Block Adjustment for Satellite Imagery Based on the Strip Constraint
Guo Zhang, Tao-yang Wang, Deren Li, Xinning Tang, Yong-hua Jiang, Wen-chao Huang, and Hongbo Pan

Abstract—Given that long strip satellite images have the same error distribution characteristics, we propose a block adjustment method for satellite images based on the strip constraint. First, the image point coordinates are calculated in the strip image coordinate system based on the offset value of the adjacent image. Second, the rational function model (RFM) of the strip image is regenerated using the RFM of single images, and the compensation grid is also generated. Third, block adjustment of the strip image is implemented based on the RFM with an affine transformation parameter. Finally, the affine transformation parameters of single images are recalculated using the affine transformation parameters of the strip image. Experiments using ZY-3 satellite images showed that block adjustment of satellite images based on a strip constraint (strip adjustment) can produce better results than block adjustment of satellite images based on a single image in sparse control conditions. The test results demonstrated the effectiveness and feasibility of the proposed method.

Index Terms—Accuracy, block adjustment, compensation grid, rational function models (RFMs), strip constraint, ZY-3 satellite images.

I. INTRODUCTION

The capacity of Chinese high-resolution Earth observation was enhanced by the successful launch of the high-resolution stereo mapping satellite ZY-3. The plotting and updating of large-scale topographic maps have been made possible using satellite remote sensing images [1], [2]. Block adjustment [3] is a method that uses aerial or satellite remote sensing images with a few ground control points (GCPs) to facilitate precise geodesic orientation, and it has played a pivotal role during surveying and the production of topographic maps. In general, satellite-based optical sensors use a line array pushbroom imaging mode. However, the strip image that indicates the length of the image is longer than that of the standard image. Taking ZY-3 as an example, the standard single image is 24,576 pixels in length and 24,516 pixels in width. If the image length exceeds 24,576 pixels, it is considered to be a strip image. Experiments using ZY-3 satellite images showed that block adjustment of satellite images based on a strip constraint (strip adjustment) can produce better results than block adjustment of satellite images based on a single image in sparse control conditions. The test results demonstrated the effectiveness and feasibility of the proposed method.

In practical applications, it is not appropriate to provide users with strip images directly. In general, the satellite image suppliers divide the strip into several products (single images) (see Fig. 1). Thus, a single image is more common and more popular than a strip image among users. Most previous studies of block adjustment using single images were based on a rigorous geometric model [7]–[12] and the RFM [13]–[16]. However, block adjustment has limitations with single images. For a large area with many satellite images, large numbers of orientation parameters need to be solved, which also requires vast amounts of GCPs. In many cases, block adjustment of single images cannot match the results obtained with “sparse control.” Thus, the development of a block adjustment method for single images, which considers the strip constraint as a rigorous geometric model, has become a major research focus. Michalis and Dowman proposed a generic model for along-track stereo sensors, which used rigorous orbit mechanics. This model was evaluated using SPOT5 HRS images with near-pixel-level precision. Using this method, the accuracy, precision, and stability of the solution were improved compared with single image models [17]. Weser et al. presented a rigorous sensor model for pushbroom scanners, which could use the orbit block adjustment for strip images using rigorous geometric models and rational function models (RFMs). Cheng et al. reported 8-m planimetric accuracy after processing SPOT5 HRS strip images using a rigorous geometric model and a block adjustment model based on a geocentric coordinate system [4]. Srivastava et al. at the Indian Space Research Organization developed a Stereo Strip Triangulation software system for Cartosat-1, which generated a digital elevation model at 0.3 arc-second intervals with height accuracy of 3–4 m over tracts of undulating land up to 15,000 km² based on 10–20 GCPs [5]. Pan et al. obtained subpixel-level precision after processing ZY-3 strip images using block adjustment based on the RFM [6].

Fig. 1. Formation of a strip image by a satellite.
information provided by data vendors [18]. Rottensteiner et al.
showed that the number of GCPs can be reduced by up to 90%
by using a generic pushbroom sensor model and strip adjust-
ment, with accuracy greater than 1 pixel [19]. The application
of this method to very long strips of Advanced Land Observing
Satellite Panchromatic Remote-Sensing Instrument for Stereo
Mapping images was reported by Fraser and Ravanbakhsh,
where the results indicated that single-pixel-level accuracy
could be achieved with strip lengths of $>50$ images, or 1500
km, using as few as four GCPs [20].

