PHOTOGRAMMETRIC POTENTIAL OF JERS-1 OPS

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ABSTRACT:

The japanese JERS-1 is the first earth resource satellite to utilize the principle of along-track stereo. The optical VNIR instrument has four spectral bands based on CCD array sensors. Bands 1-3 (green, red and near-IR) are looking at nadir, while band 4 has the same spectral sensitivity as band 3 but is looking 15.33° forward. This gives the possibility for stereo images with B/H = 0.3.
To be able to use JERS-1 OPS for photogrammetric purposes, a model for interior and exterior orientation for JERS-1 OPS is developed. A least-squares adjustment procedure is developed for estimating the orbital and attitude parameters for strips of JERS-1 scenes. After adjustment, digital elevation models (DEM) are extracted by an existing software for multi-point least-squares matching.
The photogrammetric capabilities of JERS-1 OPS using this system is evaluated in a case with six scenes acquired in a contiguous strip. The results of the tests show that a planimetric accuracy of 6 m rms error is possible, and that the stability allows us to reduce the number of control in the whole strip to only two points, without increasing the rms errors to more than 9 m. The result of the DEM extraction test shows that 20 m rms error in elevation is possible. It also shows that this accuracy can be achieved without any control at all in the stereo pair, by only using control points further away in the strip.

1. INTRODUCTION

The launch of JERS-1 in 1992 gave us new tools in optical remote sensing. The problems and discontinuation of the middle infrared bands in 1993 was unfortunate, but still the VNIR bands is a good source of data, . Also, its along-track stereo possibility is unique. The optical VNIR instrument has four spectral bands based on CCD array sensors. Bands 1-3 (green, red and near-IR) are looking at nadir, while band 4 has the same spectral sensitivity as band 3 but is looking 15.33° forward (Figure 1). This gives the possibility for stereo images with B/H = 0.3. The nominal pixelsize is 18 m across-track and 24 m along-track.

The purpose of this study is to investigate the potential photogrammetric capabilities of JERS-1, in terms of geometric accuracy both in planimetry and altimetry. Pursuing high geometric accuracy is very important in many respects, not only in cartographic applications. Change detection and other multitemporal studies often require better than half pixel accuracy to give good results. So do also multi-sensor studies, such as merging VNIR data with SPOT Pan or with SAR data.

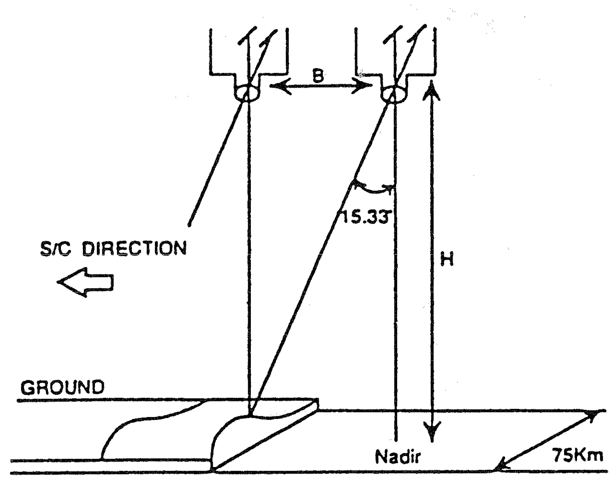

Figure 1. Imaging geometry of the JERS-1 VNIR instrument (reproduced from NASDA, 1990).

An other very important aspect investigated is the stability of the photogrammetric model, ie. if it is possible to achieve high geometric accuracy with only limited control. One of the chief advantages of satellite remote sensing is that it in short time can give access to information of remote areas. Maps for providing ground control may then be unavailable or unreliable, making it necessary to interpolate or extrapolate the geometry from surrounding better mapped areas.

Results from investigations of planimetric accuracy in JERS-1 models were reported by Westin (1995). This paper is an extension of these investigations to include also altimetric accuracy.

2. DATA SET

The satellite data used for this study consists of six scenes acquired in a contiguous strip on June 30, 1993. The strip covers an area in north-western Sweden (Figure 2) and is essentially cloudfree and of good quality. The images display moderate horizontal striping as reported by Nishidai (1993). The images were acquired in high gain mode, which reduces the potential problem with low dynamic range in the visible bands. This caused on the other hand that some bright areas in the IR band were oversaturated.

