GEOMETRIC MODELLING OF IMAGERY FROM THE MSU-SK CONICAL SCANNER[1]

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Abstract

This paper describes the development of a method for the geometric correction of imagery from the MSU-SK instrument on the Resurs-O1 satellite. This Russian instrument is unique in several aspects; its conical scan mechanism and the medium scale resolution of 160 m. The correction method is based on a rigorous orbital/attitude model. The result from testing the method demonstrates the possibility to orthorectify MSU-SK scenes to 1/2-pixel accuracy.

***Key-words**: msu-sk, conical scan, geometric model, accuracy.*

Résumé

Cet article décrit le développement de la méthode de correction géométrique d'imagerie à partir de l'instrument MSU-SK sur le satellite Resurs-01. Cet instrument russe est unique sous plusieurs aspects ; notamment le mécanisme de balayage de forme conique et la résolution à échelle moyenne de 160 m. La méthode de correction repose sur un modèle rigoureux d'orbitale. Les résultats des essais effectués sur l'instrument confirment la possibilité de rectifier de manière orthogonale les scènes MSU-SK avec une précision de ½ pixel.

***Mots-Clés**: msu-sk, balayage conique, modèle géométrique, précision.*

1. Introduction

The Russian space program Resurs-O has now been operative for almost 15 years (Trifonov, 1993). So far, four satellites in the Resurs-O1 series have been launched. The satellites are injected in circular, sun-synchronous orbits, with 98° inclination at about 650 km altitude. They carry two types of scanners for remote sensing of the environment. The MSU-E instrument is a high-resolution CCD-array scanner, operating in the visible and near-IR spectrum. The MSU-SK instrument is a medium-resolution conical scanner, operating in the visible, near-IR and thermal-IR spectrum.

Within Russia and other CIS countries the Resurs-O1 data has been used in a variety of applications, such as environmental monitoring of larger areas, ice monitoring in the arctic region, snow cover mapping, agricultural monitoring, measuring of forest fire damages, and coastal zone mapping. The Russian receiving stations in Moscow, Novosibirsk and Khabarovsk make possible covering all of Russia and its neighbouring countries in direct receiving mode, while other parts of the world can be accessed by use of the on-board tape-recorder.

Since 1995, data from Resurs-O1-3 has also been received by Swedish Space Corporation at the Esrange receiving station in northern Sweden, thus augmenting the area of direct received data to almost all of Europe (Bjerkesjö et al, 1996). This was possible through an agreement with the Russian consortium SOVZOND, which also included marketing rights for direct-mode data over Europe, and world-wide tape-recorded data for the global market. The reception at Esrange continued until the autumn 1998, when the 8 GHz transmitter failed. The satellite is, however, still operating, transmitting data to the Russian receiving stations in the 466 MHz band.

The program has continued. Resurs-O1-4 was launched in July 1998, carrying enhanced versions of both the MSU-SK and MSU-E instruments. It produced some excellent images, but was early having problems with the transmitters, and was declared not operational some months later. In July 1999, the Russian/Ukrainian satellite Okean O2-1 was launched, carrying two MSU-SK instruments. The next satellite in the Resurs series is planned for launch in 2002.

2. The MSU-SK instrument

Of the two types of instruments on-board the Resurs-O1 satellites, the MSU-SK is of special interest for a number of reasons (Gektin, 1994).

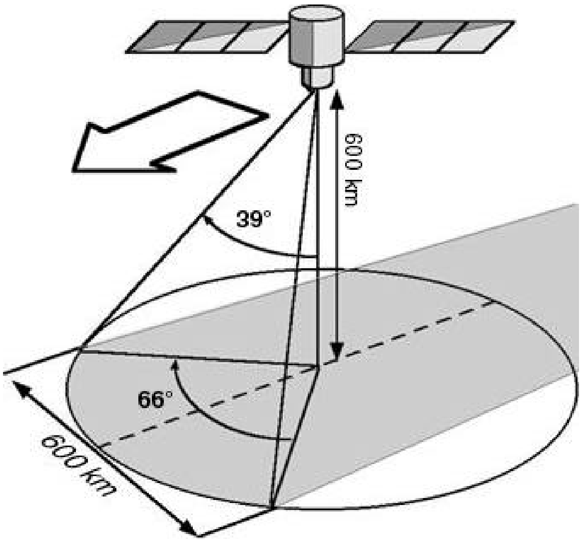

Figure 1: Geometry of the MSU-SK scan.

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It is a conical scanning device. The cone axis is pointed towards nadir, and only a forward-looking 66° segment is recorded. The off-nadir cone angle is 39°. This makes the swath width equal to 600 km (Fig. 1).

The scanner is multi-spectral, covering the visible, near-IR and thermal-IR in five spectral bands (Fig. 2). The ground resolution is 160 m for all but the thermal-IR band, which is 600 m.

