OPTIMIZED PATCH BACKPROJECTION IN ORTHORECTIFICATION FOR HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT:

The objective of this investigation is to build up a fast orthorectification procedure for high resolution satellite images. The proposed scheme comprises two major components: (1) orbit modeling, and (2) image orthorectification. In the orbit modeling, we provide a collocation procedure to determine the precision orbits. In the image orthorectification, the area of interest is sequentially subdivided into four quadrate tiles until a threshold is met. The threshold of maximum terrain variation in a tile will be optimized according to the computation efficiency and accuracy requirements. Once the ground tiles are determined, we perform adaptive patch backprojection to correspond to the image pixels. Selecting the highest elevation in the tile, the four corners of the tile are projected on the image to form a set of anchor points. Another set of anchor points with the lowest elevation are generated in the same manner. Assuming that the relief displacement in a moderate tile is linear, a groundel within the tile is projected into the image space according to the groundel elevation and the two associated anchor point sets. Tests of images include SPOT 5 supermode and QuickBird panchromatic satellites. Experimental results indicate that the computation time is significantly reduced without losing accuracy.

1. INTORDUCTION

The most rigorous way to register a remotely sensed image with a relevant spatial data layer is performing orthorectifictation to the image. The generation of orthoimages from remote sensing images is an important task for various remote sensing applications, such as cartography, environmental monitoring, city planning, etc. Moreover, GIS (Geographic Information Systems) technology often needs multi-temporal images for detection of lancover changes. Thus, ortho-rectified images have become important due to their short production time.

Nowadays, most of the high resolution satellites use linear pushbroom arrays, such as SPOT5**,** Ikonos, QuickBird and others. A number of investigations have been reported regarding the geometric accuracy for those pushbroom linear array images (Westin, 1990; Chen and Lee, 1993; Orun and Natarajan, 1994; Toutin, 2003). Traditionally, the first step of image orthorectification is to model the orientation parameters by using ground control points. Then, incorporating a DTM, an image, and the orientation parameters, a non-linear equation is formulated to determine the along-track image coordinates in terms of the sampling time for a ground element. The across-track image coordinates can thus be calculated according to the collinearity condition equations.

The traditional solution of orthorectification for pushbroom images is time-consuming due to a vast amount of non-linear equations have to be solved. This weakness is so obvious for those high resolution satellite images that an efficient way is required. Konecny *et al* (1987) emulated SPOT images as centre perspective, then, implemented the idea on an analytical plotter to achieve real time operation while maintaining some accuracy. Inspired by the idea, we propose a "Patch Backprojection" procedure for accelerating the computation in orthorectification for high resolution satellite images with large amount of pixels.

Because of the small field-of-view (FOV) of high resolution satellite, the relief displacements in a small area with moderate terrain variations may be assumed linear. We, thus, propose a method to do the orthorectification patch by patch. The patch size may be adapted for different terrain characteristics. We first divide the area of interest into a number of tiles. For corner point with highest elevation, we compute the image coordinate for each corner point of tiles using indirect method. The indirect method also applies to the corner point with lowest elevation. Using an affine transformation as a mapping function of image coordinates and object coordinates. In addition, we will analyze terrain variations for the selection of the adaptive window of the tiles. We also analyze the model error of the proposed method including transformation error and interpolation error. Affine transformation, patch size, tilt angle, and elevation range are the most important factors to be considered.

In the validation, we first analyze the model error of the proposed method. It has two parts, transformation error and interpolation error. Affine transformation, patch size, tilt angle, and elevation range are the most important factors to be considered in the analysis of model errors. Then, we check the accuracy of the determined orientation parameters. Finally, the accuracy of the generated orthoimage will be examined. Pushbroom scanner images including SPOT5 and QuickBird are considered in this investigation.

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2. METHODOLOGY

The proposed method comprises two major parts. The first part is to build up the satellite orientation by using the ground control points. The second part is to use the orbit parameters to perform the orthorectification, in which a "Patch Backprojection" method is proposed. The model error of "Patch Backprojection" will also be evaluated in this section.

