

# ACCURACY INVESTIGATION OF ORTHOIMAGES OBTAINED FROM HIGH RESOLUTION SATELLITE STEREO PAIRS

L. Zhu \*, H. Umakawa, F. Guan, K. Tachibana, H. Shimamura

Research and Development Center, PASCO Corporation, Annex 2-8-10 Higashiyama, Meguro-ku, Tokyo, 153-0043,  
Japan-(lin\_zhu, hiroko\_umakawa, fang\_guan, kikuo\_tachibana, hideki\_simamura)@asco.co.jp

**KEY WORDS:** High resolution, Satellite, Geometry, Model, Matching, Orthoimage, Accuracy

## ABSTRACT:

This study investigates the geometric accuracy of DSMs and orthoimages, which are obtained from high resolution satellite stereo pairs of in-track, cross-track and mixed satellite images. Four IKONOS and two QuickBird panchromatic images are used to constitute 15 stereo pairs, and are processed to generate DSMs and orthoimages. A geometric stereo model, which represents the stereo acquisition geometry of a satellite stereo pair is applied to investigate the relationship between the geometric accuracy of DSMs and orthoimages and the parameters of the geometric stereo model. The results showed that the geometric accuracy is mainly influenced by two parameters, i.e. base-height ratio (B/H) and bisector elevation (BIE). And, if the stereo acquisition geometry is ideal, high accuracy DSMs and orthoimages can also be obtained by cross-track stereo and mixed satellite stereo pairs.

## 1. INTRODUCTION

Spatial information has become indispensable for numerous aspects of urban and rural development, planning and management, with rapid development in spatial data capture, management and access (Kelly, 2007). The increased utilization of high resolution satellite imagery has been due to recent strides of dramatically improved spatial resolution, wider coverage, higher frequency of revisit time especially with employment of satellite constellations, as well as considerably decreased satellite launch costs. When using high resolution satellite imagery for topographic mapping, although in-track stereo pair images can ensure the geometric accuracy of generated DSMs and orthoimages, as a resource for spatial information collection, the limitation such as expensive data acquisition fee, paucity of imaging regions and archived data is apparent. However, a lot of cross-track images acquired from the same satellite or different satellites are available. The full exploitation of these images will extend the possibility of spatial information collection. Relatively few studies have been made regarding the application of high resolution satellite cross-track stereo and mixed satellite stereo images. Especially, the geometric conditions for accurate DSMs and orthoimages generation, and the influence of the stereo acquisition geometry have not been clarified.

In this study, in-track, cross-track and mixed satellite stereo combinations of IKONOS and QuickBird images are used to generate DSMs and orthoimages. The geometric accuracy of the DSMs and orthoimages is assessed. A geometric stereo model, which represents the stereo acquisition geometry of a satellite stereo pair, is used to investigate the relationship between the geometric accuracy of DSMs and orthoimages and the geometric parameters of the geometric stereo model. The influence the stereo acquisition geometry is analyzed. The results show that there is a great potential for using high resolution satellite cross-track and mixed satellite stereo images for spatial information collection.

## 2. DATASETS

The Hakone region of Japan is chosen as a test field in this study. The test field covers both mountain and urban areas. 4 IKONOS and 2 QuickBird images are used in this study. Table 1 shows the specification of the used satellite images. The 4 IKONOS images include 1 in-track stereo pair and 2 single images, and all are Geo, 11-bit, 1m panchromatic images. The 2 QuickBird single images are Basic, 11-bit, 0.65m panchromatic images. Since these images are acquired six years apart, from 2001 to 2006, from different viewing directions, there is a lot of difference among them. 15 stereo combinations are constituted from the 6 images for DSMs and orthoimages generation, including 1 in-track stereo pair, 5 IKONOS cross-track stereo pairs, 1 QuickBird cross-track stereo pair, and 8 IKONOS and QuickBird mixed stereo pairs.

	Acquisition dates	Spatial resolution	Image ID	Remarks
IKONOS (Geo)	2006/4/01	1.0m	I1	single
	2003/4/18	1.0m	I2	In-track stereo image
	2003/4/18	1.0m	I3	In-track stereo image
	2001/4/15	1.0m	I4	single
QuickBird (Basic)	2005/1/14	0.65m	Q1	single
	2006/2/14	0.65m	Q2	single

Table 1. Specification of used satellite imagery

22 Ground Control Points (GCPs) are collected within the test field and used as check points to evaluate the geometric accuracy of generated DSMs and orthoimages. The coordinates of the GCPs are measured with a Virtual Reference Station (VRS) Global Positioning System (GPS). These GCPs are chosen to be distributed over the whole test field which covers both mountain and urban areas. 1 GCP is used to remove the

\* Corresponding author.

effect of systematic errors. The distribution of GCPs in the test field is shown in figure 1.



Figure 1. Distribution of GCPs in the test field

### 3. DSM AND ORTHOIMAGE GENERATION

A processing system named Pixel Factory, which is developed by Infoterra France, is used for DSMs and orthoimages generation. The Pixel Factory system is an integrated system for aerial and satellite imagery processing. It performs image matching for all pixels in the images, and can extract dense, precise and reliable DSMs, and generate orthoimages from single- or multi-sensor imagery.

