

GENERATION OF ORTHORECTIFICATED IMAGE PATCHES FROM MULTIPLE IMAGES

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ABSTRACT:

Orthoimages can be used for several purposes. One of them is used them as control information, instead of artificial targets, to determine the exterior orientation of new aerial images. For such a purpose, the image displacements on aerial photos, usually tilted photographs, caused by topographic relief (including the relief of topographic objects) should be removed. In that case the correct geometrical and radiometric information can be obtained from those orthoimages and provided for control information. That means "true" orthoimages should be generated. However the generation of "true" orthoimages needs the accurate height information of terrain areas and the acquisition of accurate height information are always time-consuming and labour-intensive. Therefore this paper will try to propose a method to efficiently generate the orthorectificated image patches as controls for aerotriangulation. This proposed methodology will generate orthoimage patches from multiple aerial images without detailed terrain height information. A concept of floating plane, similar to the concept of floating mark, will be presented in this paper to produce several candidate sets of orthoimages for a terrain area at some height range. Each candidate set consists of several possible related orthoimage patches of a terrain area from multiple images at some height. Subsequently, a procedure will be developed to decide an optimal set from those candidate sets for this terrain area. A unique orthorectified image patch of this terrain area will be fused from this optimal set. The relevant assessment of accuracy will be also discussed and conducted in this paper. Finally, experiments prove the good geometric accuracy of proposed methodology.

1. INTRODUCTION

The procedure of orthorectification will remove the image displacements on tilted aerial photos caused by topographic relief and generate the orthoimages. Orthoimages will not only have the same property as the maps, but also have the detailed image information. Therefore, they are essential for urban plan, national plan, resource investigation, environmental monitoring and so on. Thereby, they play an important role for geographic information systems (GISs). Because of the same property as the maps, orthoimages can be also used for the extraction of topographic information. In addition, 3D Landscape simulation will be realized together with digital terrain model by using the relevant computer hardware and software. Moreover, orthoimages were also used as control information in these years, instead of artificial targets, for new aerial images [Höhle, 1999, 2001; Paszotta, 2000; Shan, 1999; Yang, 2003] Those studies select the existing orthoimage patch and DTM for automatic exterior orientation. But for better quality of control information, the "true" orthoimage should be produced. The process of orthoimage is called as orthorectification. During orthorectification process, the collinearity condition is utilized to remove the image displacements when the camera exterior orientation and terrain relief information, including the height of topographic objects, should be known accurately. That means "true" orthoimages should be generated from the accurate height information of terrain area. However the acquisition of accurate height information is always time-consuming and labour-intensive. Hence, this paper is going to propose an approach to efficiently generating the "true" orthorectificated image patches as controls in aerotriangulation from multiple aerial images with known exterior orientation, but without detailed height information of a terrain area. A concept of floating plane, similar to the concept of floating mark, will be presented in this paper to produce several candidate sets of

orthoimage patches of a terrain area at different height after the approximation height information of this terrain area is given. Each candidate set consists of several possible related orthoimage patches at some height for this terrain area. Then a procedure to decide an optimal set from those candidate sets for this terrain area will be also developed. At last, a unique orthorectified image patch for this terrain area will be fused from this optimal set of orthoimage patches. The relevant assessment of accuracy will be also discussed and conducted in this paper. Unlike the tests of Höhle, [1999, 2001], Paszotta [2000], Shan [1999], and Yang [2003] existing orthoimage and height data are used and the ground coordinates (XY) with an interpolated height value (Z) are used together with the corresponding image coordinates in an orientation program. We hope the proposed orthorectification procedure will be much more efficient to establish the more accurate control information for automatic determination of exterior orientation of new aerial images.

