HANDLING OF HIGH RESOLUTION SPACE IMAGES IN Z/I IMAGESTATION

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ABSTRACT:

High resolution space images are becoming more and more important as their resolution and availability improve. Images having a ground pixel size of 0.6 m or 1.0 m are competing with classical aerial photos. The space images cover large areas, reducing the number of control points needed. If rational polynomial coefficients (RPC) are available, the number of control points can be reduced even further. Using RPCs, mapping is also possible without control points if only relative accuracy is required, and if an absolute accuracy in the range of a standard deviation of ±12 m is acceptable.
Stereo models and individual images taken by IKONOS, QuickBird and SPOT 5 have been analyzed, as well as IRS-1C level 1B and Landsat images. The achieved accuracy is sufficient for mapping and orthoimage generation. Digital surface models (DSM) are generated by image matching, showing the height of the visible surface. DSMs can be reduced to digital elevation models (DEM), which can be used for producing orthoimages. It is not necessary to use the same sensor for achieving the DEM, so it is possible to compute an IKONOS orthoimage based on a SPOT 5 DEM.

1. INTRODUCTION

With a ground pixel size of 0.6m for QuickBird and 1m for IKONOS images, there is now direct competition between high resolution space images and aerial photos with a scale of 1:50,000 to 1:80,000. QuickBird images have a swath width of 16.5 km. This can only be achieved with aerial images at a scale of 1:80,000 from a flying height of 12.2 km, with view directions that are not optimal for the generation of orthoimages. In addition, digital images are not influenced by film grain, resulting in better radiometric quality. In the near future, several high resolution optical space systems will be put in operation, resulting in improvements in the resolution, availability, variety, and cost of space images. This will cause a permanent growth in the use of space images for mapping.

2. IMAGESTATION DIGITAL MENSURATION (ISDM) SATELLITE TRIANGULATION

ISDM Satellite Triangulation is a flexible, modular extension to the Z/I Imaging ISDM product. It performs analytical block adjustment of satellite images using fundamental, well-established photogrammetric techniques. At the core is a block adjustment engine that performs a unified, weighted, simultaneous least squares adjustment of ground point coordinates and image parameters. This core is coupled with modules that implement mathematical models for various remote sensors. This allows support for new satellite remote sensor types to be developed and added with relative ease.

The block adjustment engine is flexible. It accommodates variations in the number and scope of adjustable parameters associated with satellite images. These parameters can be the 12 well-known exterior orientation parameters (satellite position, satellite velocity, satellite attitude bias, and satellite attitude bias rate), or some other number, depending on what is needed to support the particular remote sensor type. Parameters can be associated with all images for a particular remote sensor, with all images in a single data acquisition scene, or with individual images. Table 1 lists the number and scope of parameters for the currently implemented satellite remote sensor types.

The mathematical model used for a particular satellite remote sensor is implemented in a Microsoft Common Object Model (COM)-based code module. A remote sensor module calculates image-to-ground projections, ground-to-image

Remote Sensor Type	Parameters	Scope of orientation parameters
SPOT 1-5 Level 1A Multispectral (ms), Panchromatic (pan), & Supermode pan	12 Satellite EO Parameters: Position X, Y, Z Velocity Vx, Vy, Vz Attitude Bias Ω, Φ, K Attitude Bias Rate Vω, Vφ, Vκ	Scene composed of all images from a single orbit pass
QuickBird Basic Imagery, pan & ms	12 Satellite EO Parameters	Scene
IRS-1C & 1D Level 1A pan	12 Satellite EO Parameters	Scene
Landsat TM ms Landsat7 ETM+ ms & pan	12 Satellite EO Parameters	Image
IKONOS (CARTERRA Geo) pan & ms	6 Affine Parameters: Line bias, drift, scale Sample bias, drift, scale	Image

Table 1: Parameters for ISDM Satellite Triangulation Sensor Types

projections, and parameter partial derivatives for use by the block adjustment engine. By encapsulating the math model in COM modules, ISDM Satellite Triangulation is easily adapted to work with many different models. The modules developed by Z/I Imaging for use with Landsat, SPOT, IRS, and QuickBird images all implement rigorous collinearity-based mathematical models. The module developed for IKONOS images implements a mathematical model based on rational polynomial functions modified by an affine transformation using control points (Grodecki, J., 2001 and Fraser, et al, 2001).

