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AERIAL TRIANGULATION OF CCD LINE-SCANNER IMAGES

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ABSTRACT

An attempt for the evaluation of CCD line scanner imagery is presented. This mathematical formulation considers central perspective geomtetry within a single line and allows easy implementation on analytical photogrammetric systems.

The adjustment allows the use of additional frame camera images as well as other measurements. An anchor point file for the generation of orthophotos may be generated whenever DTM data are available. First results using a combined adjustment of Metric Camera photographs and MOMS data are presented.

Keywords: Analytical photogrammetry, Aerial triangulation, image rectification, combined space sensor adjustments, MOMS, Metric Camera

1. INTRODUCTION

First simple geometrical models for the evaluation of Line-Scanner Images have been developed by DERENYI and KONECNY (1966). In 1971 a solution using collinearity equations and terrain heights has been presented by KONECNY. The photogrammetric method led to a solution with high correlations between the photogrammetric parameters, which converged by the introduction of fictive observations (DOWIDEIT 1977, SCHUHR 1982, WU 1986).
Another solution in evaluating LANDSAT images was described by BAEHR (1976). In his work the coordinates of control points were adjusted instead of observation of (uncorrelated) image coordinates.
A similar approach with very low correlated orbital parameters has been developed by IGN Paris in the course of the evaluation of SPOT images (EGELS 1983, TOUTIN 1985).
Both approaches have certain disadvantages. Within the first group the high correlations have to be reduced by the introduction of distinct fictive parameters. This is why this solution is affected by hypotheses. The second way avoids to relate the observations to photo coordinates and is therefore an approximate functional model.

This paper shows a new possibility which allows an approach using photo coordinates and avoids high correlations between the adjusted unknowns. The unknowns of the orientation are partly formulated as additional parameters. The method is of special interest for the evaluation of satellite scanner images like SPOT, MOMS, Stereo-MOMS and HRIR sensors.

2. GEOMETRY OF CCD LINE-SCANNER IMAGES

An aerial photograph is a central perspective image of part of the earth surface with a common size of 23 x 23 cm. Within one strip a number of photos which overlap to a high degree are taken in regular intervals. The exterior orientation of one photograph is given by the coordinates X_o, Y_o, Z_o and the angles ϕ,ω,κ.

A CCD-Line Scanner commonly has one or more CCD-Line-Sensors mounted in the focal plance of the optics. While the platform moves the terrain is continuously projected to the sensor. Within fixed time intervals (cycles) the measured intensities are read out of the single sensor elements of each line. In the case of a simultaneous read-out of all elements at each cycle the image of each line can be regarded to be a central perspective.

The exterior orientation of each single line is given by six parameters as in the case of aerial photography, but the parameters of neighbouring lines are highly correlated. This is especially true if the scanner is mounted on a platform of a high altitude satellite with a geocentric orbit.

The sensor is moving uniform i.e. without acceleration during the period of acquisition from A to E (see Fig.1). In case the computation of the parameters of orientation is performed in a coordinate system like Gauss-Krueger or UTM, the flight path from A to E may be considered to be straight. The center of projection moves linearly from A to E, which means:

$$\mathbf{X}_{o,i} = \mathbf{X}_{o,A} + S_i/S_{AE} \cdot (\mathbf{X}_{o,E} - \mathbf{X}_{o,A}) \qquad (1)$$

