DIGITAL MAPPING USING HIGH RESOLUTION SATELLITE IMAGERY BASED ON 2D AFFINE PROJECTION MODEL

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ABSTRACT

High-resolution satellite imagery is expected to reduce cost for medium and small scale topographic mapping. Because 1m high-resolution satellite imagery has a much narrower field angle, the projection of images is nearly approximated by parallel rather than central one. In this situation, the orientation model based on affine projection is effective for satellite imagery triangulation. Furthermore under the assumption that the satellite attitude is stable and the movement of the sensor position is almost linear, 2D affine projection model is applicable to basic equations for mapping. This paper discusses the application of the 2D affine projection model to high-resolution satellite imagery and SPOT scenes at various terrain area in JAPAN. The first topic is the approach to generate ortho-imagery using the model. The second topic is the real-time image positioning on a softcopy photogrammetric workstations for satellite imagery.

1 INTRODUCTION

Precise digital maps generated from satellite imagery are assuming growing importance in the spatial information industry. For coverage at medium to small mapping scales, satellite line scanner imagery has a number of advantages over aerial photography for topographic mapping, the production of digital ortho-images and the generation of DTMs. These advantages are likely to be further enhanced with high-resolution earth observation satellites like IKONOS. Notwithstanding the practical advantages of satellite imagery, however, the projection of satellite imagery, which is imaged with a CCD line sensor, is quite different from that of conventional aerial photographs. The line scanner imagery has geometry of central perspective in the scan line direction, and close to a parallel projection in the flight direction. Therefore stereo scopic systems are required to special positioning modules for the satellite imagery.

Since SPOT satellite was launched in 1986, many studies has been carried out to implement an accurate positioning control modules of SPOT imagery to analytical plotter. One approach of them is to incorporate the inverse collinearity equations for dynamic satellite imagery in the real-time loop (Gugan, 1987). This approach requires high performance in CPU. Then Kratky (1989) proposed his approach which saves computing time by fitting functions of inverse collinearity equations. Another approach is based on the well-known central perspective model with additional parameters and uses dense look-up tables to correct the image distortions (Konecny at el., 1987). Trinder's approach (1988) is similar to it in point of using standard central perspective equations, but each satellite image is divided into a number of segment 100 image wide. Small distortions in each segment image are corrected by second order polynomial.

In these days, some commercial softcopy photogrammetric workstations implement several satellite imagery modules with these procedures. Almost of them work effectively, but ordinarily requires high level resources to computer. End users operating GIS softwares or Mapping software need lighter software which works on even low-end PC. This paper proposes an alternative high performance procedure for real-time posisioning control of satellite imagery on digital plotting system. The approach is based on 2D affine projection model, which has simple forms (Okamoto et al. 1999)

2 MODELING APPROACH

2.1 Geometric Characteristics of High-resolution Satellite Imagery

1m high-resolution satellite imagery has a far narrower field view angle, one degrees, than mid resolution (5m-10m on the ground) satellite imagery such as one of SPOT. This kind of projection of imagery is better modeled by parallel rather than central one, since if conventional rotation angle based orientation parameters are used, high couplings occur among them. In addition, a satellite moves smoothly along the Keplerian orbit in space, and one scene covers a very small ground area. In such short term, the orientation angles are almost regarded as constant and the flight path of satellite is approximately straight, if Gauss-Krüger coordinate system is adopted as a reference coordinate system (Konecny et al, 1987). These characteristics mean that the collinearity equations between high-resolution satellite imagery and the ground points can be simplified as far as the small area mapping purposes.

