3D GEOPOSITIONING ACCURACY ANALYSIS BASED ON INTEGRATION OF QUICKBIRD AND IKONOS IMAGERY

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ABSTRACT:

Stereo high-resolution satellite imagery, such as Space Imaging's IKONOS (1 m resolution) and DigitalGlobe's QuickBird (sub-meter resolution), can provide accurate three-dimensional (3D) mapping products. Based on the rational function model, this study investigated the integration of IKONOS and QuickBird images. One pair of stereo IKONOS images and one pair of stereo QuickBird images, collected in the same region, were used in the study. The 3D geopositioning accuracy from a single IKONOS image and a single QuickBird image was compared with those from stereo IKONOS images, stereo QuickBird images, and the combination of the images.

First, 3D geopositioning accuracies of stereo IKONOS and QuickBird images were computed respectively by an improved rational function model with four ground control points. It was found that the accuracy of IKONOS images is at the one-meter level and that of QuickBird is at the sub-meter level, in the same order of their image resolutions. All four images from both pairs were then used together based on the rational function model. The calculated accuracy is at the sub-meter level. In data integration, the imaging geometries of both pairs of images were examined. The feasibility and accuracies of combinations of single IKONOS and single QuickBird images were investigated. The results show that, with the proper triangulation angle, a single IKONOS image and a single QuickBird image can form a stereo image pair that can provide sub-meter 3D geopositioning accuracy.

1. INTRODUCTION

Since the launch of Space Imaging's IKONOS earth imaging satellite in September 1999, followed by DigitalGlobe's QuickBird and OrbImage's OrbView-3, commercial high-resolution satellite imaging systems have initiated a new era of Earth observation and digital mapping (Li, 1998). Digital satellite imagery provides substantial high quality data for mapping, inventorying, monitoring, and surveying. In addition to high spatial resolution and a short revisit time of around 3 days, the flexible stereo imaging capability of these systems makes them very attractive by providing accurate three-dimensional mapping products. Table 1 lists the associated accuracies of different IKONOS and QuickBird image products (Space Imaging, 2002 and DigitalGlobe, 2002).

IKONOS		QuickBird	
Products	**Accuracy**	**Product**	**Accuracy**
Geo	25.0 m	Basic	14 m
Reference	11.8 m	Standard	14 m
Pro	4.8 m	Orthorectified (1:25,000)	7.7 m
Precision	1.9 m	Orthorectified (1:12,000)	6.2 m
Precision Plus	0.9 m	Orthorectified (Customized)	Depends on qualities of GCPs

Table 1. Accuracies of IKONOS and QuickBird image products. (Space Imaging, 2002 and DigitalGlobe, 2002).

Instead of releasing actual rigorous camera models, these imagery vendors provide a so-called rational function model (RFM) to describe the orientation information of these high-resolution imaging systems (Tao and Hu, 2001). Di et al. (2003a) explored the potentials for recovering rigorous sensor models of a frame image and a linear array image from the RFM and investigated the methods for geopositioning accuracy improvement. As a generalized sensor model, the RFM represents the relationship between the image coordinates and the object coordinates with ratios of polynomials, as shown in Equation 1,

$$\begin{cases} x = \dfrac{P_1(X,Y,Z)}{P_2(X,Y,Z)} \\ y = \dfrac{P_3(X,Y,Z)}{P_4(X,Y,Z)} \end{cases} \tag{1}$$

where the polynomial P_i (i=1, 2, 3, and 4) has the following general form

$$\begin{aligned} P(X,Y,Z) = {} & a_1 + a_2X + a_3Y + a_4Z + a_5XY + a_6XZ + a_7YZ + a_8X^2 \\ & + a_9Y^2 + a_{10}Z^2 + a_{11}XYZ + a_{12}X^3 + a_{13}XY^2 + a_{14}XZ^2 \\ & + a_{15}X^2Y + a_{16}Y^3 + a_{17}YZ^2 + a_{18}X^2Z + a_{19}Y^2Z + a_{20}Z^3 \end{aligned} \tag{2}$$

and where (x, y) are the column and row of each image point and (X, Y, Z) are, for example, the longitude and latitude (in degrees, WGS84) and ellipsoidal height (in meters, WGS84) of the corresponding ground point. All the image and ground coordinates are normalized to the range [-1, 1] by offsetting and scaling. For each image, 80 rational function coefficients

(RFCs) and ten offset and scale parameters can be provided by the vendor.