Thus, a rigorous geometric model and an RFM can both be
used for the block adjustment of strip images, whereas only
rigorous geometric models can be used for the block adjustment
of single images when considering the strip constraint.
The block adjustment of single images using only the RFM and
the strip constraint condition simultaneously has been rarely
reported. In fact, some suppliers such as IKONOS, GeoEye-1,
and CartoSat-1, however, only provide rational polynomial
coefficients (RPCs), and they do not provide the orbit, attitude,
and camera parameters, which means that rigorous geometric
models cannot be established. Some suppliers also provide
both ephemeris and attitude data, as well as RPCs, such as
Quickbird, WorldView 1 and 2, ALOS, SPOT 6, and Pleiades.
At present, the RFM is used instead of rigorous geometric
models, which is considered to be effective. Thus, the utiliza-
tion of the strip constraint on satellite images with RPCs is an
important research problem. In this paper, we propose a block
adjustment method for ZY-3 satellite sensor-corrected (SC)
images based on the strip constraint with RPCs only [6]. The
ZY-3 SC image product is processed to apply some sensor and
geometric corrections (such as CCD stitching). SC products
are the most basic products distributed to users of ZY-3. Many
single images in the same orbit are virtually stitched to produce
a strip image, which are treated as a single model during block
adjustment. The RFM of the strip image and the compensating
grid model are then generated. Next, block adjustment is per-
formed with RFM and affine transformation for strip images.
The orientation parameters, which are the affine transformation
parameters of the strip images, can be recalculated to obtain the
orientation parameters of each original single image. To
distinguish between block adjustment with and without the strip
constraint, we refer to the former as strip image adjustment and
to the latter as single image adjustment. Finally, our test results
using ZY-3 satellite images from different regions demonstrate
that strip image adjustment can deliver a better level of accuracy
than single image adjustment in sparse control conditions.

II. FUNDAMENTAL ASPECTS OF BLOCK ADJUSTMENT FOR
SATELLITE IMAGES BASED ON THE STRIP CONSTRAINT
A. Virtual Stitching of the Images in One Strip

The primary goal of strip image adjustment is to virtually join
images in the same strip, which means that we treat images in
the same strip as a single image. Thus, the image coordinates of
all the image points in the strip image coordinate system and the
RFM of the strip image need to be regenerated. The coordinates
of the image points in the original single images in the strip
image coordinates system can be calculated based on the offsets
of adjacent images that overlap in the same strip [see Fig. 2(a)].
The detailed method is described by

$$
\begin{align*}
  x_i &= x_i \\
  y_i &= y_i + i \times \text{length} - \sum_{i=0}^{\text{bias}_i} (i = 0, 1, 2, \ldots).
\end{align*}
$$

In (1), $i$ is the image in the orbit, length is the length of
the image, and bias is the overlap length of two images. When
$i = 0$ and bias = 0, $x_i$ and $y_i$ are the column coordinate and
the line coordinate of the image point in the strip coordinates,
respectively.

To ensure that the virtual strip images can be logically treated
as a single image after stitching and to ensure that the fitting
precision of the RFM is high, the image stitching condition in
the strip is also required. First, we assume that point H in image
A and point J in image B are the corresponding points, where
the points are manually measured. Next, the image point H in
the overlap area of image A [see Fig. 2(b)] is projected onto
the average elevation surface in the object space. The object
space points are then projected onto the image plane of image
B, which is adjacent to image A, and point I is obtained. The
absolute value of the original measured image coordinates of
point J minus the calculated image coordinates of point I should
be very small (the threshold is generally set to 1 pixel). If it
overruns, single images in the same strip should be divided into
two strips, and so on.

A terrain-independent scheme is used to calculate the RFM
of the strip image after stitching virtually [21]. First, a virtual
control grid (see Fig. 3) is generated using the original single
images from the image space to the object space, and the virtual

![Fig. 2. Mosaic with adjacent images in one strip.](image)

![Fig. 3. Schematic of the virtual control grid.](image)
B. Block Adjustment of Strip Images Based on the RFM

The RFM is a ratio of polynomials model, which is used to express the image point coordinates \((x, y)\) as the ratio of the polynomials relative to the ground point coordinates \((X, Y, Z)\).

