

QuickBird – Geometric Correction, Path and Block Processing and Data Fusion

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Since the successful launch of DigitalGlobe's[®] QuickBird satellite and the availability of the data, QuickBird Imagery has quickly become the best choice for large scale mapping using high-resolution satellite images. First, the satellite has panchromatic and multispectral sensors with resolutions of 61-72cm (2-2.4ft) and 2.44-2.88m (8-9.4ft) respectively, depending upon the off-nadir viewing angle (0-25°). The sensor therefore has a coverage of 16.5-19km in the across-track direction. In addition, the along-track and across-track capabilities provide a good stereo-geometry and a high revisit frequency of 1-3.5 days. Finally, the data is available in different formats, including the raw data format (Basic Imagery), which preserves the satellite geometry and is preferred by the photogrammetry and mapping community to achieve high accuracy geometric correction and geospatial products.

The QuickBird satellite's high-resolution, high-revisit frequency, large area coverage, and the ability to collect images over any area, including areas where airplanes are not permitted to fly, are certainly the major advantages over the use of airborne sensors as well as other satellite high-resolution (HR) and synthetic aperture radar (SAR) sensors. Moreover, QuickBird's ability to collect panchromatic and multispectral imagery in large ground swaths provides customers with significant financial advantages over traditional aerial photography collection method that may require numerous flight lines and extensive and expensive ground control collection.

QuickBird Products

QuickBird data is distributed in three different product levels: Basic Imagery, Standard Imagery and Orthorectified Imagery. Each product is supplied with rational polynomial coefficients (RPCs) to allow the user to correct the imagery without ground control points (GCPs). Basic Imagery products are designed for users who have access to advanced image-processing capabilities. This is the least-processed image product offered, with corrections only for radiometric distortions, adjustments for internal sensor geometry, and some optical and sensor corrections. The base price for the black and white (B/W) Basic Imagery is US\$6120 per scene worldwide.

Standard Imagery products are designed for users acquainted with remote sensing applications and image-processing tools and require data of modest absolute geometric accuracy and/or large area coverage. Each Standard Image is radiometrically calibrated, being corrected for the systematic sensor and platform-induced distortions and the topography distortions using the GTOPO30 digital elevation model (DEM), as well as resampled into a cartographic projection. The Standard Imagery product has a positioning accuracy of 23m (Circular Error with 90% level of confidence, CE90), excluding off-nadir viewing angle and terrain distortions. DigitalGlobe recently released a new Ortho Ready Standard product that is similar to the Standard Imagery Product,

except it does not include the topography correction. The QuickBird Ortho Ready Standard product is actually very similar to the IKONOS ortho kit product. The Ortho Ready Standard product has a CE90 positioning accuracy of 23m or higher, depending upon the area's relief and viewing angle. The main purpose of this product is to allow the user to post-process the data using their own DEM and the RPCs supplied with the data. The biggest advantage of Standard Imagery products over the Basic Imagery product is mainly financial because the users can purchase sub-scenes instead full scenes. The base price for the B/W Standard Imagery is US\$22.50 per square km, with a minimum order size of 25 square km from archive and 64 square km from new collection.

Orthorectified Imagery products are designed for users who require GIS-ready imagery products or a high degree of absolute positioning accuracy for analytical and geospatial applications. Each Orthorectified Image is radiometrically calibrated. They are then corrected for systematic sensor and platform-induced distortions, topography distortions, and mapped to a user-specified cartographic projection. The user has the choice of providing their own DEM and GCPs or DigitalGlobe can supply them if available. The Orthorectified Imagery product has a CE90 positioning accuracy of only a few meters, depending of GCPs and DEM. The price for this imagery product ranges from US\$40 to US\$90 per square km, depending upon the accuracy requirement.

