Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 41 (2012) 1002 – 1008

Engineering Procedia

www.elsevier.com/locate/procedia

International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012)

Evaluation of Control Points' Distribution on Distortions and Geometric Transformations for Aerial Images Rectification

Lee Hung Liew[a]*, Yin Chai Wang[b], Wai Shiang Cheah[b]

[a]*Faculty of Computer & Mathematical Sciences, Samarahan Campus,Universiti Teknologi MARA, Kota Samarahan, Sarawak and 94300, Malaysia*
[b]*Faculty of Computer Science and Information Technology, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak and 94300, Malaysia*

Abstract

Geometric distortions are inevitable in aerial images. A raw uncalibrated aerial image acquired from a non-metric digital camera which carried by an aircraft normally has lens and perspective distortions and could not be used directly without undergoing image rectification. Ground control points (GCPs) are important features used in non-parametric approach for aerial image rectification. Although the importance of GCPs in rectifying remote sensing images has been highlighted, not many recent studies research on the quality selection of GCP, effectiveness of GCPs' distribution and sufficient quantity of GCPs. A simulation test is conducted using grid images to examine the effect of different distribution patterns of control points on distortions and geometric transformations. The rectification results are measured by using the total root mean square error (RMSE). It shows that lower order global transformation has limitation in rectifying images with complex distortions. It also demonstrates that centre distribution gives the lowest total RMSE and its total RMSE is extremely low. However, the distance analysis of control points which reflects the distortion rate before rectification shows that control points distributed at the centre of the image is actually much less distorted than control points that are placed at border and corner. Hence, uniform distribution provides better distribution of control points with the consideration of overall deformation rates at the entire image for rectification.

Keywords: Aerial image; geometric distortion; image rectification; ground control point.

1. Introduction

Aerial images provide visual record to assist human in various tasks such as generating digital map, monitoring crop growth and ecology. Aerial images are helpful especially in the regions where the cloudiness hinders optical satellite imaging because aerial images can be acquired at lower altitude under the clouds [1]. With the development of digital technology, the study of uncalibrated aerial images acquired from a non-metric digital camera has become an active research nowadays. A non-metric digital camera refers to the consumer type of digital camera that is not designed for mapping purpose [2]. The potential of consumer digital camera as the aerial image acquisition tool has been showed and reported by many researchers [3-6].

Geometric distortions are inevitable in aerial images caused by different sources. Geometric distortions are more seriously found in aerial images than satellite images [7] due to the stability of the two platforms and their height relation to the distance from the Earth [8]. Therefore, a raw uncalibrated aerial image could not be used directly and image rectification is necessary as a pre-processing step in order to extract accurate information from the images.

* Corresponding author. Tel.: +6-016-882-3140; fax: +6-082-583-764.
E-mail address: lhliew@sarawak.uitm.edu.my

1877-7058 © 2012 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2012.07.275

The accuracy of geometric rectification depends on the selection of ground control points (GCPs), the number of GCPs, and the distribution of GCPs [9]. Although the importance of GCPs in rectifying remote sensing images has been highlighted, most recent research of remotely sensed image rectification focuses on transformation models and methods, only few research studies on the quality selection of GCPs, effectiveness of GCPs' distribution and sufficient quantity of GCPs. This paper attempts to study the proper distribution of control points with the consideration of distortions and geometric transformations for aerial images rectification. The efficiency of the rectification could be improved if the geometric transformation is not blindly used in reducing the effect of the expected distortions with an appropriate distribution of control points.

This paper is organised as follow. In section 2, the geometric distortions of aerial images are discussed. In section 3, the image rectification using ground control points is presented. The simulation test of control point's distribution using grid images is explained in section 4. In section 5, the experimental results are analysed to compare the performance of the different distribution patterns on distortions and geometric transformations. We conclude the paper in section 6.

2. Geometric distortions of aerial images

Aerial images with free distortions could provide useful spatial information. However, remotely sensed images are subjected to geometric distortions [10]. According to Xiang and Tian [11], distortions occur when the remotely sensed images which are in two-dimensional attempt to represent the three dimensional real world. The main sources of distortions include lens, earth curvature, topographic relief and attitude of aircraft.