The general form of the RFM is given in

\[
\begin{align*}
    x &= \frac{P_1(X, Y, Z)}{P_2(X, Y, Z)} \\
    y &= \frac{P_3(X, Y, Z)}{P_4(X, Y, Z)}
\end{align*}
\]

In (2), \(x, y\) are the image point coordinates, and \(X, Y, Z\) are the ground point coordinates. The power of each coordinate component \(X, Y, Z\) of each item in the polynomials \(P_i (i = 1, 2, 3, 4)\), or the sum of the power, is not more than 3. The form of each polynomial is given in

\[
P_i = a_{i0} + a_{i1}Z + a_{i2}Y + a_{i3}X + a_{i4}ZY + a_{i5}ZX + a_{i6}Y^2 + a_{i7}X^2 + a_{i8}XZ + a_{i9}YZ + a_{i10}YX + a_{i11}Z^2 + a_{i12}Z^2X + a_{i13}Z^2Y + a_{i14}Y^2X + a_{i15}ZX^2 + a_{i16}X^2Y + a_{i17}Z^3 + a_{i18}Y^3 + a_{i19}X^3.
\]

\[
(3)
\]

In (3), \(a_{ij} (i = 1, 2, 3, 4; j = 0, 1, \ldots, 19)\) are the RPCs.

The RFM used for strip image block adjustment is fitted, and it appears as known values. The systematic errors caused by factors other than the constant angular error are also still present. Previous studies have shown that compensation for systematic errors in the RFM can eliminate the systematic errors in the image points, which improves the geometry processing accuracy for images based on the RFM [23]. An affine transformation is added for bias compensation. Based on this principle, we modify the relationship between the image point coordinates \((x, y)\) and the ground point coordinates \((X, Y, Z)\) described in the RFM according to

\[
\begin{align*}
    x &= \frac{P_1(X, Y, Z)}{P_4(X, Y, Z)} + a_0 + a_1x + a_2y \\
    y &= \frac{P_5(X, Y, Z)}{P_4(X, Y, Z)} + b_0 + b_1x + b_2y.
\end{align*}
\]

\[
(4)
\]

The number of intact RPC parameters is 78. All of these parameters are not solved directly because the affine transformation parameters and object space coordinates of the ground points are treated as unknowns during block adjustment. Using (4), the error equation based on the RFM can be obtained, i.e.,

\[
\begin{align*}
    v_x &= \frac{\partial x}{\partial a_0} \Delta a_0 + \frac{\partial x}{\partial a_1} \Delta a_1 + \frac{\partial x}{\partial a_2} \Delta a_2 + \frac{\partial x}{\partial a_3} \Delta a_3 + \frac{\partial x}{\partial a_4} \Delta a_4 + \frac{\partial x}{\partial a_5} \Delta a_5 + \frac{\partial x}{\partial a_6} \Delta a_6 + \frac{\partial x}{\partial a_7} \Delta a_7 + \frac{\partial x}{\partial a_8} \Delta a_8 + \frac{\partial x}{\partial a_9} \Delta a_9 + \frac{\partial x}{\partial a_{10}} \Delta a_{10} + \frac{\partial x}{\partial a_{11}} \Delta a_{11} + \frac{\partial x}{\partial a_{12}} \Delta a_{12} + \frac{\partial x}{\partial a_{13}} \Delta a_{13} + \frac{\partial x}{\partial a_{14}} \Delta a_{14} + \frac{\partial x}{\partial a_{15}} \Delta a_{15} + \frac{\partial x}{\partial a_{16}} \Delta a_{16} + \frac{\partial x}{\partial a_{17}} \Delta a_{17} + \frac{\partial x}{\partial a_{18}} \Delta a_{18} + \frac{\partial x}{\partial a_{19}} \Delta a_{19} \\
    v_y &= \frac{\partial y}{\partial b_0} \Delta b_0 + \frac{\partial y}{\partial b_1} \Delta b_1 + \frac{\partial y}{\partial b_2} \Delta b_2 + \frac{\partial y}{\partial b_3} \Delta b_3 + \frac{\partial y}{\partial b_4} \Delta b_4 + \frac{\partial y}{\partial b_5} \Delta b_5 + \frac{\partial y}{\partial b_6} \Delta b_6 + \frac{\partial y}{\partial b_7} \Delta b_7 + \frac{\partial y}{\partial b_8} \Delta b_8 + \frac{\partial y}{\partial b_9} \Delta b_9 + \frac{\partial y}{\partial b_{10}} \Delta b_{10} + \frac{\partial y}{\partial b_{11}} \Delta b_{11} + \frac{\partial y}{\partial b_{12}} \Delta b_{12} + \frac{\partial y}{\partial b_{13}} \Delta b_{13} + \frac{\partial y}{\partial b_{14}} \Delta b_{14} + \frac{\partial y}{\partial b_{15}} \Delta b_{15} + \frac{\partial y}{\partial b_{16}} \Delta b_{16} + \frac{\partial y}{\partial b_{17}} \Delta b_{17} + \frac{\partial y}{\partial b_{18}} \Delta b_{18} + \frac{\partial y}{\partial b_{19}} \Delta b_{19}.
\end{align*}
\]