2.2 Geometry of Line Scanner Imagery

The projection of a CCD line scanner is one-dimensional central perspective, and each line image has different exterior orientation, though it has high correlation to neighbors. Let exterior orientation parameters for line number i be expressed by coordinates of the projection center, X_{oi}; Y_{oi}; Z_{oi} and angles $\phi_i, \omega_i, \kappa_i$. These parameters are time variant. Many studies have indicated that attitude parameters can be expressed with low-order polynomials in any Cartesian coordinate system. The collinearity equations are described as:

$$0 = a_{11}(X - X_{oi}) + a_{12}(Y - Y_{oi}) + a_{13}(Z - Z_{oi}) \tag{1}$$

$$y = -c\frac{a_{21}(X - X_{oi}) + a_{22}(Y - Y_{oi}) + a_{23}(Z - Z_{oi})}{a_{31}(X - X_{oi}) + a_{32}(Y - Y_{oi}) + a_{33}(Z - Z_{oi})} \tag{2}$$

where (X, Y, Z) is the ground coordinates of an object point, c is principal distance, y is a coordinate of image point in scanning direction, a_{ij} (i=1,2,3; j=1,2,3) are elements of rotation matrix $R_{\phi i}R_{\omega i}R_{\kappa i}$.

Assuming the scene is projected to an image by parallel projection, c can be set to infinity. In this case the second equations can be described as follows:

$$y_a = a_{21}(X - X_{oi}) + a_{22}(Y - Y_{oi}) + a_{23}(Z - Z_{oi}) \tag{3}$$

Where y_a is an affine projection image coordinate in scanning direction. Since affine projection image has actually small distortions, image coordinate y_a must be transformed to a corresponding original image coordinate, y. Now, let ΔZ indicate height difference between the average ground level and object height Z, the relation between y_a and y is given in the form

$$y_a = \frac{y(c + \Delta Z/(\lambda \cos\omega))}{c - y\tan\omega} \tag{4}$$

Where λ is a scale factor. If existing DTMs of observed area are available, this transformation can be previously carried out before on-line mapping.

2.3 2D Affine Projection Model

In small area mapping using high-resolution satellite imagery, we can assume further that the sensor moves linearly in space and the attitude is almost unchanged. The projection center in each line is described as follows:

$$X_{oi} = X_o + \Delta X i \tag{5}$$

With constant X_o and ΔX. The similar expressions are defined likewise for $Y_o i$ and $Z_o i$. Line number i is expressed from Equation 1,

$$i = \frac{a_{11}(X - Xo) + a_{12}(Y - Yo) + a_{13}(Z - Zo)}{a_{11}\Delta X + a_{12}\Delta Y + a_{13}\Delta Z} \tag{6}$$

Here line number i is replaced by image coordinate x in flight direction. Assuming that the attitude does not change, a_{ij} are regarded as constant parameters. Equation 6 arranged for the constant coefficients leads to an algebraic expression.

$$x = A_1X + A_2Y + A_3Z + A_4 \tag{7}$$

Equation 3 is expressed by similarly

$$y_a = A_5X + A_6Y + A_7Z + A_8 \tag{8}$$

where A_j (j=1,• ;8) are independent orientation parameters, which are not time-valiant. Equation 7 and 8 are basic equations of 2D affine model.

3 ADVANTAGES OF 2D AFFINE PROJECTION MODEL

2D affine projection model has superior characteristics due to the simple forms. Firstly, the model is quite robust and stable for image orientation and triangulation even without prior orbit information because of the linearity. Secondly, the higher spatial resolution of satellite imagery become, the more efficient this model will be in point of precision. Okamoto et al (1999) showed with orientation results of SPOT imagery and MOMS-2P one that the precision of this model corresponds well to that of central projection-based method. A further important point is that 2D affine projection model is very suitable for mapping. Image coordinates can be rapidly calculated from giving ground coordinates and orientation parameters.

3.1 Real-time Positioning

Stereo-plotter usually accepts ground coordinates X, Y, Z as input and the corresponding image coordinates are calculated for image positioning controls. In conventional aerial photograph, the image coordinates can be directly calculated by the collinearity equations. On the contrary, as the exterior orientation parameters of satellite imagery are described as a function of the image line number i, which is initially unknown, an initial approximation of image coordinate must be gradually refined by iterations. Whereas the collinearity equations for a pair of aerial photographs require 24 computer multiplications to transform ground coordinates to image coordinates, rigorous 1D central perspective approaches for a pair of satellite images require between 300 and 500 computer multiplications (Gugan, 1987). For the real-time image positioning on digital stereo-plotter, the number of computer multiplications must be reduced.