The variations of geometric distortion are discussed in details by Jensen [8] and Richard and Jia [12]. Some effects of geometric distortions are illustrated in Fig 1. In fact, such geometric distortions are accumulated in a raw uncalibrated aerial image which causes great deformation between the aerial image and the real world. Fig 2 shows the existence of deformation in a collected aerial image used in the research as compared with a satellite image of the same scene.

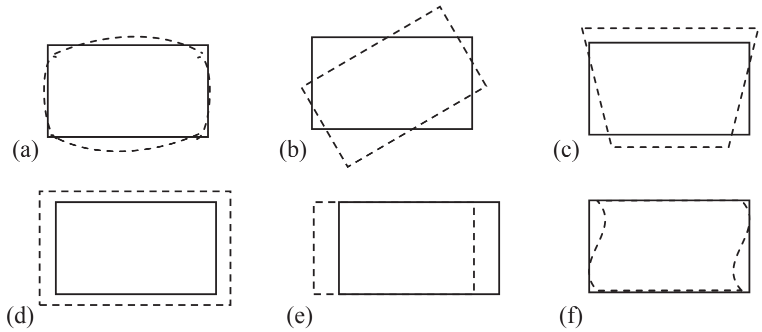


Fig. 1. Some effects of geometric distortions are denoted by the dashed lines ([8], [12]): (a) barrel effect, (b) rotation effect, (c) perspective effect, (d) scale change, (e) along track displacement and (f) across track displacement.

Fig. 2. Deformation in an aerial image as compared with a satellite image of the same scene.

Among the effects of geometric distortions, barrel effect from wide angle lens and perspective effect from inconsistencies in attitude of the aircraft are the two distortions that normally detected in aerial images. It is claimed that the lens distortion will cause straight lines to be bended and points to be moved from their correct position [13]. Aircraft attitude inconsistencies can be categorised into yaw, pitch and roll. Such variations are considered significant due to atmospheric turbulence [12].

Geometric distortions affect the relative position of objects in the scene [14]. The features in a distorted aerial image are not accurately representing the real scene [10]. Thus, the raw distorted aerial images must be rectified to ensure that the spatial information derived is correct and accurate.

3. Image rectification using ground control points

The purpose of image rectification is to correct geometric errors of a distorted image completely or partially ([15], [16]). Geometrically rectified image can be used to extract distance, polygon area and direction information with certain accuracy [7]. The parametric and non-parametric approaches are the two main approaches used for image rectification.

According to Pai [14], parametric approach is based on the modeling of the occurrence of the distortions. Commonly, the characteristics, position and attitude of imaging sensor are used to update the parameters in parametric approach [7]. However, in some cases the imaging parameters are difficult to obtain and are not disclosed by providers due to the purpose of commercial technology protection [16]. While for non-parametric approach, it is usually implemented in geographic information system (GIS) and remote sensing software [7]. Non-parametric approach uses a set of ground control points (GCPs) as reference points and with an appropriate mathematical function to generate transformation approximation without considering the imaging mechanisms that cause the distortions [14]. Besides that, non-parametric approach with GCPs has been claimed could rectify the variations caused by attitude inconsistencies of aircraft [8].

GCPs are points on the surface of the earth where both image coordinates and map coordinates can be identified [8]. The aerial images could be rectified by generating the mapping transformation through the matching of control points from reference image and raw aerial images. Generally, the process flow of aerial images rectification includes GCPs detection and selection, corresponding GCPs matching, geometric transformation determination, rectification evaluation with residual error estimation and image resampling and interpolation as shown in Fig 3.

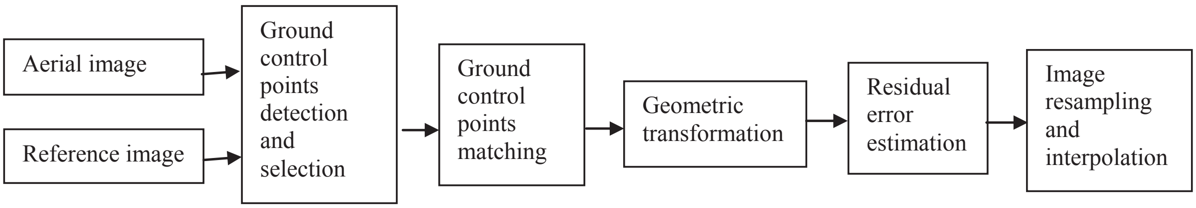


Fig. 3. Process flow of aerial images rectification.