Equations (3)–(5) can be written in matrix form using

\[
V = Ax + Bx - I
\]

where \(V\) is the residual vector of the observed value of the image point coordinates, \(t = [\Delta a_0 \Delta a_1 \Delta a_2 \Delta b_0 \Delta b_1 \Delta b_2]^T\) is the incremental vector of the affine transformation parameters, \(x = [\Delta X \Delta Y \Delta Z]^T\) is the incremental vector of the space coordinates of the target object, \(A, B\) comprise a coefficient matrix, which is the partial derivative matrix of the unknowns,
Fig. 5. Correspondence between a strip image and a single image.

\[ \mathbf{l} = [x - x^0, y - y^0]^T \]

is a constant term, \((x, y)\) is the coordinate measurement of the image point, and \((x^0, y^0)\) are the image plane coordinate values of the image point, which are calculated using an unknown approximation with (2).

If multiple image points are measured in overlapping images, a normal equation can be established using (6), according to the principles of least squares adjustment, i.e.,

\[
\begin{bmatrix}
A^T A & A^T B \\
B^T A & B^T B
\end{bmatrix}
\begin{bmatrix}
t^x \\
t^y
\end{bmatrix}
= \begin{bmatrix}
A^T l^x \\
B^T l^y
\end{bmatrix}.
\]  

(7)

The object space coordinates of the GCPs are considered to be the true values. The affine transformation coefficients and the object space coordinates of the ground points can be integrally solved using the least squares adjustment method.

C. Recalculating the Compensation Parameters in the Image Space of a Single Image

The image affine transformation parameters of the strip image can be obtained using the method described in the previous section. However, because the input data used for block adjustment are single images and RPCs, the final block adjustment results should be the affine transformation parameters of the original single images.

Given that the image points of a single image and a strip image have the correspondence shown in Fig. 5, the affine transformation parameters of a single image and a strip image should have the following relation:

\[
\text{RPC}_{\text{strip image}} + \text{affine transformation}_{\text{strip image}} = \text{RPC}_{\text{single image}} + \text{affine transformation}_{\text{single image}}. 
\]  

(8)

In (8), \(\text{RPC}_{\text{strip image}}, \text{affine transformation}_{\text{strip image}},\) and \(\text{RPC}_{\text{single image}}\) are already known, whereas \(\text{affine transformation}_{\text{single image}}\) is unknown, and it needs to be solved. Determining the affine transformation parameters of single images requires the following calculation strategy. First, an image region of the strip image is determined, which corresponds to the single image. Next, the uniform grid (e.g., 30 × 30) point O in the image space of the strip image is projected onto the ground area of the average elevation surface to obtain the ground grid point G, which is projected onto the image plane of the corresponding single image to obtain the image grid point P. These points are set as the projected image grid points. However, the same distributed image grid point coordinates of the single image can be also obtained based on the relative offset value between the strip and single images. These points are set as the original image grid points. Thus, there is an affine transformation relationship for the single image between the projected image grid point coordinates and the original image grid point coordinates. Finally, the affine transformation parameters of the single image can be obtained using the least squares method.

III. TESTS AND ANALYSIS OF RESULTS

A. Test Data

In this study, ZY-3SC images were used as the test data [6], [24], [25]. The test data included satellite images and RPCs. Two test areas of ZY-3 image data were used for block adjustment.

