Aerial Images Rectification Using Non-parametric Approach

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Abstract—Geometric distortions caused by different sources usually are accumulated and not present singly in a remotely sensed image. In addition, the effects of geometric distortions are found unequally in the entire image. Hence, aerial images should be rectified before proceed with subsequent images analysis. Control points and geometric transformation are the essential components in non-parametric approach. Barrel and perspective distortions are usually found in aerial images. This paper studies the deformation rate contributed by control points at different regions in an image before rectification according to different distribution patterns. Besides, this paper also discusses the appropriate geometric transformation through the concern of the expected distortions. Experiments are conducted using grid images and aerial images to investigate the effect of distributions of control points and the efficiency of global and local geometric transformations for aerial images rectification. It demonstrated that control points at different image regions have different deformation rates, control points distributed at image centre are less distorted and local transformation performs better in rectifying images with complex distortions.

Keywords—aerial image rectification; geometric distortions; non-parametric approach; control points distribution; geometric transformations

I. Introduction

Aerial images are acquired using a camera attached vertically to an aircraft. As one of the major platforms in capturing remote sensing images, aircraft-based system normally operate at flying height of 200m to 15,000m [1]. Aerial images are ideal for mapping small areas and easier to adapt according to specific needs. For example, the level of image details could be improved by adjusting the flying height of the aircraft and weather conditions, and the types of data captured could be controlled with changeable or multiple cameras [2]. Aerial images which provide closer look to the areas of interest are widely used in generating digital map, monitoring crop growth and managing ecology. However, like other remotely sensed images, aerial images contain geometric distortions.

Geometric distortions are one of the common types of error encountered in remotely sensed images [3]. Geometric distortions are caused by different sources such as camera lens, earth curvature, topographic relief and attitude inconsistencies of the aircraft [4]. Various studies on geometric distortions have been carried out. Jensen [3] presented the analysis of individual effect on an image based on different sources of geometric distortions. Zhao et al. [5] investigated the effect of image distortions caused by camera incline in multi-format aerial digital camera. They calculated the ratio of ground sampled distance change in image derived in the study based on single camera tilts in one direction with 15, 18 and 20 degrees. Yang et al. [6] analyzed the flight height and attitude of aircraft to propose real-time rectification. They claimed that the imaging area would be changed with the changing of the aircraft height and attitude. Xiang and Thian [7] discussed the impact of radial and tangential distortion model. They found that points at the corners of the image are displaced by as much as 100 pixels for 8 mm lens and 160 pixels for 4.5 mm lens used in their test.

Geometric distortions usually are accumulated and not present singly in an image. Geometric distortions composited in aerial images lead to deformation between the aerial images and the true environment. The relative position of objects in the scene would be affected [8] and the quality of the data collected would be degraded due to distortions [3]. Furthermore, the effects of geometric distortions are found unequally in the entire image [9]. Such ambiguous occurrence of distortions forms a higher complexity of deformation to the images. Hence, aerial images which are naturally distorted should be rectified before proceed with subsequent images analysis.

This paper studies the rectification of aerial images based on non-parametric approach. In the study, experiments are carried out firstly using simulated data of grid images with imitated distortions as a pilot study. The impact of different distributions of control points and geometric transformations in handling the imitated distortions are examined using the simulated data. Then, further testing is proceeded with real aerial images. This paper attempts to investigate the distribution of control points and the appropriateness of geometric transformation for aerial images rectification through the consideration of expected distortions.

This paper is organized with five sections. The background of image rectification is presented in Section II. In Section III, aerial images rectification using non-parametric approach is discussed. The experiments conducted in the study by using grid images and aerial images are explained in Section IV. In Section V, experimental results are shown to compare the rectification rate. The conclusions of this study are summarized in Section VI.
II. Background of Aerial Images

Rectification

Image rectification is defined as an image pre-processing procedure to solve or reduce geometric errors found in a distorted image [10]. After rectification, the spatial information such as distance, polygon area and direction could be extracted and accepted with certain accuracy [9]. Generally, the two main approaches used for image rectification are parametric and non-parametric approaches.