The Pixel Factory system has a fully integrated architecture that manages full processing workflow, resources and data. All the processing is performed in a fully automated way, including automated generation of thousands of tie points, automated tie point filtering to remove blunders, automated global multi-sensor spatial adjustment to refine geometric models, automated dense DSM extraction, and automated orthoimage rectification using DSM information and taking into account occlusion. All image processing are parallelized in order to speed-up computation. Figure 2 shows the flow chart of Pixel Factory system for DSM and ortho-image generation.

In this study, all the 15 stereo combinations of the IKONOS and QuickBird images are processed to generate DSMs and orthoimages automatically of the test field. A regular grid DSM with 4m spacing is generated from the raw measurement for

each stereo pair. The computation of orthoimage is made by projecting the terrain geometry on the raw images using the DSM. The resolution of generated orthoimages is 1m for in-track and cross-track IKONOS stereo pairs, and 0.65m for cross-track QuickBird stereo and mixed satellite stereo pairs.

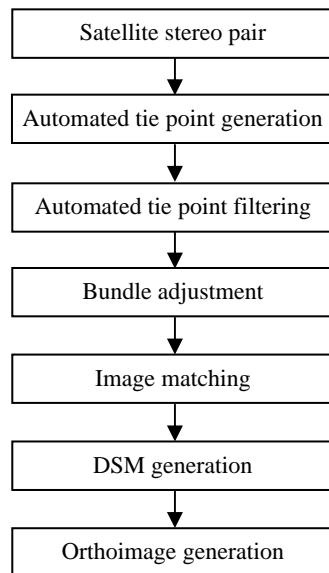


Figure 2. Flow chart of DSM and ortho-image generation

## 4. ACCURACY ASSESSMENT

### 4.1 Geometric Stereo Model

In conventional photogrammetry, the base-height ratio (B/H), which is defined as the ratio of the baseline of a stereo pair to the average flying height above ground level, is used to represent the stereo acquisition geometry and to predict the geometric accuracy. However, a major disadvantage is that this is valid only for stereo models which have no roll. Compared to standard in-track stereo imaging, high resolution satellite pointing camera systems provide a variety of stereo geometries. Thus, a geometric stereo model is necessary to analyze the relationship between the stereo acquisition geometry and the geometric accuracy in a variable stereo model geometric environment (Cain, 1989).

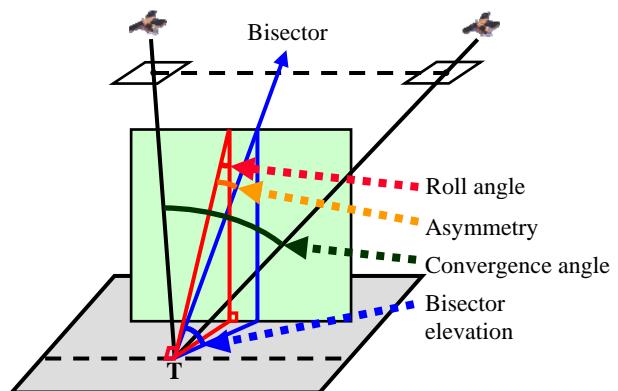


Figure 3. Representation of geometric stereo model

Figure 3 shows the geometric stereo model which is used in this study. The stereo model can be expressed by four parameters, roll angle (RA), asymmetry angle (AA), convergence angle (CA) and bisector elevation angle (BIE). The roll angle is the angle between the epipolar plane and the local vertical, which represents the rotation of the epipolar plane about flight line between satellite cameras. The asymmetry angle is the angle between the bisector of the convergence angle and the projection of the local vertical onto the epipolar plane. The convergence angle is the angle in the epipolar plane between the two rays from the perspective centers of satellite cameras to the certain ground target point. And the bisector elevation angle is the angle between the horizontal plane at the target ground and the bisector ray in the epipolar. In this study, the four parameters are used together with the B/H ratio to analyze their relationship to the geometric accuracy of the DSMs and orthoimages.

## 4.2 Results and Discussions

22 GCPs measured by VRS-GPS are used as check points to evaluate the geometric accuracy of DSMs and orthoimages in vertical and horizontal directions. Table 2 shows the accuracy results of the DSMs and orthoimages generated from cross-track stereo pairs, and the corresponding stereo acquisition geometry parameters. Table 3 shows the accuracy results of the DSMs and orthoimages generated from mixed satellite stereo pairs, and the corresponding stereo acquisition geometry parameters. From table 2 and table 3, it can be seen that high accuracy DSMs and orthoimages can be acquired by using the Pixel Factory system, and the effect of systematic error is removed by using 1 GCP.

