# GEOMETRICAL PROCESSING OF QUICKBIRD HIGH RESOLUTION SATELLITE DATA

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**ABSTRACT:**

The full commercial availability of very high resolution satellite data has disclosed a large number of new opportunities for the operative use of the Earth Observation data. It is now possible to carry out, with EO data, many applications that in the recent past were exclusive to airborne and on site surveys. One key requirement for almost all the applications is the geometric accuracy of the products that can be obtained from the processing of the base QuickBird products (Basic, Standard, Standard Ortho Ready) that are available from DigitalGlobe. The geometrical processing of QuickBird data can be carried out with several approaches, and starting from each of the three QuickBird base products. The results that can be obtained in terms of accuracy are strongly dependent on the starting product, on the morphology of the area and on the quality of the ancillary information (GCPs and Digital Elevation Model) that are involved in the processing. In the following paper, the results of orthorectification tests carried out by applying the RPCs approach on different area, with different data sets and starting from different base products, are described, in order to evaluate the expected geometrical accuracy of the final product in different operative conditions, by using a simple processing approach that can be adopted by almost all data end-user.

## 1. INTRODUCTION

### 1.1 High resolution satellites

The availability of high resolution satellite data, enables the generation of cartography products to be used as a valid alternative to orthophoto derived from the traditional processing of aerial photos. QuickBird, Ikonos and Eros, and in the next months Orbview satellite data are available on the market, and can potentially cover almost every location on the earth with a resolution, in panchromatic mode, ranging from 1.8 up to 0.61 meters, and in multispectral mode between 2.44 and 4 meters. This geometric resolution, coupled with a proper geometric processing, enables the generation of products that can be compared with traditional cartography products, even in scale 1:10.000. Main new application fields can be identified for satellite data are for example in:

- Topographic and urban maps updating (analysis and monitoring up to scale 1:1.000; updating up to 1:5.000 scale)
- Utilities planning (feasibility, project and monitoring of service corridors for electric lines, telecom, oil & gas pipelines, transportation, etc.
- Building services (real estate and tourism facilities)
- Urban parks and interesting local biotopos monitoring
- Agricultural and cadastral parcel updating
- Illegal building detection
- Road network monitoring
- Environmental risk management assessment and monitoring
- Woodland assessment and management
- Archaeology
- Media

### 1.2 Geometrical processing

A key issue for mapping information from space is the geometrical processing of satellite data, that is mandatory when a full exploitation of satellite data capabilities is required. The position of the two main data providers, SpaceImaging and DigitalGlobe, regarding the possibility of enabling the users to perform a full geometrical processing of their data, is different. SpaceImaging, that is the operator that handles the Ikonos satellite, does not enable a fully geometrical processing of the satellite data, and the most used way to perform it relies on the use of the "Ortho Kit" based on RPCs (Rational Polynomial Coefficients) method for the orthorectification of the data. The use of a rigorous model is not possible for the generic client, since it is used by SpaceImaging for the generation of its value-added products. The policy of DigitalGlobe, owner of the QuickBird satellite, is different. The camera model has been released to the main image software companies, that are embedding a module for the orthorectification of the QuickBird images within their software suites. Since all the products are delivered with the RPCs file, it is in any case possible to process the data with this technique, but when starting from Basic QuickBird data, it is also possible to work with a rigorous sensor model, since also ancillary orbital information are delivered with the image. The present work focuses on a first evaluation of images generated by the orthorectification of single QuickBird panchromatic images, using ground control points (GCPs) and Digital Terrain Models (DTM) with different accuracies, and with a processing technique based on the application of the Rational Polynomial Functions .

## 2. QUICKBIRD PRODUCTS

The same QuickBird scene can be purchased in four different formats:

- Basic Product
- Standard Product
- Standard Ortho Ready Product
- Ortho Product

The first three products can be submitted to a geometrical processing by the user, while the last one has been already orthorectified by DigitalGlobe.