The RFCs are usually computed by satellite image providers without using ground control points (GCPs). Instead, the object space is sliced in the vertical direction to generate virtual control points for calculating the RFCs (Tao and Hu, 2001; Di et al., 2003a). The ground coordinates derived from such RFCs typically have the accuracy of Geo products (about 25 m). If quality GCPs are available, there is a potential to use the GCPs for enhancing the ground accuracy. Li et al. (2003) found a systematic error of 6 meters between RF-derived coordinates and the ground truth. A similar result was reported in Fraser and Hanley (2003). It is desirable that such errors in the image products be reduced or eliminated by users employing relatively simple methods that can be used for many different applications that require higher mapping accuracy.

Before the availability of the actual IKONOS image, Li (1998) discussed the potential accuracy of high-resolution imagery using basic photogrammetry principles. Zhou and Li (2000) simulated 1-m resolution IKONOS imagery based on pushbroom sensor imaging geometry to estimate the potential accuracy of ground point determination and an accuracy of 2 to 3 meters was achieved. Dial (2000) estimated the stereo mapping accuracy of IKONOS products with GCPs as 2 m CE90 (1.32 m RMS) in the horizontal and 3 m (1.82 m RMS) in the vertical. Di et al. (2003b) used a "RFC+3D affine" model for IKONOS geopositioning improvement and achieved accuracies of better than 1.5 m in planimetry and 1.6 m in height. Noguchi et al. (2004) investigated the geopositioning accuracy of QuickBird stereo imagery and obtained 0.6 m in planimetry and 0.5 m in height. Wang et al. (2005) compared the results of different methods in both image space and object space, including translation, translation and scale, affine, and 2nd-order polynomial transforms with different GCP distributions, in the improvement of the IKONOS stereo geopositioning accuracy. It was found that the affine transform can produce better accuracies with evenly distributed GCPs. Similar results have been found in the geopositioning research of QuickBird stereo images done by Niu et al. (2004).

However, availability of appropriate timely data and relatively high cost may be of concern to many applications of stereo images. Based on the rational function model, this study investigated the integration of IKONOS and QuickBird images with different imaging geometry. A pair of IKONOS stereo Reference product images and a pair of QuickBird stereo Basic product images were used in the study.

2. EXPERIMENTAL DATA

The QuickBird and IKONOS stereo pairs used in this experiment were taken in September 2003 and July 2004, respectively, in south Tampa Bay, Florida. RFCs of imagery were supplied by DigitalGlobe, Inc. and Space Imaging, Inc. Figure 1 shows the orbital geometry of the QuickBird and IKONOS satellites.

Nominal collection azimuth and nominal elevation angles of both satellites as viewed from the scene centers were provided by the vendors. With these parameters, the convergent angles of both stereo pairs were calculated (see Table 2). The convergent angle is calculated by an intersection of 2 lines: a line from the first position of the satellite to the center of the scene and another line from the second position of the satellite to the center. Equation 3 shows the formula used to calculate the convergent angles.

$$\cos\delta = \sin\alpha_1 \sin\alpha_2 + \cos\alpha_1 \cos\alpha_2 \cos(\theta_2 - \theta_1) \quad (3)$$

The four GCPs and sixteen check points (CKPs) used in this experiment were obtained from triangulated aerial photographs as shown in Figure 2, in which four red triangles represent the positions of GCPs, sixteen green circles the positions of CKPs, and the background image is the first image of the IKONOS stereo pair. The accuracies of the aerial triangulation are 1.96cm, 1.08cm and 3.00cm in the X, Y, and Z directions.

