# Fast Orthorectification for High Resolution Satellite Images Using Quadtree-Based Patch Backprojection 

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#### Abstract

High resolution satellite images have huge amount of pixels in common. Thus, an efficient method is required for the generation of orthoimages. Patch backprojection method is a feasible way to improve the efficiency with respect to the point-by-point patch backprojection. We will propose an Adaptive Patch that optimizes the patch size for different terrain variations. The essence of the patch optimization is quadtree structuring for terrain variations. The area of interest is, thus, sequentially subdivided to four quadrate tiles until a preset criterion is met. The experiment results indicated that the proposed method is efficient without losing accuracy.


KEY WORDS: Orthorectification, Satellite Image, Quadtree, Backprojection.

## 1. INTRODUCTION

Since the trend is to integrate satellite images with relevant spatial data layers, orthorectification for the images is an important task. High resolution satellite images have huge amount of pixels in common. Thus, an efficient method is preferable. Patch backprojection method is a feasible way to achieve the goal. Adaptive patch approach, which optimizes the patch size by analyzing the terrain variations, would be a better way. The objective of this investigation is to propose a scheme that employs the quadtree structure to represent the terrain variations in backprojection for image orthorectification.

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 orthorectification, we first use quadtree structure to analysis the terrain, 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. Once the ground tiles are determined, we perform patch backprojection to correspond the image pixels [1]. Selecting the highest elevation in the tile, the four corners of the tile are projected into the image space 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 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. Images of SPOT 5, Quickbird, and EROS A satellites are to be tested to validate the performance of the proposed scheme.

## 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 "Quardtree-Based Patch Backprojection" method is proposed.

### 2.1. Orbit Adjustment

The first step in the orthorectification for an image is to model the 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 correct the orbital parameters. That means, we will use the attitude information provided from the on-board ephemeris data as known values, the position vectors are adjusted accordingly. Three steps are included in this
investigation. The first step is to initialize the orientation parameters using on-board ephemeris data. Then, we fit the orbital parameters with low order polynomials using GCPs. Once the trend functions of the orbital parameters are determined, the fine-tuning of the orbit is performed by using Least Squares Filtering technique [2].

### 2.2. Orthorectification

Once the orientation parameters are determined and a DTM is given, the corresponding image position for a ground point may be determined by the indirect method. Fig. 1 shows the geometry of indirect method. Given a ground point $\mathbf{A}$, we can create a vector $\mathbf{r}(\mathbf{t})$ from ground point $\mathbf{A}$ to image point $\mathbf{a}$. The vector $\mathbf{r}(\mathbf{t})$ vector is located on the principle plane and $\mathbf{n}(\mathbf{t})$ is the normal vector on the principal plane. The mathematics shows that, at time $\mathbf{t}, \mathbf{r}(\mathbf{t})$ is orthogonal to the normal vector $\mathbf{n}(\mathbf{t})$. When $\mathbf{r}(\mathbf{t})$ is perpendicular to $\mathbf{n}(\mathbf{t})$, the inner product of $\mathbf{r}(\mathbf{t})$ and $\mathbf{n}(\mathbf{t})$ is equal to zero. The function $\mathbf{f}(\mathbf{t})$ is defined to characterize the coplanarity condition

$$
\begin{equation*}
f(t)=r(t)] \quad n(t)=0 \tag{1}
\end{equation*}
$$



Figure 1. Illustration of indirect method
We apply Newton-Raphson method to solve the nonlinear Eq. (1), to determine the sampling time $t$ for ground point A. For an image point sampled at time $t$, we can decide a principal plane. The image coordinate (line and sample) can be calculated by Eq. (2) and (3).

> Line=(t-t0)/(IntegrationTime)

Sample=(S/FOV)*PixelsPerLine
where, $t$ is the sampling time; $t_{0}$ is the sampling time for first scan line; IntegrationTime is the sampling interval; S is the angle between vector of first CCD and $\mathbf{r}(\mathbf{t})$; FOV is field of view angle; PixelsPerLine is number pixel in a line

The pixel by pixel indirect method spends too much
computation time in backprojection. We, thus, propose a "Quadtree-Based Patch Backprojection" method, to minimize the orthorectification computation load without losing positioning accuracy. 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 moderate area is considered. The model errors of the two assumptions will be validated in the experiments.

The procedure of the Quadtree-Based Patch Backprojection is illustrated in Fig. 2. We first use the quadtree concept [3] to analyze the terrain and divide the area of interest into a number of tiles. Selecting the lowest elevation in the tile, the corners of the tile are projected into the image space 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 quadtree-based patch backprojection

## 3. EXPERIMENTAL RESULTS

The experiments include three parts of validation. The first one is to check the accuracy of the determined orientation parameters. The second one is to examine the accuracy for the generated orthoimage. The third one is to compare the computation performance of equal grid and quadtree patch backprojection. The test data include SPOT5 supermode, EROS A and QuickBird images. The related information is shown in Table 1.

