

Rectification of aerial images using piecewise linear transformation

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Abstract. Aerial images are widely used in various activities by providing visual records. This type of remotely sensed image is helpful in generating digital maps, managing ecology, monitoring crop growth and region surveying. Such images could provide insight into areas of interest that have lower altitude, particularly in regions where optical satellite imaging is prevented due to cloudiness. Aerial images captured using a non-metric cameras contain real details of the images as well as unexpected distortions. Distortions would affect the actual length, direction and shape of objects in the images. There are many sources that could cause distortions such as lens, earth curvature, topographic relief and the attitude of the aircraft that is used to carry the camera. These distortions occur differently, collectively and irregularly in the entire image. Image rectification is an essential image pre-processing step to eliminate or at least reduce the effect of distortions. In this paper, a non-parametric approach with piecewise linear transformation is investigated in rectifying distorted aerial images. The non-parametric approach requires a set of corresponding control points obtained from a reference image and a distorted image. The corresponding control points are then applied with piecewise linear transformation as geometric transformation. Piecewise linear transformation divides the image into regions by triangulation. Different linear transformations are employed separately to triangular regions instead of using a single transformation as the rectification model for the entire image. The result of rectification is evaluated using total root mean square error (RMSE). Experiments show that piecewise linear transformation could assist in improving the limitation of using global transformation to rectify images.

1. Introduction

Remote sensing is defined as the acquisition and record of information about an object, area or phenomenon without being in direct physical contact with it [1]. This technology is utilized in many applications to obtain a consistent view of the Earth or human activities. Satellite and aircraft-based systems are the two major platforms which are commonly used to acquire remotely sensed visual records [2]. In general, satellite images provide broader spatial coverage with fewer shots due to the height of the platform. However, aerial images are easier to adapt according to the specific needs of applications and ideal for mapping small areas. For instance, image details could be improved by adjusting the flying height of aircraft and weather conditions, and the types of data captured could be controlled with changeable or multiple cameras [3]. Furthermore, aerial images could provide closer look to the area of interest with lower altitude under the clouds, particularly in the regions with problem of optical satellite imaging being blocked by cloudiness [4].

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Aerial images are widely used in different activities such as generating digital maps, managing ecology, monitoring crop growth and region surveying. However, aerial images not only contain the real details, such images also contain distortions as well. The main sources of distortions include lens, earth curvature, topographic relief and the attitude of the aircraft that is used to carry the camera. Distortions that composited differently, collectively and irregularly in the entire image, would affect the actual length, direction and shape of objects in the images. Consequently, the features derived from a distorted aerial image are incorrect and the accuracy of subsequent image analysis would be affected.

Image rectification is an essential image pre-processing step to eliminate or at least reduce the effect of distortions. In this paper, aerial image using on non parametric approach with piecewise linear transformation will be discussed. Non-parametric approach requires a set of corresponding control points obtained from a reference image and a distorted image. Conventional methods usually applied the same rectification transformation for the whole image without considering distortions are different in the entire image. Hence, using the same rectification coefficients is difficult to describe the true distortions of a whole image [5]. This paper studies piecewise linear transformation from a given set of control point correspondences. Piecewise linear transformation divides the image into regions by triangulation and different linear transformations are employed separately to triangular regions instead of using a single transformation as the rectification model.

This paper is organized as follow. The related work of image rectification is presented in Section II. In Section III, piecewise linear transformation is discussed in details. The explanation of experiments conducted and the analysis of results obtained are described in Section IV. The conclusions of this study are summarized in Section V.