2.1 Rational Functions

While the satellite triangulation itself may be performed using a variety of mathematical models, third-order rational polynomial functions are used as a sensor independent math model for working with satellite images within the Z/I Imaging suite of products (Madani, 1999). These rational polynomial functions have the form:

$$r_n = \frac{p_1(X_n, Y_n, Z_n)}{q_1(X_n, Y_n, Z_n)}, \quad c_n = \frac{p_2(X_n, Y_n, Z_n)}{q_2(X_n, Y_n, Z_n)} \tag{1}$$

where r and c are the row and column of an image point, X, Y, Z are coordinates of an object point, and p_1, p_2, q_1, q_2 are third-order polynomials in X, Y, and Z. These polynomials have 20 terms each.

By setting selected coefficients to zero, the power of the rational functions can vary for each dimension as well as for the numerator and the denominator. In fact, by setting all non-constant denominator coefficients to zero, the rational functions can be reduced to polynomial functions.

It is not uncommon to encounter coordinate systems with extremely large coordinate values. If, in addition to large coordinates, a relatively high-order polynomial is employed, numerical instability or overflow can occur. In order to avoid such problems, a normalization scheme has been implemented. Each object point coordinate variable is normalized to a range of -1 to 1 before they are used in the rational polynomial functions. The ranges of the rational polynomial functions are also –1 to 1, so the final row and column values are obtained by "de-normalizing" the results.

Image-to-ground calculations are performed using a remote sensor module in order to populate a regular grid that captures the mapping between image coordinates and ground coordinates at different ground elevations. This grid is then used to produce RPCs that approximate the mapping from ground coordinates to image coordinates. Initial RPCs are produced for each image as its photo is created within ImageStation Project Manager (ISPM) or ISDM. After triangulation has been performed on one or more images, new RPCs are produced for the images using the adjusted values of the satellite image parameters. The initial or adjusted RPCs are used by ISDM and other applications when measuring points on images, creating stereo views, etc.

3. ISDM SATELLITE TRIANGULATION WORKFLOW

3.1 Project Initialization

The general ISDM Satellite Triangulation workflow begins with creating a new project. When the New Project command is executed in ISPM or ISDM, the "New Project" wizard guides the user through the project creation process. If the user selects a project type of "Satellite Imagery", the project is configured for use with the Satellite Triangulation block adjustment engine and the currently registered remote sensor modules. It is important to note that Satellite Triangulation projects are currently configured to use a WGS84 geographic coordinate system with an ellipsoidal vertical datum, and all functions are performed within that coordinate system basis. Once the project has been created, the Edit Photos command is used to create photos from satellite images and their associated support data files (Figure 1). These images have been processed using the

