ENHANCING THE PROSPECTS FOR MAPPING FROM HIGH-RESOLUTION SATELLITE IMAGERY IN THE DEVELOPING WORLD

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ABSTRACT:

High-resolution satellite imagery (HRSI) has demonstrated the capability of generating orthoimagery and DTMs that meet topographic map specification to 1:10,000 scale. Moreover, the generation of image-derived products from HRSI requires very little in the way of ground survey data, thus making this imagery an ideal mapping tool for the developing world. However, the cost of HRSI remains a significant factor limiting its application for large-scale mapping where metric tolerance are most stringent. Taking IKONOS imagery as an example, base-level, 15m accurate (CE90) *Geo* imagery sells for about $US 20/km^2, whereas the 4m accurate *Precision* image product can cost upwards of $US 120/km^2 in Africa and Asia. A very attractive proposition for mapmakers in the developing world, therefore, would be to have the capability of generating the metre-level accuracy of *Precision* imagery at the price of base-level *Geo* imagery.

This paper addresses the means to realize this prospect through discussion of the results of experimental testing of stereo IKONOS *Geo* imagery in Northern Thailand. Geopositioning accuracy to better than 1m RMS in planimetry and around 1.3m in height was achieved with very few control points. The technique of bias-compensated rational functions was applied, along with a second sensor orientation model, using 6-8 ground control points. This produced geopositioning accuracy that met map specifications at 1:10,000 scale. The paper highlights that lowest-cost HRSI products can meet the large-scale mapping needs of developing countries, thus leading to a more economical means of providing this important spatial data infrastructure component.

1. INTRODUCTION

High resolution satellite imagery such as 1-m resolution IKONOS has generated much interest in the mapping and geo-information community in Thailand. To date, any mapping project using aerial photographs must seek permission from the military, the Royal Thai Survey Department (RTSD), who also control all the processes from taking the photographs through to archiving and distributing the data. Although lately control has been relaxed, the time period required before users get the data is still quite considerable. The availability of HRSI in the international market, coupled with the promise of fast data delivery, is much welcomed by users. However, for a large mapping project the price of HRSI may not be as competitive at present as aerial photograph, though this is still the subject of much debate.

There are situations in which HRSI clearly has advantages over aerial photographs. An example in the Thai context is the mapping of small remote areas, especially those close to national borders where mobilization of airplanes can be very expensive and flying airplanes is normally prohibited by the Government in these regions. Another example is the mapping of islands and off-shore natural resources such as coral reefs. There are more than 400 coral reefs in Thai waters and a substantial portion of the economy, particularly fishing and tourism, are underpinned by these resources. Again the problem here is either the high cost of mobilizing the plane to take only a few photographs or the inaccessibility of the areas, which may lie too close to border areas. As a result, there are areas where large and medium scale maps are non-existent. Using satellite imagery is arguably the only practical way to remedy the situation. But spatial resolution provided by previous generation spaceborne imaging systems such as Landsat or SPOT is too low for many mapping purposes. For example, in the case of coral reef mapping, a study by Trisirisatayawong and Samanloh (2003) that used Landsat 7 imagery to detect small shallow-water coral reefs which are the majority type in Thailand, showed that only limited success can be achieved and higher spatial resolution imageries are required for more detailed reef mapping. HRSI exhibits significant spectral advantages over lower resolution satellite imaging systems such as Landsat and Spot, as well as strong geometric capabilities that previously have not been available. These include much better photogrammetric stereo capability and a higher revisit rate (Li, 1998).

A large number of technical papers have demonstrated the metric capability of HRSI for large scale mapping. A user can opt for off-the-shelf image products such as 4-m accurate (CE90) *Precision Plus* IKONOS imagery provided by Space Imaging. The users, however, have to supply ground control points to the company. Alternatively, users can purchase less accurate but also less expensive products such as *Geo* or *Reference* and get more accurate output by applying further processing themselves. In a country of low-wages, but with a solid technological base, like Thailand, the latter approach seems to be more attractive. The gain from purchasing cheap product can easily offset the cost incurred from extra data processing.

This paper addresses the means to realize this prospect through discussion of the results of experimental testing of stereo IKONOS *Geo* imagery in Northern Thailand. The paper reports positional accuracy of products generated from IKONOS stereo images by applying a bias-correction technique as described below. Result from a second sensor orientation model are also shown.

2. METHODOLOGY

Obtaining three dimensional coordinates from two dimensional images requires that the position and orientation of the images in space are known. However, although exterior orientation parameters of IKONOS imageries are measured onboard, they are withheld. To get around this problem, other mathematical models are used instead of a rigorous model. A review of replacement sensor models, which are mainly in the form of polynomial or ratio-of-polynomial equations, can be found in Tao et al (2000) and Tao and Hu (2001).