2. METHODOLOGY

In this study, a method to generate a unique orthorectified image patch of a terrain area from multiple aerial images with known exterior orientation will be proposed. The basic assumption is that this terrain area is composed of horizontal plane and the approximation of height information about this terrain area is provided. That is, only the approximation of height information is used for the orthorectification. No precise height information must be measured by the operator. After the approximation of height information of a terrain area is provided, this corresponding 3-D space is subdivided into several equal-spacing horizontal planes according to the desirable height accuracy, e.g. 20cm, and the possible range of height. Each horizontal plane will be further divided into the regular grids according to the necessary planmetric accuracy,

e.g. 15 cm. The grid points are called as groundel. All the groundel in each horizontal plane will be projected back to the related aerial images by means of collinearity condition to produce the possible orthoimage of this terrain area at some height. Therefore, several orthorectified image patches can be generated from several related aerial images. Those orthorectified image patches constitutes a candidate set. Therefore, for possible height information, several candidate sets of orthoimage patches for this terrain area will be generated from those horizontal planes.

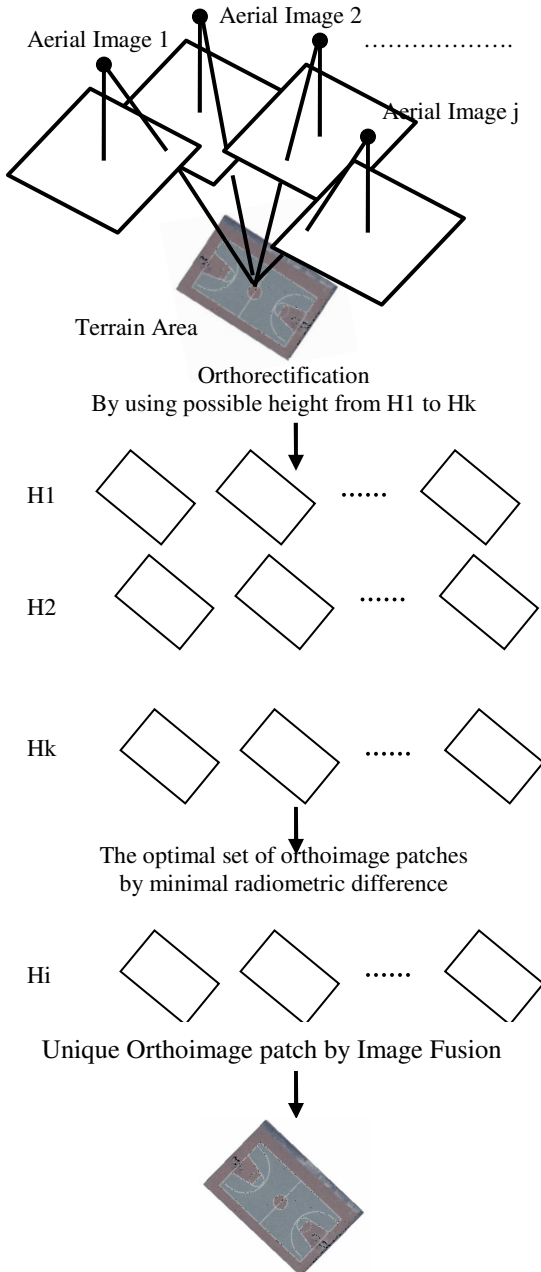


Figure 1 Study Methodology and Flowchart

As Fig. 1 shown, each height H_i will produce a candidate set of orthorectified image patches for a terrain area. By evaluating the radiometric difference information among orthoimage patches in each candidate set, the optimal set of orthoimage patches at some height will be decided. In other words, a procedure to decide corresponding height information of this terrain area will be developed. Section 2-2 will describe this elaborate process.

After the optimal set of orthoimage patches is decided, an image fusion approach will be developed to integrate the multiple image radiometric information into unique orthorectified image patch. Data snooping method [Baarda, 1968; Wolf and Ghilani, 1997] is often used in the adjustment for blunder detection. This method will be employed to exclude the inappropriate radiometric information in the optimal set of orthorectified image patches. Afterwards, a simple data fusion method is used to integrate the relevant radiometric information from multiple image patches into a unique orthorectified image patch. Subsection 2-3 will describe the method in more details.

The relevant assessment of accuracy, especially geometric accuracies, is also conducted in this paper. Section 3 will discuss the relevant problems in accuracies. Experiments and discussions will be presented in Section 4. The short occlusion will be given in final section. Next subsection will discuss the proposed concept in this method in advance. It is called "floating plane". The concept of "floating plane" will be compared with the "Floating Mark" employed in stereoscopic view photogrammetry.

