A Study on Ortho-rectification of SPOT6 Image
Guo-dong YANG, Xiu-wen XIN and Qiong WU*
School of Earth Exploration Science and Technology, Jilin University, Changchun, China
*Corresponding author

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Abstract. Orthorectification of SPOT6 image based on Rational Function and Rigorous Orbit Model was conducted using the rational polynomial coefficient file (PRC), ASTER and SRTM DEM data and the field control point data in Huludao, Liaoning Province. The accuracy difference of orthorectify model and DEM was analyzed. The results showed that both orthorectification models based on the ASTER data and SRTM data can meet the 1: 10000 digital orthophoto mapping accuracy, different DEM has no influence on the accuracy of Rigorous Orbit Model without control points, The rational function model with control point correction method using SRTM data correction precision is higher. The correction accuracy of SRTM data in using 3-4 control points reached 2.85m, the application of ASTER data correction accuracy up to 3.30m.

Introduction
The SPOT6 remote sensing satellite was successfully launched in September 2012, based on maintaining the original SPOT series satellite advantages, spatial resolution is improved to 1.5m, which was widely used in mapping, ecological environment, defense construction and so on[1]. Remote sensing images are subject to a certain degree of deformation due to acquisition of remote sensing image is affected by many factors, such as the attitude of the sensor, earth curvature and the topographic relief, so it is necessary to find a suitable calibration model for remote sensing image processing[2]. Orthorectification is the tilt correction and projection error correction by using DEM data and control point data, so as to eliminate the pixel displacement caused by the terrain undulation and sensor error[3].

The traditional physical model is represented by the collinearity equation, which has the characteristics of high precision but very difficult to obtain the parameter information, so has some limitations[4]. The Push broom satellite image Rigorous Orbit Model based on Collinearity equation is built between image coordinate and ground coordinate, which is widely used in space positioning without control points[5]. As a general model, the rational function model does not need the accurate imaging parameters, and it is independent of the sensor platform[6,7], which is widely used in high resolution satellite image correction[8]. The rational function model is used to solve the unknown parameter by the least square method[9], and the solution is more simplified after introducing DEM. By adjusting the image control point grid and elevation layers can improve parameter accuracy of rational function model[10]. The accuracy of the rational function model and DEM will affect the accuracy of the image correction, the method of rational function model based on object and image can greatly improve the precision of geometric positioning[11]. In this paper, Orthorectification of SPOT6 image based on Rational Function Model with control point and Rigorous Orbit Model without control point was conducted using ASTER,SRTM DEM data and the field control point data. Analyzed the influence of the control points with different number and spatial distribution on the positioning accuracy of the Rational Function Model and the accuracy different of the two kinds of DEM are applied to two methods.
Research Method

Rational Function Model

The Rational Function Model is a generalized sensor model that relates the object coordinates to image coordinates in the form of a polynomial ratio. In order to improve the accuracy and stability of the RFM model and to facilitate the calculation of RPC parameters, the image coordinates and the object coordinates are regularized to (-1, 1). The Rational Function Model is independence of photographic platform and sensor parameters, and it does not need any transformation to the object and image coordinate system that is suitable for any map projection coordinate as (Eq. 1)

\[
\begin{align*}
\begin{cases}
    r &= \frac{P_i (X,Y,Z)}{P_j (X,Y,Z)} \\
    c &= \frac{P_i (X,Y,Z)}{P_j (X,Y,Z)}
\end{cases}
\end{align*}
\] (1)

The image coordina \( (r, c) \) and the object coordinate \( (X, Y, Z) \) are the regularization coordinate, which value in \((-1, 1)\). \( P_i (i = 1,2,3,4) \) is a rational polynomial as (Eq. 2):

\[
P = \sum_{i=0}^{m_1} \sum_{j=0}^{m_2} \sum_{k=0}^{m_3} a_{ijk} X^i Y^j Z^k = a_0 + X + a_1 Y + a_2 Z + a_4 XY + a_5 X + a_6 YZ + a_7 X^2 + a_8 Y^2 + a_{10} Y Z + a_{11} X^3 + a_{12} X^2 Y + a_{13} X^2 Z + a_{14} X Y^2 + a_{15} X Y Z + a_{16} X Y^2 + a_{17} X Z^2 + a_{19} Z^3
\] (2)

where \( a_{ijk} \) is the undetermined coefficient. Coordinate regularization method is shown by (Eq. 3)

\[
\begin{align*}
X &= \frac{X_r - \text{LONG}\_\text{OFF}}{\text{LONG}\_\text{SCALE}} \\
Y &= \frac{Y_r - \text{LAT}\_\text{OFF}}{\text{LAT}\_\text{SCALE}} \\
Z &= \frac{Z_r - \text{HEIGHT}\_\text{OFF}}{\text{HEIGHT}\_\text{SCALE}}
\end{align*}
\] (3)

where \( X_r, Y_r, Z_r \) are original coordinates, \( \text{LONG}\_\text{OFF}, \text{LAT}\_\text{OFF}, \text{HEIGHT}\_\text{OFF} \) are offsets values, and \( \text{LONG}\_\text{SCALE}, \text{LAT}\_\text{SCALE}, \text{HEIGHT}\_\text{SCALE} \) are scale values. The SPOT6 image orthorectification can be supported by the 80 rational function parameters provided in the RPC.XML source file.