The proper distribution of GCPs could be studied through the consideration of possible distortions that might exist in the aerial images and the geometric transformations used. An evaluation of control points' distribution is carried out to explore the effect of distribution patterns based on different distortions and commonly used geometric transformations.

4. Simulation test of control point's distribution using grid images

This paper presents a simulation test to investigate the effect of four different distribution patterns of control points on four different distortions and four types of geometric transformation using grid images. In order to reproduce and present barrel and perspective effects as the expected distortions of aerial image, grid images are used in the simulation test. The grid images consist of one reference image and four distorted images as illustrated in Fig 4. The reference image is created with 21 x 14 grid lines. The four distorted images are generated using the same image for reference but with barrel, vertical perspective, horizontal perspective and accumulation of the previous three types of distortion. All the images are fixed in size of 4272 x 2848 pixels, which are equivalent to the size of the acquired aerial images.

The simulation test is carried out with a set of 30 corresponding control points which are manually selected from the intersections of grid lines. The number of 30 control points is defined as the most common number of control points obtained on the manual geometric correction [17]. The control points are distributed with four different patterns: uniform, border, corner and centre distributed. Uniform pattern denotes that control points are not biased positioned at the whole image; border pattern means control points are placed around the image perimeter; corner pattern indicates that control points are gathered at the four ends of the image while centre pattern represents control points are assembled at the middle of the image. The control points are matched properly between the reference image and the distorted images.

The rectification is performed using four commonly employed geometric transformations which could be found in ArcGIS software: first, second, third order polynomial transformations and adjust transformation. The geometric transformation converts the distorted image coordinates into the desired coordinates based on the reference image. The coordinates of control points are used to calculate a set of best-fit coefficients for the terms in the equation [18]. Its order represents the highest exponent used in the equation. Higher order of polynomial transformation could be used to solve distortions with higher complexity [19]. First order polynomial transformation as the simplest transformation in image processing, is a combination of translation, scaling, rotation and shearing transformation [20]. Second and third order polynomial transformations are usually applied to handle nonlinear distortions. Adjust transformation optimizes both global and local accuracy with a polynomial transformation and followed by a triangulated irregular network interpolation to adjust the control points locally to have a better match for the target control points [19].