Fitting to a polynomial equation with small number of terms is an efficient approach (Kratky, 1989). But, 2D affine projection model is faster than Kratky's fitting model. The same process requires only 20 multiplications. If the translations from original imagery to affine imagery are carried out in advance, the number of multiplications is reduced to only 12.

3.2 Generation of Ortho-Image with Existing DTMs

With existing DTMs, ortho-image can be generated from single satellite image. The ground coordinates of object field are given by DTMs and the corresponding image coordinates are computed by collinearity equations. In 1D central perspective model, however, image coordinates are acquired by iterative calculation as discussed in the previous sections. 2D affine projection model has an advantage here again, which the image coordinates can be directly calculated by the collinearity equations. Figure 1 indicates the essential features of the process.

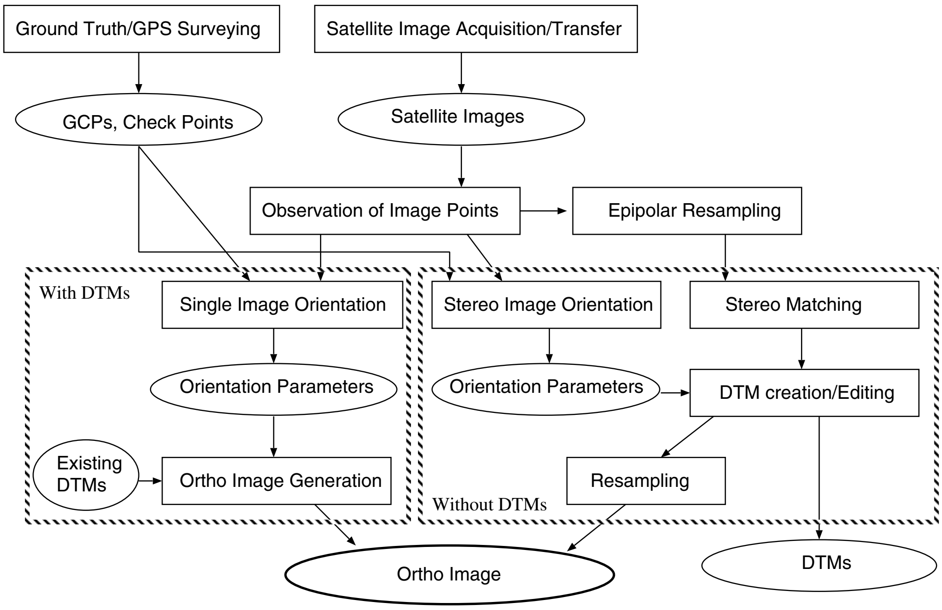

Figure 1: Scheme for ortho-image production from satellite imagery

3.3 Generation of Ortho-Image without DTMs

In case of ortho-image generation without existing DTMs, the necessary DTMs must be acquired via stereo matching methods. The sequence of the operations is followed: epipolar resampling, stereo matching and, finally, stereoscopic image editing. The majority of operational stereo matching algorithms for aerial photography require epipolar resampled images. However, conventional epipolar resampling methods are not directly applicable to satellite line scanner imagery. Proposed approaches for SPOT image resampling have included approximate methods, but mostly involve a requirement for accurate attitude parameters (Otto, 1988).

Here, again, the 2D affine projection model can be used as the basis for epipolar resampling. This method is straightforward to apply without accurate attitude parameters. The first author proposed the method of epipolar resampling using 2D affine projection model, which requires only over 6 stereo matched image points, a principal distance c and an incidence angle of ω (Ono, 1999). Experimental results in the study show that the accuracy better than half a pixel of residual vertical parallaxes is achievable.

After stereo matching of satellite images is completed, DTMs are computed from stereo pairs of the image points coordinates. In case of using standard central perspective model, ground coordinates are easily calculated by the inverse collinearity equations. 2D affine projection model, however, requires iteration in the calculation of ground coordinates. The reason for this is that height difference ΔZ is used in transformation form from affine imagery to central perspective one (inverted form of Equation 4). But, according to our experience, the number of the iteration is no more than twice.