Space Imaging supplies rational polynomial coefficients (RPCs) for photogrammetric processing by the imagery user. The RPCs describe the relationship between the image and object space and can be considered as a replacement model for the modified collinearity equations which are widely used for line scanner imagery. The model for 'forward' rational functions for image i and ground point j can be given as (Fraser and Hanley, 2003):

$$x_{ij} = \frac{P_{i1}(X,Y,Z)_j}{P_{i2}(X,Y,Z)_j}$$
$$y_{ij} = \frac{P_{i3}(X,Y,Z)_j}{P_{i4}(X,Y,Z)_j} \qquad (1)$$

where x_{ij}, y_{ij} = image coordinates
$(X,Y,Z)_j$ = corresponding ground coordinates
$P_{i1} - P_{i4}$ = 3rd degree polynomial functions

The absolute accuracy derived from IKONOS stereo pairs without ground control points (GCPs) at *Reference* level is 25m (CE90) horizontal and 22m (LE90) vertical (Space Imaging, 2002). Using RPCs supplied by Space Imaging, Ager (2003) measured coordinates on IKONOS stereo pairs over 14 test sites in various countries and reported an average of 7.9 m horizontal error (CE90) and 7.6 vertical error (LE90). An initial test conducted by the authors on a stereo pair of Chiengmai, Thailand showed an RMS error of about 7 m. These results are far better than the stated specifications from Space Imaging.

While the accuracy attained is impressive, further improvement can be achieved. As shown in Figure 1, the error vectors which represent the differences between horizontal coordinates obtained from stereo measurement and those accurately determined from GPS measurement indicate the presence of systematic error. Since the pointing error during stereo measurements is much smaller than the resulted systematic errors, it means that the supplied RPCs must contain biases. Corrections must be applied somewhere along the processing line.

The removal of systematic errors can occur at the end using simple 2D transformation to correct the image product. Alternatively, the bias correction of RPCs may be done first, before the other steps of product generation. The latter approach seems more attractive because the correction is carried out at the beginning of the mapping process and so the accuracy of all intermediate products such as DEM are guaranteed. The bias correction technique used in this research is detailed in Fraser and Hanley (2003) and will be briefly described below.

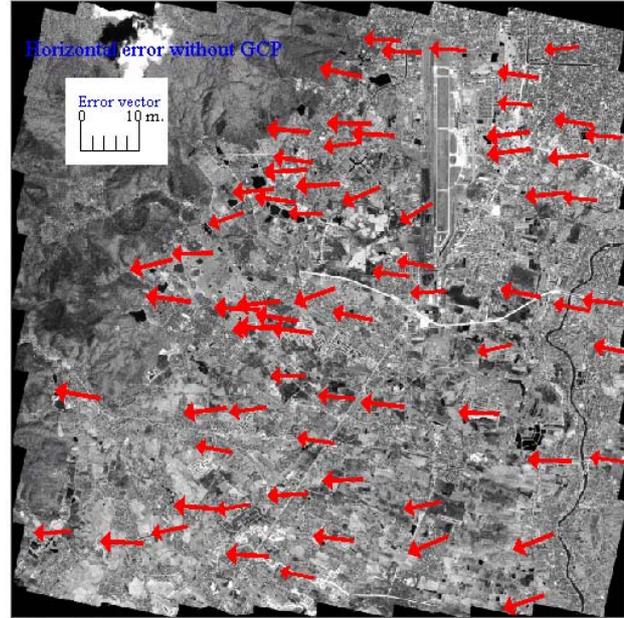Horizontal error without GCP
Error vector
0   10 m.

Figure 1. Error vectors at check points.

Under the assumption that RPC biases manifest themselves for all practical purposes as image coordinate shifts, a model for spatial intersection with bias compensation, which comprises one offset parameter per image coordinate, can be derived as follows

$$\begin{bmatrix} v_x \\ v_y \end{bmatrix}_{ij} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 1 & 0 \\ a_{21} & a_{22} & a_{23} & 0 & 1 \end{bmatrix}_{ij} \begin{bmatrix} \delta X_j \\ \delta Y_j \\ \delta Z_j \\ \Delta x_i \\ \Delta y_i \end{bmatrix} + \begin{bmatrix} x^0 - x \\ y^0 - y \end{bmatrix}_{ij} \quad (2)$$

where v_x and v_y are observational residuals in pixels; $\delta X_j, \delta Y_j, \delta Z_j$ are corrections to approximate values for the object point coordinates; $\Delta x_i, \Delta y_i$ are image coordinate perturbations or biases that are common to image i; x^0, y^0 are the image coordinates corresponding to the approximate object coordinates; $a_{11}, a_{12}, ..., a_{23}$ are partial derivatives of the functions in (1) with respect to X, Y and Z; and x, y are the measured image coordinates