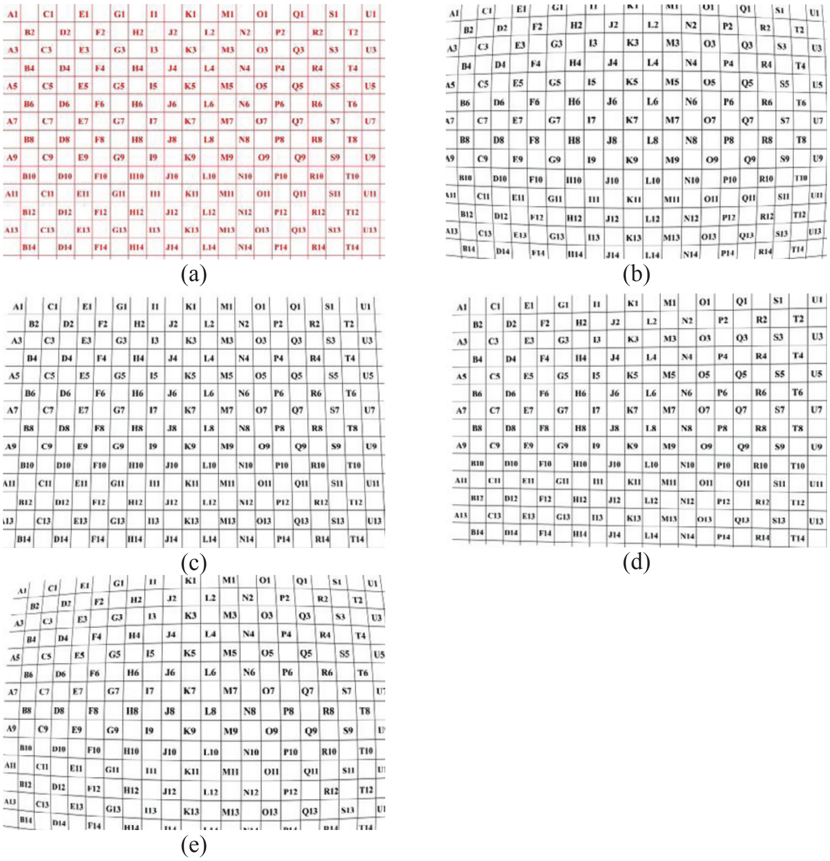


Fig. 4. Grid images used in the simulation test: (a) reference image, (b) distorted image with barrel effect, (c) distorted image with vertical perspective effect, (d) distorted image with horizontal perspective and (e) distorted image with accumulation of the previous three types of distortion.

5. Experimental results and analysis

The performance of the control points' distribution on distortions and geometric transformations are measured using the total root mean square error. Root mean square (RMS) of residual is the broadly used measurement in the evaluation of image rectification [17]. The total RMS error is measured between the control points from the reference image and the rectified one as denoted in Equation 1. After obtaining the rectification result, another experiment on distance analysis of control points before undergoing rectification has been carried out. The distance analysis is evaluated using Euclidean distance between the control points of reference image and distorted one. The objective of the distance analysis is to verify the significance of rectification results by checking the actual differential of the control points.

$$RMSE = \sqrt{\frac{1}{N}\left(\sum_i \|(x,y)_i - (x',y')_i\|^2\right)} \quad (1)$$

Table 1, 2, 3 and 4 show the rectification results obtained from the simulations test with uniform, border, corner and centre distribution respectively. The first order polynomial transformation gives the highest total RMSE in each distribution pattern for the four different distortions. However, the total RMSE in each distribution pattern is reduced when second and third polynomial transformations are used. The lowest total RMSE of less than 1.5 pixels is achieved when using adjust transformation in all the distribution patterns. This reflects that first order polynomial transformation is not well performed in rectifying complex distortions such as barrel and perspective distortions.

Table 1. Total RMSE of the simulation test with uniform distribution pattern

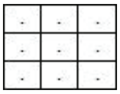
Distribution pattern	Distortion	Geometric transformation			
		1st order	2nd order	3rd order	Adjust
Uniform	Barrel	32.45129	32.29725	2.12844	0.67553
	Vertical perspective	29.13250	1.70835	1.39326	0.71722
	Horizontal perspective	29.02161	1.99613	1.84894	0.48650
	Barrel, vertical, horizontal perspective	54.56734	33.26257	2.64072	0.98069

Table 2. Total RMSE of the simulation test with border distribution pattern

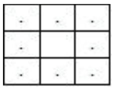
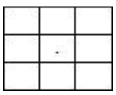
Distribution pattern	Distortion	Geometric transformation			
		1st order	2nd order	3rd order	Adjust
Border	Barrel	25.45844	23.71110	2.01996	0.91672
	Vertical perspective	32.19204	1.94650	1.60083	0.95314
	Horizontal perspective	28.57310	1.90681	1.70332	0.84420
	Barrel, vertical, horizontal perspective	56.11092	24.09833	2.18036	1.10062

Table 3. Total RMSE of the simulation test with corner distribution pattern

Distribution pattern	Distortion	Geometric transformation			
		1st order	2nd order	3rd order	Adjust
Corner	Barrel	16.35088	16.12460	2.85168	0.98063
	Vertical perspective	42.88528	2.70937	2.23527	0.88496
	Horizontal perspective	29.15755	2.36911	2.07801	0.69072
	Barrel, vertical, horizontal perspective	56.85835	16.06877	3.10684	1.47094

