Correcting the Data
Mapping of IKONOS Images Using

This article illustrates the steps required to correct a large block of IKONOS data. When Space Imaging (now called Geoeye) successfully launched the IKONOS satellite in 1999, it made history with the world’s first one-meter commercial remote sensing satellite. To date, IKONOS has collected more than 275 million square kilometers of imagery that is readily available in digital archive.

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Over the past few years, the RPC method of correcting high resolution images has become more popular as it requires only a small number of ground control points (GCPs), and in some cases, no GCPs at all. For small areas with a few accurate GCPs or large areas with many accurate GCPs, it is possible to achieve high geometric correction accuracy within 1 to 2 pixels. In practice this is usually not the case where the number of accurate GCPs may be very limited. The collection of GCPs could be prohibitively expensive and sometimes impossible to collect for areas inaccessible by road. The question in such cases is how to correct a large block of IKONOS data accurately when only a limited number of accurate GCPs are available. This article will explore answers to this question by examining a large block of IKONOS data using a different number and distribution of GCPs.

RPC Method and Software
The RPC method uses an empirical/statistical model developed by GeoEye, which approximates the 3D physical sensor model of IKONOS. Occasionally used during the 1980s, this method received a great deal of renewed attention with the launch of Space Imaging’s IKONOS satellite, as IKONOS’s sensor and orbit parameters are not included in the image metadata. The RPC method could be a useful one for avoiding the development of 3D...
physical models because it enables users having little familiarity with the IKONOS sensor to perform a geometric correction without GCPs; only a digital elevation model (DEM) is required. Since biases or errors still exist after computing the RPCs, the results can be post-processed with a translation and several precise GCPs; alternatively, the original RPC parameters can be refined with linear equations and precise GCPs. Several recent articles and papers addressing IKONOS data showed good results for small areas by using RPCs together with a few GCPs to apply a complementary first order polynomial adjustment to the data. More details about the RPC method can be found in the paper by Grodecki and Dial, “Block Adjustment of High-Resolution Satellite Images Described by Rational Functions”, Photogrammetric Engineering & Remote Sensing, January 2003.

Usually the initial RPCs provided with the image data do not have very high accuracy due to the limitation of the onboard system accuracy of the satellite. The accuracy improves after several refinements are applied by the satellite data vendors. This is true for IKONOS images—the accuracy of their RPC data has significantly improved recently due to refinements in the geometric calibration of the sensor. For example, the horizontal positional accuracy is 15m CE90 for the Geo-Ortho Kit product, and better than 2.0m CE90 for the PrecisionPlus product. The latest version of PCI Geomatics’ OrthoEngine software was used for this testing. This software supports reading of the data, manual or automatic GCP/tie point (TP) collection, geometric modeling of different satellites using Toutin’s rigorous model or the RPC method, automatic DEM generation and editing, orthorectification, and either manual or automatic mosaicking. OrthoEngine’s RPC method is based on the block adjustment method developed by Grodecki and Dial and was certified by Space Imaging (www.pcigeomatics.com/support_center/tech_papers/rpc_pci_cert.pdf). The method computes the polynomial adjustment math model for each image.

$$\Delta P = A_0 + A_1 \cdot \text{Sample} + A_2 \cdot \text{Line} + A_3 \cdot \text{Sample} \cdot \text{Line} + ...$$

$$\Delta R = B_0 + B_1 \cdot \text{Sample} + B_2 \cdot \text{Line} + B_3 \cdot \text{Sample} \cdot \text{Line} + ...$$
Where \( A_0, A_1, A_2, \ldots \) and \( B_0, B_1, B_2, \ldots \) are the image adjustment parameters, Line and Sample are the line and sample coordinates of an image, and \( \Delta P \) and \( \Delta R \) are the adjustable functions expressing the differences between the measured and the nominal line and sample coordinates. For IKONOS images a zero order polynomial adjustment (\( A_0 \) and \( B_0 \)) is sufficient to achieve the best results for image length within 100km. The OrthoEngine software supports zero, first and second order RPC polynomial adjustments.