	QuickBird		IKONOS	
	Forward	Backward	Forward	Backward
Acquisition date & time (GMT)	2003-09-12 15:58:08	2003-09-12 15:59:17	2004-07-08 16:17:17	2004-07-08 16:18:08
Image size (row * column)	25776 * 27552	24620 * 27552	8484 * 12160	8484 * 12160
Collection azimuth (θ)	17.7 degrees	184.5 degrees	40.7986 degrees	120.1049 degrees
Collection elevation (α)	58.7 degrees	59.2 degrees	60.75331 degrees	74.14089 degrees
Convergence angle (δ)	61.6434 degrees		30.2213 degrees	

Table 2. Parameters of panchromatic stereo imagery used in the experiment.

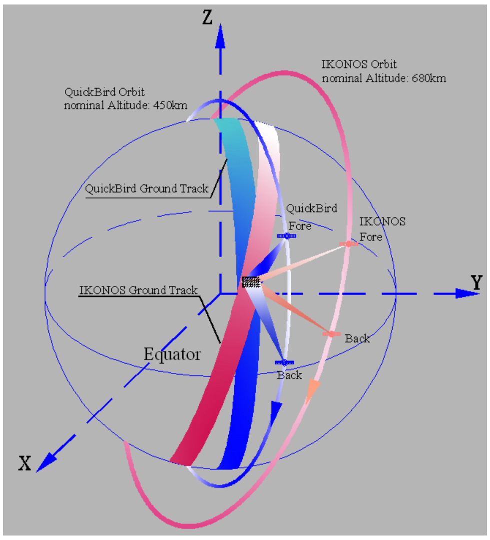

Figure 1. Orbital Geometry of QuickBird and IKONOS Satellites (inclination angles: QuickBird is 97.2°; IKONOS 98.1°; the difference is exaggerated in illustration)

3. EXPERIMENTAL RESULTS

Equation 4, the affine transform in image space, is used to improve the accuracies of the RFM results as shown below (Di et al. 2003b).

$$\begin{aligned} I' &= a_0 + a_1 I + a_2 J \\ J' &= b_0 + b_1 I + b_2 J \end{aligned} \quad (4)$$

Figure 2. Distribution of GCPs and CKPs (red triangle – GCP; green circle – CKP).

Stereo Image Combination	**Geopositioning Accuracy** (RMSE: meter)		
	X	**Y**	**Z**
QuickBird	0.554	0.593	0.825
IKONOS	1.140	1.057	1.286
Four Images	0.912	0.789	0.885

Table 3. Geopositioning accuracies of QuickBird, IKONOS, and the integration of both pairs.

Table 3 shows the geopositioning accuracies of stereo QuickBird, stereo IKONOS, and the integration of the both pairs. It can be observed that:

- The accuracies of QuickBird in the X, Y, and Z directions are better than one meter, among which the planimetric accuracies reach the sub-pixel level and the elevation accuracy is about the same level, close to the pixel size of the QuickBird imagery,
- The accuracies of IKONOS images are very close to one meter, and
- The accuracies of the integration of four images are between those of QuickBird and IKONOS.

From the integration results, we can see that the combination of the two stereo pairs should, in principle, improve the geometry of triangulation to some extent. However, the resolution difference would not necessarily make it better than the QuickBird result. To further investigate the results of QuickBird and IKONOS integration, the geopositioning accuracies of four different combinations of a single QuickBird image and a single IKONOS image are calculated using the same set of GCPs and CKPs. The results are shown in Table 4. To facilitate comparison, the geopositioning accuracies of IKONOS stereo images and QuickBird stereo images are also listed in the table along with their convergent angles. The rows in the table are sorted in the descending order of the convergent angles.