Only one GCP is required in solving the bias parameters in (2). The process has been carried out via the Barista software developed by the photogrammetry research team at the University of Melbourne. Bias-corrected RPCs were written into another file using the same format as supplied by Space

Imaging. The Erdas Imagine photogrammetric software package was then used to automatically generate both a DEM at the resolution of 10m, and an orthorectified image from the near-nadir IKONOS image. Figure 2 outlines the procedure.
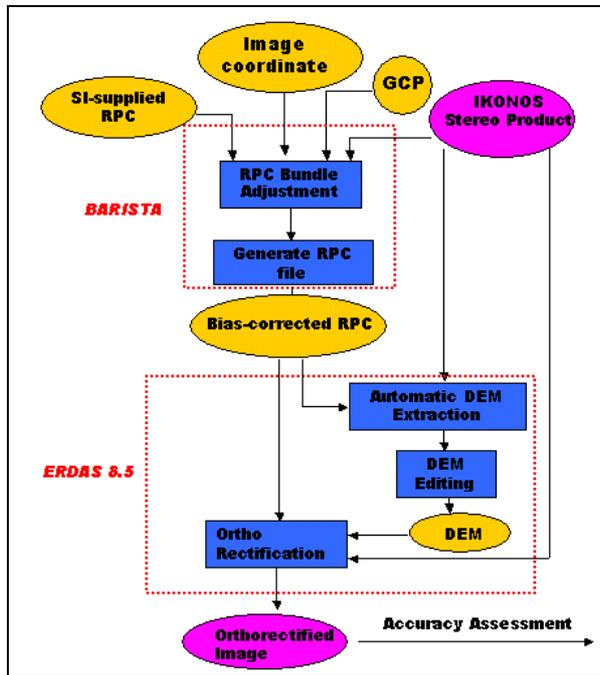

Figure 2. Processing steps and the software tools.

3. TEST FIELD AND THE STEREO PAIR

3.1 Chiengmai Test Field

The city of Chiengmai was selected as a study area for the evaluation of HRSI metric accuracy for large-scale mapping. The city is the second largest in the country and is situated about 700 km north of Bangkok near the foothills of Doi Suthep. The test field covers an area of about 120 sq. km of the south-western portion of the city including the airport. The test area is relatively flat with only about 60m of height variation. Since all major urban areas in Thailand are also flat, the test field was considered as well representative for the evaluation.

3.2 The IKONOS Stereo Pair

A stereo pair of IKONOS images were provided to the research team by GISTDA. Table 1 summarizes relevant information from the image metadata file.

Details	Left Image	Right Image
Acquisition Date	17 Mar 2001	17 Mar 2001
Local Acquisition Time	10:57	10:56
Collection Azimuth	182.0105^o	55.733^o
Collection Elevation	64.27186^o	83.04073^o
Sun Angle Azimuth	127.8738^o	127.6030^o
Sun Angle Elevation	59.16122^o	59.00376^o

Table 1. Information about the test IKONOS images.

3.3 GCPs and Check Points

Initially, a total of 101 well-defined points throughout the images were selected and their image coordinates measured by manual pointing. Corresponding ground coordinates were measured by a combination of rapid static and real-time kinematic GPS techniques using three Leica SR530 GPS receivers. The quality of estimated GPS coordinates is about 0.1m or better, though correspondence of the measured feature point with the image feature point was probably at about the 50cm level. Figure 3 shows an example of these selected points.

Figure 3. Left: A well-defined point on the image. Right: Corresponding point measured by GPS on the ground.
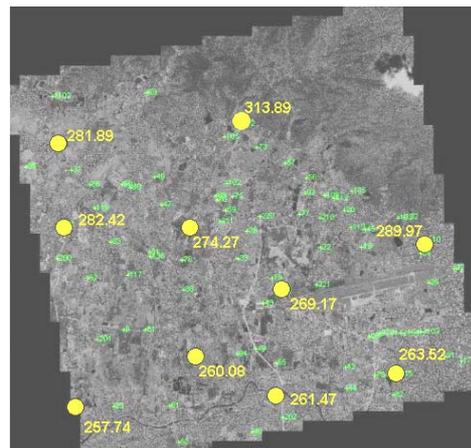

Figure 4. GCPs and check points.

Points with large standard deviation were discarded to ensure the integrity of estimated coordinates. There were also points which could not be determined on the ground with confidence and these points were discarded. The remaining 81 points were divided into two groups, 10 points as GCPs and the other 71 points as check points. Figure 4 shows the distribution of these points.