In parametric approach, the prior knowledge of the sources of distortions is required. For instance, the characteristics, position and attitude of imaging sensor are employed as the parameters for modeling the occurrence that produces distortions [8]. Sometimes this approach is unsuitable when the imaging parameters are unknown and not released because of commercial technology protection [10].

Conversely, the imaging mechanisms that cause distortions are not involved if using non-parametric approach [8]. In other words, non-parametric approach is independent of the platform used for image acquisition [11]. Moreover, the distortions caused by inconsistencies of the attitude of aircraft could be rectified using this approach [3]. Non-parametric approach requires a set of corresponding control points obtained from a reference image and a distorted image. The control points are then applied with an appropriate mathematical function to generate geometric transformation. This approach is commonly implemented in geographic information system (GIS) and remote sensing software [9].

Conventionally, the same rectification transformation is applied for the whole image without considering that the deformation rate is actually found differently in the whole image. Therefore, this paper attempts to demonstrate the deformation rate at different regions of a distorted image based on the distribution patterns of the control points. Besides that, the rectification rate of each distribution pattern is measured to determine the proper distribution of control points. The experiments also examine on the efficiency of global and local transformations in the rectification.

III. Non-parametric Rectification

The common procedure of non-parametric aerial images rectification includes control points detection and selection, corresponding control points matching, geometric transformation determination, rectification evaluation with residual error estimation and image interpolation. The rectification is carried out when the mapping transformation is performed through the matching of corresponding control points from the reference image and the raw aerial image. Hence, control points and geometric transformation are the essential components in non-parametric approach.

In aerial images, barrel and perspective distortions are usually found. Barrel distortion is caused by the wide angle lens of the non-metric digital camera [12] while perspective distortion is caused by unstable movements of the aircraft due to atmospheric perturbations [13]. Thus, both distortions are the significant problem in rectification of digital aerial images.

Geometric transformations have different ability in handling different distortions complexity. 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 existed in images that are being transformed. The proper distribution of control points and the appropriate geometric transformation could be explored through the concern of the expected distortions.

A. Distribution of Control Points

Control points are the points used in the images to determine the parameters of a transformation [14]. Control points could be selected manually or automatically. The accuracy of image rectification depends on the selection, quantity and distribution of control points [15]. However, most of the researchers concentrate on the transformation models in their study.

In this study, control points are selected manually and four different distribution patterns of control points are examined. The distribution patterns are uniform, border, corner and centre distribution. Uniform pattern denotes that control points are regularly or evenly located at the whole image; border pattern means control points are placed at image boundary or periphery; corner pattern indicates that control points are positioned at four ends of image; while centre pattern represents control points that are assembled at the middle of image. The description of each distribution pattern is summarized in Table 1. The designs of the four distribution patterns are illustrated in Fig. 1. Control points are situated in the shaded area. These distribution patterns represent different regions in an image.

<table>
<thead>
<tr>
<th>Distribution Patterns</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>Control points are located regularly at the whole image</td>
</tr>
<tr>
<td>Border</td>
<td>Control points are placed at image boundary</td>
</tr>
<tr>
<td>Corner</td>
<td>Control points are positioned at the four ends of image</td>
</tr>
<tr>
<td>Centre</td>
<td>Control points are assembled at the middle of image</td>
</tr>
</tbody>
</table>

![Figure 1. The designs of distribution patterns.](image)

B. Geometric Transformations

Geometric transformations are functions that describe geometric differences between two images with the same or overlapping contents [14]. A geometric transformation redefines the spatial relationship between points in an image.
It converts the coordinates of distorted image into the desired coordinates based on the reference image.