Image Combination (F: Forward B: Backward)	**Geopositioning Accuracy** (RMSE: meter)			**Convergent Angle** (degree)	**Geometry in Figure 3**
	X	**Y**	**Z**		
QuickBird (F) – QuickBird (B)	**0.554**	**0.593**	**0.825**	**61.64337**	(a)
IKONOS (F) – QuickBird (B)	0.542	0.851	1.071	56.76096	(b)
QuickBird (F) – IKONOS (B)	0.873	1.020	1.268	37.67997	(c)
IKONOS (F) – IKONOS (B)	**1.140**	**1.057**	**1.286**	**30.22133**	(d)
QuickBird (B) – IKONOS (B)	0.622	1.171	1.642	27.53404	(e)
IKONOS (F) – QuickBird (F)	0.993	2.079	2.999	11.76017	(f)

Table 4. Geopositioning accuracies and convergent angles for different combinations of IKONOS and QuickBird Images.

Figure 3 (a)-(f) displays the imaging geometries of each combination of IKONOS and QuickBird images. The angles in red are the nominal azimuth and elevation angles of IKONOS satellite, the angles in green are the nominal azimuth and elevation angles of QuickBird satellite, and the angles in blue are the convergent angles of the combined stereo pairs.

In Table 4, we can see that there are linear relationships between the accuracies in the Y and Z directions and the convergent angles. The greater the convergent angle, the better are the accuracies in the Y and Z directions. There is no apparent relationship between accuracies in the X direction and the convergent angles.

Essentially, Figures (a)-(d) in Figure 3 have a combination of F-B. Figures (e) and (f) are F-F or B-B and their convergent angles are smaller than those of (a)-(d). Accordingly, their accuracies are worse.