The range of the Taihangshan test area was 113.6°–116.0° in the longitude direction and 37.1°–42.0° in the latitude direction, which is a mountainous region located in Henan Province, East China. There were two strips, where the longest strip was

<table>
<thead>
<tr>
<th>Item</th>
<th>Taihangshan test area</th>
<th>Weinan test area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nadir image resolution (m)</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Forward and backward image resolution (m)</td>
<td>3.5×3.7</td>
<td>3.5×3.7</td>
</tr>
<tr>
<td>Number of tracks</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>GCPs</td>
<td>287</td>
<td>45</td>
</tr>
<tr>
<td>TPs</td>
<td>109</td>
<td>28</td>
</tr>
<tr>
<td>Maximum elevation (m)</td>
<td>1480</td>
<td>767</td>
</tr>
</tbody>
</table>
550 km, and the elevation range was 50–1530 m. The terrain was high in the northwest and low in the southeast. Each strip contained three sets of forward-nadir-backward images, with a total of 57 images.

The range of the Weinan test area was 107.7°–109.3° in the longitude direction and 33.9°–35.3° in the latitude direction, which is a mountain and plain region located in Shanxi Province, Central China. The test area was high in the north and south, but low in the middle. The surface morphology could be divided roughly into mountains and plains, but mainly plains. There were three strip data sets for the Weinan test area, and each strip contained three sets of forward-nadir-backward images, with a total of 27 images. Further details of these two test areas are shown in Table I.

All of the GCPs represented salient ground features, such as road intersections and building corners. The GCPs in the Taihangshan test area were obtained from field surveys using GPS, where the accuracy in the object space was ±0.1 m. The homologous feature points in the Weinan test area were obtained based on the homologous points of the ZY-3 satellite images and manually produced control images. The control images were the basic national survey product, which comprised 1:10,000 digital orthophoto maps. All of the GCPs that were manually measured in the ZY-3 images had a uniform distribution, where the accuracy in the object space was ±0.1 m. The distributions of the GCPs in the test areas are shown in Fig. 6.

### B. Strip RPC Generation and Grid Compensation

One strip was selected in the Taihangshan test area (12 images in one strip), and a virtual control grid was generated, which was used to produce the RFM. Statistical analyses of the RFM fitting accuracy for the nadir, forward, and backward strip images are shown in Table II.

Table II shows that the RFM of the strip image for the ZY-3 nadir-forward-backward images in the Taihangshan test area, which was regenerated by fitting the virtual control grid, had poor fitting accuracy, with more than 1 pixel and even larger than 10 pixels in the nadir image. This RFM was unable to meet the fitting precision requirements. This is because the ZY-3 production system replans the line integration time to produce SC images, which means that the line integration time for each scanned CCD line might be different; thus, the replans unify the line integration time for each scanned CCD line of an image by taking their average. Thus, the line integration time of different images in the same strip may be inconsistent. If the images in one strip are forcibly treated as a single image, there is a loss of internal geometric accuracy. However, after using grid compensation, the RFM fitting accuracy was significantly enhanced, reaching the 0.01-pixel accuracy level. This shows that the compensated RFM of the strip image had high fitting accuracy, and it could replace the original RFM of a single image during subsequent processing.

### C. Block Adjustment With and Without Grid Compensation

The fitting accuracy of the RFM of the strip image was greatly improved by using the compensation grid, but the final accuracy of block adjustment still required further verification. Thus, block adjustments with and without grid compensation were implemented using the two test area data sets aforementioned. The accuracy value used is the root-mean-square error (RMSE) of independent check points (ICPs). The results are shown in Table III.

Table III shows that the compensation effect was generally associated with the fitting precision of the virtual control grid. For the test area in Taihangshan, grid compensation without GCPs increased the plane accuracy from 18.309 to 5.691 m and the elevation accuracy from 5.921 to 5.362 m. With GCPs,
TABLE III
COMPARISON OF THE STRIP ADJUSTMENT RESULTS FOR ZY-3 IMAGES WITH AND WITHOUT A COMPENSATION GRID

<table>
<thead>
<tr>
<th>Test area</th>
<th>Compensation grid</th>
<th>GCP</th>
<th>ICP</th>
<th>Maximum residual (m)</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td>N</td>
</tr>
<tr>
<td>Taihangshan</td>
<td>without</td>
<td>0</td>
<td>287</td>
<td>14.378</td>
<td>52.334</td>
</tr>
<tr>
<td></td>
<td>with</td>
<td>4</td>
<td>283</td>
<td>15.301</td>
<td>56.621</td>
</tr>
<tr>
<td>Weinan</td>
<td>without</td>
<td>0</td>
<td>287</td>
<td>11.813</td>
<td>11.277</td>
</tr>
</tbody>
</table>