### 2.1 Basic Product

The *Basic Product* is the least processed of the QuickBird imagery products, and has been designed for customers having advanced image processing capabilities. It can be purchased only on a whole frame basis. This product has radiometric and sensor corrections (internal detector geometry, optical distortion, scan distortion, scan rate variations) applied, but has not been geometrically corrected and mapped to a cartographic projection. Basic Imagery is delivered together with the so-called ISD (Image Support Data) files containing:

- *general image metadata*: information related to acquisition and processing, image quality, cloud cover, corner coordinates, collection angle, pixel size, etc.
- *attitude parameters*: sampled mean and covariance estimates of the attitude of the spacecraft, often computed each 0.020 seconds, starting at least four second before image collection, and ending at least four seconds after image collection.
- *ephemeris parameters*: sampled mean and covariance estimates of the position of the spacecraft, often computed each 0.020 seconds, starting at least four second before image collection, and ending at least four seconds after image collection
- *camera model information*: standard photogrammetric parameters of a virtual camera modelling the imaging and optical system. This camera models the system as a moving camera with a single continuous linear detector array on the focal plane for each spectral band.

By using these files, it is possible to orthorectify the imagery by applying a rigorous sensor model. It is also possible, anyway, with a simpler approach, to process a QuickBird Basic imagery starting only from the RPCs.

### 2.2 Standard Product

The *Standard Product* is an imagery that has the same radiometric and sensor corrections applied to the Basic Product, but has also been geometrically processed and mapped to a cartographic projection. Geometrical processing is fully based on spacecraft detected parameters, and uses a coarse DEM for taking into account topographic relief. The declared geolocation accuracy of this product is 23-meters CE90%, excluding any topographic displacement and off-nadir angle. A Standard QuickBird imagery can be processed again with the RPC, but very accurate geometric positioning cannot be targeted, since image has been distorted in a irreversible way by using the coarse DEM; therefore, this type of product is not suitable for precision orthorectification purposes. Standard Product is for users that are not much interested in an high positional accuracy, that don't want to deal with geometrical processing, but need plug & play data for their applications.

### 2.3 Standard Ortho Ready Product

The *Standard Ortho Ready Product* can be considered as an intermediate product between Basic and Standard. The original data has been submitted to the same type of corrections applied to the Standard product, but the geometrical processing has been carried out with no topographic corrections, that is no DEM has been used in the process. In this case, geometrical processing with RPCs and a detailed DEM is possible in order to achieve good accuracies. The Standard Ortho Ready Product is available on a full frame basis or for part of it.

## 3. THE ORTHORECTIFICATION THROUGH THE RPCs APPROACH

The most correct way of processing data for a digital rectification is the orthophotoprojection, the needs the reconstruction of sensor collection geometry for each line of the imagery. The classic photogrammetric approach is based on the extraction of the DTM from a stereo pair processing, followed by the orthorectification of one of the two images; it is also possible to use a pre-existing DTM, with a quality compliant with the scale of the final product, and to introduce some GCPs. This last processing chain is the one normally followed for the processing of satellite data, since not all the satellite sensors have stereo pairs collection capabilities, and in most of the cases the processing of single frames is required. The most used methods for the rectification are based on sensor-related information, by using a sensor model that can be of two types: physiscal or generic. The main difference is that the physical models are rigorous, and require the knowledge of the specific sensor for which they have been designed; each parameter involved has a physical meaning. The generic sensor models, on the other side, are sensor-independent, that is the knowledge of the sensor and of the physical meaning of the image collection process are not required.

A rigorous model enables an accurate three-dimensional description and orthorectification of the imagery. A generic sensor model supplies the relationship existing between the three-dimensional coordinates of an object, and the corresponding image coordinates in a generic mathematical form. The Rational Function Model can be considered one of the generalised models used by more then ten years (Greve et al., 1992) instead of rigorous models. It expresses the relationship between object and image coordinates through the use of ratio of polynomial expressions. The coefficient of the polynomial are the Rational Polynomial Coefficients (RPCs).

