Orthorectification of EROS A1 images

Torbjörn Westin and Jörgen Forsgren

Abstract--**This paper describes the development of a method for the geometric correction of imagery from the EROS A1 satellite. The correction method is based on a rigorous orbital/attitude model. The result from testing the method demonstrates the possibility to orthorectify EROS A1 scenes to sub-pixel accuracy. The method is now used in the standard production of ortho-rectified EROS A1 images at the Metria production facility.**

Index Terms— **Accuracy, EROS A1, rectification, satellite image.**

I. INTRODUCTION

The EROS A1 satellite was successfully launched on December 5, 2000. It is the first in a series of six high-resolution imaging satellites to be launched by ImageSat International. The A1 satellite produce images of 1.8 m resolution, while the following B1-B5 satellites will provide images with better than 1 m resolution. The A1 satellite can also operate in a special over-sampling mode, which makes the effective resolution in the order of 1 m.

Fig. 1. The EROS A1 satellite.

EROS A1 was launched into a sun-synchronous, polar orbit at an altitude of 480 km. The data received is downloaded to a global network of receiving stations. The data transmission rate is 70 Mbit/s in X-band frequency. The receiving stations acquire, store and process the down linked data, and make system corrected scenes, quick-looks and metadata available through the ImageNet infrastructure. ImageNet is an e-commerce and catalogue system that connects locally stored databases. Orthorectified images and other value-added products will also become available through ImageNet.

The Swedish company Spacemetric AB has developed a physical imaging model for EROS A1 to be used for ortho-correction of EROS A1 images. This model has been implemented in the image production system at Metria, Kiruna, who since September 2001 has the capacity to ortho-correct EROS A1 images to sub-pixel accuracy.

II. THE EROS A1 CAMERA

The NA30 camera on the EROS A1 satellite is a push-broom scanner with two CCD arrays, including a total of 7800 detectors in the focal plane. The detectors are sensitive in the spectral range 0.5 – 0.9 μm and are sampled with a quantization depth of 11 bits.

The camera is rigidly attached to the satellite frame, so pointing the camera is done by using the attitude control system to rotate the whole satellite. The sensor scans asynchronously, allowing the satellite to move at a faster ground speed than its rate of imaging. The satellite rotates at a constant rate backwards, to achieve imaging at a slower speed, enabling the detectors to dwell longer over each area. In this way the sensor is able to get more light, and improve contrast and signal-to-noise ratio.

The ground scan width is 12.5 km. The satellite can turn up to 45 degrees in any direction as it orbits, providing the power to take shots of many different areas during the same pass. The ability to point and shoot the camera also allows for stereo imaging during the same orbit.

The satellite and camera characteristics are summarized in Table I.

TABLE I
EROS SYSTEM PARAMETERS

Parameter	EROS A1 specification
Orbit	480 km circular sun-synchronous
IFOV	1.8 m
Swath width	12.5 km
Scanning	Asynchronous (up to 750 lines/s)
Sensor type	CCD
Spectral band	Panchromatic, 0.5 – 0.9 μm
Quantization	11 bits
Pixels-in-line	7043
S/N	> 2048 / 2
Data link rate	70 Mbits/s

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III. GEOMETRICAL MODEL

EROS A1 scenes are available in two formats, 1A raw data and 1B system corrected data. The model here developed applies only to 1A raw data, because it allows us to relate pixel positions to the camera focal plane.

The geometrical model selected for the modellisation of EROS A1 scenes can be divided into different parts. The exterior orientation includes a satellite orbit model and an attitude variation model. The interior orientation includes the instrument scan model. This general model has successfully been applied to a number of different satellite sensors ([1], [2], [3], [4]).

A. Satellite orbit model

The satellite model is based on the six Kepler parameters (Fig 2). These, together with the constant second-degree zonal component (J_2) of the earth gravitational potential, are able to describe the satellite motion with high enough precision for the EROS A1 correction requirements.

a	semi-major axis
e	eccentricity
i	inclination
$\Omega = \Omega_0 + d\Omega/dt * t$	right ascension of ascending node
$\varpi = \varpi_0 + d\varpi/dt * t$	argument of perigee
$M = M_0 + dM/dt * t$	mean anomaly

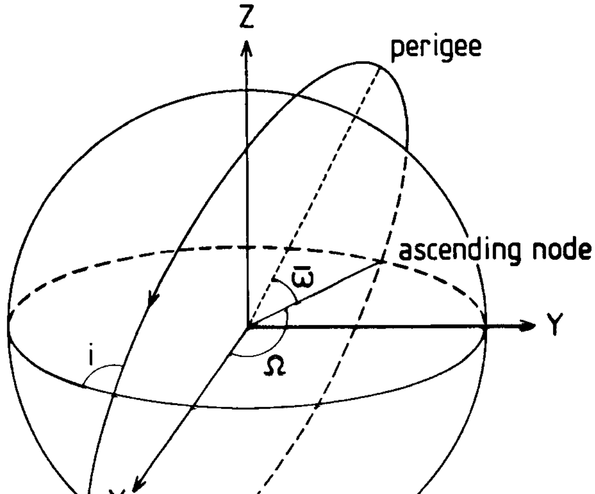

Fig. 2. Satellite orbit parameters.