2.1 Floating Plane

In this study, after the approximation height range of a terrain area is known, several horizontal planes corresponding to this terrain area will be produced according to the necessary height accuracy. In photogrammetry, if we imagine that the operator stereoscopically measures terrain characteristic points or features by using photogrammetric equipments. The operator will move floating mark up and down vertically to obtain the accurate height information. The idea used in this study is likely to the concept of "Floating Mark". The concept of "Floating Mark" is expanded to the concept of "Floating Plane". Therefore, if the algorithm is developed and used to find the optimal orthorectified image patch set at some height range is just like the operator to manipulate the "Floating Plane" to locate the accurate plane location according to the provided radiometric information among multiple images. Similar concept of "Floating Plane" can be found in [Collins, 1996].

2.2 The Optimal Set of Orthoimage Patches by Minimal Radiometric Difference

As shown in Fig.1, all the groundels in each horizontal plane will be projected back to the related aerial images by means of collinearity condition to produce one candidate set of orthoimage patches for selected terrain area. A procedure must be developed to decide the height information for this terrain area among all candidate sets of orthoimage patches.

Firstly, the distances between the central location of this terrain area and the relevant aerial images locations (X,Y,Z) are calculated and used to decide the nearest aerial image. The orthoimage patch generated from this nearest aerial image is called as the major orthoimage patch. Then, for each candidate set of orthoimage patches, the sum of absolute value of radiometric difference information between other orthoimage patches and this major orthoimage patch are calculated. Among the absolute value of radiometric differences from all candidate sets, the minimal is selected as the optimal set of orthoimage patches. Namely, the height information is decided in the meantime while this optimal orthoimage patch set is decided.

2.3 Unique Orthoimage Patch from Image Fusion

When an optimal set of orthoimage patches is found from all candidate sets. The subsequent task is to fuse the radiometric

information from multiple orthoimage patches into unique one. As Fig. 1 shown, multiple orthoimage patches corresponding to a terrain area means multiple measurements corresponding to same ground locations. As the preceding section mentioned, a major orthoimage patch is decided in an optimal set of orthoimage patches. If we supposed the radiometric difference between this major orthoimage patch and other orthoimage should be a constant. Meanwhile those differences should conform to the theory of normal distribution. But due to some factors in imaging process, e.g. sun location, atmospheric interference, terrain surface material, terrain occlusion and so on, some radiometric differences could not meet this assumption. That means that occasionally large random errors, i.e. blunders, will occur. When blunders exist, a least-squares adjustment may not be possible or will produce poor or invalid results. Therefore, in this study, Data Snooping method will be utilized to exclude the inappropriate radiometric differences during fusing the multiple orthoimage patches into a unique one.

2.3.1 Data Snooping: Data Snooping was proposed by Baarda [1968] for blunder detection. In this study, this method is used to isolate the large radiometric difference between two orthoimage patches corresponding to the same groundel at some confidence level. The detailed derivation of this method can also be found in [Wolf and Ghilani, 1997]. In this study, the adjustment of radiometric difference between two orthoimage patch can be expressed in matrix form as

$$L + V = AX \quad (1)$$

where $A^T = [1 \ 1 \ \dots \ 1]_{1 \times n}$ is the coefficient matrix, $X = [x]_{1 \times 1}$ is the estimated radiometric difference parameter vector. $L^T = [l_1 \ l_2 \ \dots \ l_n]_{1 \times n}$ is the observation matrix of radiometric difference between two orthoimage patches. $V^T = [v_1 \ v_2 \ \dots \ v_n]_{1 \times n}$ is the residual vector. The observation is regarded as the same weight, therefore, Eq.(1) has a covariance matrix $W_{n \times n}^{-1} = S_0^2 Q_{ll}$.