where

$\mathbf{X}_{o,i}$: Positional vector of the center of projection at time i

$\mathbf{X}_{o,A}$: as above, but for the first line

$X_{o,E}$: as above, but for the last line

S_i : Distance from $X_{o,A}$ to $X_{o,i}$

S_{AE} : Distance from $X_{o,A}$ to $X_{o,E}$

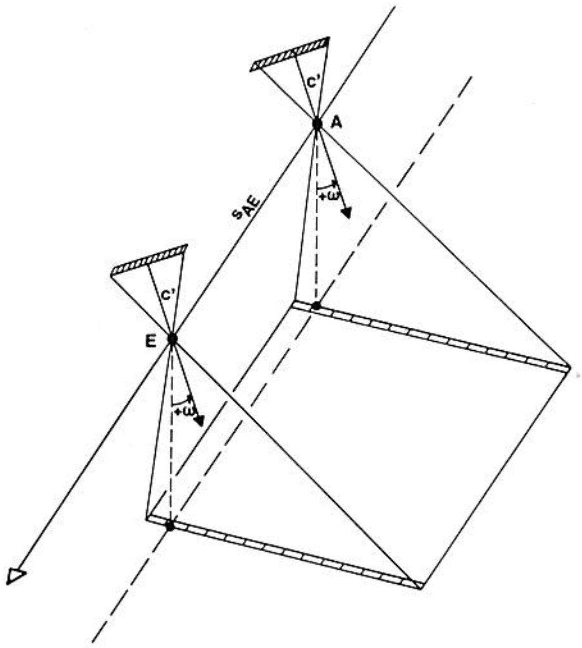

Figure 1: CCD Line-Scanner Imaging with Non-accelerated Uniform Movement

The ratio of the distance in (1) may be replaced by

$$i/n = S_i/S_{AE} \tag{2}$$

where

i : Number of actual line (time of exposure)
n : Total number of lines

The orientation angles ϕ,ω and κ are regarded to be constant in a first approximation.
If the computation is done in a geocentric coordinate system the linear interpolation in (1) has to be replaced by a circular or elliptic one. In this case the Pitch-angle ϕ is not constant any more but has to be interpolated in a similar way. For a discrete point of one line in the image its collinearity equation may be formulated:

$$X - X_o = \lambda \cdot R \cdot x' \tag{3}$$

where

$$x' = (0, y', -c) \tag{4}$$

y' corresponds to the pixel number j within that particular line and is related to the center of the line, while c is the focal length of the instrument.

Figure 2 shows the photo coordinate system of a CCD scanner having its x' axis in flight direction.

The approximation used i.e. the linear not-accelerated movement represents the ideal case. In reality accelerations caused by maneuvering actions and/or movements caused by the nonuniform gravity field of the earth cause the platform movement to deviate from a mathematically defined orbit and the angles ϕ, ω and κ are not constant any more. All six parameters of orientation are a function of time. Unfortunately the function itself is a priori not known and must be approximated by methods like polynomials or time series (WU 1986).

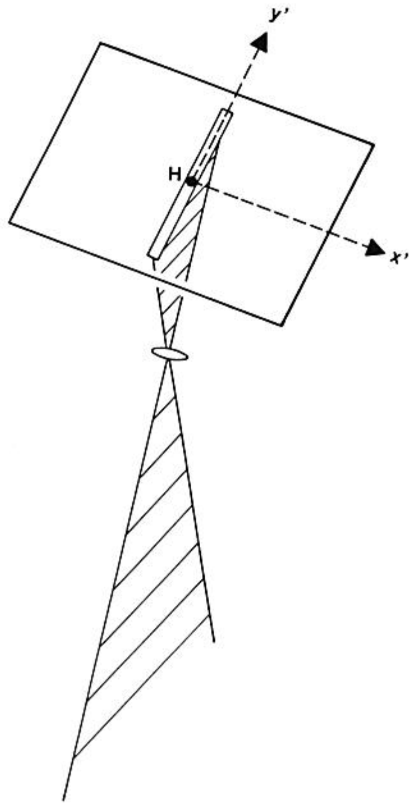

Figure 2: Photo Coordinate System of a CCD-Line-Scanner

3. PROPOSED APPROACH

Referring to chapter 2 it becomes clar that the equations developed so far do not meet the reality, but in case of a satellite based CCD-sensor a very simple solution for the refinement of the approach may be given. A satellite compared to an aircraft has a very smooth orbit. In addition the terrain heights are small compared to the flying altitude. Because of this, the 6 orientation parameters of a perspective projection are highly correlated among each other, i.e. ϕ with X_o and ω with Y_o, assuming a flight in X-direction. In terms of the coordinates on ground it is therefore unimportant if ϕ or X_o is changed. Because of that in the refinement the orbit may be expressed straight or uniform curved if changes of ϕ, ω and κ are allowed.

These angular changes are a function of time i. Mathematically they may be expressed as additional parameters, which change the image geometry. Therefore the orientation angles are treated to be time invariant.

The question which distortions are most likely leads to a set of 8 parameters, which are shown in Figure 3. This set of parameters may be expanded if desired.