B. Attitude model

Attitude measurements from the on-board gyros are available in the form of piece-wise polynoms of 3rd degree in time for roll, pitch and yaw. Additional corrections to the attitude angles are modelled by 2'nd degree polynomials in time:

$$\text{roll} = \text{roll}_{\text{measured}}(t) + a_0 + a_1 * t + a_2 * t^2$$

$$\text{pitch} = \text{pitch}_{\text{measured}}(t) + b_0 + b_1 * t + b_2 * t^2$$

$$\text{yaw} = \text{yaw}_{\text{measured}}(t) + c_0 + c_1 * t + c_2 * t^2$$

where the coefficients a_i, b_i and c_i remains to be determined. It is assumed that 2'nd degree polynomials will be sufficient for the modellisation of the attitude errors in he time interval of a complete scene.

C. Push-broom scan model

The basic scan model is a line-of-sight vector, from the detector in the focal plane, through the optical center of the telescope, to the ground point. This vector is orthogonal to the satellite platform roll-axis. A slight deviation from this orthogonality is taken into account through the camera-body alignment matrix available in the scene metadata.

IV. MODEL PARAMETER ADJUSTMENT

To be able to achieve a high precision model for a specific scene, the model parameters have to be estimated and refined by the use of ground control points. The parameter adjustment follows the method developed in [1]. It is a least-squares adjustment, with the possibility to weight the parameters. The parameter weights are used to determine which parameters are to participate in the adjustment.

Only the exterior orientation parameters are adjusted. Of the six Kepler parameters, two are kept constant. Due to the very small eccentricity of the orbit, the eccentricity and argument of perigee can be kept constant without significant loss of accuracy. Of the 9 attitude parameters, different subset can be adjusted. There is a trade-off between stability and precision in the result that has to be considered when deciding which of them to keep constant.

The adjustment method requires *a priori* values for the parameters. A number of ephemeris are provided with the raw EROS scene. One of these is used to initiate the orbit. The attitude correction parameters are initiated to zero. The initial position calculated from the metadata is rather inaccurate, usually up to 1 km off, but still close enough to be within the pull-in range of the method.

V. ACCURACY EVALUATION

The model performance was evaluated in seven EROS A1 scenes from three different sites in southern Sweden (Table II).

TABLE II
TEST DATASET

Scene	Area	Date
1	Stockholm	2001-05-09
2	Stockholm	2001-06-14
3	Stockholm	2001-07-24
4	Stockholm	2001-07-31
5	Örebro	2001-06-28
6	Örebro	2001-07-09
7	Hyssne	2001-05-08

The ground control points for the test sites were measured in digital aerial orthophotos from the Swedish National Land Survey. The pixel size in the digital orthophotos is 1 m, with an estimated planimetric accuracy of 1 – 1.5 m. The heights were interpolated from a DEM with 50 m grid interval from the Swedish National Land Survey, with an estimated elevation accuracy of 2 m at the grid nodes. The Swedish RT90 was adopted as the reference geodetic system.

The control point positions were then measured in each scene with an estimated planimetric accuracy of 0.25 pixels. On average, 26 points could be measured in each scene. The control points were in all cases well distributed over the whole scene area.

The control point measurements were used for least-squares adjustment of the model parameters in each scene. As only 11 free model parameters were adjusted, the adjustments involved highly over-determined systems (already at 6 control points the system starts to become over-determined). This means that the residual errors in the models after the adjustment give a good estimate of the model accuracy. The results from the adjustments are shown in Table III.

TABLE III
ADJUSTMENT RESULTS

Scene	No of gcp	rms x (m)	rms y (m)
1	30	1.3	1.4
2	21	1.6	1.7
3	13	1.5	1.5
4	22	1.8	1.4
5	30	1.7	2.4
6	30	1.6	1.6
7	33	1.3	1.9
Average		1.5	1.7

To get an independent verification of the final product accuracy under more normal production conditions, the first scene was adjusted with only 9 control points. The rms errors in the final rectified scene were then evaluated by use of 21 checkpoints, which were independent from the control points. The result of this evaluation is shown in Table IV.

TABLE IV
CHECKPOINT EVALUATION RESULTS

Scene	No of gcp	No of check	rms x (m)	rms y (m)
1	9	21	1.7	1.8

VI. PRODUCTION

Metria has together with its Italian consortium partner IPT (informatica per il territorio) agreements with ImageSat International (ISI) to acquire, archive and distribute system corrected EROS products within Europe and value-added products, such as ortho-corrected products, worldwide. Under these agreements ISI has also provided equipment for the acquisition and processing of level 1A and 1B products. The consortium has three receiving stations, one in northern Sweden, one in southern Sweden and one in Sardinia, Italy.

Metria has since mid-80's had the capacity to produce precision- and ortho-correction of satellite data by using production software based on in-house developed specifications. New sensor models have been added continuously, and at present the system handles images from Landsat, SPOT, JERS, Resurs, IRS, Ikonos and EROS. The new module to produce ortho-corrected EROS products is integrated into the environment described above with a capacity to process approximately 50 EROS scenes per week.

VII. CONCLUSIONS

The result of the evaluation of the EROS sensor model shows that EROS A1 scenes can be corrected to better than 1 pixel accuracy. The fact that all 7 scenes used for the test had equal or lower than 1 pixel rms residuals (except y direction in scene 5) demonstrates the stability of the method. It was also shown that subpixel accuracy can be achieved with as few as 9 control points in the adjustment. Altogether, this made it possible to successfully implement the EROS model into a real production environment.

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