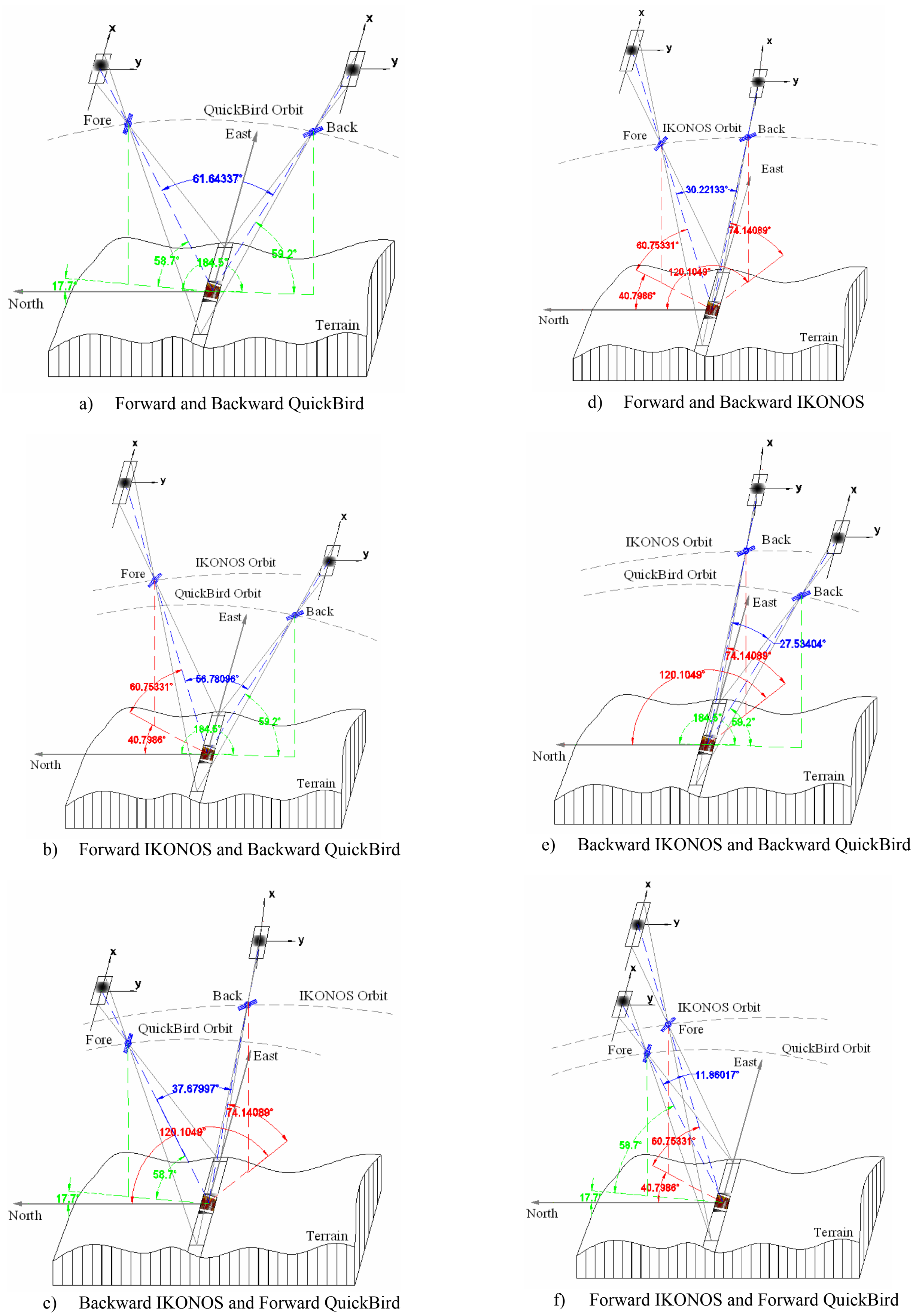

Figure 3. Imaging geometries of different IKONOS and QuickBird combinations
(Sorted in a descending order of the convergent angle)

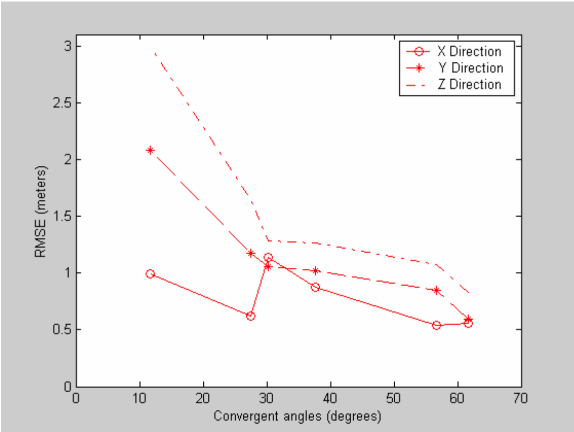

Figure 4. The relationships between geopositioning accuracies and convergent angles.

4. DISCUSSION AND CONCLUSIONS

In this research, one QuickBird stereo pair and one IKONOS stereo pair are collected in the same region. We compared the three-dimensional geopositioning accuracies of the different combinations from these four images with different convergent angles. Figure 4 plots the relationships between geopositioning accuracies and the convergent angles. As the convergent angle increases, accuracies in the Y and Z directions increase significantly. However, there is no such relationship in the X direction.

Comparing these observations to the imaging geometries of different combinations, we can see that X is the cross-track (east-west) direction, Y is the along-track (north-south) direction, and Z is elevation. If we explain the relationships in Figure 4 in terms of imaging geometry, the following conclusions can be made.

- The accuracies of the coordinates in the cross-track direction are close to the resolution of the images and are not affected by the imaging geometries.
- The accuracies in the along-track direction and the elevation from (a)-(d) (F-B combination) in Figure 3, are better than those from (e)-(f) (F-F or B-B combinations) in Figure 3.
- Also, for accuracies in the north-south direction and the elevation, a greater convergent angle will give better accuracies for all combinations.
- The accuracies of three coordinates are also related to the resolution of the images as can bee observed in Table 4, where the results of the four-image integration are seen to be between those of the QuickBird and the IKONOS stereo pairs.

In this research, the QuickBird stereo pair happens to have the greatest convergent angle, and it also has the best accuracies in all directions. We wanted to find a stereo pair of an IKONOS (F) - QuickBird (B) combination, or other way around, which would have a greater convergent angle than that of the QuickBird stereo pair. Such a combination would help us answer the question: Does the convergent angle affect the geopositioning accuracies of the object coordinates more than the image resolution does?

In the future, we would like to carry out more in depth research on cross-track multi sensor integration, and relation among orbital knowledge, resolution, and terrain types.

5. ACKNOWLEDGMENTS

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