The first order adjustment is useful for QUICKBIRD data and the second order adjustment is beneficial for IRS AWiFS data with RPC.

Although the RPC method only requires a small number of GCPs and TPs, high accuracy may not be achieved if the GCPs are not well distributed within the block. To improve the relative accuracy, a DEM can be used if it is available. During each bundle adjustment iteration, the computed elevation of each tie point can be replaced by the elevation at the computed TP X and Y coordinates from the DEM, similar to the results of changing the planimetric TPs into altimetric points. This method helps to improve the relative accuracies between the ortho images, which helps to minimize differences during the mosaicking process. This option is available within the OrthoEngine software.

Test Data
A total of twelve IKONOS Geo-Ortho Kit scenes of Madrid, Spain were provided by European Space Imaging. Each scene consists of panchromatic and multispectral 11-bit images resampled at 1m and 4m, respectively. The acquisition dates were between August 2004 and September 2005 with a total coverage of approximately 50km in width and 88km in length. The area has an elevation range of approximately 500m to 1400m mainly consisting of urban areas and some vegetation. 1:10000 DGN vectors and 3 arc-seconds DEM were provided by Madrid Regional Government. The authors would like to thank European Space Imaging and Madrid Regional Government for providing the data.

Pan-sharpening
The availability of a 1m panchromatic band, in conjunction with 4m multispectral bands, provides the opportunity to create a 1m multispectral pan-sharpened image by fusing these images. The concept of fusion for multispectral images is not new. Landsat MSS data (bands 4, 6 and 7) have been spatially enhanced (from 240m to 80m resolution) by using weighted high-frequency information from band 5 at 80m resolution. Previous techniques used different weighting coefficients for the panchromatic band and multispectral bands. The RGB-IHS transformation is another common approach, where the high-resolution panchromatic band replaces the intensity channel derived from the lower resolution multispectral channels. Although these alternate techniques yield enhanced imagery that appear to be sharper, they destroy the spectral characteristics of the data.

Since most earth resource satellites, such as SPOT, IRS, Landsat 7, IKONOS, and QuickBird, provide both multispectral images at a lower spatial reso
olution and panchromatic images at a high spatial resolution, it is possible to perform pan-sharpening for both of these images. However, most of the existing techniques, which perform suitably well with medium-resolution images, can hardly satisfy the pan-sharpening of multispectral and panchromatic high resolution images.

Based on the thorough study and analysis of existing pan-sharpening algorithms and their fusion effects, a new automatic pan-sharpening algorithm has been developed by Dr. Yun Zhang at the University of New Brunswick in Fredericton, New Brunswick, Canada. This new technique solved the two major problems in pan-sharpening – color distortion and operator dependency. A method based on least squares was employed for a best approximation of the grey level value relationship between the original multispectral, panchromatic, and the pan-sharpened image bands for a best color representation. A statistical approach was applied to the pan-sharpening process for standardizing and automating the pan-sharpening process. The new algorithm is available within the PCI Geomatics software.

Usually the panchromatic and multispectral images have to be processed separately to ensure both data are aligned with each other before pan-sharpening. These steps include reading of data, collection of ground controls (GCPs), and orthorectification with a DEM. Since the GCPs are collected separately and the images are orthorectified separately, it may cause a slight misalignment between the orthorectified panchromatic and multispectral images due to the GCP location and distribution. One advantage of the IKONOS Geo-Ortho Kit product is that the panchromatic and multispectral images are resampled exactly on top of each other. In general, it is possible to perform pan-sharpening of the data first for gentle terrain before further processing. Thus, the user would only need to perform GCP collection and orthorectification once to the pan-sharpened image. To test this method, pan-sharpening was first applied to the Geo-Ortho Kit data. Figure 1a shows the urban area example of the multispectral data at 4m resolution, Figure 1b shows the corresponding panchromatic image at 1m resolution, and Figure 1c shows the pan-sharpened image. Figures 2a, 2b and 2c show similar examples for a semi-urban area. Both pan-sharpened results did not show any problems and verified that it is possible to pan-sharpen the Geo-Ortho Kit data first.