Table 4. Total RMSE of the simulation test with centre distribution pattern

Distribution pattern	Distortion	Geometric transformation			
		1st order	2nd order	3rd order	Adjust
Centre	Barrel	2.69134	2.51848	2.15559	0.60714
	Vertical perspective	3.10185	2.10773	1.80027	0.63009
	Horizontal perspective	3.22346	2.10012	1.78060	0.64470
	Barrel, vertical, horizontal perspective	4.76054	2.16590	1.64263	0.51380

Among the four types of distribution patterns, it is noticed that centre distribution not only gives the lowest total RMSE in each geometric transformation and on the distortions tested, its total RMSE for each case is extremely low which is less than 5 pixels. In order to validate the significance of the rectification results, the actual differential between the control points of reference image and distorted images are analysed. The distance analysis could reflect the deformation rate before rectification and the results are presented in Fig 5.

From the results, it shows that barrel and accumulative distortions have the highest average distance of control points under border distribution while vertical and horizontal perspective distortions have the highest average distance of control points under corner distribution. This illustrates that the higher deformation rate of the image with barrel and accumulative distortions happens at the border while the higher deformation rate of the image with vertical and horizontal perspective distortions occurs at the corner. Besides that, it is found out that the average distance of control points under centre distribution is the lowest for each type of distortions tested. This means that control points distributed at the centre of the image are basically less deformed than control points that are placed at the border and corner of the image. Consequently, the total RMSE of the rectification for centre distribution is obviously low compared to other patterns of distribution. On the other hand, uniform distribution consists of control points positioned consistently at the entire image. In this case, the deformation rate has been equally averaged. Hence, control points used should distribute uniformly in order to achieve unbiased result in aerial image rectification.

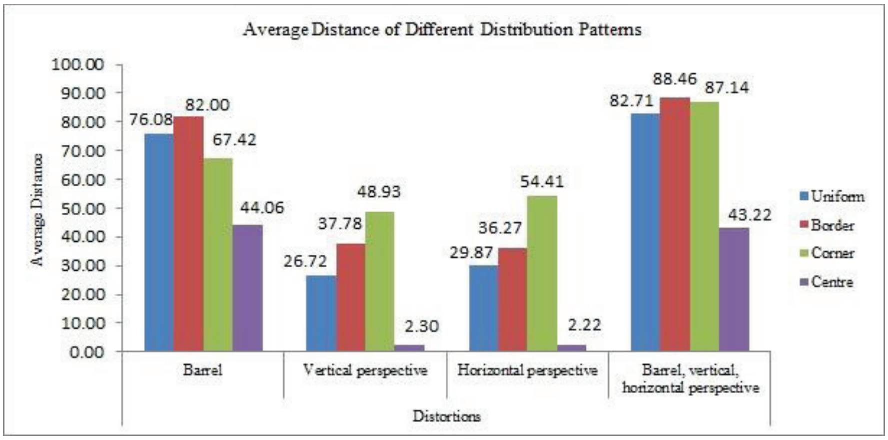


Fig. 5. Distance analysis of control points for different distribution patterns.

6. Conclusion

Ground control points are important features used in non-parametric approach for aerial image rectification. The effect of control points' distribution patterns on distortions and geometric transformations is studied through a simulation test using grid images. Besides that, the deformation rate for each distribution pattern has been considered through the distance analysis of the control points to verify the rectification achieved. The simulation test shows that lower order global transformation has limitation in rectifying images with complex distortions and images with different distortions and distribution patterns of control points have different deformation rates. It is also experimentally demonstrated that the extremely low of total RMSE for centre distribution is influenced by its lowest deformation rate at the image centre compared to image border and corner. Therefore, uniform distribution provide better distribution of control points with the consideration of overall deformation rates at the entire image for rectification.

It is expected that this study would able to assist in identifying a proper distribution pattern of control points for the purpose of aerial images rectification through the concern of expected distortions and commonly used geometric transformations. In future, further investigation on the effect of other factors such as different density of control points should be carried out. The findings should later be verified using aerial images.

References

[1] Silva,D. C. D., 2006. "Non-metric digital camera images versus high resolution satellite images in regions with high cloudiness", Proceedings of XXIII International FIG Congress. Munich, Germany, poster and oral presentation.