Geometric transformations could be divided into global and local transformations. A global transformation employs all the control points to estimate the mapping parameters for the entire image [17]. Hence, changing a single coefficient will affect the entire resampled image [14]. On the other hand, a local transformation treats the image as a composition of patches [17] and only maps a part of the image into a part of another image [14].

In this study, the first, second, third order of polynomial transformations and adjust transformation are tested. These four geometric transformations are typically used in ArcGIS software. Polynomials are global transformations while adjust transformation is as local transformation.

The definition of a polynomial transformation of degree M is expressed in equation (1). Parameters \( a \) and \( b \) are determined by a number of corresponding control points in the reference image and distorted image [14].

\[
\begin{align*}
    x & = \sum_{j=0}^{M} \sum_{k=0}^{M} a_{j,k} x^j y^k \\
y & = \sum_{j=0}^{M} \sum_{k=0}^{M} b_{j,k} x^j y^k
\end{align*}
\]  

First order polynomial transformation is a combination of translation, scaling, rotation and shearing transformation [18]. Six parameters from three control points are needed to build the first order polynomial. Second and third order polynomial transformations are usually used when handling nonlinear distortions. At least six control points and ten control points are requested to perform second and third order polynomial respectively. Adjust transformation works with a polynomial transformation and a triangulated irregular network interpolation. It optimizes both global and local accuracy by adjusting the control points locally in order to have a better match for the target control points [19].

IV. Experiments

Experiments are conducted with grid images as Experiment I and aerial images as Experiment II. A set of 30 corresponding control points are manually selected and matched between the reference image and the distorted image. The number of 30 control points is defined as the most common number of control points obtained on the manual geometric correction [20].

A. Experiment I: Rectification of Grid Images

The grid images are created with 21 x 14 grid lines. The distorted image is built using the same image for reference but with combination defects: barrel of value -10, vertical perspective of value +10 and horizontal perspective of value +10. The defects are added into the image using distort function of Adobe Photoshop CS3 software.

Both the reference and distorted grid images are fixed in size of 4272 x 2848 pixels. The size of the grid images is equal to the size of aerial images used in Experiment II. The grid reference image and the grid distorted image used are illustrated in Fig. 2 and Fig. 3 respectively.

B. Experiment II: Rectification of Aerial Images

Four aerial images are involved in the second experiment. These aerial images are captured using a non-metric digital camera which is carried by a helicopter with flying height of 1200m approximately. The aerial images of flat areas used in the experiment are named as Aerial Image 1, Aerial Image 2, Aerial Image 3 and Aerial Image 4 as shown in Fig. 4, Fig. 5, Fig. 6 and Fig. 7. The reference images used are QuickBird images with spatial resolution of 0.5m.

![Figure 4. Aerial Image 1.](image_url)
v. Results Discussion

Two types of analysis, named as deformation analysis and rectification analysis, have been performed for both Experiment I and Experiment II. The deformation rate and rectification rate for different distributions of control points are measured using total root mean square error (RMSE). The total RMSE is the broadly used quantitative measure in evaluation of geometric correction [20]. It is used to measure the differences between values predicted and the actual values, which is also useful for determining the differences between two images [21]. The total RMSE measurement is denoted in Equation 2.

\[
\text{total RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \| (x, y)_i - (x', y')_i \|^2}
\]  

(A. Deformation analysis)

Deformation analysis studies the actual differential between control points of reference image and distorted image. The purpose of deformation analysis is to indicate the deformation rate in an image before rectification process. Deformation rates of different distribution patterns of control points show the distortion level at different regions in an image. The deformation analysis also could validate the significant of rectification results by considering the actual differential of the control points.

Deformation analysis of grid images is presented in Fig. 8. Grid images are deformed with barrel and perspective effects that represent the expected distortions occurred in aerial images. It is found out that the total RMSE of control points with centre distribution is the lowest. This shows that control points distributed at centre of the grid image are more stable and could be considered less distorted than control points that are distributed uniformly or at border and corner.