According to [Wolf and Ghilani, 1997], the relation between the residual vector and the true error vector can be expressed as the following form

$$V = -Q_{vv} W \mathcal{E} \quad (2)$$

where

$$Q_{vv} = W^{-1} - A Q_{xx} A^T = W^{-1} - Q_{ll}$$

$$Q_{xx} = (A W A^T)^{-1}.$$

Now consider the case when all measurements have zero errors except for a particular observation l_i which contains a blunder of size Δl_i . A vector of the true errors, $\Delta \mathcal{E}$, can be expressed

$$\begin{aligned} \Delta \mathcal{E} &= [0 \ 0 \ \dots \ 0 \ \Delta l_i \ 0 \ \dots \ 0]^T \\ \text{as} \\ &= \Delta l_i [0 \ 0 \ \dots \ 0 \ 1 \ 0 \ \dots \ 0]^T \end{aligned}$$

If the original measurement are uncorrelated, the specific correction for Δv_i can be expressed as

$$\Delta v_i = -q_{ii} w_{ii} \Delta l_i = -r_i \Delta l_i \quad (3)$$

where q_{ii} is the i th diagonal element of the Q_{vv} matrix, w_{ii} is the i th diagonal term of the weight matrix, W , and $r_i = q_{ii} w_{ii}$ is the observational redundancy number.

From Eq.(3), the v_i to an observation can be calculated and used to isolate measurement blunders by computing the standardized residuals from the diagonal elements of the Q_{vv} matrix as

$$w_i = \frac{v_i}{\sigma_{v_i}} = \frac{v_i}{\sigma_0 \sqrt{q_{ii}}} = \frac{v_i}{\sigma_{t_i} \sqrt{r_i}} \quad (4)$$

where w_i is the standardized residual, v_i the computed residual, q_{ii} the diagonal element of the Q_{vv} matrix, σ_0 is the known unit weight standard deviation. When the σ_0 is unknown, the t_i test statistic can be defined from Eq.(4) by replacing σ_{t_i} with

$$t_i = \frac{v_i}{\sigma_t \sqrt{q_{ii}}} \sim t_{n-u-1} \quad (5)$$

As Eq.(5) defined, where

$$\sigma_t = \frac{1}{n-u-1} (V^T W V - \frac{w_i v_i^2}{r_i}).$$

The approach is to use a rejection level given by a t distribution test with $n-u-1$ degree of freedom. The observation with the largest absolute value of t_i as given by Eq. (5) is rejected when it is greater than the rejection level.

2.3.2 Image Fusion: After the greater radiometric difference between each orthoimage patch and the major orthoimage patch corresponding to all groundels are excluded, the final orthoimage patch should be fused from this optimal set. The concept of data fusion could be utilized in this step. The original definition of data fusion is to fuse the data from different sensors. Although the orthoimage patch data are from the same kind of sensor, aerial camera, the idea could be used without violation. There are many approaches to dealing with this problem. [Jin *et al.*, 2002] In this study, the simplest approach is employed to fuse the radiometric information into unique one from multiple information. Namely, the major orthoimage patch is used as basic radiometric information. Then radiometric information that is not rejected in each groundel are summed up and averaged to obtain the final radiometric information in each groundel. If only one radiometric information is obtained from basic radiometric information, then the radiometric information of this groundel will be null.

3. INVESTIGATION INTO THE QUALITY OF FINAL ORTHOIMAGE PATCH

This section discusses the quality about the generated orthoimage patch. The whole processes of orthoimage patch generation from aerial photos can be simple separated into the following steps: (1).the imaging, (2).the digitizing, (3).the determination of the exterior parameters of aerial images, (4).the acquisition the surface elevation, (5).the rectification process, and (6).the output.

Although many steps will affect the quality of final orthorectified image patch, the camera quality definitely have important influence on the quality of aerial images and aerotriangulation is largely concern with the quality of exterior parameters. However, in this study, the accuracies of aerotriangulation and the quality of aerial images are supposed to be sufficient for providing good conditions for orthorectification. Then, the quality about the final orthoimage

patch can be discussed more simply. Subsequently, let's discuss the quality of final orthoimage from the geometric quality and radiometric quality.