Although the Orthorectified Imagery product seems to be the easiest choice for the user, it is also being 2-4 times more expensive than Basic Imagery and therefore may not be affordable for all users. In addition, it is subject to the availability of GCPs and DEMs. A viable alternative method for the user is to correct the data by themselves. Since the Standard product has the terrain correction applied using GTOPO30 DEM, performing another correction to achieve a highest accuracy is no longer possible. The Basic Imagery product and the Ortho Ready Standard product therefore become the two choices for the user. One of the main purposes of this article is to introduce and compare geometric correction methods used for correcting Basic Imagery and Ortho Ready Standard products.

Geometric Correction of QuickBird Data

Three 3D geometric correction methods can be used to correct the data: (1) 3D RPCs computed by the user, (2) 3D RPCs supplied with the data, and (3) 3D rigorous physical method.

The first method computes the unknowns of RPCs using GCPs acquired by the user. The results of this method, published in a previous article (*Toutin and Cheng*, EOM April, 2002), showed that this method is not recommended due to instability. In an operational environment, the solution is highly dependent on the number, accuracy, and distribution of GCPs, and also on the actual terrain relief. More details can be found in the above mentioned article (<http://www.eomonline.com/Common/currentissues/Apr02/cheng.htm>).

The second method uses an empirical/statistical model developed by DigitalGlobe, which approximates the 3D physical sensor model of QuickBird. While occasionally used during the 1980's, this method has recently received a great deal of renewed attention because of the IKONOS satellite. Since its sensor and orbit parameters are not included in the image meta-data. 3D RPCs could be an alternative method used to avoid the development of 3D physical models because it enables a user, having little familiarity with the QuickBird sensor, to perform a geometric correction without GCPs, but with a DEM. Although this method does not have a very high degree of accuracy in high relief areas, RPCs could be useful when no GCPs are available. Since biases or errors still exist after applying the RPCs, the results need to be post-processed with a translation and several precise GCPs, or the original RPC parameters can be refined with linear equations with more precise GCPs. Several articles and papers recently published using IKONOS, with data acquired over *flat areas*, showed good academic results by using RPCs together with a few GCPs to apply a complementary first order polynomial adjustment to the data.

Since the 1960's, the third method has been the traditional approach, which mathematically models all physical components of the viewing geometry (satellite, sensor, and terrain environment). Such a "viewing-geometry" model is often called a "rigorous", "physical", or "deterministic" model. The major advantages of physical modeling over empirical modeling is mainly due to the fact that the mathematical functions correspond to the physical reality of the viewing geometry and take into account all the distortions generated in the image formation. Empirical model parameters, on the other hand, do not have any physical meaning. In fact, the mathematical parameterization of physical and deterministic models has always been a major issue in scientific research and achievements, and has always been considered as the "best" method. In operational environments, this method also has the advantages of a high modeling accuracy (approximately one pixel or better), a great robustness, and to achieve consistent results over the full image with the use of only a few GCPs.

Four methods can be used to correct the QuickBird data: (1) Correct the Basic Imagery products using the RPCs supplied with the data, (2) Correct the Basic Imagery products using a 3D rigorous method, (3) Correct the Ortho Ready Standard products using the RPCs supplied with the data, and (4) Correct the Ortho Ready Standard products using a 3D rigorous method. Results of the first method published in a previous article (*Toutin and Cheng*, EOM April, 2002) showed that the first method can produce large errors and is not recommended. Most people will ask the following question: What are the differences in using the remaining three methods. If the differences are negligible, it may be more advantageous to use the Ortho Ready Standard product because the user can order smaller scenes which are cheaper instead of full scenes. The following section will try to answer this question.

Geometric Correction of the QuickBird data

In this section we compare the following correction results: Basic Product corrected using a rigorous model, Ortho Ready Standard Product corrected using a rigorous model, and Ortho Ready Standard Product corrected using the RPCs with GCPs for post-processing. Both Basic Imagery and Ortho Ready Standard products of an area in Castle Rock, Colorado, U.S.A., were provided by DigitalGlobe. The image contains approximately 70% mountainous area and 30% residential area. A total of 15 GCPs with elevation ranges from 1800m to 2050m were derived from aerial photo triangulation, with cartographic and image pointing accuracy within one meter.