2.1 Orbit Modeling

In the modeling of orientation parameters, the position vectors and the attitudes of the satellite are expressed with low order polynomials in terms of sampling time. Due to the extremely high correlation between two groups of orbital parameters and attitude data, we only adjust the orbital parameters followed by a collocation procedure to compensate for the local systematic errors. Two steps are included in the orientation modeling. The first step is to initialize the orientation parameters using on-board ephemeris data. We then fit the orbital parameters with low order polynomials using GCPs (Chen and Teo, 2002). Once the trend functions of the orbital parameters are determined, the fine-tuning of an orbit is performed by using Least Squares Filtering technique (Mikhail and Ackermann, 1982).

2.2 Image Orthorectification

The objective of image orthorectification is to determine the corresponding image pixel for a ground element. In addition to providing the traditional pixel-by-pixel procedure, we proposed a "Patch Backprojection" method and a patch size optimization approach as well. It is demonstrated that the indirect method performs better than the direct method in terms of quality and efficiency (Kim *et al*, 2001). Thus, we select the indirect method to determine the corresponding image pixels from a ground element.

2.2.1 Pixel-by-pixel Backprojection

Figure 1 shows the geometry of indirect method. Given a ground point **A**, we can create a vector **r(t)** from ground point **A** to image point **a**. The vector **r(t)** vector is located on the principle plane and **n(t)** is the normal vector on the principal plane. The mathematics show that, at time t, **r(t)** is orthogonal to the normal vector **n(t)**. When **r(t)** is perpendicular to **n(t)**, the inner product of **r(t)** and **n(t)** is zero. The function **f(t)** is defined to characterize the coplanarity condition.

$$f(t)=r(t) \cdot n(t)=0 \qquad (1)$$

We apply Newton-Raphson method to solve the nonlinear equation (1), and to determine the sampling time t for ground point **A**. Using the trigonometric calculation, the image coordinate respect to ground point can be determinate from the principal plane. After determining the corresponding image point for ground element, the grey value on the orthoimage is calculated by image resampling, while the orthoimage is done by pixel-by-pixel backprojection.

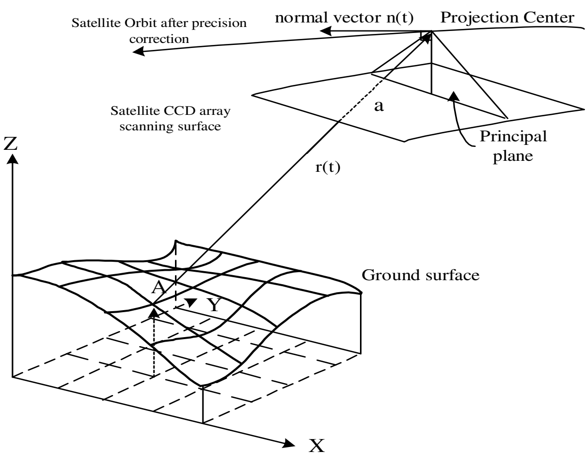

Figure 1. Illustration of indirect method

2.2.2 Patch Backprojection

The indirect method in pixel-by-pixel way is very time consuming. Thus, we proposed a "Patch Backprojection" method to minimize the orthorectification computation load with negligible model error. The proposed method is based on the following two assumptions: (1) the relief displacements in a small area with moderate terrain variations are linear, and (2) the mapping geometry between image coordinates and object coordinates may be expressed by affine transformation when a small area is considered.

The procedure of the patch backprojection is illustrated in Figure 2. We first divide the area of interest into a number of equal-sized tiles. Selecting the lowest elevation in the tile, the corners of the tile are projected on the image to form a set of anchor points. Another set of anchor points with the highest elevation are generated in the same manner. Assuming that the relief displacement in a small tile is linear, a groundel within the tile is projected into the image space according to the groundel elevation and the two associated anchor point sets.