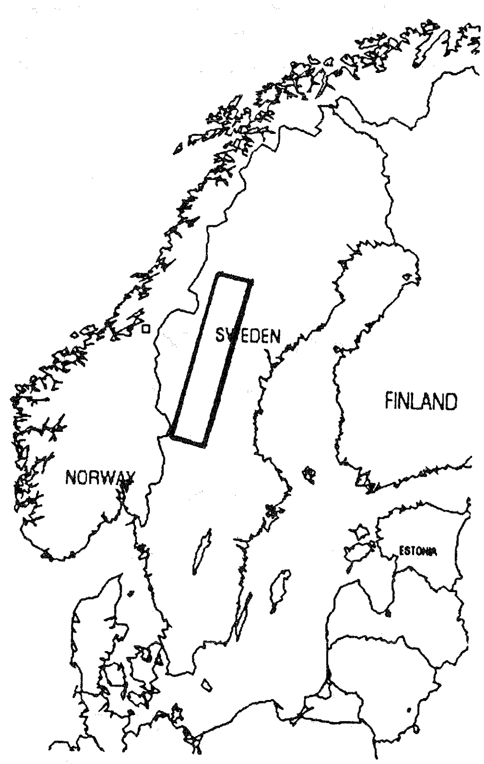

Figure 2. Location of the study area.

The scenes were provided preprocessed to level 1. This means that the scenes were geometrically uncorrected, but that a radiometric correction of detector gain and bias was performed. No further radiometric correction was applied in this study.

The ground control points were extracted from the 1:10,000 topographic orthophoto maps from the Swedish Land Survey. These maps allow the extraction of control point features with a positional accuracy of 3-4 m in three dimensions.

A digital elevation model from the Swedish Land Survey was used for evaluation of the computed DEM. It has a height accuracy of about 2 m, with 50 m grid distance.

3. EXTERIOR ORIENTATION

3.1 Adjustment model

The similarities between the JERS-1 VNIR instrument and the SPOT XS instrument made it feasible to implement the JERS-1 model in an already existing and well proven system for rectification of SPOT scenes. This model will here briefly be explained, while a more detailed description can be found in Westin (1990,1991).

The system uses a satellite orbital model based the six Keplerian parameters. Investigations in Westin (1990) showed that it was possible to reduce these parameters to the following four without loss of accuracy:

t_0	time at the ascending node
Ω	right ascension of ascending node
i	inclination
r_0	orbit radius at t_0

The attitude modelling is utilizing the gyro rate measurements present in the telemetry. Integration of the gyro rates gives a detailed description of relative attitude changes within the scene. The unknown constant offsets remains to be estimated and are introduced as parameters in the model:

ω_0	roll
ρ_0	pitch
κ_0	yaw

Each control point give rise to an observation vector with five parameters:

y_s	coordinate for the detector position
t	time for control point imaging
ϕ	control point latitude
λ	control point longitude
h	control point elevation

These are feed into a least squares adjustment. In this adjustment, *a priori* estimates of the parameters are used to resolve singularities and to allow solutions also for the cases where only one or two control points are available.

In the processing of strips of scenes, the attitude time series are concatenated, and the individual scene parameters are connected by orbital constraints (Westin, 1991). In this way, the number of parameters used for the whole strip can be limited to the same 7 parameters used for one single scene. This is of great importance for the stability of strip triangulation.

3.2 Analysis of attitude rates

Before the tests, the attitude data were analyzed by integrating the gyro rates present in the telemetry data. Figure 3 shows the development of attitudes over the six scenes in the strip. Especially the roll rates are very high. Part of the time, it is higher than the roll rate 3 σ specification of 0.0007 deg/sec (NASDA, 1990). This gives rise to about 500 m distortion in the cross track directions and it is obvious that a rigorous attitude correction is essential.