Besides that, the total RMSE of control points distributed at the border and corner of the grid image are higher than the total RMSE of control points with uniform distribution. This indicates that control points distributed at border and corner of the image contain higher distortions. Uniform distribution consists of control points positioned all over the entire image. It might cause the deformation rate being equally averaged.

Similar outcome has been achieved when using aerial images as shown in Fig. 9. Aerial Image 1, Aerial Image 2, Aerial Image 3 and Aerial Image 4 have the lowest total RMSE of control points with centre distribution. The second lowest total RMSE of control points for the four aerial images used in the experiment is obtained with uniform distribution.

The experiments demonstrated that image centre has lowest deformation rate compared to image border and corner before performing image rectification. Deformation rate of the entire image might be evenly managed if control points are distributed with uniform distribution.
B. Rectification analysis

Rectification analysis evaluates the difference between control points of reference image and rectified image. Rectification rates of different distribution patterns of control points illustrate the error after correction at different regions in an image. In this study, the impact of different types of geometric transformations in treating different levels of distortions according to the distribution of control points is also examined through the rectification analysis.

Rectification analysis of grid images is presented in Fig. 10. Among the four different geometric transformations tested, it is shown that the global first order polynomial transformation gives the highest total RMSE in each distribution pattern. The rectification rates are reduced when using second and third polynomial transformations.

However, it is noticed that the local adjust transformation performs better than the previous three polynomial transformations in the four distribution patterns. In addition, the lowest total RMSE of control points is achieved with centre distribution in each geometric transformation tested for the rectification of grid images. Uniform distribution has been predicted to give the second lowest error rate after centre distribution through deformation analysis, but it is not when using 2nd and 3rd order polynomial transformations.

The rectification results of Aerial Image 1, Aerial Image 2, Aerial Image 3 and Aerial Image 4 are shown in Fig. 11, Fig. 12, Fig. 13 and Fig. 14 respectively. Similar to the rectification of grid images, the first order polynomial transformation tested in aerial images rectification gives the highest total RMSE in all the distribution patterns. The total RMSE of the four distribution patterns are also reduced when using the second and third polynomial transformations.

The lowest total RMSE is achieved when using adjust transformation with the four distribution patterns tested for aerial images. It is also noticed that centre distribution provides the lowest of total RMSE for the aerial images tested. Uniform distribution with centre distribution is probably due to its lowest deformation rate at the image centre. Uniform distribution is not necessary could perform better than border and corner distribution when using higher order global transformations. For examples, it has higher error rates in Aerial Image 1 when using 2nd order and 3rd order polynomial transformations. It also shows higher error rates in Aerial Image 2 when using 2nd order polynomial transformation compared to corner distribution and in Aerial Image 4 when using 3rd order transformation compared to border distribution.
VI. Conclusions

Control points are important features and geometric transformation is the essential process in non-parametric approach of aerial image rectification. Distributions of control points and the appropriateness of geometric transformation are investigated through experiments of rectification using grid images and aerial images. The rectification of grid images serves as pilot study which imitates the expected distortions of barrel and perspective effects founded in the aerial images.

The deformation rate at each pattern of distribution before rectification has been considered through the deformation analysis. It is experimentally demonstrated that the lowest of total RMSE for centre distribution is possibly caused by its lowest deformation rate at the image centre. Higher deformation rate is found at the border and corner of the image. Uniform distribution would average the overall deformation rates at the entire image.

This study would contribute in determination of proper distribution of control points through the concern of expected distortions. It also verifies that the common practice of using global geometric transformation has limitation in aerial images rectification. Using a single global transformation for the entire image rectification might not appropriate since distortions occur irregularly in the image. Image centre could be considered as the image region which is more stable with less deformation.

The results obtained are based on the images used in the experiments. In future, experiments could be extended by using aerial images of hilly areas. Further investigation on automated control points selection and the effect of number of control points used also could be carried out.

References


BIOGRAPHIES

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