TABLE IV
COMPARISON OF THE BLOCK ADJUSTMENT RESULTS FOR ZY-3 IMAGES BASED ON STRIP IMAGES AND SINGLE IMAGES

<table>
<thead>
<tr>
<th>Test area</th>
<th>Adjustment Type</th>
<th>GCP</th>
<th>ICP</th>
<th>Maximum residual (m)</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>281</td>
<td>10.651</td>
<td>10.620</td>
</tr>
</tbody>
</table>

the plane accuracy increased from 20.590 to 2.306 m, and the elevation accuracy increased from 3.019 to 2.521 m. There was only a minor effect on the positioning precision for the test area in Weinan with or without a compensation grid, and there was almost the same level of accuracy with no GCPs. However, the use of a small number of GCPs in the test area significantly improved the grid compensation adjustment results in the plane or the elevation direction relative to that without grid compensation adjustment. The plane accuracy increased from 4.355 to 4.061 m, and the elevation accuracy increased from 2.976 to 2.895 m.

D. Comparison of Strip Image Adjustment and Single Image Adjustment

To verify the effectiveness of the proposed method, we selected data from the two different areas for block adjustment based on strip images and single images. The test results are shown in Table IV.

Table IV compares the results obtained for the two test areas using adjustment based on strip images and adjustment based on single images. In the uncontrolled situation, the accuracy of both adjustment methods was the same in the plane or the elevation direction. In the controlled situation, however, block adjustment based on strip images clearly improved the adjustment precision, particularly in the elevation direction. For the Taihangshan test area, the plane accuracy increased from 5.416 to 3.216 m, and the elevation accuracy increased from 4.669 to 2.521 m with four GCPs in the strip image adjustment compared with the single-image-adjustment mode. The accuracy increased further when two more GCPs were added to the middle of the two stereo strip model, i.e., the plane accuracy increased from 3.216 to 3.026 m, and the elevation
accuracy increased from 2.521 to 1.758 m. This is because the side angle of the ZY-3 satellite is about 0°; whereas the ZY-3 satellite image width is 50 km, the satellite flight altitude is 550 km, and the degree of overlap between adjacent tracks is 10%. Taking the nadir image as an example, the intersection angle is less than 10° according to the statistics. Thus, the connection between the different strip models was weak. To improve the adjustment accuracy, particularly the elevation accuracy, GCPs should be added at the connection with the adjacent model, and it is recommended that a GCP is placed at both ends of the strip.

For the Weinan test area, the plane accuracy improved from 8.211 to 4.242 m, and the elevation accuracy improved from 10.175 to 8.571 m with four GCPs using strip image adjustment compared with the single-image-adjustment mode. When the number of GCPs increased in the middle strip, the plane precision slightly improved, whereas the elevation accuracy significantly increased from 8.571 to 2.895 m.

Block adjustment of strip images unifies the affine transformation model of a strip, which enhances the rigidity of the geometric model of the entire strip, thereby ensuring the internal accuracy of the strip image in a consistent manner. Therefore, only a small number of GCPs needs to be solved for this unified affine transformation model to determine the orientation of the overall strip image. Using the Weinan area as an example, the residual distributions of the ICPs were determined in different control conditions. Figs. 7–9 clearly show that the size and directions of the ICP residuals were almost the same after...
IV. CONCLUSION

We have tested ZY-3 satellite SC images from two different regions using our proposed block adjustment method for satellite images based on strip constraints, and we have compared the results obtained with those produced using a block adjustment method based on single images. The results of the test suggest the following.

1) The use of the proposed block adjustment method based on strip constraints is feasible for satellite images, and final adjustments can ensure the accuracy of this method in sparse control conditions.

2) The use of a grid compensation method can significantly improve the RFM fitting accuracy because the fitting accuracy of the rebuilt RFM of the strip image is low. The final adjustment accuracy with grid compensation was also significantly better than the accuracy without grid compensation adjustment.

3) Tests using ZY-3 images from different regions showed that our proposed block adjustment method for satellite image based on strip constraints satisfies the accuracy requirements for 1:50,000 mapping using a small number of GCPs.

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