It must be considered that, even if the generalised model enables photogrammetric procedures without knowing the physical rigorous sensor model, the type of sensor and the procedure followed for image collection, for the computation of the unknown coefficients of the model it is better to introduce in the computation the rigorous sensor parameters, whose accuracy influences the precision of the final products, even if the coefficients can also be computed starting only from an appropriate number of GCPs, recognized on the image and measured on maps. (Tao et al. 2001). Recently, the method based on the RPCs has improved its importance within the photogrammetric and remote sensing community since it has been adopted by DigitalGlobe and SpaceImaging. It must be considered that, from a satellite data provider point of view, by exposing the coefficients of the rational functions, the information on the sensor can be partially hided, preserving a technological know-how. On the other side, for a common user the availability of the RPCs, and of software based on them, facilitates the accurate geometrical processing of the imagery, and enables the processing of a large variety of sensors without having to add new modules to their software processing suites.

As mentioned before, QuickBird images are supplied with their RPCs file, computed by applying a rigorous sensor model. By using the RPC file, it is possible to compute the normalized column and row in an image as a ratio of polynomials of the normalized geodetic latitude, longitude and height. The expressions to be applied for these computations are the following:

$$r_n = \frac{\sum_{i=1}^{20} Lin\_n\_c_i * p_i(P,L,H)}{\sum_{i=1}^{20} Lin\_d\_c_i * p_i(P,L,H)}$$

(1)

$$c_n = \frac{\sum_{i=1}^{20} Sam\_n\_c_i * p_i(P,L,H)}{\sum_{i=1}^{20} Sam\_d\_c_i * p_i(P,L,H)}$$

where $c_n$ ,$r_n$ , P, L and H are normalized values, expressed as:

$$P = \frac{(LATITUDE - Lat\_off)}{Lat\_scale} \quad (2)$$

$$H = \frac{(HEIGHT - Hgt\_off)}{Hgt\_scale} \quad (3)$$

$$L = \frac{(LONGITUDE - Lon\_off)}{Lon\_scale} \quad (4)$$

$$r_n = \frac{(ROW - Lin\_off)}{Lin\_scale} \quad (5)$$

$$c_n = \frac{(COLUMN - Sam\_off)}{Sam\_scale} \quad (6)$$

and:
*Lin_n_c* = List of 20 coefficients, for the row numerator polynomial
*Lin_d_c* = List of 20 coefficients, for the row denominator polynomial
*Sam_n_c* = List of 20 coefficients, for the column numerator polynomial
*Sam_d_c* = List of 20 coefficients, for the column denominator polynomial
*Lat_off* = latitude offset in decimal degrees
*Lon_off* = longitude offset in decimal degrees
*Lin_off* = row offset in pixels
*Sam_off* = column offset in pixels
*Hgt_off* = height offset in meters
*Lin_scale* = normalizing factor for row
*Sam_scale* = normalizing factor for column
*Lat_scale* = normalizing factor for latitude
*Lon_scale* = normalizing factor for longitude
*Hgt_scale* = normalizing factor for height

Each polynomial is up to the third order in P, L, H. Therefore, it is possible to compute, for each combination of latitude, longitude and height, which is the (sample, line) pixel to be considered

In order to use the RPC approach, it is mandatory to have a DEM, otherwise the processing must be carried out with a constant value elevation, for example for totally flat areas. The solution can be improved by using one or more GCPs (Ground Control Points).

The RPCs algorithm is supported by several software packages. In the implementation within Erdas Imagine, the software that has been used for the tests which are reported in the following, it is also possible to refine the solution offered by the RPCs with a polynomial with variable order, with an appreciable improvement in the results

## 4. GEOMETRICAL PROCESSING TEST OVERVIEW

### 4.1 Starting data

The tests have been based on the processing of single Basic full scenes, in panchromatic mode, located in several countries in Europe, with different morphological situation, and with different quality of the ancillary data (GCPs and DEM) used in the orthorectification process. All the images involved in the processing have been collected with an acquisition angle below 15°.

Two different ancillary data configurations have been considered:

- topographic maps in scale 1:5.000, in raster format and scanned with a 0.3175 meter pixel, and DEM in raster format, obtained from the same maps with 10 meters postings and accuracy LE90% < 5 meters.
- GPS collected points, with RMSE < 1 meter in x,y and RMSE < 2 meter in z.