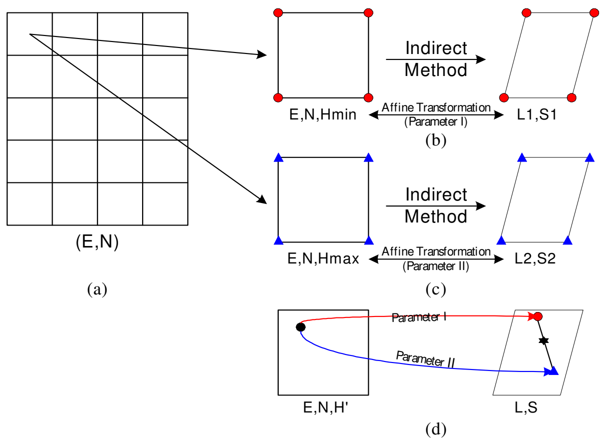

Figure 2. Illustration of patch backprojection
(a) Tiles with equal size
(b) Anchor point generation for the top layer
(c) Anchor point generation for the bottom layer
(d) Interpolation

2.2.3 Patch Size Optimal Backprojection

To reduce the interpolation error when terrain variation is considered, it would be better that the patch size changes according to the terrain characteristics. The patch size should be large for rolling terrain and, on the contrary, small for rugged one. Quadtree structure (Mather, 1999) that segments the terrain coverage with a given elevation range is a straightforward and yet effective way to characterize the terrain variations. Based on this consideration, we select quadtree structure to optimal the window size in the patch backprojection.

The method discussed in this section is a modified one stated in the previous section. In the quadtree analysis, the allowed elevation range is selected according to that the model error will not exceed the tolerance. The analysis of the model errors will be given in the next section. After performing the terrain subdividing, tiles with different sizes are projected into the image space one by one using the process described in the previous section. Figure 3 illustrates the concept of the patch size optimal backprojection.

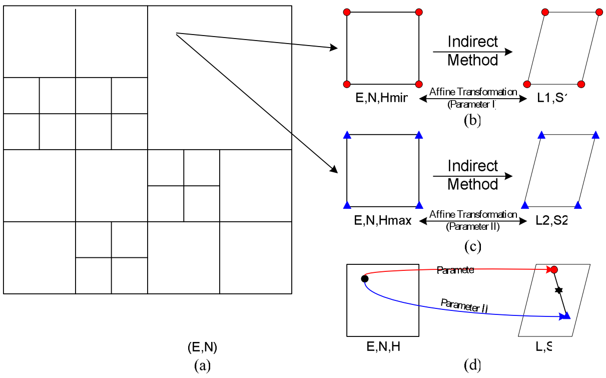

Figure 3. Illustration of patch size optimal backprojection
- (a) Optimal tiles size by quadtree structure
- (b) Anchor point generation for the top layer
- (c) Anchor point generation for the bottom layer
- (d) Interpolation

2.3 Model errors estimation

Patch size is crucial when doing computation. The larger the patch size, the faster the computation time, but the model error increases as well. Hence, patch size optimal should consider the model error of the proposed method. Two steps, including affine transformation for anchor point sets and linear interpolation in patch backprojection could introduce model errors. Considering the imaging geometry, patch size, tilt angle, and elevation range are the three most important factors to be considered in the analysis of model errors. Simulations are employed on SPOT5 supermode images. The model error is defined as the difference of the proposed method and the rigorous point-by-point backprojection.

The evaluation items and parameters are shown in Table 1. The evaluation items includes: transformation model error, variation of terrain model error and tilt angle model error. The tilt angle is within 30°. The elevation ranges from 0m to 2000m. The patch size is within 40m by 40 m and 3000m by 3000m for each evaluation item.

Table 1. SPOT5 model error analysis

	Transformation Model Error	Interpolation Model Error	
Evaluation Item / Variable	Affine transformation	Variation of terrain	Tilt angle
Tilt angle (deg)	30	30	1~30*
Elevation (m)	0 and 2000	0~2000**	0 and 1000
Patch size (m * m)	80*80~ 2000*2000***	80*80~ 2000*2000***	80*80~ 2000*2000***

*Tilt angle step (deg): 1, 2, 4, 8, 16, 20, 25, and 30.
**Elevation step (m): 80, 160, 320, 500,640, 750, 1000, and 2000.
***Patch size step (m*m): 80, 160, 320, 640, 1280, 1500, and 2000,

2.3.1 Affine transformation model error

Given a tilt angle of 30° and elevation in 0m and 2000m, the errors due to affine transformation are shown in Figure 4. It indicates that when the patch size of 1500pixel by 1500pixel is selected, the model error is within the tolerance, i.e., 0.05 pixels, in this investigation.