After elevation of all grid ground points is obtained by interpolation, the pixel value of the corresponding image point to each ground point is also acquired by resampling. Ortho-imagery is thus generated as a by-product in a process of DTMs production.

4 PRACTICAL EVALUATION

In this study, accuracy tests for SPOT ortho-image generation were performed with existing DTMs at Hanshin area in JAPAN.

4.1 Test Fields and Images

Table 1 shows the data of the test images. The stereo scene covers Hanshin area (Osaka, Kobe and the suburbs) in JAPAN. The southern area of test field is an almost flat urbanized area. The northern area and the western area are mountainous. The maximum height difference is about 1,000m. 141 ground points were previously observed by aerial photogrammetry and GPS. The Estimates of accuracy of these points are 0.3m in planimetry and 0.6m in height. 9 points of them were used as control points for orientation. The rest points were utilized for evaluation of generated ortho-image. Image coordinates of the corresponding points to GCPs and check points were measured manually. The measurement accuracy of these points is probably 1/2 pixel to 1/4 pixel. Figure 2 shows the test images and the distribution of the measured points.

Table 1: Test Image Data

	Left Image	Right Image
Image type	SPOT pan Level-1A	
Date	1996.11	1995.2
Lat./Long.	N34.7/E135.5	N32.7/E135.2
Incident angle	L23.0	R17.9

To serve as height information, elevations were extracted from existing DTMs with about 50m grid spacing, which are supplied by Japan Geographical Survey Institute. The height resolution of the DTMs is 1m, but the accuracy are supposed less than 5m. Since spatial resolution of SPOT imagery is about 10m, the DTMs are interpolated to 10m grid by bi-linear method.

4.2 Test Results

In order to obtain the orientation parameters of each of left and right SPOT images, orientation of single image was conducted. Image coordinates are calculated by collinearity equations from the obtained orientation parameters and ground coordinates of a check point. Accuracy of the orientation was evaluated by RMS errors which are derived from difference of image coordinates between an observed image point and the corresponding check point. The same way was conducted for ascertainment of the ortho-images.

Table 2 shows accuracy of ortho-image and the orientation. According to the results, accuracy of ortho-image in flight direction is almost same as one of orientation. In the other hand, ortho image has a larger error than orientation in scanning direction. As expected, errors in the scanning direction were more significantly influenced by distortions in the DTMs.

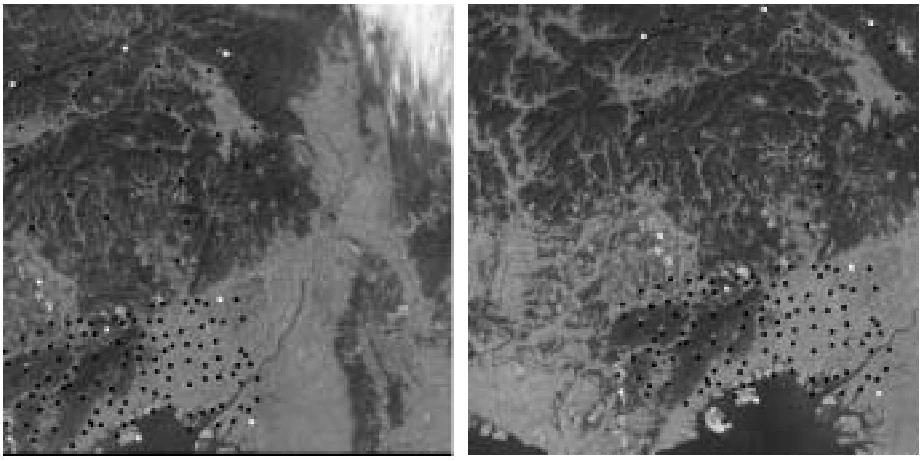
Left Image Right Image
(Black points: Check Points White Points: GCPs)

Figure 2: Test Images and Measured Points

Table 2: Accuracy of Ortho-Image and the Orientation (pixel)