In ERDAS IMAGINE 2014, orthorectification of panchromatic and multispectral data was performed using the Tranform & orthocorrect tool under Panchromatic label and Multispectral label. Calculating the coordinates of each pixel in the image by using the Dim_XXX.XML file in the SPOT6 folder. The geometry model was set to the SPOT6RPC model, which was added in ERDAS IMAGINE 2014 for the SPOT6 image correction. Image coordinates projection information was WGS84 coordinate system and the UTM projection, and select the control point and correct the coordinates after loading the RPC file and DEM file of the loaded image. The resample method was set to cubic convolution, and then outputed the orthophoto. The flowchart of the correction is as (Figure 1).
Rigorous Orbit Model

The imaging equation of the Rigorous Orbit Model is established between the image coordinate system and the earth coordinate system\(^{[13]}\), The specific form is as shown by (Eq. 4).

\[
\begin{bmatrix}
    X \\
    Y \\
    Z
\end{bmatrix}_p =
\begin{bmatrix}
    X \\
    Y \\
    Z
\end{bmatrix}_s + \hat{\lambda}_p A \begin{bmatrix}
    x \\
    y \\
    - f
\end{bmatrix}.
\] (4)

where \((X,Y,Z)_p\) are the ground point coordinates, \((X,Y,Z)_s\) are the coordinate which are the sensor projection center \(S\) in the ground and \((x,y,-f)\) are the image coordinates. \(\hat{\lambda}_p\) is the value of imaging ratio denominator, \(f\) is the value of principal distance of camera and \(A\) is the rotation matrix, which is the sensor coordinate system relative to the ground coordinate system.

\[
A = \begin{bmatrix}
    a_{11} & a_{12} & a_{13} \\
    a_{21} & a_{22} & a_{23} \\
    a_{31} & a_{32} & a_{33}
\end{bmatrix} = \begin{bmatrix}
    \cos \phi & 0 & - \sin \phi \\
    0 & 1 & 0 \\
    \sin \phi & 0 & \cos \phi
\end{bmatrix} \begin{bmatrix}
    1 & 0 & 0 \\
    0 & \cos \omega & - \sin \omega \\
    0 & \sin \omega & \cos \omega
\end{bmatrix} \begin{bmatrix}
    \cos \kappa & - \sin \kappa & 0 \\
    \sin \kappa & \cos \kappa & 0 \\
    0 & 0 & 1
\end{bmatrix}. \] (5)

where \(\phi, \omega, \kappa\) are the three attitude angle elements of the camera.

No control point correction is a location method which is based on DEM data and RPC file and correction accuracy depends mainly on the above documents. The Rigorous Orbit Model is an orthorectification model supported by SPOT6 images in ENVI5.1, and no control point correction is accomplished by adding remote sensing image meta file and DEM data in RPC Orthorectification Workflow, therefore the coordinates and the projection information of the corrected image depend on the DEM data.
**Precision Evaluation**

The control points in the study area that do not participate in the orthorectification are used as the check points for checking the accuracy of the orthophoto, the RMS error of all the points is obtained by counting the coordinates of the check points and the coordinates of the corresponding points on the corrected image, the RMS error can be described as (Eq. 6).

\[
RMS = \sqrt{\frac{\sum_{i=1}^{n} (u_i - v_i)^2}{n}}.
\]  

where RMS is the root mean square error, \( n \) is the number of checkpoints, \( u_i \) is the coordinates of the checkpoint on the orthophoto, and \( v_i \) is the coordinates of control points measured by GPS.

**Study Area and Experimental Data**

This article uses the 1A SPOT 6 satellite images (Figure 2) on July 14, 2015. The study area is about 3000 km\(^2\) and includes Huludao urban area, Yangjiazhizi Town, Guojia Manchu Town and Niangniangmiao Town and other areas. The elevation of whole area is between 0-900m. The eastern area is the elevation of 0-100m of the coastal zone and plain areas, the north of the elevation of 900m for the Dahangluo Mountain and there are all steep mountains extending to the west. The surface cover includes woodland, shrubs, arable land, bare land, towns and cities and other complex features. So it has a better representation for SPOT6 image orthographical correction. The orthographical correction benchmark baseline is the WGS84 coordinate system and projection method is UTM projection. The ground control points at centimeter level are measured by the network RTK. DEM data includes ASTER data of 30m resolution and SRTM data of 90m resolution (Figure 2).