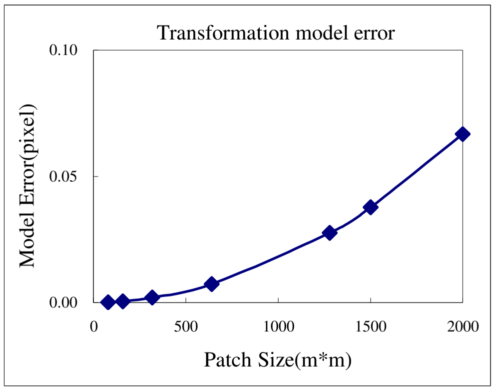

Figure 4. Transformation model error for SPOT5

2.3.2 Variation of terrain model error

Given a tilt angle of 30°, the errors due to terrain variation are shown in Figure 5. It indicates that when the variation of terrain is less than 1000m and patch size is less than 640m by 640m, the model error is within the tolerance, i.e., 0.05 pixels, in this investigation.

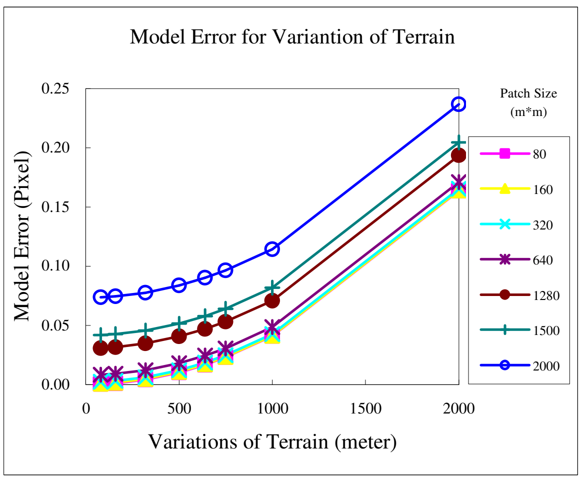

Figure 5. SPOT5 model error for variation of terrain

2.3.3 Tilt angle model error

Given the variation of terrain in 1000m, the errors due to tilt angle are shown in Figure 6. It indicates that when the patch size is smaller than 640m by 640 m, the model error is smaller than 0.05 pixels in different tilt angles.

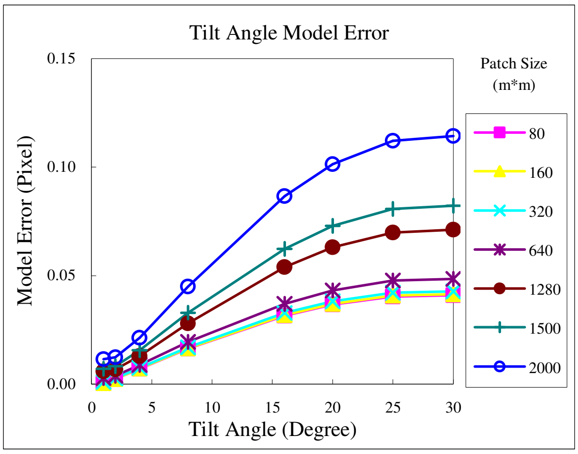

Figure 6. SPOT5 model error for tilt angle

3. EXPERIMENTAL RESULTS

The test data include a SPOT5 and a QuickBird images. The GCPs and check points (CHKPs) were measured from 1:1000 scale topographic maps. The position accuracy is better than 50 centimeters. The distributions of those points are shown in Figure 7 and Figure 9 respectively. In the figures, triangles represent the GCPs while boxes are the CHKPs. The respective DTMs are illustrated in Figure 8 and Figure 10 respectively. The related information is shown in Table 2.