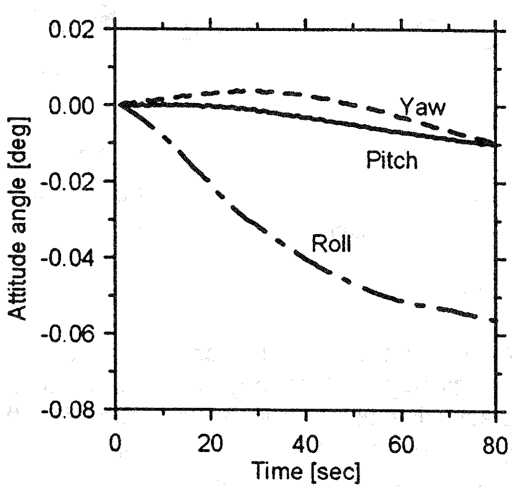

Figure 3. Attitude variation in the strip.

A close-up of the pitch variation (Figure 4) also reveals a high frequency variation with an amplitude of about 0.5 10^{-3} degrees. This causes short time distortions of about 5 m, and is further evidence of the necessity of correct treatment of the attitude information.

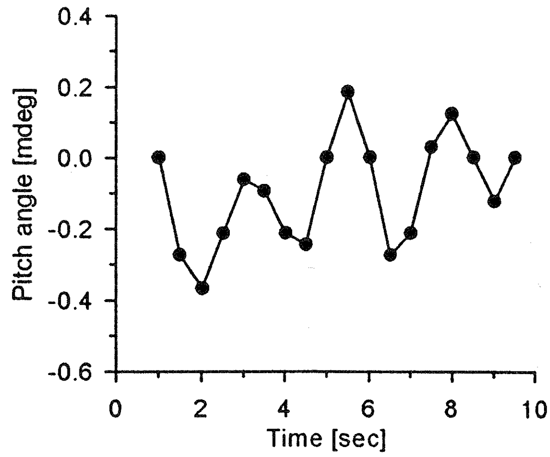

Figure 4. Pitch short time variation.

4. PLANIMETRIC ACCURACY

4.1 Test strategy

A number of tests were designed to investigate different aspects of the planimetric accuracy and stability of JERS-1 rectification:

1. Single scenes with many control points.

2. Strip of 6 scenes with many control points.

3. Strip of 6 scenes with one control point in each end of the strip (interpolation).

4. Strip of 6 scenes with two control points in the first scene of the strip (extrapolation).

5. Strip of 6 scenes with only one control point in the first scene of the strip (extrapolation).

The first two tests are intended for verifying the correctness of the model and for investigating the potential accuracy achievable. The last three test are rather extreme cases for investigating stability of rectification. In these tests, only VNIR band 1 was used.

A total of 123 control points were collected from the topographic maps, distributed with approximately 20 points in each scene. In the first two test cases, all control points were used in the adjustment. In the last three test cases only two or one control point were used in the adjustment, while all 123 points were later used as check points in the evaluation. Figure 5 shows the distribution of the control in the different cases.

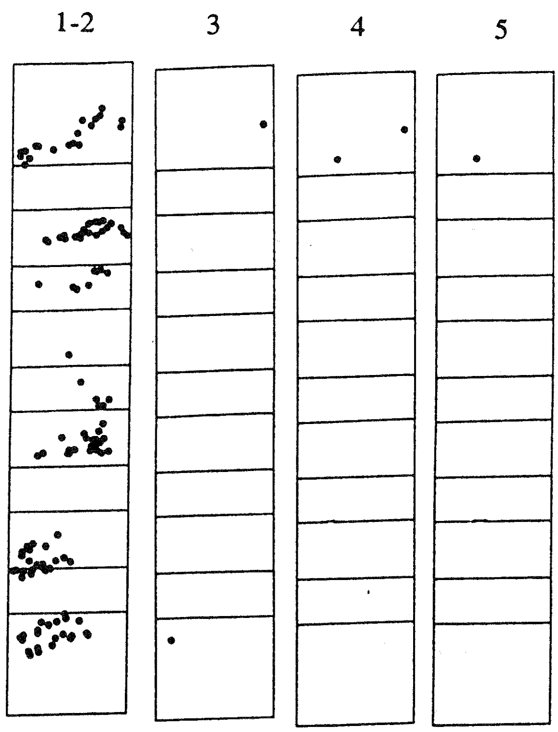

Figure 5. Distribution of control in the different test cases.