4. RESULTS FROM BIAS-CORRECTION

Different combinations of GCPs were used in bias-compensation followed by DEM and orthoimage generation. The coordinates of checkpoints on the products were measured and compared with those obtained from GPS. Table 2 lists the results.

RMSE	Number of GCPs			
	1	3	6	10
Horizontal	0.959	0.979	0.992	0.951
Vertical	1.319	1.263	1.284	1.302

Table 2. Accuracy obtained from different number of GCPs.

It can be seen that there is no significant difference in the RMSE with varying numbers of GCPs. In all cases it can be seen that IKONOS imagery with bias-corrected RPCs produces RMS error of around 1m in planimetry and 1.3m in height. The approach yielded accuracy surpassing specifications for the much more expensive *Pro* and *Precision* products. The accuracy obtained is around the same as *Precision Plus*, which is the most accurate product provided by Space Imaging.

Further investigation was undertaken by fixing the number of GCPs at three and varying their location, as shown in Figure 5. Three different cases were investigated: i) all points at the center, ii) all points at different corners, and iii) all points in the same corner. From table 3, case III produces less desirable results as compared with the other two, but such a GCP arrangement may be necessary in particular cases such as mapping over the national border where GCPs can only be established on one side.
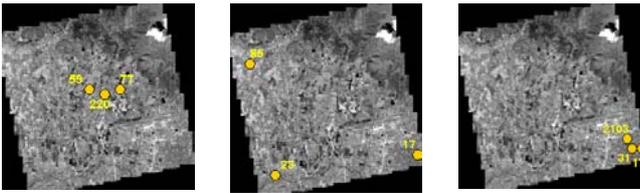

Figure 5. Three different configurations of GCPs.

RMSE	Case I	Case II	Case III
Horizontal	0.951	0.902	1.247
Vertical	1.302	1.229	1.305

Table 3. Accuracy obtained from the cases in Figure 5.

5. ALTERNATIVE SENSOR MODEL FOR RPC

In instances where RPCs are not provided, eg with standard IKONOS Geo image products, further alternative orientation models need to be considered. Once such model is based on affine projection (Fraser et al, 2003). The general form of the model describing transformation from 3D object space (*X, Y, Z*) to 2D space (*x, y*) for a given point *i* within an image is given as

$$x_i = A_1 X_i + A_2 Y_i + A_3 Z_i + A_4$$
$$y_i = A_5 X_i + A_6 Y_i + A_7 Z_i + A_8 \quad (3)$$

The affine model can be considered as a special case of the more general rational function model where the polynomial degree is one and the denominator is also one. The coefficients A_7 and A_8 can be interpreted as translation parameters. The A_1, A_2, A_3, A_5, A_6 and A_7 coefficients contain combined effects of rotation and scale. Despite its simplicity, which may raise a degree of suspicion, recent research by Fraser et al (2002) has shown that this model can produce high geopositioning accuracy comparable to that produced via RPCs for IKONOS *Geo* imagery..

The attractive feature of this approach is that no RPCs need to be purchased and this leads to an even more economical means of acquiring and using HRSI. The tradeoff is that more GCPs are required. As can be seen in (3), at least four GCPs are required versus one in the case of bias-correction described in Section 2. However, in the case of mapping remote areas, the major portion of cost of the ground measurement is to get there. Since GPS measurement techniques are now very efficient, establishing a few more control points does not necessarily generate substantially more cost. Another favourable feature of this approach, especially when using Barista software, is that whenever RPCs are required they can easily be generated.

Three different sets of 6 GCPs with 75 check points were tested with the affine model and all yielded almost identical results. The planimetric accuracy was just above 1m while vertical was again around 1.3m. These results are effectively the same as obtained from the bias-correction method in Table 2.

6. CONCLUDING REMARKS

This paper has highlighted that lowest-cost HRSI products can meet large-scale mapping needs of developing countries. The experimental results clearly demonstrate the capability of HRSI for large-scale mapping. In metric terms, a 1:10,000 scale topographic map can be derived from IKONOS imagery and even up to a 1:5,000 scale line map can also be produced. In the test reported, however, the resulting RMS errors were only just below the threshold and thus could be considered a little too close to allowable tolerance limits for 1:5,000 mapping.

Apart from metric quality, factors such as whether the desired features at the required scale can be clearly identified on the source images need to be taken into consideration. Though this topic was not addressed in the current research, it is worthwhile to note that this user requirement is no less important than the metric accuracy. It should also be emphasised that results shown in this paper are from the use of only one stereo-pair. Further evaluation of both metric and non-metric aspects of HRSI is warranted, particularly on the larger blocks of overlapping imagery that are often the case in real-world mapping projects.

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