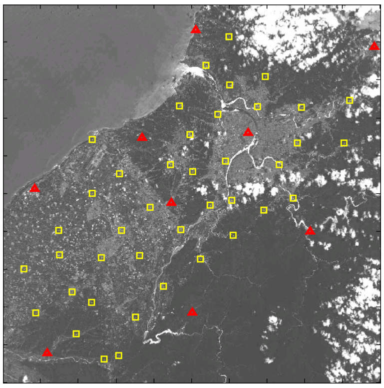

Figure 7. SPOT5 images

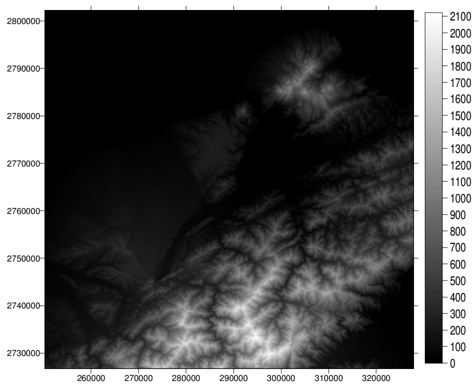

Figure 8. The DTM used in SPOT5 orthorectification

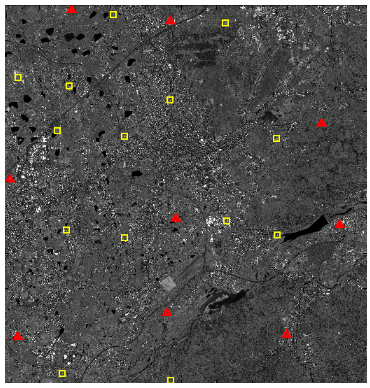

Figure 9. QuickBird images

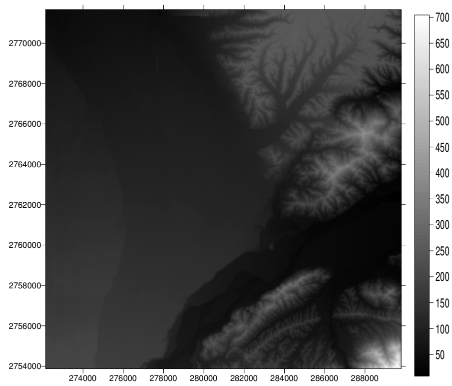

Figure 10. The DTM used in QuickBird orthorectification

Table 2. Related information of test images

	SPOT5	QuickBird
Location	Taipei,Taiwan	YingKe,Taiwan
Date	2002/07/02	2002/05/26
GSD (meter)	2.5 (Supermode)	0.6
Test Area (km*km)	60 * 60	16 * 18
Image Size (pixel*pixel)	24000*24000	28764*27552
Tilt Angle (degree)	14.23	12.52
Number of GCP	9	9
Number of CHKP	40	14
GCP & CHKP Data source	1/1000 topographic maps	
DTM	40m Topographic Data Base of Taiwan	

The experiment includes three parts: (1) patch size selection for test data, (2) accuracy analysis, and (3) computation time analysis. In order to get the adaptive patch size, we set a tolerance of model error to do the analysis. The real ephemeris data and simulate terrain are consider in the analysis. When the patch size is determined, we checked the accuracy of the orbit modeling and examined the accuracy for the generated orthoimage. The difference between orbit modeling and orthoimage is corresponding to the model error that we setup. The computation time is also compared in point-by-point, equal patch backprojection, patch size optimized backprojection.

3.1 Patch Size Selection

Considering the differences of the covering area, the elevation ranges for SPOT5 and QuickBird images are 80m to 2000m and 80m to 600m, respectively. Given tilt angles of 14.23° and 12.52° for the two satellites, the model errors behaved as shown in Figure 11. It is expected that larger patch size will lead to less computation time. In these two test cases, the tolerance of model error is selected as 0.05 pixels. Thus, the patch for both sensors should be 160m by 160m and the terrain variation should be smaller than 500m.

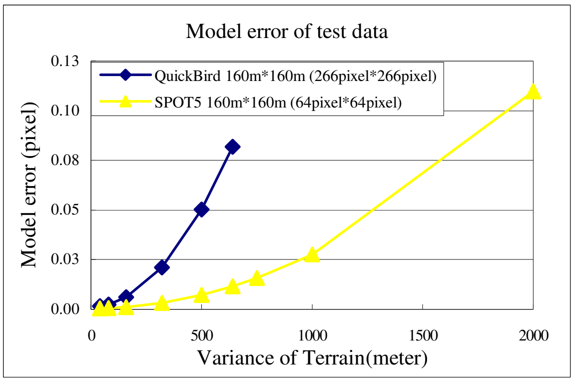

Figure 11. Model error of test data

3.2 Accuracy Analysis

The ray-tracing method is applied to evaluate the orbit accuracy. Given the satellite orientation and image point, we calculate the intersection point of DTM and ray direction. We provide Table 3 for the summary of accuracy. Table 3 illustrates the accuracy performance of GCPs and CHKPs, when 9 GCPs were employed. The accuracy of SPOT5 and QuickBird are better than two pixels.