To process the Basic Imagery product using a rigorous model, the PCI Geomatica OrthoEngine software, developed by PCI Geomatics, was used. The satellite rigorous model (Toutin's model) was developed by one of the authors at the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada. This is the first commercial rigorous model that supports the QuickBird data (<http://spatialnews.geocomm.com/dailynews/2002/oct/01/news4.html>). This 3D rigorous model, based on principles relating to orbitography, photogrammetry, geodesy, and cartography, integrates and correlates all geometric distortions of the complete viewing geometry with respect to platform, sensor, Earth, and cartographic projection that occur during the imaging process. This model has been successfully applied with few GCPs (from three to six) to visible infrared (VIR) data (ASTER, Landsat, SPOT 1-5, IRS, MOS, KOMPSAT, IKONOS, and QuickBird), and also to SAR data (ERS, JERS, SIR-C, and RADARSAT). Based upon well-defined and good quality GCPs, the accuracy of this model was proven to be within one-third of a pixel for medium resolution VIR images, one pixel or better for HR images, and within one resolution cell for SAR images.

Toutin's rigorous model requires a theoretical minimum of six well-defined and accurate GCPs for the Basic imagery. Hence, six of the GCPs provided were then used as GCPs and the remaining nine GCPs were used as independent check points (ICPs). To correct the Ortho Ready Standard Imagery using Toutin's model, eight GCPs were required in order to achieve accurate results. This is mainly due to the Ortho Ready Standard Products, which have been resampled to a map projection, destroyed the satellite geometry related to the satellite and sensor. Two more GCPs are required in order to obtain an accurate model.

The RPC method has no minimum number of GCPs. All GCPs were used as ICPs initially. Then, the same six GCPs used in the rigorous model for the Basic Imagery were systematically changed to GCPs one after the other in the RPC method.

Table 1 shows a summary of the results with the root mean square (RMS) and maximum errors of models computation over ICPs. It can be seen from Table 1 that the results from the rigorous model when applied to the Basic Product and the Ortho Ready Standard Product are very similar, except two more GCPs are required when using the Ortho Ready Standard Product. For the RPC method the errors are consistent regardless

of the number of GCPs used. However, these RMS/maximum errors are about 2.5 to 3 times higher than the RMS/maximum errors from the rigorous model.

It should be noted that the study area has only an elevation difference of 250m. The error value may go higher for the RPC method, which is only an empirical/statistical model, for areas with rugged terrain because the complementary first order polynomial adjustment to the data may not be adequate enough to compensate for the errors. More tests are required using the RPC method for areas with different terrain. The Toutin's rigorous model, which has been tested using different satellite sensors and terrain, should still achieve high accuracy in all cases.

The finding of this comparison clearly indicates that the rigorous model should be employed as a primary choice. The RPCs model is still a viable alternative when the accuracy requirement is not a high priority or when the number of GCPs is very limited.

Table 1: Comparison of results using rigorous model with the Basic and the Ortho Ready Standard Product, and RPCs with the Ortho Ready Standard Product. All units are in meters.

| Model | No. of GCPs | No. of ICPs | ICP RMS Errors | | Maximum Error | |
|-------------------------------|-------------|-------------|----------------|-----|---------------|-----|
| | | | X | Y | X | Y |
| Rigorous (Basic) | 6 | 9 | 0.5 | 0.8 | 1.1 | 1.1 |
| Rigorous (Ortho Ready) | 8 | 7 | 0.9 | 0.8 | 1.2 | 1.0 |
| RPCs (Ortho Ready) | 6 | 9 | 1.6 | 1.7 | 2.6 | 2.6 |
| | 5 | 10 | 1.7 | 1.6 | 2.9 | 2.6 |
| | 4 | 11 | 1.6 | 1.5 | 3.0 | 2.6 |
| | 3 | 12 | 1.5 | 1.4 | 2.9 | 3.0 |
| | 2 | 13 | 1.5 | 1.5 | 2.2 | 3.5 |
| | 1 | 14 | 2.2 | 1.6 | 3.3 | 2.4 |
| | 0 | 15 | 11.7 | 4.3 | 13.8 | 5.8 |