Table 1. Related information of test images

|  | SPOT5 | EROS A | QuickBird |
| :---: | :---: | :---: | :---: |
| Location | Taipei, <br> Taiwan | KaoHsiung, <br> Taiwan | KaoHsiung, <br> Taiwan |
| Date | 2002/07/02 | 2001/04/15 | 2002/03/02 |
| GSD (meter) | 2.5 (Supermode) | 1.9 | 0.6 |
| Image size (pixel*pixel) | $\begin{aligned} & 24000^{*} \\ & 24000 \\ & \hline \end{aligned}$ | $\begin{array}{\|l\|} \hline 7043 * \\ 6572 \\ \hline \end{array}$ | $\begin{aligned} & 28716^{*} \\ & 27552 \\ & \hline \end{aligned}$ |
| Tilt Angle(deg) | 14.23 | 11.60 | 11.73 |
| No. of GCP/CHKP | 9/40 | 9/44 | 9/111 |
| GCP \& CHKP <br> Data source | 1/1000 topographic maps |  |  |
| DTM | 40m Topographic Data Base of Taiwan |  |  |
| DTM Variation (m) | 0~2100 | 0~340 | 0~340 |

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 the ray vector. Table 2 illustrates the orbit accuracy, when 9 GCPs are employed.

Table 2. Root-mean-square error of orbit modeling
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|  |  | GCP |  | CHKP |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Unit: meter | GSD | RMSE E | RMSE N | RMSE E | RMSE N |
| SPOT5 | 2.5 | 1.78 | 1.96 | 3.98 | 3.12 |
| EROSA | 1.9 | 1.47 | 2.72 | 3.34 | 4.37 |
| QuickBird | 0.6 | 1.85 | 0.91 | 2.43 | 1.63 |

In order to evaluate the quality of the generated orthoimage, we check it by the same set of check points. Table 3 shown the RMSE of the generated orthoimages. It is observed that the RMSE behaves similarly to orbit modeling.

Table 3. Root-mean-square error of orthorectification
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|  |  | GCP |  | CHKP |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Unit: meter | GSD | RMSE E | RMSE N | RMSE E | RMSE N |
| SPOT5 | 2.5 | 1.91 | 1.69 | 3.75 | 3.01 |
| EROSA | 1.9 | 1.80 | 3.10 | 3.13 | 3.74 |
| QuickBird | 0.6 | 1.83 | 1.02 | 2.57 | 2.08 |

We use equal grid patch backprojection to do the orthorectification, where bilinear interpolation is applied in resampling. First, we analyze the model error of equal grid patch backprojection for respective images. When the model error is controlled within 0.05 pixels, the statistics of calculations for three images are shown in table 4.

Table 4. Orthorectification computation time

|  | SPOT5 | EROSA | QuickBird |
| :--- | :--- | :--- | :--- |
| Computation Time (min) | 85 | 5 | 30 |
| Size of Tile $(\mathrm{m} * \mathrm{~m})$ | $80 * 80$ | $40 * 40$ | $320 * 320$ |
| Orthoimage Size $(\mathrm{mb})$ | 874 | 127 | 1744 |

In order to compare the computation time of equal grid patch backprojection, quadtree patch backprojection and point-by-point backprojection, we select SPOT5 data because the image covers much complex terrain
variations. The model error of equal grid and quadtree are controlled with the same condition, i.e. 0.05 pixels . Two criteria should be met for the quadtree test: (1) the patch size should be smaller than $1280 \mathrm{~m}^{*} 1280 \mathrm{~m}$, and (2) the terrain variations should be smaller than 500 meter in a tile. For the equal grid test on the other hand, we use $80 \mathrm{~m} * 80 \mathrm{~m}$, which yield model error smaller than 0.05 pixels too. The result is shown in Table 5. When using quadtree patch backprojection, it takes only 11 minutes for orthorectification, and both the quality and computation time is satisfactory. We spend 85 minutes for equal grid patch backprojection, and more than 10 hours for point-by-point method.

Table 5. Comparison of computation time for SPOT5

|  | Quadtree | Equal Grid | Point-by-Point |
| :--- | :--- | :--- | :--- |
| Computation time <br> (min) | 11 | 85 | $>10 \mathrm{hr}$ |
| Patch Size $(\mathrm{m} * \mathrm{~m})$ | Max:1280*1280 <br> Min:80*80 | $80 * 80$ | NULL |
| Terrain allowance <br> in a patch(m) | 500 | NULL | NULL |
| Num. of Patch | 6367 | 874056 | Number of Point : <br> 5760000 |

## 4. CONCLUSIONS

We have proposed a procedure of fast orthorectification for satellite images. Data sets including SPOT5, EROS A, QuickBird have been tested in validating the proposed method. The generated orthoimage has the similar accuracy to the one in orientation modeling. That indicates the proposed patch backprojection method does not lose accuracy. In the aspect of computation efficiency, the patch approach is superior to point-by-point in the backprojection. Comparing the two patch processing method, quadtree concept is more efficient.

## REFERNENCES

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