Table 3. Root-Mean-Square error of orbit modeling

		GCP		CHKP	
Unit: meter	GSD	RMSE E	RMSE N	RMSE E	RMSE N
SPOT5	2.5	1.78	1.96	3.98	3.12
QuickBird	0.6	0.55	0.48	0.71	0.87

In order to evaluate the quality of orthoimage, we checked it by enough number of check points. Table 4 shows the RMSE of orthoretification. It is observed that the RMSE behaves similarly to orbit modeling. The orthoimage and error vectors of SPOT5 are illustrated in Figure 12 and Figure 13. The orthoimage and error vectors of QuickBird are illustrated in Figure 14 and Figure 15. Please note that the accuracy results of orthoimages are similar to those in orbit modeling. This indicates that the accuracy loss is insignificant.

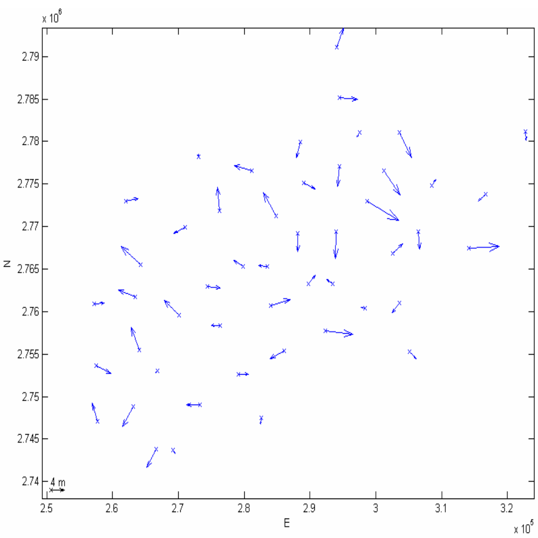

Figure 12. Error Vector for Generated SPOT5 Orthoimage

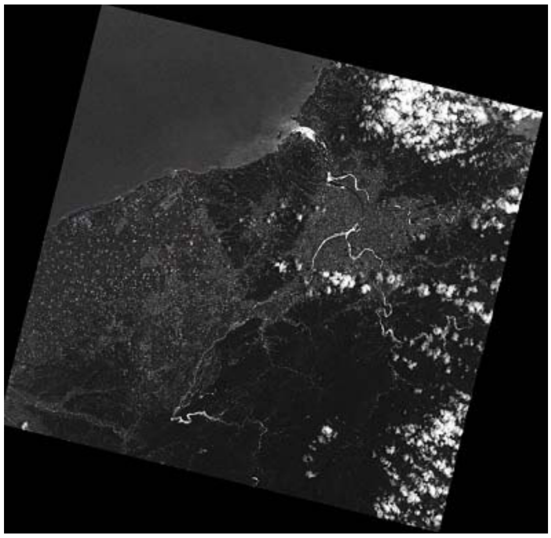

Figure 13. Generated SPOT5 Orthoimage

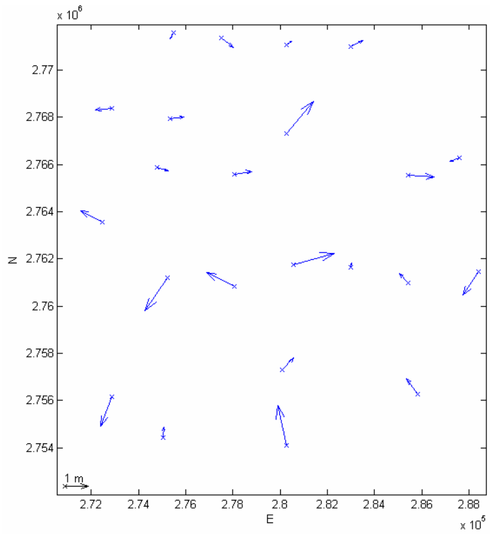

Figure 14. Error Vector for Generated QuickBird Orthoimage

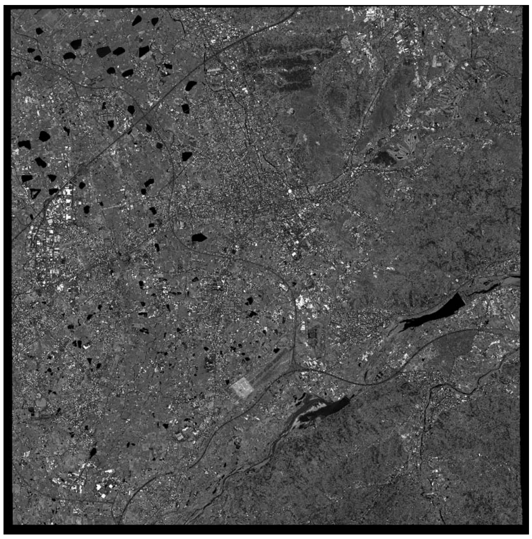

Figure 15. Generated QuickBird Orthoimage

Table 4. Root-Mean-Square error of orbitimage

		GCP		CHKP	
Unit: meter	GSD	RMSE E	RMSE N	RMSE E	RMSE N
SPOT5	2.5	1.91	1.69	3.75	3.01
QuickBird	0.6	0.60	0.51	0.83	0.90

3.3 Computation Time

We used a personal computer with 3GHz CPU for orthorectification. The equal grid patch backprojection method is applied in the orthorectification. Table 5 is the statistics of calculations for two images. We setup the model error should be less than 0.05 pixel in patch backprojection. Referring to Figure 11, for SPOT5 and QuickBird data, the variance of terrain in single tile should be smaller than 500m. We used the actual DTM to do the terrain analysis for both sensors. The elevation range of SPOT5 is from 0 to 2100 meter, when the terrain variance is smaller than 500 meter in single tile. The smaller patch size is 160 by 160 meter, so we used tile sized 160m*160m to do the equal grid patch backprojection. The elevation range of QuickBird is in between 0 to 700 meter. We analyzed the DTM with respect to QuickBird. When the terrain variance is smaller than 500 meter in single tile, the smaller patch size is 160 by 160 meter. We spent 45 minutes in doing QuickBird's orthorectification. As for SPOT5, we spent 55 minutes.