Path and Block Processing of QuickBird Data

To map large areas it may be necessary to use a large amount of QuickBird data. For each set of data this involves reading the data, collection of GCPs, satellite modeling, and orthorectification. The final orthorectified images are then mosaicked together using a manual or automatic mosaicking tool. Consequently, it is necessary in operational environments to reduce the time and cost in generating the final products. One solution is to use the path-processing process by stitching consecutive QuickBird data acquired

along the same satellite path. The first advantage to using this process is the reduction in the number of GCPs, proportional to the number of stitched images in the path. The same number of GCPs is theoretically required for a stitched-image path as for a single image, saving the time and cost of field campaign with GPS survey. The second advantage is that the ortho-rectification of the path can be directly generated in one step instead of separately ortho-rectifying each individual scene. The resulting orthorectified path is thus continuous without geometric or radiometric discontinuity and the mosaicking process is eliminated. It should be noted that this method could only be applied to the Basic Imagery data, which preserve the original image geometry. The other QuickBird products have been resampled to a map projection image path; hence, stitching and processing are no longer possible. Finally, adjacent image paths, generally in the East-West direction, can be used to generate an image/path block. The advantage of block processing is, again, a reduction in GCP collection and surveys, and hence in cost and time. However, block processing with less GCPs can be only performed if the viewing angles between adjacent image paths are greater than 25-30°. This generates acceptable intersection geometry in the overlaps. If not, each path requires that the minimum number of GCPs to be used. However, larger intersection angles, such as 40-50°, are strongly recommended to insure robustness and better results in operational environments.

To test the path and block processing, four QuickBird Basic images, acquired along two paths over Phoenix, Arizona, U.S.A, were provided by DigitalGlobe (Figure 1). There is approximately 15% overlap between consecutive images for each path and 20% overlap between adjacent paths. Seven DGPS GCPs with accuracy within one meter in both horizontal and vertical directions were also provided for each image, with five GCPs are common to both paths. To generate the stitched-image paths automatically, software code was written within OrthoEngine software to find the overlap line using a line correlation technique and to stitch the consecutive images into a stitched-image path. Afterwards, Toutin's rigorous model can be applied to correct the stitched-image path for the two-path block, in the same way that it is used for a single image. A total of 8 GCPs and 12 elevation tie points (ETPs) were used in the image block computation and 16 ICPs were available for accuracy assessment. Figure 1 shows the mosaicked results of the two 2-image paths using automatic mosaicking and color balance tools within PCI OrthoEngine software. It also shows the location of points (red for GCP/ICP and blue for ETP) and the image/path overlaps. Table 2 provides details results related to the two-image paths and block as well as the RMS and maximum errors of ICPs using Toutin's block bundle adjustment model.

Fig 1: QuickBird panchromatic paths and block formed with four Basic Imagery products acquired over Phoenix, U.S.A.