4.2 Planimetric results

The results of the five test cases are summarized in Table 1. The residual planimetric errors are represented as X and Y components, where X is in the direction of the CCD array (across track direction) and Y is in the direction perpendicular to the CCD array (along track direction).

	Std. Dev. [m]		Mean [m]	
	x	y	x	y
Test 1	6.3	6.3	0.5	-0.3
Test 2	6.5	8.1	-0.1	-0.1
Test 3	8.7	8.9	-1.9	-2.8
Test 4	7.9	8.9	-6.1	-3.2
Test 5	8.8	17.1	-9.2	-11.2

Table 1. Statistics of residual planimetric errors

Case 1: In the independent scene adjustment, each of the 6 scenes were adjusted by their respective 20 control points. As expected, this results in the lowest residual errors of the five cases. This is due to the high total number of parameters used (6x7=42), which can account for some of the errors in the model which only become apparent in strip processing. If we assume an error variance component corresponding to 4 m introduced by the map inaccuracy, the scene residual rms error would be only 5 m, corresponding to 1/4 pixel.

Case 2: Strip triangulation of 6 scenes, using all 123 control points in the adjustment, would ideally give the same residual errors as case 1 if there where no modelling errors. In Table 1 we can see this is true for the X component, but the Y component shows an increase in std.dev. from 6.3 m to 8.1 m. This is caused by a linear trend in the Y-component over the scenes, which can be seen in Figure 6. One possible cause for this trend is a bias in the pitch rate measurements amounting to 23 10^{-6} deg/sec.

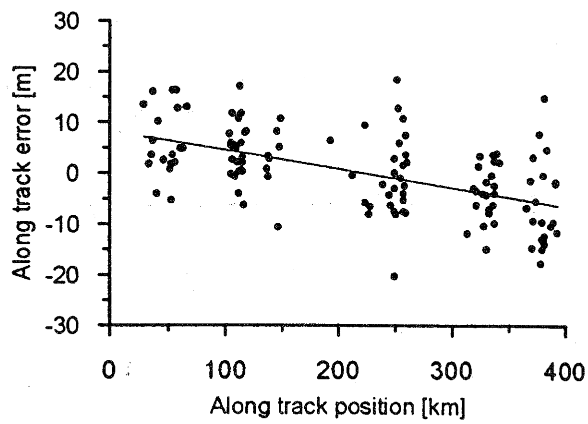

Figure 6. Pitch trend.

Case 3-4: In both cases, the two control points where selected purposely so that they were spread in the across track direction. This is important for the possibility to estimate the orbit radius and the yaw angle offset. Both cases show remarkably good results, with rms residual errors less than 1/2 pixel.

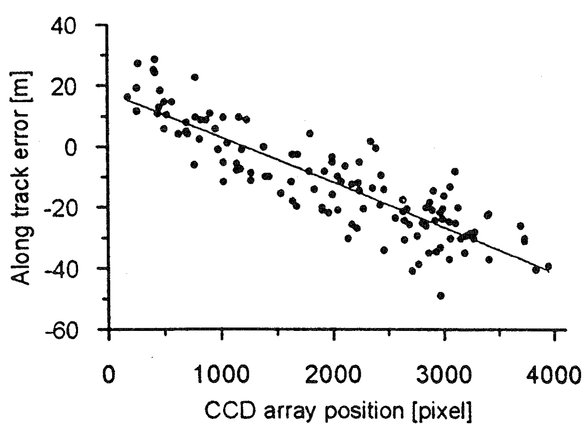

Figure 7. Errors in 1-control point case due to missing yaw estimate.

Case 5: This is the most extreme case possible, using only one control point in the first scene. As expected, it is then not possible to estimate the orbit radius and the yaw angle offset. This is most clearly seen in the Y component where there is a trend in the across track direction (Figure 7) corresponding to a missing yaw estimate of 0.05 degrees. Still, the total rms errors are kept close to 1 pixel.