For the first group of ancillary data, four images have been considered. In table 1 have been reported the satellite collection angle (in-track and cross-track), the maximum elevation difference between considered points, and the number of measured points

| Test area code | Collection angles (in-track; across-track) | Elevation difference (m) | Measured points |
|---|---|---|---|
| Area11 | 7.62; 5.96 | 580 | 88 |
| Area12 | 5.05; 5.06 | 840 | 55 |
| Area13 | 11.26; -6.84 | 150 | 88 |
| Area14 | -11.52; -5.14 | 240 | 88 |

Table 1. General information about the four test area of the first group

Area12 has been covered for 60% of its surface, due to the unavailability of maps

For the second group, three images have been considered. For the Area22, only 40% of the imagery has been covered by measured points, due to the unavailability of ground measurements. The same information reported in table 1 have been reported in table 2 for this group.

| Test area code | Collection angles (in-track; across-track) | Elevation difference (m) | Measured points |
|---|---|---|---|
| Area21 | -0.79; 4.75 | 106 | 12 |
| Area22 | 13.91; -2.29 | 125 | 17 |
| Area23 | -1.61; 2.44 | 13 | 17 |

Table 2. General information about the three area of the second group

## 4.2 Methodology

The methodology followed for the tests has been the same for all the frames. First of all, a dataset of points has been generated. For each point, ground coordinates measurements (collected the reference maps or by GPS campaign) and imagery sample/line coordinates, have been computed. The points have been selected in order to be well distributed over the whole frame, and to cover different height layers. Up to 88 points have been considered per single frame.
Then, a fixed number of GCPs has been considered, and that number of GCPs has been selected from the dataset, trying to guarantee an homogeneous distribution over the whole frame. The remaining points of the dataset have been considered as Check Points (CPs). The RPCs approach has been applied and the resulting RMSE on the CPs has been evaluated. The RPC approach has been applied with a polynomial zero order refinement for less then five GCPs, and with a first order polynomial refinement for five or more GCPs.

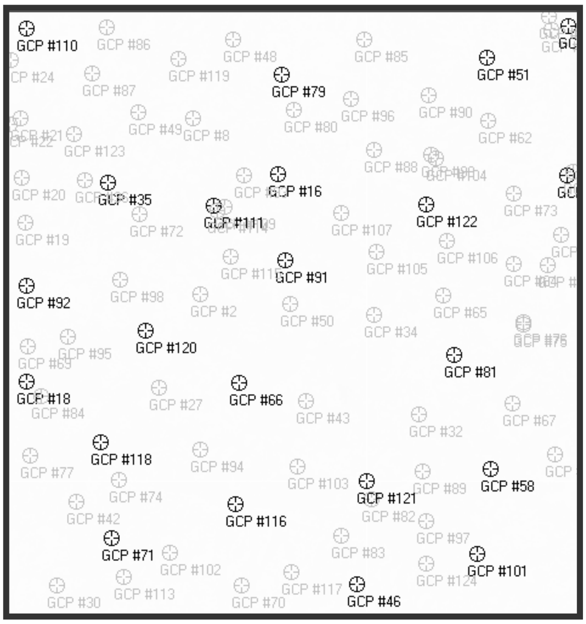


Figure 1 – Example of distribution of GCPs (in black) and CPs (in grey) for a QuickBird frame

For each fixed number of GCPs, several combinations (from 2 to 12) of different points have been considered, and for each combination the RMSE has been computed. A global RMSE for a given number of GCPs has then been computed as the average RMSE computed on all the considered points combinations. An example of point distribution and distinction between GCPs and CPs within a frame has been reported in figure 1.

# 5. RESULTS

## 5.1 Results on first group images

The results in terms of RMSE on the CPs have been summarized in table 3 for an increasing number of GCPs.