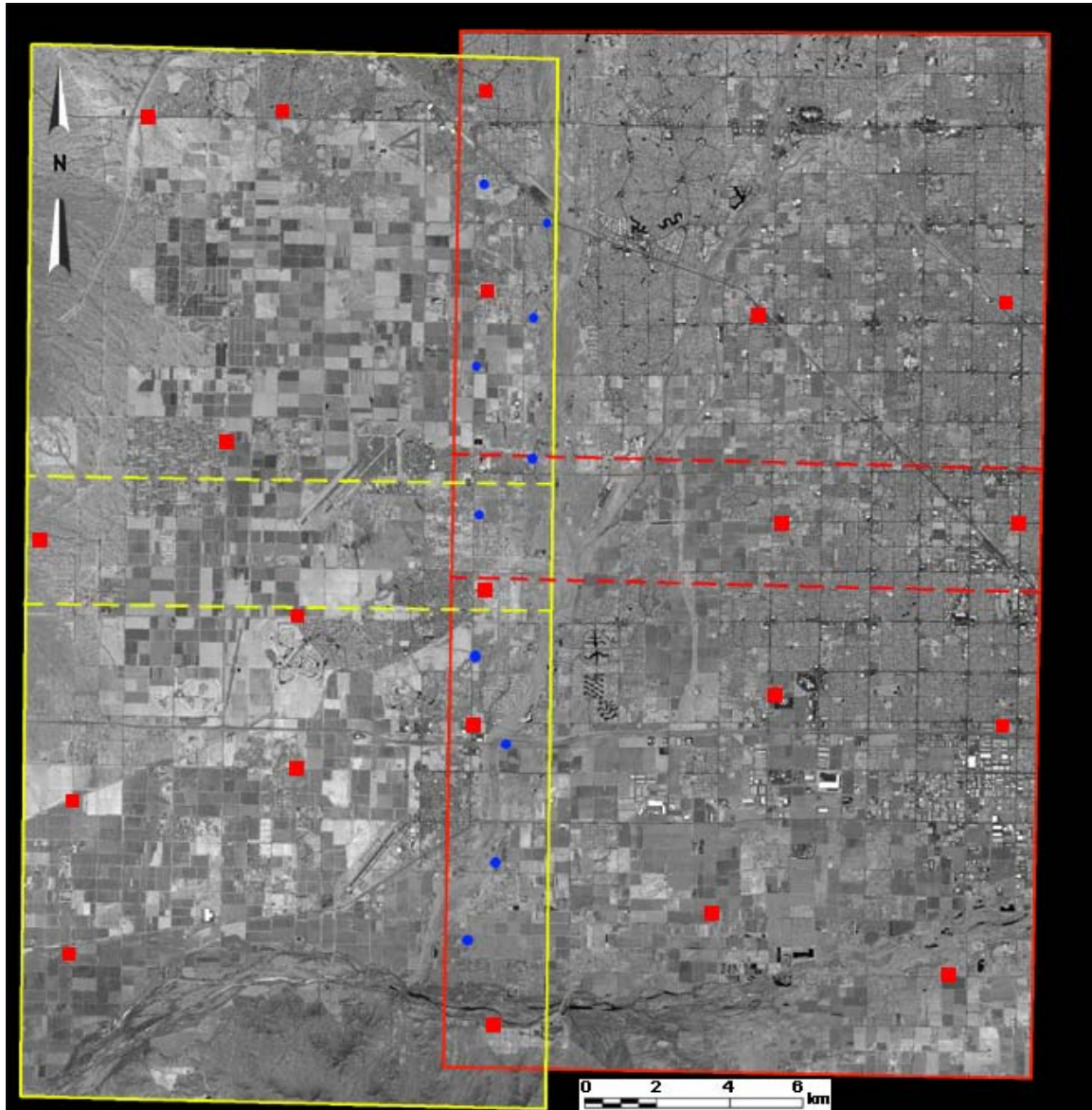


Table 2: RMS/maximum error results of bundle adjustments of path/block generated with Basic Product using Toutin's rigorous model. Error units are in meters.