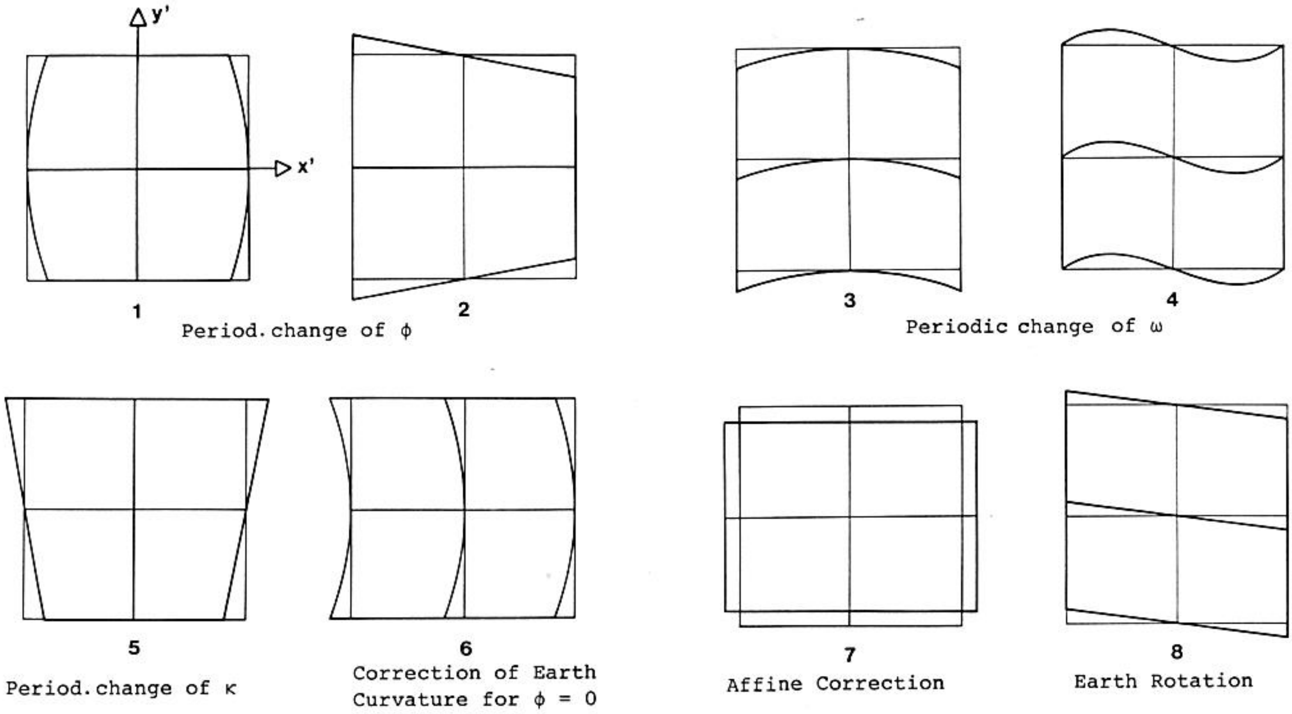

Figure 3: Additional Parameters to Account for the Non-uniform Movement and Earth Rotation

4. PARAMETERS AND RESULT OF ADJUSTMENT

Within the presented approach for each image the coordinates of the center point M (Figure 4) and the orientation angles ϕ, ω and κ as well as the additional parameters are considered to be unknowns.

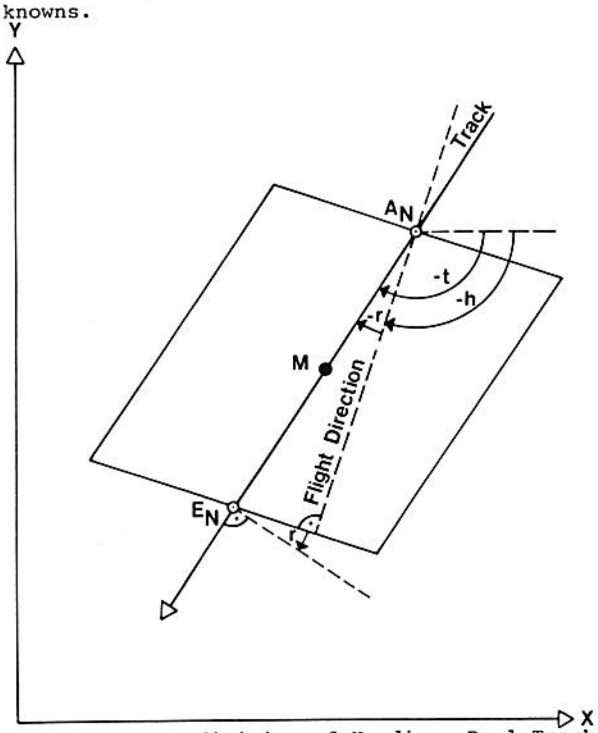

Figure 4: Definition of Heading, Real-Track Heading t and Earth Rotation r

By using orbital data (ephemeris) of a satellite information about these unknowns can be computed.

Figure 4 sketches part of a terrain covered by an image. Because of the rotation of the earth the direction of flight h (heading) is not identical with the direction of the flight track t_{AE} on ground (Real Track Heading).

The angle of difference r (Rotation) is a function of the angular speed of the earth, of the geographic latitude, the inclination and the time for one orbit period of the satellite:

$$h + r = t_{AE} \tag{5}$$

and

$$\kappa \sim h \tag{6}$$

In a similar way the direction of the flight track t, the distance S_{AE} and the height difference between A and E may be extracted from existing maps or measurements.