[2] Harintaka, S., Susanto, A., Hartono, 2009. "Assessment of low cost small format aerial photogrammetry for cadastral mapping (Case study in Klaten Regency, Central Java, Indonesia)", 7th FIG Regional Conference on Spatial Data Serving People: Land Governance and the Environment-Building the capacity. Hanoi, Vietnam.

[3] Ahmad, A., 2006. "Digital photogrammetry: An experience of processing aerial photograph of UTM acquired using digital camera", AsiaGIS 2006. Johor, Malaysia.

[4] Rodriguez, B. D. D., García, S. H. G., Piñero, Y. B., 2008. "Experience using non-metric cameras in photogrammetry", International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVII, part B5, pp. 769 – 772.

[5] Rieke-Zapp, D., Tecklenburg, W., Peipe, J., Hastedt, H., Haig, C., 2009. "Evaluation of the geometric stability and the accuracy potential of digital cameras-comparing mechanical stabilisation versus parameterisation", ISPRS Journal of Photogrammetry and Remote Sensing, vol. 64, issue 3, pp. 248 – 258.

[6] Samad, A. M., Ahmad, A., Ishak, N., 2010. "Assessment of digital camera for mapping stream using close range photogrammetric technique", 6th International Colloquium on Signal Processing and Its Applications (CSPA), pp. 1 – 6.

[7] Wang, C., Zhang, Y., Wu, Y., Gu, Y., 2011. "Highly accurate geometric correction for seriously oblique aero remote sensing image based on the piecewise polynomial model", Journal of Computational Information Systems, vol. 7, no. 2, pp. 342 – 349.

[8] Jensen, J. R., 2005. Chapter 7: Geometric Correction. *Introductory Digital Image Processing: A Remote Sensing Perspective*, Upper Saddle River, NJ: Prentice Hall.

[9] Wu, D., Liu, Y., Guo, L., Cheng,F., Li, G., 2008. "Spatial projection rectification for densifying ground control points", Proceedings of the 8th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, pp. 51 – 58.

[10] Eltohamy, F., Hamza, E. H., 2009. "Effect of ground control points location and distribution on geometric correction accuracy of remote sensing satellite images", 13th International Conference on Aerospace Sciences & Aviation Technology (ASAT – 13).

[11] Xiang, H., Tian, L., 2011. "Method for automatic georeferencing aerial remote sensing (RS) images from an unmanned aerial vehicle (UAV) platform", Biosystems Engineering, Feb 2011, vol. 108, issues 2, pp. 104 – 113.

[12] Richards, J. A., Jia, X, 2006. *Remote Sensing Digital Image Analysis-An Introduction*, Fourth Edition, Springer-Verlag Berlin Heidelberg, Germany.

[13] Linder, W., 2006. *Digital Photogrammetry A Practical Course, Second Edition*, Springer-Verlag Berlin Heidelberg, The Netherlands.

[14] Pai, D. T., 2010. Auto rectification for robotic helicopter aerial imaging, Thesis Master of Science in Computer Science, San Diego State University.

[15] Temiz, M. S., Külür, S., 2008. "Rectification of digital close range images: sensor models, geometric image transformations and resampling", International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVII, part B5, pp. 89 – 93.

[16] Xiangyang, S., Conggui, L., Yizhen, S., 2010. "Comparison and analysis research on geometric correction of remote sensing images", International Conference on Image Analysis and Signal Processing (IASP).

[17] Goncalves, H., Goncalves, J.A., Corte-Real, L., 2009. "Measures for an objective evaluation of the geometric correction process quality", IEEE Geoscience and Remote Sensing Letters, issue 2, pp. 292 - 296.

[18] TNTmips Tutorial Booklets, 2011. "Rectifying images", retrieved online at: http://www.microimages.com/documentation/Tutorials/rectify.pdf, 30 May 2011.

[19] ArcGIS Desktop Help 9.2, 2011. "Georeferencing a raster dataset", retrieved online at: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?id=2710&pid=2701&topicname=Georeferencing_a_raster_dataset, 8 Mac 2011.

[20] Zhang Y., 2009. "Image processing using spatial transform, International Conference on Image Analysis and Signal Processing (IASP)", 11 – 12 April 2009, pp. 282 – 285.