2. Geometric transformations for aerial images rectification

In the process of aerial images rectification two images are involved, a reference image and a target image. Geometric transformation is a vector function that maps the pixel in a reference image to a new position in a target image [6]. In other words, the reference image is kept uncharged and the target image is resampled to take the geometry of the reference image. As an instance, assumed that the coordinates of N corresponding control points in two images of a scene is defined as equation (1), the coordinates (X, Y) of the target image could be determined by referring to the coordinates (x, y) of the reference image if the proper geometric transformation function, $h(x, y)$ could be identified as denoted in equation (2).

$$(x_i, y_i), (X_i, Y_i): i = 1, \dots, N \} \quad (1)$$

$$\begin{aligned} X_i &= h_x(x_i, y_i) \\ Y_i &= h_y(x_i, y_i), \quad i = 1, \dots, N \end{aligned} \quad (2)$$

The geometric transformation is constructed after the correspondence of control points has been established. The transformation model maps the distorted image to the reference image. Various geometric transformations have been used for image rectification. However, choosing an appropriate geometric transformation and its parameter for estimation is a challenging task in image rectification [7]. The efficiency of the rectification would be affected if the geometric transformation is blindly used without knowing how well it could perform in handling the distortions in the images that are being transformed [8]. Geometric transformations have different ability in handling different distortions complexity.

Geometric transformations normally are divided into global and local transformations. Polynomial models are global transformations which are commonly used for the purpose of image rectification [9]. A global transformation employs all control points to construct one single transform equation as mapping function for the entire image [10]. Hence, changing a single coefficient will affect the entire resampled image [11]. Besides that, global transformation averages out the local geometric distortion equally over the entire image [10].

In many cases the geometric distortions in images are due to local factors such as scene elevation, atmospheric turbulence and sensor nonlinearity [12]. Thus a global transformation has limitation and could not fit the whole image properly [10]. A transformation function that could adapt to local geometric difference between the images should be studied.

3. Piecewise Linear Transformation

Piecewise linear transformation divides images into regions by triangulation. Using a set of corresponding control points from two images, the control points in reference image are triangulated by Delaunay triangulation. Delaunay triangulation is a set of lines connecting each point from a set of given points to its natural neighbors [13]. Delaunay triangulation of the points ensures that the circumference associated with each triangle contains no other point in its interior [13].

The corresponding triangles in the target image are determined from the correspondence between the control points. After that, a linear transformation is used to map each triangular region in the target image to its corresponding triangular region in the reference image. Unlike global transformations, different linear transformations are employed separately to triangular regions instead of using a single transformation as the rectification model for the entire image. Besides that, piecewise linear transformation is claimed would keep inaccuracies in the correspondences local without spreading them over the entire image domain [14].

Piecewise linear transformation has been studied by researchers from the field of image processing. For instance, Zagorchev and Goshtasby [14] have discussed piecewise linear transformation in details in their research for non-rigid image registration. They explored the properties and examined the behaviors of piecewise linear transformation with comparison of other three popular transformations. Guo et al. [10] presented an automatic registration approach based on Speed Up Robust Features (SURF) and piecewise linear transformation. They discussed the parallel implementation of both methods in order to accelerate the speed of registration procedure. However, they only stated that the results of experiments could achieve acceptable accuracy and did not analyze the registration error. Wang et al. [5] introduced piecewise polynomial correction method to solve the problem of nonlinear variability of geometric distortions in different imaging angles. They used piecewise quadratic polynomial model to partition the whole image into contiguous subspaces. Their experiments demonstrated that the piecewise polynomial correction method consistently outperforms the whole image-based correction.

4. Experiments

Aerial images used in the experiments are acquired using a non-metric digital camera which is attached to a helicopter with flying height of 1200m approximately. The aerial images are in the size of 2848 x 4272 pixels. Since the areas of interest are flat areas, there are no hilly or mountainous aerial images involved in the testing. The reference images used in the rectification process are satellite QuickBird images with a spatial resolution of 0.5m. A total of 30 corresponding control points are manually selected and matched between the reference image and the distorted aerial images to ensure that the correct match of correspondence control points are applied in the experiments. Figure 1 shows an example of aerial image with selected control points.

In order to investigate piecewise linear transformation in rectifying distorted aerial images, the piecewise transformation function from Matlab is used in the experiment. Piecewise linear transformation would divide the image into triangular regions. Each triangular region in the target image would be mapped to its corresponding triangular region in the reference image using a linear transformation. Figure 2 illustrated the triangulation formed after performed piecewise linear transformation. Besides that, the experiment also obtains the result of the same set correspondence control points with affine transformation as a global transformation. The rectification results of both transformations are compared and analysed.



