# Correction of IKONOS and QuickBird data for orthophotomaps generation

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**Abstract:** IKONOS and QuickBird digital images and Meta data have been tested with the use of rigorous Toutin's model. RPC data which is provided by vendors and RPC estimated independently on the basis of GCP's. IKONOS Pan sharpened data can be corrected with the use of RPC provided by Space Imaging and 5 GCP's distributed on the entire scene. QuickBird pan data have been corrected with the use of Toutin's model implemented in the PCI Geomatica software with the use at least 9 GCP's. DTM with accuracy of RMSE (Z) < 1.5m has been used for generation of orthophotomaps. Orthophotomaps were generated with pixel size 1m for IKONOS and QuickBird. RMS (XY) = 0.45m using IKONOS and RMS (XY) = 0.56m for QuickBird data.
Accuracy of orthophotomaps generated from QuickBird with pixel 0.5m were with RMS (XY) = 0.45m.
**Keywords:** high-resolution satellite imagery, Ikonos, QuickBird, radiometric correction, DEM, orthoimages, accuracy analysis.

## 1. Introduction

At present the high resolution satellite systems, supported the modern technicians of spatial positioning of the objects, supply of the images, which can elaborate with accuracy obtained for the aerial photos in 1:26,000 scale. The compositions of multispectral and panchromatic bands (Pan Sharpened) are characterized of high radiometrical resolution recorded in 11-bits or 16-bits scale, as well as high geometrical resolution. The radiometrical resolution of Ikonos and QuickBird exceed therefore the radiometrical resolution of traditional aerial photographs, which are devoid of registered in close infra-red radiation information.

However, comparison this does not it concern of the aerial photographs from digital camera, which have perfect geometry of the image. In high resolution satellite systems in small temporary interval be recorded the image of large surface from one orbit, which eliminates often happened of the tonal balance problem on aerial photographs.

High resolution satellite image, as source material for orthoimage generating in scale from 1:2000 to 1:10,000 should replace scanned aerial photographs and determine new standard in digital photogrammetry. What is them actual poetical in this range show the authors of present article.

## 2. Technical parameters of the Ikonos system

The high-resolution commercial satellite, IKONOS, was launched by Lockheed Martin for Space Imaging in September of 1999. From a 680 km sun synchronous orbit, the IKONOS satellite simultaneously collects one panchromatic and multispectral images in 4 bands. Both the panchromatic and all four multispectral bands have 11-bit dynamic range. With 11-bit resolution, details in shadows, highlights, and low contrast scenes can be more easily discerned than in 8-bit images.

The ground sampling distance (GSD) of the IKONOS sensor is 0.82 m (at nadir) for panchromatic images and 3.28 m (at nadir) for multispectral images. At 30 degrees off nadir the GSD is 1 m for panchromatic and 4 m for multispectral images. Nominal swath width at 1 m GSD is 13 km. All currently offered commercial IKONOS image products are resample to 1 m GSD, either map projected or epipolar projected.

Interior and exterior orientations are derived from a sophisticated attitude and ephemeris determination systems, a stable optical assembly, and a solid state focal plane.

## 3. Technical parameters of the QuickBird system

The QuickBird satellite was launched into a circular, sun synchronous orbit on Oct 18, 2001. The spacecraft was built by Ball Aerospace Systems Division and is owned and operated by Digital Globe Inc.

The satellite has panchromatic and multispectral sensors with resolutions of 61-72cm and 2.44 - 2.88 m respectively, depending upon the off-nadir viewing angle (0-25°). The sensor therefore has coverage of 16.5 -19 km 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. The image data is available in different formats, including the raw data format (Basic Imagery), which preserves the satellite geometry and is preferred by the photogrammetry.

QuickBird data is distributed in three different product levels: Basic Imagery, Standard Imagery and Orthorectified Imagery. Each product is supplied with rational polynomial coefficients (RPC's) to allow the user to correct the imagery without ground control points (GCP's).