![Figure 2](image)

(a) SPOT6 image  (b)ASTER DEM  (c)SRTM DEM

**Analysis of Orthorectify Results and Accuracy**

**Rational Function Orthorectification**

At least 3 control points are needed when the rational function model is used to correct the image, therefore, Orthorectification of SPOT6 image based on Rational Function Model was conducted using 3-15 control points, the ASTER and SRTM DEM data sequentially, and then the influence of the control points with different number and spatial distribution were analyzed. The RMS error of check points is shown in Table 1.

**Rigorous Orbit Model Orthorectification**

Orthorectification of SPOT6 image based on Rigorous Orbit Model in the absence of control points, and then 10 check points which is the same as that of the control points were selected for accuracy assessment. The RMS error of check points is shown in (Table 1).
### Table 1. The statistics of Rational function model and Rigorous Orbit Model orthorectification accuracy.

<table>
<thead>
<tr>
<th>Correction model</th>
<th>GCP number</th>
<th>ICP number</th>
<th>RMSX[m]</th>
<th>RMSY[m]</th>
<th>RMSE[m]</th>
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<td></td>
<td></td>
<td>AS</td>
<td>SR</td>
<td>ASTE</td>
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<td></td>
<td></td>
<td></td>
<td>TER</td>
<td>TM</td>
<td>R</td>
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### Accuracy Analysis of Orthorectification

First of all, the orthorectification accuracy of rational function model is analyzed with the different number of control points and the different spatial distribution in the application of two kinds of DEM data. Secondly, this paper analyzes and compares the accuracy of no control points orthorectification based on the Rigorous Orbit Model on using two kinds of DEM data. Finally, contrastive analysis of the accuracy of two kinds of models by using the two kinds of DEM data.

**Correction Accuracy of Rational Function Model.** When ASTER DEM was used, with the increase of the number of control points, the accuracy of image correction increases gradually, and finally tends to be stable (Figure 3). Because the 3 control points cannot be evenly distributed in the image, the correction accuracy is the lowest, which is 3.97m. The correction accuracy is increased by 0.6m when the number of control points is increased to 4. Correction accuracy is maintained at about 2.5m when the number of control points increased to 8. Therefore, the above analysis shows that the distribution of control points has a great influence on the results, and then with the increase of the number of control points, there is no significant change in the correction accuracy when the number of control points is greater than 8 (Figure 4). On the other hand, when SRTM DEM was used. The correction accuracy of 3-4 control points is about 2.85m, and then the correction accuracy is maintained at about 2.5m and does not change with the number and distribution of the control points. When the number of control points is increased to 5 (Figure 3). The statistical results show that the correction accuracy of SRTM data is significantly higher than that of ASTER when the number of control points is less than 7, and the biggest difference of the correction accuracy is 1.12m when the 3 control points are used, the correction accuracy of the two kinds of DEM tends to be similar when the number of control points is greater than 8, which is maintained at about 2.5m.
Correction Accuracy of Rigorous Orbit Model. The application of ASTER DEM data without control points orthorectification precision is 4.21m, the application of SRTM DEM data without control points orthorectification precision is 3.98m, so the both of two DEM data based on the Rigorous Orbit Model of orthorectification accuracy have no significant difference.

Comparison of Correction Accuracy between Rational Function Model and Rigorous Orbit Model. The accuracy of ASTER DEM data Rigorous Orbit Model without control point Orthorectification compared to the Rational Function Model is reduced by 50%. The accuracy of SRTM DEM data Rigorous Orbit Model without control point Orthorectification compared to the Rational Function Model is reduced by about 1.5m. So no matter what kind of DEM is used, the accuracy of the control point correction method is obviously higher (Table 1).

Summary

In this paper, orthorectification of SPOT6 image based on Rational Function and Rigorous Orbit Model was conducted using ASTER and SRTM DEM data. The conclusions are as follows:

1) The correction precision of 3-8 control points can meet the 1:10000 digital orthophoto mapping accuracy when the ASTER data is used in the correction of SPOT6 images by the rational function model. In the case of control data scarce, using 3-4 control points which were distributed at the edge of the survey area can reach digital orthophoto mapping accuracy, when the control points are evenly distributed and the number is equal to or greater than 8, the correction accuracy can be higher.
(2) The correction precision of 3-4 control points can meet the 1:10000 digital orthophoto mapping accuracy when the SRTM data is used in the correction of SPOT6 images by the rational function model. When the control points are evenly distributed and the number is equal to or greater than 5, the correction accuracy can be higher.

(3) The correction accuracy of SRTM data is better than that of ASTER data by using 3-4 control points for orthorectification based on rational function model. Although the resolution of ASTER data is higher, the accuracy of SRTM data is higher than that of ASTER data on a global scale.

(4) The correction precision of the ASTER and the SRTM data can be used to meet the precision of the 1:10000 digital orthophoto map when the model is used in the Rigorous Orbit Model. When there is no control point data, it is possible to use the Rigorous Orbit Model.

(5) The accuracy of the two models both can meet the accuracy of 1:10000 digital orthophoto map when the ASTER and SRTM data are applied respectively, however, the correction accuracy of the control point rational function model is significantly higher than that of the without control point Rigorous Orbit Model.

References