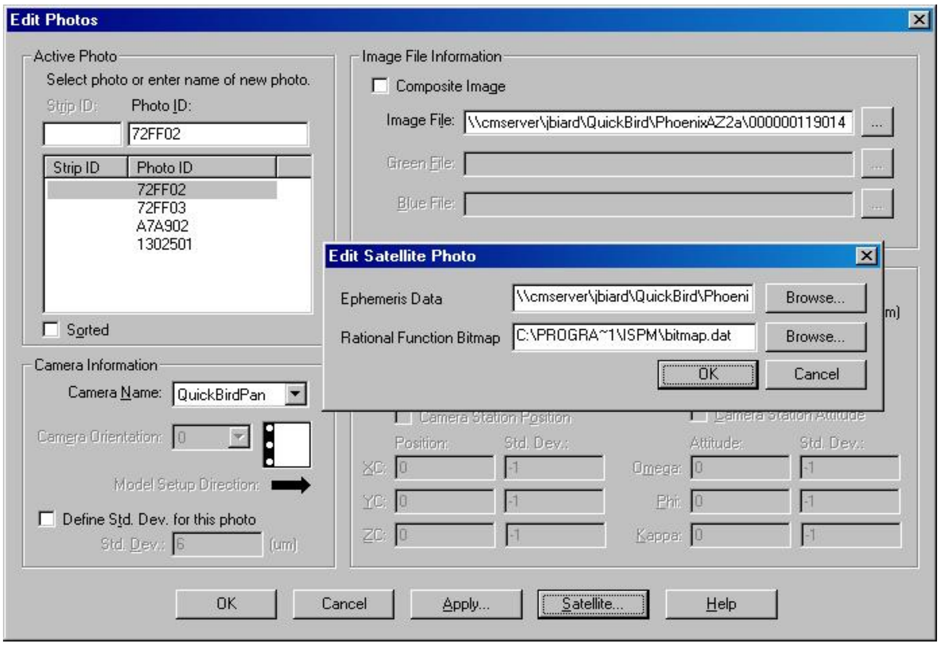

Figure 1: Edit Photos Dialog

Z/I Imaging Image Translators and Raster Utilities in order to prepare them for use within the ImageStation application suite. As each photo is created, it is associated with a particular remote sensor type, and initial RPCs are calculated for it and stored in the project photo file. The support data files for each image are copied from their original locations to a subdirectory within the project directory. An initial grid file is also produced and stored with the support data files. A rational function bitmap file is also associated with a photo when it is created. This bitmap file specifies which terms in the rational polynomial functions will be used, and which corresponding parts of the RPCs will be calculated by the software when working with the photo.

The final step in project initialization is the collection of control and check points. Ground point coordinates are stored within the project as longitude-latitude-elevation triplets. The longitude and latitude are represented in degrees/minutes/seconds in a quasi-decimal format (dd.mmssssss), and the elevation is represented in meters. Control and check points may be entered manually using the Edit Control Points command, or they may be imported from files in a variety of formats. When importing, it is possible to specify a coordinate system and/or units for the incoming points that is different from that of the project. In that case, the points will be converted into the project WGS84 ellipsoidal system and units as they are imported.

It is also possible to capture control and check points using map photos. Map photos are orthoimages or scanned topographic maps that have been geo-referenced. If map photos are created within the project, they can be used to obtain control and check point coordinates, either with or without the use of digital elevation models (DEMs). The control and check point coordinates are automatically converted from the coordinate system of the map photo to that of the project.

3.2 Measurement and Triangulation

After the project has been initialized, the Multiphoto command is used to measure control, check, and tie points on the project photos (Figure 2). The Multiphoto command allows the user to display multiple photo images simultaneously, and to display stereo views of overlapping regions. Unmeasured control and check points are displayed on the images in the locations predicted for them by the photo RPCs. The user measures the actual locations of the control and check points within the images, and measures tie points by marking the locations of a ground point in multiple images.

Once control, check, and tie points have been measured, the Satellite Triangulation command can be used to perform triangulations on photos, either singly or in blocks (Figure 3). As mentioned in the previous section, the block adjustment engine in combination with the appropriate remote sensor modules is used to perform the adjustment of the selected photo or block of photos. The Satellite Triangulation dialog displays a variety of statistics about the adjustment, as well as detailed lists of the residuals for the photo and ground points. If the user is not satisfied with the results, points may be withheld or deleted on the photos or on the ground, and the adjustment can be repeated. If the user decides to accept the results, new photo