## 4. Description of the Ikonos data

For estimation of usefulness degree of Ikonos system data in process of digital orthoimages generation in scale from 1:2000 to 1:10,000 the Pan-Sharpened scene was elaborated. This scene was covered the test area about 130 square kilometers situated in the west from Warsaw in borders of administrative districts of Grodzisk Mazowiecki as well as Pruszkow with 20 m elevation range (flat topography). Pan-Sharpened image was acquired on May 01, 2004 with nominal collection azimuth and nominal collection elevation angles of 6º and 61º, respectively. It scene was registered on Standard processing level in GeoTiff format with radiometrical resolution 8 bits / pixel in every band. With matrix of image were delivered Rational Polynomial Coefficients, which were used during geometrical correction of the scene.

## 5. Description of the QuickBird data

Degree of usefulness QuickBird data to generation of orthoimages in scale range from 1:2000 to 1:10,000 was estimated on the basis of panchromatic scene, which was covered the area of south-west part of Warsaw agglomeration. Small elevation range as well as varied relief characterized this test area.

QuickBird Pan scene was acquired on May 04, 2003 with nominal collection azimuth and nominal collection elevation angles of 261º and 84º, respectively, and was registered on Basic-1B processing level in GeoTiff format with radiometrical resolution 16 bits/pixel. Clouds on image of scene were registered, which they made up small percent of the image pixels.

Similarly how in case of Ikonos scene in matrix of image added the metadata's set including the Rational Polynomial Coefficients describer the preliminary orientation of scene.

## 6. Realization of the GCP project for Ikonos and QuickBird projects

Aerial photography in scale of 1:26,000 was used for choosing of 14natural GCP's and 24 independent check points on the scene of Warsaw region. Accuracy of identification and measurement of CGP's for panchromatic QuickBird scene should be with RMS (X) = RMS (Y) < 0.3m and RMS (Z) < 0.3m.

Aerial photography in the same scale was used for choosing of 31 GCP's and check points together in the borders of pan-sharpened Ikonos scene. Planimetric accuracy of these points amount RMS (X) = RMS (Y) < 0.5m but height accuracy RMS (Z) < 0.3m. The number of GCP's and their distribution on scene was function of definite variant of geometrical correction. In each variant establish that from at least one control point should be designed in every corner of the scene as well as one in the central part. Check points were covered the places of scene where control points did not appear and performed the character of objective valuation of geometric correction of each scenes. The places at choice of ground control points determine the corners of contrasting contours like the concrete plates, sidewalks, tombstones as well as the intersection points of axis or edges of local roads width from 2 to 4 meters. Examples of a GCP's are shown on Fig.1.


**"Fig. 1" GCP's on QuickBird Pan (left) and Ikonos Pan (right) scenes**

Geodetic coordinates were measured by GPS technique using 5 Ashtech Z-XII instruments and one GPS Javad model Legacy. On each GCP measuring session lasted from 40 to 45 minutes. Two permanent stations in Warsaw were used as reference data. Measured coordinates (BLH) in WGS-84 system were transformed to Polish coordinates system PUWG 1992.

## 7. Methodology of geometric correction of Ikonos scene

Four geometric correction methods can be used to correct Pan-Sharpened Ikonos image. The analysis of the influence of number and distribution of the control points on scene on result of geometric correction have been realized in each of variants. Introduced in individual variants the proportions refer to control points and check points responded to optimum result of above mentioned analysis.

In first variant witch based on mathematical sensor model of Ikonos (Toutin's model) 9 control points and 22 check points evenly distribute on scene have been measured. Only Rational Polynomial Coefficients added to set of metadata's have been used in second variant of orientation of scene. In this case all ground control points have been measured as check points. Accuracy of geometric correction was definitely lees then in first variant. Besides use of RPC the image coordinates of 5 control points, from which 4 were distributed in corners and one in their central part, have been measured in third variant of geometric correction of Pan-sharpened Ikonos scene.