	I1I2	I1I3	I1I4	I2I4	I3I4	Q1Q2	I2I3
RA	15.3	9.7	2.6	1.5	2.3	9.0	6.1
AA	18.8	9.1	12.6	8.1	8.2	6.4	3.8
CA	11.2	35.8	31.8	24.1	9.3	27.7	30.8
BIE	65.9	76.7	77.1	81.8	81.5	78.9	82.8
B/H	0.25	0.67	0.59	0.43	0.14	0.51	0.55
STDV(Dxy)	0.63	0.86	1.04	0.69	1.3	0.59	0.65
RMS(Dxy)	1.7	1.42	1.8	1.46	1.75	1.4	1.18
STDV(Dh)	3.04	1.93	2.34	1.63	8.76	0.8	1.18
RMS(Dh)	3.27	1.96	2.66	2.74	8.77	1.45	1.72

Table 2. Accuracy results of generated DSMs and orthoimages from cross-track stereo pairs

	I1Q1	I1Q2	I2Q1	I2Q2	I3Q1	I3Q2	I4Q1	I4Q2
RA	11.0	7.1	12.1	2.5	8.8	4.5	4.1	1.1
AA	3.6	18.6	1.2	15.7	5.3	0.7	10.4	3.8
CA	45.8	18.4	34.8	8.6	30.0	23.1	22.7	15.8
BIE	78.4	70.2	77.8	74.1	79.7	85.4	78.8	86.1
B/H	0.88	0.37	0.67	0.16	0.53	0.4	0.44	0.27
STDV(Dxy)	0.79	0.81	0.98	3.46	0.98	0.6	1.14	0.75
RMS(Dxy)	1.43	1.79	1.57	4.76	2.04	1.21	2.05	1.59
RMS(Dh)	2.52	3.88	3.09	30.0 4	4.31	2.86	5.52	6.16
RMS(Dh)	2.73	4.06	3.61	29.7 8	4.88	2.84	5.4	6.07

Table 3. Accuracy results of generated DSMs and orthoimages from mixed satellite stereo pairs

There are six cross-track stereo pairs in table 2 and 8 mixed satellite stereo pairs in table 3. In table 2, besides 5 IKONOS

cross-track stereo pairs and 1 QuickBird cross-track stereo pair, 1 in-track IKONOS stereo pair, i.e. I2I3, is used to provide a reference for geometric accuracy comparison.

The geometric accuracy is assessed from horizontal and vertical direction, respectively. Regarding the horizontal accuracy, it turns out that there is no significant difference among the in-track IKONOS stereo pair, IKONOS and QuickBird cross-track stereo pairs, and mixed satellite stereo pairs. For cross-track stereo pairs, the I1I4 shows relatively lower accuracy due to the difference of image quality caused by the large time interval of image acquisition. Also, it is confirmed that although the stereo acquisition geometry has the tendency to influence the accuracy to some degree, the accuracy does not degrade so much even if the B/H ratio is small. For mixed satellite stereo pairs, it is noticed that the accuracy changes considerably with the change of the stereo acquisition geometry. If the B/H is too small, the accuracy degrades drastically. Moreover, the influence of the bisector elevation angle can be confirmed in the case of that the B/H ratios of two stereo pairs are almost same.

In comparison with the horizontal accuracy results, the stereo acquisition geometry exerts a remarkable influence on the vertical accuracy. In the case of cross-track stereo pairs, the accuracy degrades when the B/H ratio becomes small. In the case of mixed satellite stereo pairs, since the altitude of IKONOS and QuickBird satellite are much different, the geometrical relationship of a satellite stereo pair exerts a critical influence on the accuracy. Not only the B/H ratio is one of the main factors that affect the accuracy, the bisector elevation angle is also an important factor. Moreover, from the accuracy results, it is confirmed that if the stereo acquisition geometry is good, the same level accuracy compared with the in-track stereo pair can also be obtained by both the cross-track and mixed satellite stereo pairs.

## 5. CONCLUSIONS

In this study, the in-track, cross-track and mixed satellite stereo combinations of high resolution IKONOS and QuickBird satellite images are utilized to generate DSMs and orthoimages. The geometric accuracy for all combinations is assessed, and the relationship between the stereo acquisition geometry parameters and the geometric accuracy is analyzed. It is confirmed that if the stereo acquisition geometry is relatively good, the same level accuracy compared with an in-track stereo pair can be obtained by cross-track and mixed satellite stereo combinations. It is shown that although the factors such as large time interval of image acquisition, seasonal change of land cover, and the difference of image quality have the tendency to influence the accuracy to some degree, they are not the main factors. The stereo acquisition geometry of satellite stereo pairs exerts a critical influence on the geometric accuracy. Also, the effects on accuracy degradation exhibit different trends in cross-track stereo pairs and mixed satellite stereo pairs. Although further analysis is necessary by using more satellite images and test fields, the assessment results showed the great potential of using cross-track and mixed satellite stereo images for spatial information collection.

## References

- Cain, J., 1989. Stereomodel Acquisition Geometry. Ph.D. thesis, U.C. Berkeley.

Kelly, P., 2007. Role of Spatial Data Infrastructures in Managing Our Cities. International Federation of Surveyors Commission 3 2007 Annual Meeting and Workshop “Spatial Information Management Toward Legalizing Informal Urban Development”, Athens, Greece, 28-31 March 2007.  
[http://www.fig.net/pub/monthly\\_articles/may\\_2007/may\\_2007\\_kelly.html](http://www.fig.net/pub/monthly_articles/may_2007/may_2007_kelly.html).