3.1 Geometric Quality

If the lens distortion and the atmospheric affection can be neglected, the geometric quality are concerned with (1).scanning accuracy of aerial photos, (2).the transformation accuracy between photo coordinates and image coordinate, (3).the accuracy of exterior orientation parameter from aerotriangulation, (4).the 3-D coordinate accuracy of this terrain area, and (5).ground sampling distance (GSD). Of course, the factor (3) is completely affected by the accuracy of ground controls and the aerotriangulation. If the aerotriangulation accuracy completely meets the requirements, the major factor should be from the determination of the 3-D coordinates no matter what it is identified by the operator interactively or by image matching automatically. Shadows and occlusions are two great factors to seriously affect the identification and determination of 3-D points.

3.2 Radiometric Quality

If the geometric quality is sufficient, the radiometric quality depends on (1).terrain material, (2).sun location, (3). atmospheric condition, (4).camera quality, (5).resampling algorithm as well as (6).image balancing and enhancement techniques. The shadow from adjacent terrain areas is one of the most serious factor that affect the radiometric information. Another serious factor is occlusion effect from other adjacent higher building. These are two different topics to reconstruct the radiometric information from shadow and occlusion area.

From the above discussion, shadows and occlusions are two serious problems when producing orthoimage patches. Therefore, the choice of orthoimage patches should take these two important factors into consideration, especially for control information in aerotriangulation. By selecting the local highest terrain, these two problems can be avoided.

4. EXPERIMENTS AND DISCUSSIONS

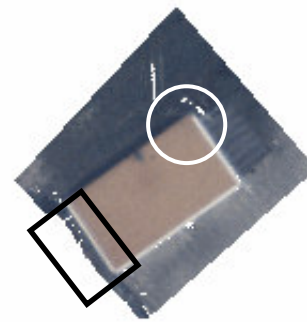
The photos used in this study were taken by 304.921000 mm focal-length aerial camera in 2000. The photo scale is about 1/5,000. The scanning pixel size is about 15 μ m, which is about 7.5 cm ground resolution.

According to analytical aerotriangulation, X and Y coordinates of pass points can quite routinely be located analytically to an accuracy of within about 1/15,000 of the flying height, and Z coordinates can be located to an accuracy of about 1/10000 of the flying height.[Wolf and Dewitt, 2000] Therefore, the spacing in X, Y, and Z coordinate components are set to 0.15m, 0.15m, and 0.20m according to its reachable accuracies. And the range of height approximation is supposed to it's true height +/- 2m. The true height is determined by multiple image space intersection in this test.

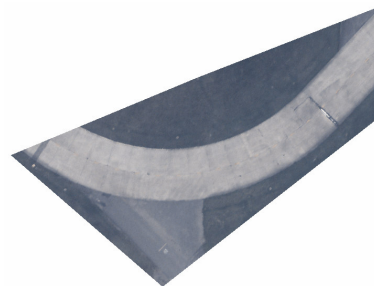
From Table 1, it is shown that a total 17 orthoimage patches were generated by this proposed methodology. The number in parentheses after each point number indicates the number of related aerial images used to generate the orthoimage patch. Except one concrete floor and one bridge surface, the selected horizontal terrain areas are almost classified into 3 kinds: buildings, roads, and basketball courts, as shown in Fig. 2.

Now, let's examine the generation of building orthoimage patch 75550677 from Fig. 3. The optimal set of orthoimage patches, composed of 3 related orthoimage patches, are generated by

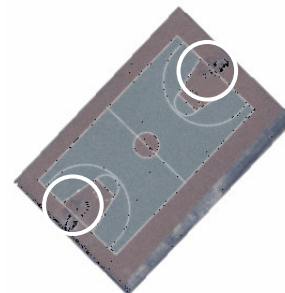
minimal radiometric difference, described in Section 2.2. In this case, orthoimage patch shown in Fig. 3B is selected as the major orthoimage patch. Then Data Snooping was used to exclude possible gross errors during image fusion. Obviously, if Data Snooping was not employed, the result of image fusion by simply averaging will be affected by the occlusion area, as seen the areas in black rectangular in Figs. 2 and 3. Another obvious example is the area in the white circles. A streetlight is imaged in this area. Its imaging locations were different because of the different aerial camera location. Data snooping remove the image information out (see Fig. 2) successfully. The excluded image information is given by grey level 0 or 255 in this study. As Fig. 2C shown, the areas in white circles are the image of basketball stands. Their image information was also excluded by Data Snooping. These three cases can clearly state the effectiveness of Data Snooping used before the process of image fusion.