Table 5. Orthorectification computation time

	SPOT5	QuickBird
Computation time (min)	55	45
Patch Size (m*m)	160*160	160*160
Patch Size (pixel*pixel)	64*64	266*266
Orthoimage Size (pixel*pixel)	29480*30320	30786*29186
Orthoimage Size (mb)	874	1744

We used SPOT5 data to do the Patch Size Optimal Backprojection instead of QuickBird, because its terrain variations and patch size is small. Also, when using quadtree to do the terrain analysis, the result is same as equal grid. The result is shown in Table 6. When using Patch Size Optimal Backprojection, it takes only 28 minutes for orthorectification, and both the quality and computation time is satisfactory. We spent 55 minutes for equal grid patch backprojection, and more than 10 hours for point-by-point method.

Table 6. Comparison of computation time for SPOT5

	Patch size optimal backprojection	Equal grid patch backprojection	Point-by-point
Computation time (min)	28	55	>10 hr
Terrain variation (m)	0~2100	0~2100	0~2100
Patch size (m*m)	Max:1280*1280 Min:160*160	160*160	NULL
Terrain allowance in a patch(m)	500	NULL	NULL
Number of patch	6367	217580	Number of point : 5760000

3.4 Summary

The experimental results indicate that: (1) we proposed a scheme for patch size optimization while the model error is less than 0.05 pixels, (2) the orbit adjustment accuracy is better than 2 pixels when 9 ground control points is applied, (3) the proposed "Patch Backprojection" reduced the computation time of orthorectification, and (4) the orthorectifation result is better than 2 pixels, which is almost identical to the one tested in orbit modeling.

4. CONCLUSIONS

In this study, we have proposed a procedure of fast orthorectification for satellite images. The proposed method used the patch backprojection in orthorectification. Patch backprojection method is a feasible way to improve the efficiency with respect to the point-by-point backprojection. In order to control the model error of patch backprojection, the model error analysis of the proposed method is also presented. Data sets including SPOT5 and QuickBird have been tested in validating the proposed method. Experimental results indicated that the proposed scheme may minimize the orthorectification computation time, while the model error is insignificant.

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