Test Results
A total of 79 GCPs and 40 tie points were collected using the 1:10000 vectors provided. According to the United States National Map Accuracy Standards, the accuracy of 1:10000 vector is approximately 8.5m CE90 (approximately 4m RMS). Ideally, the accuracy of GCPs should be within sub-meter accuracy. The elevations for the GCPs were extracted from the DEM provided. Additionally, as previously mentioned, the DEM was also used by the tie points to change the points from planimetric to altimetric points during the bundle adjustment to improve accuracy.

Several cases were used to test the accuracy and distribution of GCPs. First all GCPs were changed to independent check points (ICPs). Then the following cases were tested by changing some of the ICPs into GCPs: (1) no GCPs, (2) one GCP per image, (3) two GCPs per image, (4) three GCPs per image, (5) one GCP per corner image of the block, (6) two GCPs per corner image of the block, (7) one GCP per bottom corner image of the block, and (8) two GCPs per bottom corner image of the block. Table 1 shows a summary of the results.

The table illustrates how the accuracy is affected by the number and distribution of GCPs. In general, it is better to collect at least one or two GCPs per image. Collecting more GCPs per image did not improve the result significantly. An alternative is to collect at least one GCP per corner image of the block when the number of GCPs is limited. Both cases would produce results within 4m RMS, i.e. within the accuracy of the GCPs. Collecting GCPs on just one side of the block is not recommended for high accuracy.
Orthorectification
A geometric correction process called orthorectification was performed for each image. A DEM is required for orthorectification. Generating each orthorectified pan-sharpened 4-band image with a file size of approximately 5 gigabytes took approximately 25 minutes on a Pentium IV 3.0 GHz machine running Windows XP. Figure 3 shows an example of the orthorectified image overlaid with the vectors in green.

Automatic mosaicking
After generating the orthorectified images, it is necessary to mosaic the images together with color balance. This is usually a very time-consuming process, especially if it is being done manually. The user has to find the best cutlines between images with the minimum differences. If the images were not acquired near the same period, a good color balancing method is required. An automated mosaicking and color balance process can be used to save operating costs.

Table 1: Comparison of RMS results in meter for different number of GCPs and ICPs.

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of ICPs</th>
<th>ICP RMS Errors</th>
<th>Max. ICP Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>No ICPs</td>
<td>79</td>
<td>6.7</td>
<td>7.6</td>
</tr>
<tr>
<td>1 GCP per image</td>
<td>67</td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>2 GCPs per image</td>
<td>55</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>3 GCPs per image</td>
<td>43</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>1 GCP at each corner</td>
<td>75</td>
<td>2.2</td>
<td>4.1</td>
</tr>
<tr>
<td>2 GCPs at each corner</td>
<td>71</td>
<td>2.1</td>
<td>4.6</td>
</tr>
<tr>
<td>3 GCPs per corner</td>
<td>77</td>
<td>3.6</td>
<td>9.2</td>
</tr>
<tr>
<td>1 GCP per corner</td>
<td>75</td>
<td>3.3</td>
<td>5.9</td>
</tr>
</tbody>
</table>

For The Best Results...
It is possible to pan-sharpen the panchromatic and multispectral Geo-Ortho Kit data first for gentle terrain before further processing. The RPC method can be used as the geometric model to correct the IKONOS data. For best results it is preferable to collect at least one GCP per image. If only limited numbers of GCPs are available, at least one GCP per corner image of the block should be collected. Tie points with elevation should be used to improve the accuracy of the bundle adjustment. Automatic mosaicking and a color balance process can be used to save operating costs.

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