A. Orthoimage patch of Building terrain (75550677)



B. Orthoimage patch of Road terrain (5661118)



C. Orthoimage patch of Basketball Court terrain (1261375)

Figure 2: Different terrain area selected as orthoimage patches

As concerned with geometric quality, sharp locations were selected in each orthoimage patch for the evaluations of geometrical accuracies. The 3-D coordinates of each sharp location were measured manually and calculated by multiple images least squares space intersection. These 3-D coordinates are viewed as ground truth. Also, the 3-D coordinates about these same sharp locations were identified by the operator in generated orthoimage patch and calculated from the relevant orthoimage information. The coordinate differences were listed

as Table 1. A total of 60 sharp points are selected for comparisons. As Table 1 shown, the average error in X,Y, and Z direction is 0.02m, 0.03m, and -0.05, respectively. Meanwhile, the root mean square errors (RMSE) is 0.15m, 0.19m, and 0.29m in X,Y, and Z coordinate components. In this study, the comparison didn't take the error of aerotriangulation into account. If aerotriangulation error is considered, the geometrical accuracy will be inferior to the above-mentioned test result from the principle of error propagation. But it is believed that geometric accuracy is still suitable for control information.

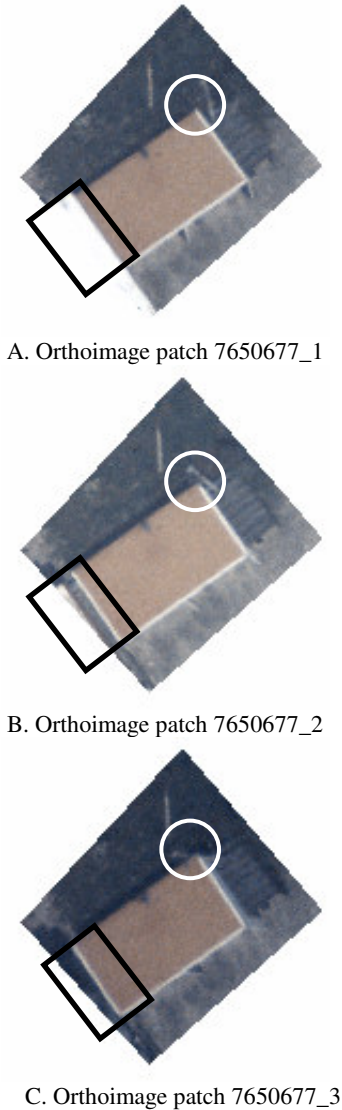


Figure 3: Three orthoimage patches to generate orthoimage patch 7650677.

Orthoimage No.	Coordinate differences		
	dX(m)	dY(m)	dZ(m)
650595(3) Building	-0.08	0.17	-0.22
	0.13	-0.01	-0.43
	-0.10	-0.25	-0.01
7650677(3) Building	-0.04	-0.01	0.07
	-0.11	0.25	-0.08
6420418(3) Road Intersection	-0.13	0.05	-0.10
	0.01	0.26	-0.16
	0.29	-0.15	-0.12
4340091(3) Road	-0.03	0.08	0.14
	0.05	-0.02	-0.08