In above mentioned variants the measurement of image coordinates of control points as well as check points was performed with use manual methods in environment of the PCI Geomatica - Ortho Engine v.9.1.6 software. Fourth variant concerned determination of the RPC on the basis of relations between ground and image coordinates of GCP's. In this variant the measurement of image coordinates has been done with the use of modules of Image Station Automatic Triangulation v.4.1-Z/I Imaging. Estimatation of accuracy of geometric correction in each variant was realized on independent check points. Results are shown in table 1.

**Table 1. Results of geometric correction of Ikonos scene in different variants.**

| Variant | Number of GCP's | Number of Check Points | RMSE [m] | | | |
|---|---|---|---|---|---|---|
| | | | GCP's | | Check Points | |
| | | | X | Y | X | Y |
| **first** | 9 | 22 | 0.19 | 0.14 | 0.38 | 0.29 |
| **second** | 0 | 31 | - | - | 2.37 | 6.92 |
| **third** | 5 | 26 | 0.30 | 0.31 | 0.39 | 0.39 |
| **fourth** | 12 | 19 | 0.11 | 0.13 | 0.41 | 0.42 |

Pan-sharpened Ikonos scene is characterized the correct interior geometry on the accuracy level 0.3 - 0.4 m. It confirms results witch obtained in variants first: RMSE (X) = 0.4 m and RMSE (Y) = 0.3 m as well as third one: RMSE (X) = 0.4 m and RMSE (Y) = 0.4 m. In case of second variant observed, that still exist the shift of the image matrix in ground coordinate system corresponds to orientation of scene. Mean value of this shift amount 2.0 m for X-coordinate and 6.5 m for Y-coordinate. The high accuracy of geometric correction was obtained in fourth variant due to those rational function coefficients appointed independently on the basis of 12 control points. In consideration of labor consumption and cost of elaboration the third variant of orientation Ikonos Pan-sharpened scene is recommended to use.

## 8. Methodology of geometric correction of QuickBird scene

Three geometric correction methods can be used to correct BASIC QuickBird image. One method is 3D rigorous Toutin's model which integrates all components of the viewing geometry and sensor, the Earth and cartographic projection. This model requires minimum of 6 well identified and distributed GCP's. This model has been implemented in PCI Geomatica software.

PCI Ortho Engine v.9.1.6 with the Toutin model of QuickBird data have been improved with the use from 5 to 14 GCP's. Accuracy of the corrections has been checked on well defined 24 check points. Results are shown in table 2.

The rigorous Toutin model with the use of 9 GCP's is sufficient for geometric correction of QuickBird Pan BASIC scene. Accuracy achieved on the in depended check points: RMS X = 0.31m and RMS Y = 0.35m. Cheng and Toutin reported accuracy for geometric correction of BASIC data using rigorous model with the use of 6 GCP's: RMS X = 0.5m and RMS Y = 0.8m [2].

The second method uses empirical and statistical model which approximates 3D sensor model supplied by Digital Globe with the QuickBird BASIC scene. Accuracy of the orientation of the BASIC scene with the use of only RPC data RMS=10m in direction of the flight and RMS=7m in scanning direction have been achieved. Usually this method is used when no GCP's are available.

**Table 2. Results of geometric correction of QuickBird with the use rigorous Toutin model.**

| Number of GCP's | Number of Check Points | RMSE [m] | | | |
|---|---|---|---|---|---|
| | | GCP's | | Check Points | |
| | | **X** | **Y** | **X** | **Y** |
| 14 | 24 | 0.17 | 0.30 | 0.30 | 0.27 |
| 11 | 24 | 0.02 | 0.27 | 0.30 | 0.36 |
| **9** | **24** | **0.02** | **0.21** | **0.31** | **0.35** |
| 7 | 24 | 0.02 | 0.01 | 0.52 | 1.09 |
| 5 | 24 | 0.01 | 0.01 | 14.81 | 2.93 |

These data with different numbers of GCP's have been used for geometric correction. Using the RPC and additional GCP's accuracy of the geometric correction is much better. Using RPC with additional GCP's from 2 to 7 gives the RMS (X, Y) about 1m (see table 2). It seems that RPC provided by Digital Globe are not accurate enough, which has been reported also by Dr. Wolniewicz (EURIMAGE Meeting, Rome, 2004). Using RPC with only 7 GCP's gives acceptable results RMS (X, Y) < 1m).