Figure 2: Multiphoto Dialog

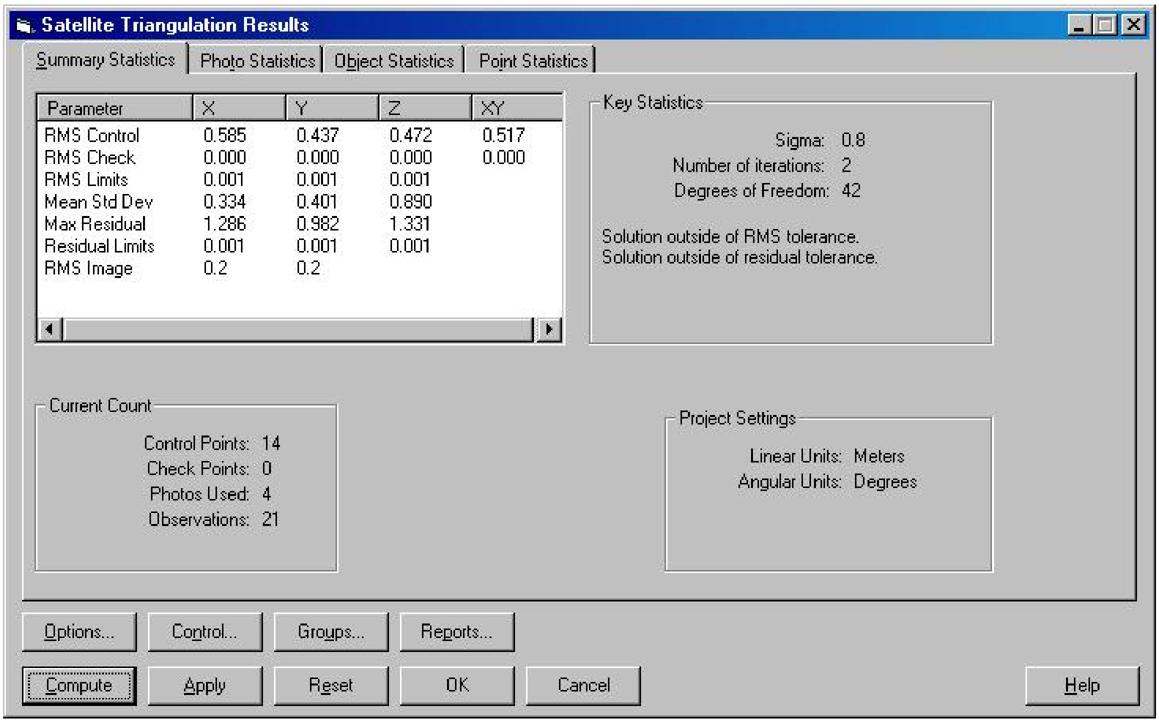

Figure 3: Satellite Triangulation Dialog

RPCs will be calculated for all photos in the block. The user may also exit the Satellite Triangulation dialog without accepting the results or calculating new photo RPCs. Using the Multiphoto and Satellite Triangulation commands, the user can withhold, delete, re-measure, or add points as needed until satisfactory results are obtained.

4. EXPERIENCES

Single images or stereo models can be oriented without problems. Satellite orientation information has achieved a high level of accuracy, but in most cases it must still be improved upon through the use of ground control points. The orientation of CARTERRA Geo (IKONOS) scenes uses RPCs distributed by Space Imaging and improves upon them by an affine transformation applied to the image coordinates of control points. The number of transformation unknowns can be changed, so it is possible to reduce the transformation to a shift in X and Y.

In several cases a simple shift is completely sufficient (see Büyüksalih et al 2004), so in theory just one control point would be enough. Of course, overdetermination of the system is required to produce reliable results. An advantage of satellite triangulation is the combination of several images. Blocks of satellite images can be handled similarly to aerial photos. In Madani 1999 the handling of a block of 12 SPOT scenes is described in detail. By using tie points, the number of ground control points can be reduced.

Internal handling of space images by means of rational polynomial functions makes it quite easy to handle images with special geometric relationships. Only the mathematical model for the orientation has to be changed. The use of rational polynomial functions during model handling does not result in any loss of accuracy compared to the use of a rigorous mathematical model.