6389908(3) Building	-0.39	0.11	0.32
	0.46	0.49	0.10
	0.19	-0.16	-0.24
	-0.08	-0.10	-0.17
8659373(3) Building	-0.26	0.43	0.03
	-0.08	0.26	0.28
	0.07	0.05	0.08
	0.07	-0.11	-0.20
2099601(3) Road	-0.09	0.08	0.24
	-0.36	0.37	0.69
	-0.22	0.09	0.23
3280329(3) Basketball Court	0.04	-0.11	-0.10
	0.03	0.01	-0.12
	-0.03	-0.11	0.17
	0.00	0.08	0.23
9290104(4) Road	-0.07	0.00	0.06
5500052(3) Road	0.02	0.08	0.08
	0.05	-0.06	0.26
	0.17	-0.36	-0.12
	0.17	0.01	-0.06
7901192(3) Building	0.13	-0.01	-0.19
	-0.08	0.23	-0.39
	0.10	-0.19	-0.34
	-0.08	0.21	-0.19
	0.31	0.01	-0.40
	0.03	0.01	0.46
	0.14	0.31	-0.22
0.17	0.07	0.05	
1550396(2) Concrete floor	-0.07	-0.12	-0.17
	0.11	-0.34	-0.59
	0.23	-0.28	-0.42
5661118(4) Road	0.07	0.17	-0.52
	0.08	-0.06	-0.58
2281807(2) Road	-0.08	0.09	-0.27
	0.06	0.20	-0.46
	-0.03	0.08	-0.35
	0.04	0.03	0.15
8170724(4) Building	0.00	0.41	0.26
	0.16	0.16	-0.09
	0.19	-0.19	-0.23
4861413(3) Building	-0.13	0.27	-0.55
	0.06	0.27	-0.60
	0.08	-0.28	0.13
	-0.25	-0.14	-0.03
1261375(4) Basketball Court	-0.05	-0.02	0.17
	-0.02	-0.07	0.21
	0.19	0.02	0.40
	0.19	0.01	0.25
	0.09	-0.09	0.42
	-0.01	-0.20	0.39
Average	0.02m	0.03m	-0.05m
R.M.S.E	0.15m	0.19m	0.29m
Maximum Error	-0.39m	-0.36m	-0.60m
Minimum Error	0.46m	0.49m	0.69m

Table 1 Results of orthoimage patches and coordinate comparisons

In this study, non-horizontal terrain areas are also selected and tested, e.g. two gable roofs shown in Fig. 4. The coordinate differences of non-gable corners are not very obvious. From Point number 7901192 and 4861413 in Table 1, it shows that

max absolute is 0.31m, 0.31m, and 0.60m in X, Y, and Z coordinate components respectively. Two distinct gable corners are selected and compared from orthoimage patch 7901192, their coordinate difference in X,Y are only (0.23m, 0.07m) and (0.42m, -0.04m), but the Z difference reached -1.14m and -1.71m. A gable corner in orthoimage number 4861413 is measured and compared. It's difference is 0.26m, 0.01m, and -1.23m in X,Y, and Z direction. Obviously, the height difference is large. But the X,Y coordinate differences are not so large from these results.



A. Orthoimage patch of terrain area 7901192



B. Orthoimage patch of terrain area 4861413

Figure 4 The orthoimage patch from non-horizontal terrain area

During the process, some difficulties are found in this proposed methodology. That means how to (1).find a time-invariant flat terrain area (2).obtain well-contrast orthoimage patches with suitable size and texture. Actually it is very difficult to find lots of terrain areas that meet the (1) and (2) requirements. But the reachable geometrical accuracies motivate us to do more studies. For example, it is necessary to develop a mechanism to evaluate whether an orthoimage patch is suitable for criterion (2) and self-verify the output results. Namely, the criteria for self-examination of geometric and radiometric quality should be developed in order to ensure what the operator choose is good enough for controls.

Additionally, the evaluations of radiometric quality and the accuracy assessment of exterior orientation by using these orthoimage patches as controls should be done in the future. Meanwhile, tests by matching new aerial images with orthoimage patches for orientation parameters no matter what interactively or automatically should be done.

Some improvements could be also conducted for generating orthoimage patches much more efficient and more accurate, for example, the selection of suitable terrain area and the provision of height approximation. In this study, only the approximation of height information is used for the orthorectification. No precise height information must be measured by the operator. In the future test, digital surface model (DSM) could be included for provision of approximation height information. Additionally, the radiometric model in Data Snooping can be improved more accurate.

Finally, horizontal plane is basic assumption, this is too limited. The test for non-horizontal plan or the refinement of the result from generated orthoimage patches can be done in the future.

5. CONCLUSIONS

A methodology is proposed to generate the orthorectified image patches as controls for aerotriangulation in this paper. Even further investigation and study should be conducted in order to get more verification, the preliminary tests show that the RMSE can reach 0.15m, 0.19m, and 0.29m in X,Y, and Z coordinate components. The good geometric accuracy proves the feasibility of the proposed method for the controls in aerial triangulation.

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