**Table 3. Results of geometric correction of BASIC QuickBird with the use RPC and different number of GCP's.**

| Number of GCP's | Number of check points | RMSE [m] | | | |
|---|---|---|---|---|---|
| | | GCP's | | Check Points | |
| | | **X** | **Y** | **X** | **Y** |
| 14 | 24 | 1.48 | 1.15 | 0.78 | 1.10 |
| 11 | 24 | 1.44 | 1.23 | 0.78 | 1.15 |
| 9 | 24 | 1.53 | 1.36 | 0.85 | 1.12 |
| **7** | **24** | **1.43** | **1.25** | **0.78** | **1.00** |
| 5 | 24 | 1.05 | 1.10 | 0.87 | 1.10 |
| 3 | 24 | 1.05 | 1.16 | 0.90 | 1.01 |
| 2 | 24 | 1.46 | 1.27 | 0.94 | 1.06 |
| 1 | 24 | 0.26 | 0.20 | 1.00 | 1.52 |
| 0 | 24 | - | - | 10.86 | 6.88 |

Third method of the geometric correction uses a number of GCP's. Unknowns of RPC are calculated on the basis of X, Y, Z coordinates of GCP's measured in the field and on the image. The accuracy of RPC parameters depends on the number of GCP's, accuracy of identification in the field and on the image, and distribution on the scene [2].

RPC data have been estimated independently from different number of GCP's. The results of geometric correction are shown in table 3.

**Table 4. Results of geometric correction of QuickBird BASIC with the use RPC calculated form different number of GCP's.**

| Number of polynomial coefficients | Number of GCP's | Number of Check Points | RMSE [m] | | | |
|---|---|---|---|---|---|---|
| | | | On GCP's | | Check Points | |
| | | | **X** | **Y** | **X** | **Y** |
| **3** | 14 | 24 | 0.61 | 0.48 | 0.75 | 0.37 |
| **4** | | | 0.53 | 0.29 | 0.80 | 0.31 |
| **5** | | | 0.14 | 0.25 | **0.30** | **0.26** |
| **6** | | | 0.12 | 0.18 | 0.34 | 0.38 |
| **7** | | | 0.11 | 0.17 | 0.36 | 0.35 |
| **3** | 11 | 24 | 0.56 | 0.51 | 0.70 | 0.38 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **4** | | | 0.42 | 0.29 | 0.54 | 0.41 |
| **5** | | | 0.03 | 0.26 | **0.31** | **0.30** |
| **6** | | | 0.02 | 0.03 | 0.33 | 1.91 |
| **3** | 9 | 24 | 0.56 | 0.43 | 0.78 | 0.51 |
| **4** | | | 0.44 | 0.20 | 1.19 | 0.41 |
| **5** | | | 0.02 | 0.01 | 0.31 | 1.41 |
| **3** | 7 | 24 | 0.27 | 0.49 | 0.86 | 0.41 |
| **4** | | | 0.03 | 0.01 | 0.98 | 0.72 |
| **3** | 5 | 24 | 0.01 | 0.01 | 0.75 | 0.55 |

RPC calculated on the basis of 11 to 14 GCP's are sufficient for geometric correction of QuickBird BASIC scene with accuracy achieved on check points RMS(X) = RMS(Y) = 0.3m. This accuracy of orientation is similar to the accuracy achieved with the use of aerial photography in the scale 1:26 000 taken from H=4 km.

## 9. The results comparison of geometric correction of Ikonos and QuickBird scenes

The panchromatic scene of QuickBird on Basic processing level as well as the Pan-sharpened scene of Ikonos on Standard processing level provided for photogrammetric workflow has to be subjected in additional process of geometric correction. Geometric correction of these scenes exclusively based on the RPC coefficients didn't give the accepted results. The accuracy of RPC coefficients for Ikonos is satisfactory whereas the coefficients corresponded with the pixel matrix of QuickBird arouses the respectable restrictions. The correlation of rational polynomial coefficients with image matrix can be corrected by realization of additional observations of control points and the same by densification of nodal points of spatial grid. For these grid points RPC were calculated.