	Left Image		Right Image	
Direction	flight	scanning	flight	scanning
Orientation	0.922	0.524	0.763	0.625
Ortho-Image	0.923	0.652	0.755	0.711

5 IMPLEMENTATION

The authors developed the digital stereo plotter KYOTO-P, which can handle satellite imagery with 2D affine projection model. It is mainly written in interpreter language ”Tcl/Tk”, but it is fast enough on PC with Pentium 200Mhz. KYOTO-P uses 3D glasses Crystal EYES for stereo viewing and another special device is not required. KYOTO-P consists of four components: orientation module, epipolar resampling module, digital stereo comparator and digital stereo plotter. The whole process is as follows. As the first step, relative orientation points and GCPs are identified on the original satellite images with digital stereo comparator. Secondly, epiplar resampling module generates epipolar resampled image based on affine projection. Orientation calculations are carried out to determine the relationship between the epipolar images and object space. Mapping operator stereoscopically views the epipolar images, scrolls the images in real-time and compiles topographic maps on the monitor.

6 CONCLUSION

This paper has reported on the application of the 2D affine projection model to satellite ortho-image generation and also has referred to real-time positioning. It has shown that 2D affine projection model has advantages in stability and speed in these application. The model has some limitations in the employment, but the model are efficiently applicable to small area mapping. Also, our testing has supported the contention that SPOT ortho-imagery to 1-pixel ground accuracy can be produced using ground control and DTM data from existing published map of the Japanese large scale map series. Considering the characteristics of affine based approach, 2D affine model is also appropriate for high resolution satellite imagery. Furthermore, the module based on the model has been implemented easily on softcopy photogrammetric workstations and has worked very well in speed.

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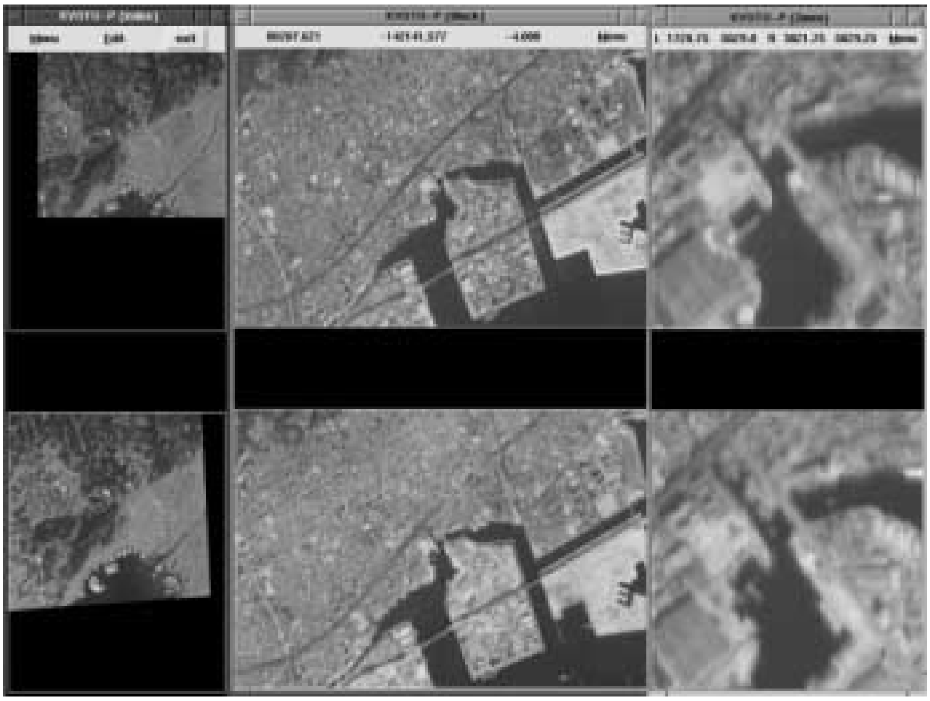

Figure 3: Digital Stereo Plotter KYOTO-P

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