Band	Spectral range	Resolution	IFOV
1	0.5 - 0.6 µm	160 m	42”
2	0.6 - 0.7 µm	160 m	42”
3	0.7 - 0.8 µm	160 m	42”
4	0.8 - 1.1 µm	160 m	42”
5	10.4 - 12.6 µm	600 m	140”

Figure 2: The MSU-SK spectral bands

The conical scanning has some advantages, which are of importance for accurate radiometric measurements and thematic classification:

- The ground resolution is constant over the swath
- The optical thickness of the atmosphere is almost constant over the swath
- The viewing angle is constant over the swath

A schematic cross-section of the MSU-SK instrument is shown in Fig. 3. The primary image is formed by a large stationary spherical mirror (1). This image is scanned by small-size optical elements (2-5) arranged in four arms, rotating around a vertical axis (0). The light is led through a spectral splitter system (9), and finally to the photodiodes (10).

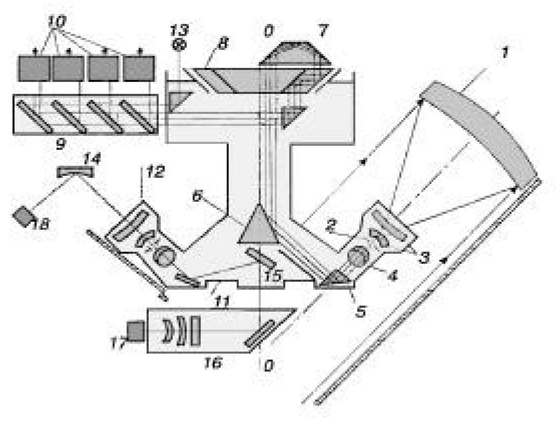


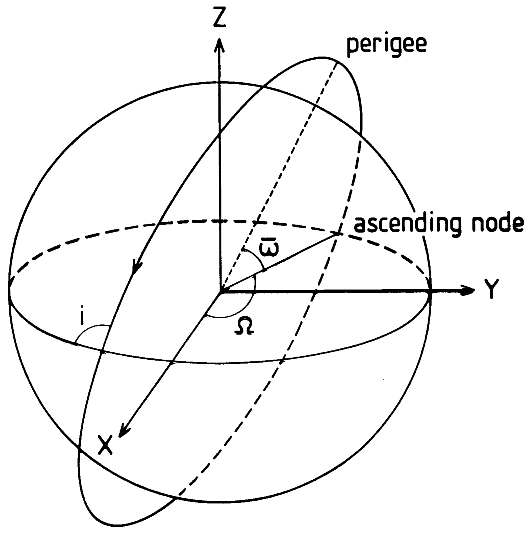
Figure 3: Optical scheme of the MSU-SK scanner (after [Gekt 94]). 1 – spherical mirror, 2 – rotating analysing diaphragms, 3 – two-lens corrector, 4,5,6 – optics, 7,8 – image stabilisation system, 9 – spectral splitter, 10 – radiation receivers (silicon avalanche photodiodes), 11 – scanning wheel, 12 – IR-band optical system, 13,14 – system of internal calibration, 15 – inclined mirror, 16 – matching lens, 17 – cooled receiver, 18 – black body, 0-0 – rotation axis.

3. Geometrical model

The geometrical model selected for the modellisation of MSU-SK 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 conical scan model.

3.1 Satellite orbit model

The satellite model is based on the six Kepler parameters (Fig 4). 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 Resurs MSU-SK correction requirements.



a	orbit half major axis
e	eccentricity
i	inclination
Ω	right ascension of ascending node
ϖ	argument of perigee
M	mean anomaly

Figure 4. Satellite orbit parameters

3.2 Attitude model

No attitude measurements are available from Resurs-O1-3. The attitude angles are modelled by 2’nd degree polynomials in time.

$\text{roll} = a_0 + a_1 * t + a_2 * t^2$

$\text{pitch} = b_0 + b_1 * t + b_2 * t^2$

$\text{yaw} = c_0 + c_1 * t + c_2 * t^2$

where the coefficients a_i, b_i and c_i remains to be determined. It is assumed that a 2’nd degree polynomial will be sufficient for the modellisation of the time interval of a complete scene.

3.3 Conical scan model

The basic scan model consists of four line-of-sight vectors. These are inclined 39° from the cone axis, which is parallel to the instrument z-axis (yaw axis). Their projections on a plane perpendicular to the cone axis are 90° apart. This arrangement rotates around the cone axis with the frequency 12.5 Hz. All parameters in this model have been treated as fixed, and have not been subject to adjustment.

4. 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 (Westin, 1990). 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. One ephemeris is provided with the raw Resurs data. This data is rather inaccurate, usually 10-30 km off, but still close enough to be within the pull-in range of the method. No attitude data are available, so the attitude coefficients are simply initialised to zero, as this is the expected output of the satellite attitude control system.

5. Evaluation

The model was evaluated by using four Resurs-O1-3 MSU-SK scenes over southern Scandinavia (Fig. 5).

Scene no.	Orbit no.	Date
1	10065	1996-09-19
2	13855	1997-06-04
3	14369	1997-07-09
4	8640	1996-06-14

Figure 5: Test data set.