In case of Ikonos scene this process based on measurement of image coordinates of only just five control points caused the correction of image geometry on level value 0.4 m for both coordinates in PUWG 1992 coordinates system. Independently of the number of control points participated in QuickBird correction with use RPC, geometry of image was resoluteness worse. The root mean square errors of ground coordinates from 0.8 m to 1 m characterized of QuickBird geometry.

The very promising results of geometrical correction were got in process of independent delimitation of RPC for each image matrix. Somewhat better results in this variant obtained for QuickBird image matrix. The method of geometrical correction basing on rigorous mathematical model of satellite gives the better results for QuickBird system as universal for choice of control points. On the basis of methodical research provided to achieved of optimum results of geometrical correction of Ikonos and QuickBird was affirmed that range of this correction is imperceptibly larger for QuickBird, despite that the resolution of compared source images differs fundamentally.

## 10. Principles of orthorectification process of Ikonos and QuickBird images

The influence of ground height difference on accuracy of orthoimage generated from nadir satellite images is smaller than in case of aerial photographs. Therefore to their orthorectification one can use of Digital Elevation Model with less accuracy. The authors of present article disposed of adjustment results for two aerial triangulation blocks. Each block contained the aerial photographs in scale 1:26,000. Field range of these aerial photographs was the same how the covering of satellite scenes.

Stereoscopic models of aerial photographs with exterior orientation were used to measurement of DEM. It was accepted that accuracy of DEM shouldn't be worse than 1.5 m [9]. The measurement of DEM grid size 25 m was executed by correlation method of digital images on Image Station SSK Pro - Intergraph with use the modules of Image Station Automatic Elevation Collection software. The structural components of relief like: break lines, ridge lines, obscure areas, planar areas and areas with regular slope of the ground were measured additionally and determined supplement for measured automatically of the mass points. The position of regular grid points has been corrected manually by operator on stereoscopic models with the use of tools of Image Station Data Collection software. It was affirmed that from 15 to 25 percent measured automatically of DEM points required the manual edition.

The accuracy of measured DEM points were examined on the basis of their comparison with reference profiles of terrain with use of MGE Terrain Analyst version 7.1 software. Four profiles by GPS technique were measured on the area which covered the stereoscopic models of aerial photographs. The 140 height points were measured in first profile, in second 85 and in remaining profiles (third and fourth) 200 points each. RMSE calculated on the basis of differences of height for separate profile: 0.64 m, 0.74 m, 0.60 m and 0.55 m respectively. Theoretical analyses affirm that the DEM with above mentioned accuracy is sufficient for elimination of denivelation errors on the orthoimage generated from high resolution satellite scenes.

On the basis of source Ikonos images with resolution GSD = 1 m is possibly to generate of orthoimage with pixel size 1m. According to standards valid in Poland this pixel size correspond with orthophotomaps in scale 1:10,000. In case of source QuickBird images (GSD = 0.61 m) the orthophotomaps can be generating with resolution 0.5 m or 1 m. One meter pixel size is the result of unfavorable resapmling of source image pixels and can to cause the loss of interpretation quality of orthophotomaps from QuickBird. The orthoimage generated with pixel size 0.5 m doesn't pose similar problem. Taking into account the above mentioned observation, authors affirmed, that the high resolution images of QuickBird should be the source for generation of orthophotomaps in scale 1:5000 as well as 1:10,000. Next analyses shows, what is the real influence of pixel size of orthoimage on the planimetric accuracy.