5. ALTIMETRIC ACCURACY

5.1 Test area

A 25km x 25km area corresponding to a topographic map sheet 1:50,000 was selected for evaluation of the DEM computations. The area is situated in the southernmost scene of the strip (scene 6). The terrain is varied. Boreal forest with clearcuts dominates to the east, low treeless mountains to the west, and a river, bordered by agriculture, is running in the middle. The height ranges from 300 m to 900 m. The image pair is of good quality, except for a small cloud, and cloud shadow, near the centre of the map area. The nadir looking image over the map area is shown in Figure 8.

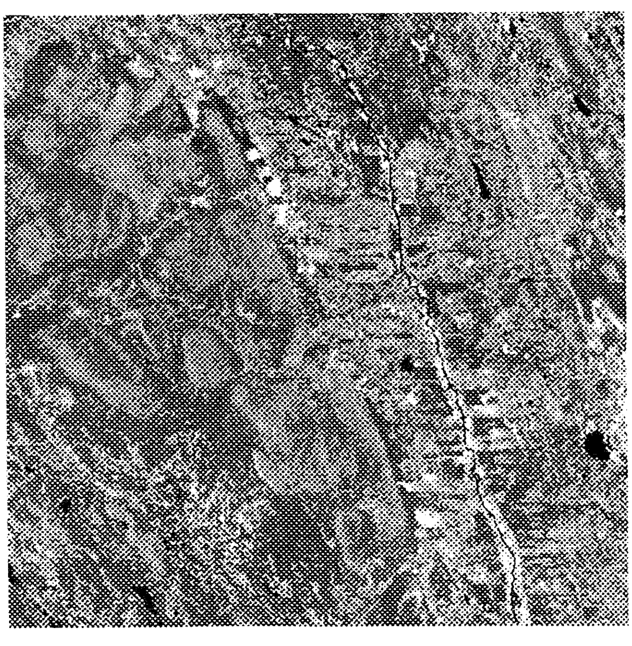

Figure 8. Nadir looking image (band 3), showing the area covered by the reference DEM.

5.2 Test strategy

The JERS-1 stereo model was adjusted by the method described in paragraph 3.1. The strategy of the test was to set up different configurations of control which were successively more difficult and demanding. The numbering of the scenes is from north to south, with number 6 being the one containing the test map area. The following configurations were tested:

1. Control points only in scene 6.
2. Control points only in scene 5.
3. Control points only in scene 4.
4. Control points only in scene 3.

4a. 4 control points only in scene 3.
4b. 3 control points only in scene 3.
4c. 2 control points only in scene 3.
4d. 1 control points only in scene 3.

The last test is most extreme, with only one control point available 225 km away from the map area.

5.3 Altimetric results

The DEM's were computed using multi-point matching (Rosenholm, 1987). The procedure is completely automatic, and no post-editing was performed to eliminate effects of the cloud. The DEM was calculated with 200 m grid distance. The computed DEM from test case 1 is shown as a grey-tone image in Figure 9. The results were compared to the reference DEM from the Swedish Land Survey. Statistics in the form of mean and standard deviation were calculated for the differences between computed and reference DEM. The results are shown in Table 2.

Figure 9. DEM computed in test case 1.

	Mean [m]	Std.Dev.[m]
Test 1	-2.0	10.5
Test 2	3.5	13.3
Test 3	4.7	11.9
Test 4	1.7	10.7
Test 4a	4.6	11.1
Test 4b	6.0	11.7
Test 4c	14.6	11.2
Test 4d	24.6	11.0

Table 2. Height errors in the computed DEM

The results are remarkable in that the standard deviation seems to be unaffected by the distance and distribution of control. The mean error is also very stable, showing only minor fluctuations with the distance of the control. However, when reducing the number of control to very few, the mean error increases.

6. CONCLUSIONS

The investigation demonstrates the high geometrical performance of the JERS-1 system regarding VNIR scenes. The investigation had two objectives: accuracy and stability. The results show that it is possible to achieve planimetric accuracies in the order of 1/4 pixel, and that the stability allows 1/2 pixel accuracies in strip triangulation with as few as two control points. The altimetric accuracy was found to be better than 20 m rms error, also when the control was extrapolated from over 200 km distance.

These results were achieved despite an extremely high roll rate, which proves the high quality of roll rate measurements. On the other hand, a small trend can be seen in the residuals which indicate a possible bias in pitch rate measurement. This should be investigated further.

7. ACKNOWLEDGEMENT

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