5. DIGITAL ELEVATION MODELS

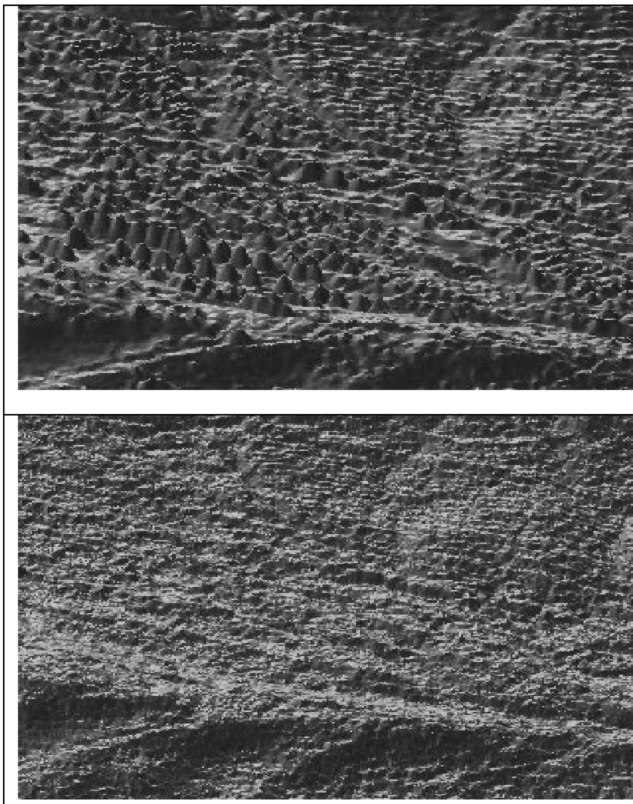

Figure 4:
Above - DSM determined by matching of IKONOS images
Below – DSM filtered to DEM

A digital model of the elevation of the visible surface, known as a Digital Surface Model (DSM), can be generated from satellite images through the use of automatic image matching. However, a digital model of the elevation of the bare earth, or DEM, is what is usually requested. In some cases and depending upon the applications and accuracy requirements, a manual reduction of a DSM to a DEM is too time consuming, but this step can also be done automatically by qualified filtering (Jacobsen 2001). A sequence of geometric tests can be used to detect and remove the points located above the bare earth. The model is classified as flat, rolling or mountainous and the required tolerance limits are determined by data analysis (Figure 4).

When doing automatic image matching with high resolution space images it is important to have images acquired under similar conditions – similar sun elevation and atmospheric conditions, and no change of the object. This is best achieved using images acquired during a single orbit. If this is not the case, problems with automatic image matching cannot be avoided, and matching may fail entirely. The DSM shown in figure 5 is based on IKONOS images acquired 12 seconds apart. Most of the points have been correlated with a correlation coefficient exceeding 0.95. On the other hand, matching of an IKONOS image pair acquired three months apart with a change of sun elevation from 67° to 42° failed nearly entirely. Some modestly accurate results were obtained in built-up areas. A time interval as short as 12 seconds is not usually necessary, so two QuickBird images acquired 10 days apart produced good results.

6. CONCLUSIONS

Mapping with high resolution space images is becoming more and more important. For several applications there is direct competition between aerial and space images, and the choice of which product to use is purely economic. Satellite triangulation is integrated in the Z/I ImageStation application suite, allowing individual images or blocks of images to be rectified. By processing blocks, the number of ground control points can be reduced and misalignments between neighboring images will be avoided.

REFERENCES

Büyüksalih, G., Oruc, M., Jacobsen, K., 2004. Precise Georeferencing of Rectified High Resolution Space Images, ISPRS Congress, Istanbul 2004

Dowman, I., Dolloff, J.T., 2000. An Evaluation of Rational Functions for Photogrammetric Restitution, ISPRS Amsterdam 2000, IAPRS, VOL XXXIII

Fraser, C.S., Hanley, H.B. and T. Yamakawa, 2001. Sub-metre geopositioning with Ikonos GEO imagery. *Proc. Joint ISPRS Workshop "High Resolution Mapping from Space 2001"*, Hanover, 19-21 September, 8p. (on CD ROM)

Grodecki, J., 2001. Ikonos stereo feature extraction - RPC approach. *Proc. ASPRS Annual Conference*, St. Louis, 23-27 April, 7 p. (on CD ROM)

Jacobsen, K. 2001. New Developments in Digital Elevation Modeling. Geoinformatics, June 2001, pp 18 – 21

Madani, M, 1999. Direct Versus Indirect Methods of Sensor Orientation, workshop of ISPRS Commission III, Barcelona, November 25-26, 1999, (on CD-ROM)