| GCPs quantity | Area11 | Area12 | Area13 | Area14 |
|---|---|---|---|---|
| 1 | 7.49 | 5.01 | 7.60 | 4.30 |
| 2 | 5.34 | 3.96 | 6.58 | 3.17 |
| 3 | 5.34 | 3.72 | 6.59 | 3.26 |
| 4 | 5.37 | 3.70 | 6.44 | 3.17 |
| 5 | 2.29 | 2.34 | 2.22 | 2.29 |
| 6 | 2.11 | 2.22 | 2.11 | 2.01 |
| 7 | 2.21 | 2.05 | 2.08 | 1.88 |
| 8 | 2.02 | 1.98 | 2.09 | 1.80 |
| 9 | 1.99 | 1.94 | 2.08 | 1.73 |
| 10 | 2.00 | 1.95 | 2.07 | 1.72 |
| 11 | 2.00 | 1.97 | 1.97 | 1.72 |
| 12 | 2.00 | 1.97 | 2.00 | 1.70 |
| 13 | 2.02 | 1.97 | 1.94 | 1.60 |
| 14 | 1.99 | 2.00 | 1.94 | 1.60 |
| 15 | 1.99 | 2.00 | 1.91 | 1.57 |
| 16 | 1.92 | 1.91 | 1.91 | 1.58 |
| 17 | 1.97 | 1.90 | 1.89 | 1.57 |
| All | 1.82 | 1.77 | 1.84 | 1.47 |

Table 3. RMSE in meters computed over the CPs for an increasing number of GCPs on images belonging to the first group. In the last row, has been reported the RMSE on the GCPs by considering all available points as GCPs.

When applying a polynomial refinement with a zero order, that is just applying a shift, the error decreases by increasing the number of GCPs, with results in the range 3-6 meters RMSE. When collecting around 10 GCPs, and working with a first order refinement, the RMSE is lowered to about 2 meters on all the frames. Slightly better results can be obtained by increasing the number of GCPs. It is interesting to note that by applying a second order polynomial refinement of the solution, and by considering 17 points as GCPs, the RMSE on the four area is lowered to: 1.53, 1.75, 1.44, 1.36 meters. Therefore, even if a second order polynomial may introduce more severe distortions and this procedure cannot be recommended, since the CPs are well distributed over the whole imagery and the RMSE is sensibly lowered (in the range 10-20%), it seems suitable to take (carefully) into consideration the second order refinement when a large number of well distributed GCPs (at least 20) are available and the differences in elevation are very limited.

## 5.2 Results on second group images

In Table 4 have been reported the results achieved on the three considered images. With one to three GCPs, a zero order polynomial refinement has been used, while for the other cases a first order has been applied.
It is clear as the improvement in the accuracy of the input data enables better results on all the three considered frames. Again, the results are depending on the number of GCPs involved in the analysis, but accuracies in the order of one meter can be targeted.

| GCPs quantity | Area21 | Area22 | Area23 |
|---|---|---|---|
| 1 | 2.00 | 1.86 | 4.21 |
| 2 | 1.73 | 1.37 | 2.99 |
| 3 | 1.47 | 1.35 | 2.76 |
| 4 | 1.60 | 1.15 | 1.22 |
| 5 | 1.20 | 0.96 | 1.14 |
| 6 | 1.21 | 0.88 | 0.97 |
| 7 | 1.20 | 0.85 | n.a. |
| All | 0.89 | 0.66 | 0.82 |

Table 4. RMSE in meters computed over the CPs for an increasing number of GCPs on images belonging to the second group. In the last row, has been reported the RMSE on the GCPs by considering all available points as GCPs.

### 5.3 Discussion of results

The achieved results, based on the use of the RPCs supplied with the QuickBird frame, and refined with the use of a polynomial (zero or first order depending on the number of GCPs) show a dependence of the resulting geometrical accuracy from the quality of the ancillary data used for the orthorectification, and from the number of GCPs involved in the analysis. It is not necessary, anyway, to collect a very large number of GCPs, since the accuracy do not change in a appreciable way when considering more the 10-15 GCPs. In figure 2 these considerations are clearly visible. Orthocorrection based on more accurate ancillary data (dashed lines) shows a better accuracy on CPs when increasing the number of GCPs, with the RMSE stabilizing near to 1-meter for all the three considered frames. The same trend for the four images processed with less accurate GCPs and DEM (solid lines), but with an RMSE stabilizing near 2 meters.

