the images was determined. If this match rating was sufficiently high, the obtained affine transformation was used to register the images. Otherwise, the process was repeated until either an affine transformation was found that could produce a sufficiently high match rating or the maximum allowed number of iterations was reached.

Krüger (2001) extended the RANSAC-based affine registration to homography registration. By selecting two random lines from each image, considering them as corresponding lines, and using their endpoints as corresponding points, the parameters of a homography to register the images was determined. If the endpoints of the lines truly correspond to each other, the obtained homography will establish correspondence between many other lines in the images. After lines in the sensed image are transformed with the obtained homography, if the degree of overlap between lines in the images is sufficiently high, the computed homography is considered correct and used to register the images. Rather than using the degree of overlap between matching lines, Volegov and Yurin (2008) used the average color difference of pixels around matching lines and, by minimizing the sum of average color differences of matching lines, determined the best homography to register the images.

A number of methods find the parameters of a transformation, one at a time, by clustering in the parameter space (Habib and Kelley, 2001; Stockman et al., 1982). To determine the rotational difference between two images, a 1-D accumulator array is used to quantize all possible rotational differences between the images. Array entries are initially set to 0. Then, the rotational difference between a randomly selected line in the reference image and a randomly selected line in the sensed image is determined and the corresponding array entry is incremented by 1. All randomly selected lines that truly correspond produce about the same rotational difference, showing the true rotational difference between the images. Randomly selected lines that do not correspond, produce rotational differences that randomly fill the accumulator space. After processing a sufficiently large number of line pairs in the images, a peak will emerge in the accumulator array, showing the most likely rotational difference between the images. Knowing the rotational difference between the images, both images are brought into the same orientation and the same clustering process