Figure 1. An example of aerial image with selected control points.

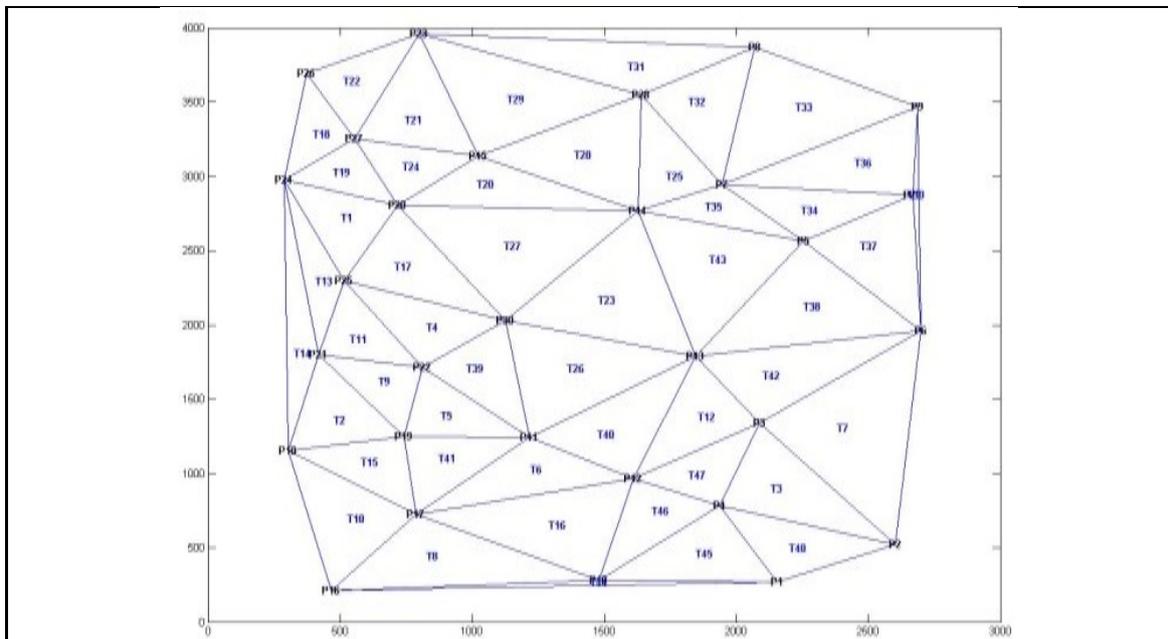


Figure 2. An example of triangulation formed.

5. Results Discussion

The total root mean square error is evaluated as the performance of the transformations in rectification. It is measured between the control points from the reference image and the rectified image as denoted in equation (3).

$$\text{total root mean square} = \sqrt{\frac{1}{n}(\sum_i \|(x, y)_i - (x', y')_i\|^2)} \quad (3)$$

Both experiments has performed piecewise linear transformation and affine transformation. The total root mean square error of the experiments are shown in Table . The results of the experiments depict that error rate of using a global transformation is higher than piecewise linear transformation. It is noticed that piecewise linear transformation could assist in improving the limitation of using global transformation in rectification of images. The error rates of using piecewise linear transformation are very low might due to the images are of flat areas and with simple distortions.

Table 1. Total root mean square error (in pixels).

Experiment	Piecewise linear transformation	Affine transformation
I	1.647479 x 10 ⁻¹³	5.111628
II	1.475923 x 10 ⁻¹³	6.852379

6. Conclusion

Piecewise linear transformation has been studied and used in aerial images rectification. The error rates of using piecewise linear transformation has been compared with the error rates of using affine transformation. In this study, the piecewise linear transformation is outperformed global transformation in rectifying the aerial images tested.

The error rates obtained from the experiments are extremely low. This might be caused by the simple and consistent distortions that occurred in the aerial images of flat areas. However, the behaviour of piecewise linear transformation and its advantages in aerial images rectification could be further verified by using aerial images of hilly or mountainous areas.

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