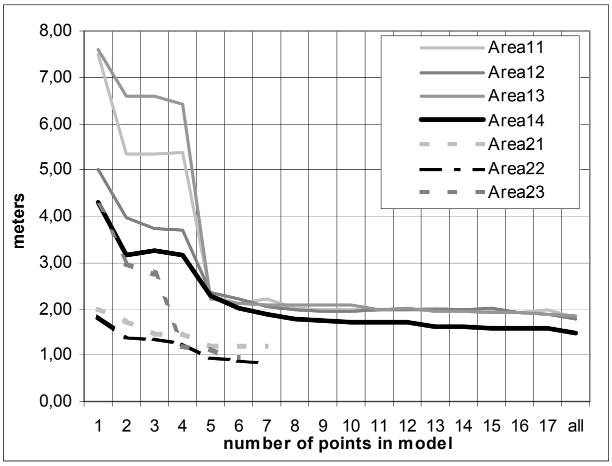


Figure 2. RMSE computed on CPs for the seven test area as function of the number of GCPs used in the model.

The results show that accurate mapping in scale 1:10.000 can be targeted when processing QuickBird Basic frames with the RPC approach

## 6. OTHER APPROACHES FOR THE ORTHORECTIFICATION

In the presented tests, the RPC approach has been applied to the Basic QuickBird imagery. This is just one solution to the issue of the orthorectification of a QuickBird frame. Other approaches can be followed:

- Orthorectification of the Basic product by using a rigorous sensor model
- Orthorectification of the Standard Ortho Ready product by using the RPC approach
- Orthorectification of the Standard product by using the RPC approach

From a theoretical point of view, for the same QuickBird frame the potential geometrical accuracy achievable levels are different according to the used approach. In an hypothetical ranking, the best results should be those obtained when starting from the Basic product, and applying a rigorous sensor model with an advanced photogrammetric approach. This methodology requires a software implementation of the QuickBird camera model, at the moment not ready on the market. It is possible, anyway to use a more generalized model, as for example the Toutin model, already implemented in a commercial software suite, that is a rigorous 3D parametric model that corrects all geometric distortions due to platform, sensor, earth and cartographic projection (Cheng, 2002). Not yet documented tests carried out at Eurimage premises, show interesting results in the application of this software, especially when accurate ancillary data are available, and at least 10-12 GCPs can be used in the model, even if the theoretical minimum number of GCPs for the model is six.

The second position in the hypothetical accuracy ranking is for Basic frames processed by using the RPCs, as shown before in the described tests. The RPCs are obtained by using the rigorous model, but the use of the RPCs approach can be considered as a "model of a model" , therefore potentially introducing a very slight degradation in the results.

Both these approaches require that the processing must be carried out on a full frame, that is on an area of about 16.5 x 16.5 km. The other two possible approaches can be applied also to images that are a subset of the whole frame, since Standard and Standard Ortho Ready products are also available on a portion of the original full frame.

The third hypothetical position in the ranking is for the use of the Standard Ortho Ready product with the RPCs, for which geometrical processing has been partially carried out during the generation of the product, but a DEM has not been used in the processing chain. According to internal tests carried out at Eurimage premises, the results achieved by starting with this product over only a single scene covering a quite hilly area, are very similar to those obtained with a Basic product with the RPCs. According to DigitalGlobe documentation, the results that can be obtained should be slightly worst then those achievable when using RPCs starting from a Basic frame.

The last position in the ranking is for the processing of the Standard product. Since, in this case, the imagery has been processed with a coarse DEM, introduced distortion cannot be removed, even is further geometrical processing with the RPC is still possible. The quality of the achievable geometrical accuracy is dependent on the morphology of the area, and rapidly decreases when relief conditions become more severe.

The choice of the approach to follow depends on which are the accuracies to be targeted, which is the available software for processing, how is the morphology and the extension of the area and which is the quality of the available ancillary data. For example, when no ancillary data are available, the best solution could be to skip totally geometrical processing, and to use a Standard imagery, already processed.

## 7. CONCLUSIONS

The results of several orthorectification tests of QuickBird Basic frames, based on the use of the RPCs approach with a first order polynomial refinement, have been presented. The tests have been carried out over data sets that can be split in two groups, according to the quality of the control points and of the DEM involved in the processing. The results show similar trends and accuracy levels for all the images belonging to the same group, and a clear influence of the quality of the ancillary data on the achievable geometrical accuracy. It is important to note that the analysed approach is just one of the possible solutions to the issue of the geometrical processing of QuickBird data. The results that should be achieved with the other approaches have been briefly discussed.

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