The first scene is shown in Fig. 6. The ground control points for the test were measured in topographic maps in scale 1:50,000. Maps from both Sweden and Norway were used. The Swedish geodetic datum, RT90, was adopted as the reference geodetic system.The coordinates from Norwegian maps were transformed from the Norwegian datum WGS84 to RT90 before use. A total number of 41 ground control points were measured. Due to partial cloud cover, not all of these were visible in all scenes. On average, 28 points could be measured in each scene. The estimated ground control coordinate accuracy is 20 – 25 m.

The control point measurements were used for least-squares adjustment of the model parameters for the scene. The residual errors in the adjustment were then analysed to determine the model fidelity. An important aspect to investigate was to determine which coefficients in the attitude polynomial model that need to be present. This was analysed by repeating the adjustment with 0'th, 1'st and 2'nd order coefficients present, and then analysing the different results. The results are summarised in Fig. 7-9.

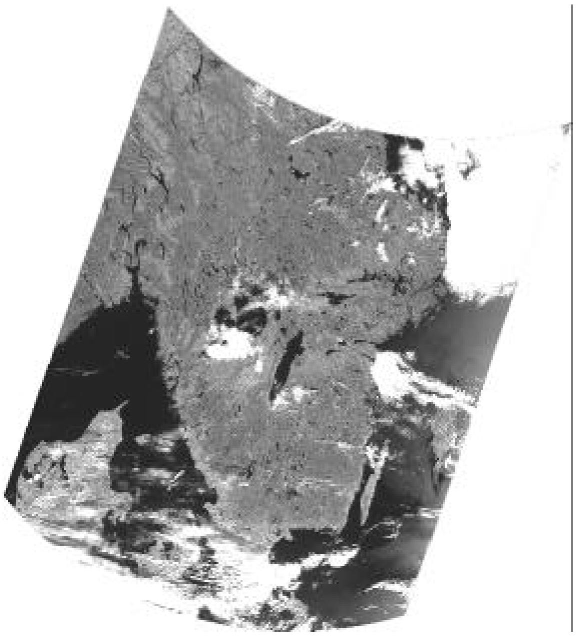


Fig. 6: Test scene from orbit 10065, spectral band 4.

Attitude polynom order	RMS column residual error	RMS line residual error
0'th	2.57	10.56
1'st	0.60	1.23
2'nd	0.32	0.64

Fig. 7: Average RMS residual errors in test images

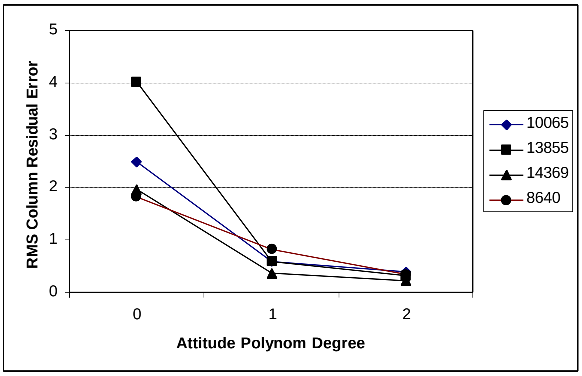


Fig 8: Column residual errors in the test scenes

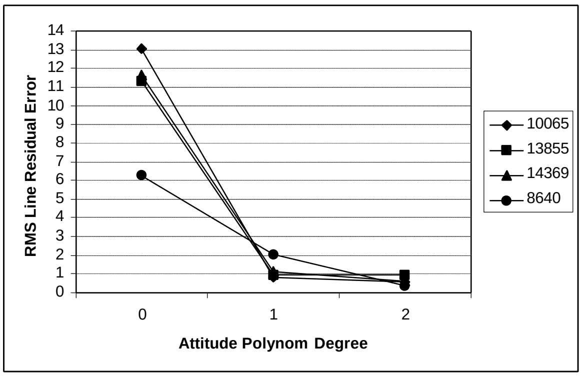


Fig. 9: Line residual errors in the test scenes.

6. Discussion

An analysis of the residual errors in the adjustments shows clearly the necessity of modelling at least a linear trend in the attitudes. The 0’th order adjustments (including 4 orbit parameters and 3 attitude offset parameters) shows large errors, especially in the line dimension. This indicates a strong linear drift in pitch. The 1’st order adjustment (10 parameters) is able to model this linear drift very well, leaving the residual error in the order of only one pixel. Finally, the 2’nd order adjustment (13 parameters) is able to lower the residual error down to close to 1/2 pixel.

The line residual result in orbit 8640 differs somewhat from the rest of the orbits. It has a relatively lower error in the 0’th order adjustment, but a relatively larger error in the 1’st order adjustment. This could indicate a general change in linear pitch trend within this scene. Such a change would result in an increased curvature of the pitch time series, making the 2’nd order correction more important.

The possibility to model the attitude change with polynomial functions depends on the length of the orbital segments covered by the scene. In the present test the control point measurements covered segments of 4000 – 5000 lines (80 – 100 seconds). For segments longer than this, the attitude variations might require higher order polynomials to be accurately modelled, which would put too high demands on gcp density and distribution to be practically feasible. In these cases, it would be better to split the segments into shorter scenes and adjust them separately.

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