## 11. Estimation of orthoimage accuracy generated from Ikonos and QuickBird

Estimation of accuracy of orthorectification process were RMSE's of position of situational details on orthophotomaps calculated on the basis of differences between coordinates reading on orthoimage and catalogue coordinates. Analysis of accuracy of orthoimages has been performed using the tools of Image Station Ortho Pro software. The orthoimages were generated taking into account the best results of geometrical correction in the individual variants.

**Table 5. Accuracy of the orthoimages for particulars variants of the Ikonos geometric correction.**

| Variant description | RMSE (XY) [m] | Criterion of accuracy for the orthophotomaps in scale | |
|---|---|---|---|
| | | from | to |
| Rigorous model with 9 GCP's | **0.44** | 1 : 2000 | 1 : 10,000 |
| RPC with 5 GCP's | **0.45** | 1 : 2000 | 1 : 10,000 |
| RPC from 12 GCP's | 0.94 | 1 : 5000 | 1 : 10,000 |

The results in table 5 refer to 31 check points which did not participate in geometrical correction of Ikonos scene. In all of variants have got the planimetric accuracy of 1 meter resolution orthoimages corresponding with accuracy of position of detail on basic map in 1: 5000 and smaller scales. The variant using RPC and measurement of five control points deserves on special note. In this case the accuracy of position of orthoimages was RMSE (XY) = 0.45 m and corresponds with accuracy of map in 1: 2000 and smaller scales. Similar accuracy of orthoimage has been achieved using rigorous mathematical model of Ikonos sensor, yet in this case for orientation of scene were required the larger number of control points. The somewhat worse accuracy of orthoimage obtained in variant of geometrical correction based on calculation of RPC is the result of too small number of appointed RPC coefficients. However, this accuracy attends the criterion for map in scale 1:5000 as well as in 1:10,000.

**Table 6. Accuracy of the orthoimages for particulars variants of the QuickBird geometric correction.**

| Variant description | RMSE (XY) [m] | Criterion of accuracy for the orthophotomaps in scale | |
|---|---|---|---|
| | | from | to |
| Rigorous model with 9 GCP's | **0.56 (0.45)** | 1 : 2000 | 1 : 10,000 |
| RPC with 7 GCP's | 1.25 (0.95) | 1 : 5000 | 1 : 10,000 |
| RPC from 11 GCP's | 0.65 (0.55) | 1 : 5000 | 1 : 10,000 |

Estimation of accuracy of orthoimages generated from QuickBird data has been realized on the basis of 21 independent check points. Results presented in table 6 refer to the orthoimages generated with 1m pixel size. For all variants of geometrical correction the obtained accuracy's corresponds to the accuracy of the base maps in scale 1:5000 as well as 1:10,000. Additionally, for the variant basing on the use of rigorous mathematical model of satellite sensor of QuickBird the accuracy obtained of orthoimage corresponds with the accuracy of the base map in scale 1:2000. It was affirmed, that the accuracy of orthoimages generated with pixel size 0.5 m is significantly higher (the results in table 6 in parentheses), and confirms the usability of images of QuickBird for elaborations of orthophotomaps in large scales.

## 12. Conclusions

The high resolution satellite scenes of Ikonos and QuickBird, which are the source image data to generation of orthoimages, should be well geometrically corrected. Range of this correction is the function of the used methodology, which take into account the influence of RPC coefficients as well as the number and distribution of control points.

The transformation of pixels of each image registered in Ikonos and QuickBird satellite systems to ground coordinate system is possible to perform with accuracy of half pixel. For the Ikonos as well as QuickBird images these accuracy are 0.4 m and 0.3 m respectively.

The effect of terrain denivelation in rectification process of the geometrically corrected of Ikonos Pan-Sharpened and QuickBird Pan scenes is necessary to take into account through involvement to this process of Digital Elevation Model with accuracy better than 1.5 m.

On the basis of nadir Ikonos images as well as QuickBird, the orthoimages can be generated which accuracy corresponds to accuracy of base maps in scales from 1:2000 to 1:10,000, as well as in smaller scales. However, for this range of scale of orthophotomaps was realized geometric standards obligatory in Poland then theirs interpretability refer to 1:10,000 scale only.

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