| Path/Block | Size (km x km) | Viewing angle | No. of GCPs | No. of ICPs | ICP RMS Errors | | Maximum Errors | |
|------------|-------------------|------------------|----------------|----------------|-------------------|-----|-------------------|-----|
| | | | | | X | Y | X | Y |
| Left Path | 16 x 33 | 4° | 7 | 7 | 0.9 | 1.2 | 1.6 | 1.6 |
| Right Path | 16 x 31 | -21° | 7 | 6 | 0.5 | 1.2 | 1.1 | 2.4 |
| Block | 32 x 34 | | 8 | 16 | 1.4 | 2.3 | 3.3 | 4.6 |

Data Fusion of QuickBird Data

The availability of a 61cm panchromatic band, in conjunction with 2.44m IR bands, affords the opportunity to create an effective 61cm IR 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) has been spatially enhanced (from 240m to 80m resolution) by using weighted high-frequency information from band 5 at 80m resolution. Other previous techniques used different weighting coefficients for the panchromatic band and IR bands. Another common approach is the RGB-HIS transformation, where the high-resolution panchromatic band replaces the intensity channel derived from the lower resolution multispectral channels. Although all of these techniques yield enhanced imagery that appears to be sharper, these techniques destroy the spectral characteristics of the data

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

Based on a thorough study and analysis of existing fusion algorithms and their fusion effects, a new automatic fusion approach has been developed by Dr. Yun Zhang at the University of New Brunswick, New Brunswick, Canada. This new technique solved the two major problems in image fusion – colour distortion and operator dependency. A method based on least squares was employed for a best approximation of the grey value relationship between the original multispectral, panchromatic, and the fused image bands for a best colour representation. Statistical approaches were applied to the fusion for standardizing and automating the fusion process.

The new fusion approach has been extensively applied to the fusion of different HR IKONOS and QuickBird multispectral and panchromatic image bands as well as to Landsat 7 data. All the multispectral bands of a satellite can be fused with the corresponding panchromatic band at one time, resulting in optimal fusion results with minimized colour distortion, maximized feature detail, and natural integration of color and spatial features from multispectral and panchromatic bands. The algorithm is now available within the PCI Geomatics software. The fusion can be performed with an easy-to-use single step process.

To demonstrate the fusion technique, small sub-scenes were extracted from the QuickBird images. Figures 2a, 2b, and 2c show the original panchromatic, multispectral, and the pan-sharpened fused images of a residential area, respectively. It can be seen from the fused image that all features, including roofs and driveways, from the original panchromatic image were extracted together with the color from the multispectral image. Similarly, Figures 3a, 3b, and 3c show the original panchromatic, multispectral, and the pan-sharpened fused images of a business area, respectively. Again, features such as parking lines and roof vents were extracted together with the color from the multispectral image.

Figure 2a: QuickBird Panchromatic Image of a residential area



Figure 2b: QuickBird Multispectral Image of a residential area



Figure 2c: QuickBird Pan-Sharpened Image of a residential area



Figure 3a: QuickBird Panchromatic Image of a business area



Figure 3b: QuickBird Multispectral Image of a business area



Figure 3c: QuickBird Pan-Sharpened Image of a business area



Conclusions

The QuickBird product is the best choice for high-resolution mapping using satellite data. To achieve high geometric accuracy, the QuickBird Basic Imagery or the Ortho Ready Standard product, together with the Toutin's rigorous model can be used effectively. If high accuracy is not a major priority, or if the number of GCPs is limited, the Ortho Ready Standard product together with the RPCs can be a useful alternative choice.

To map large areas, stitched-image paths and adjacent-path block generated with QuickBird Basic Imagery products can be processed with Toutin's rigorous model in order to produce a highly accurate orthorectified mosaic with respect to geometry and radiometry. This processing also helps to drastically reduce field surveying for GCP collection and processing, and consequently reduces the cost and time for generating the final products.

If both panchromatic and multispectral images are available, the fusion of panchromatic and multispectral images can be performed using a new fusion technique developed by Dr. Zhang at the University of New Brunswick, Canada. The resulting fused image displays sharp features from the panchromatic image while preserving the color from the multispectral image.

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