According to the empirical a priori standard deviation a wight is assigned to the unknowns ϕ, ω, κ in order to stabilize the block. The parameters t_{AE}, S_{AE} and ΔH_{AE} are used to interpolate the centers of projection between A and E.

In addition control points and tie points are included in the adjustment.

This approach is similar to standard bundle adjustments with central perspective projections and hence easy to implement into existing bundle adjustment programs. In the same way it becomes possible to adjust simultaneously photographs with central perspective and CCD-images.

The utilization of all the other options of existing software is part of this approach. The presented algorithm has been integrated as an option to the Hannover bundleblock adjustment program BINGO (KRUCK 1983, 1985). Further to the above mentioned 8 parameters (see Fig.3) an additional set of 24 existing parameters per image may be selected as a standard.

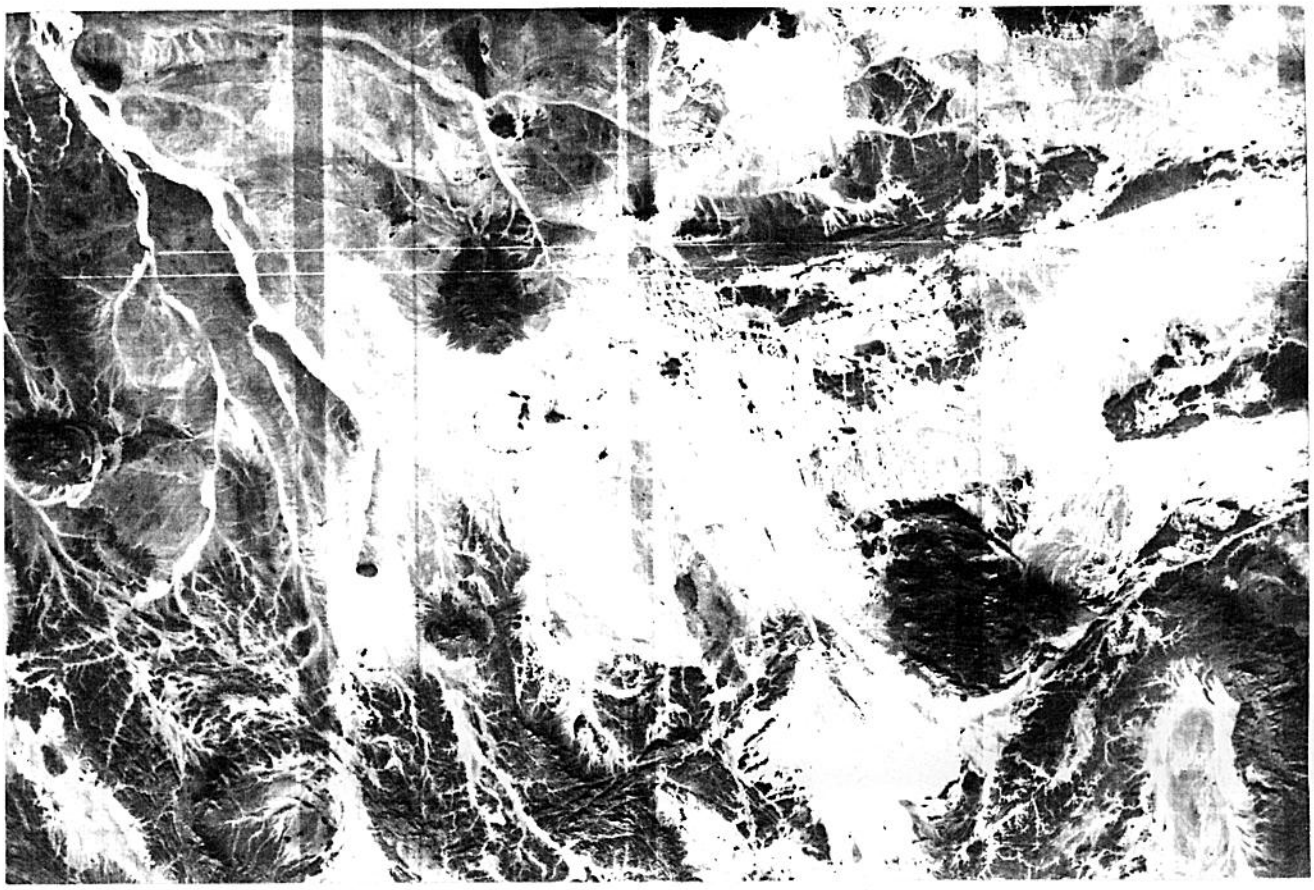

Figure 6: MOMS Image Sudan 11-76-237 Jabal Todu

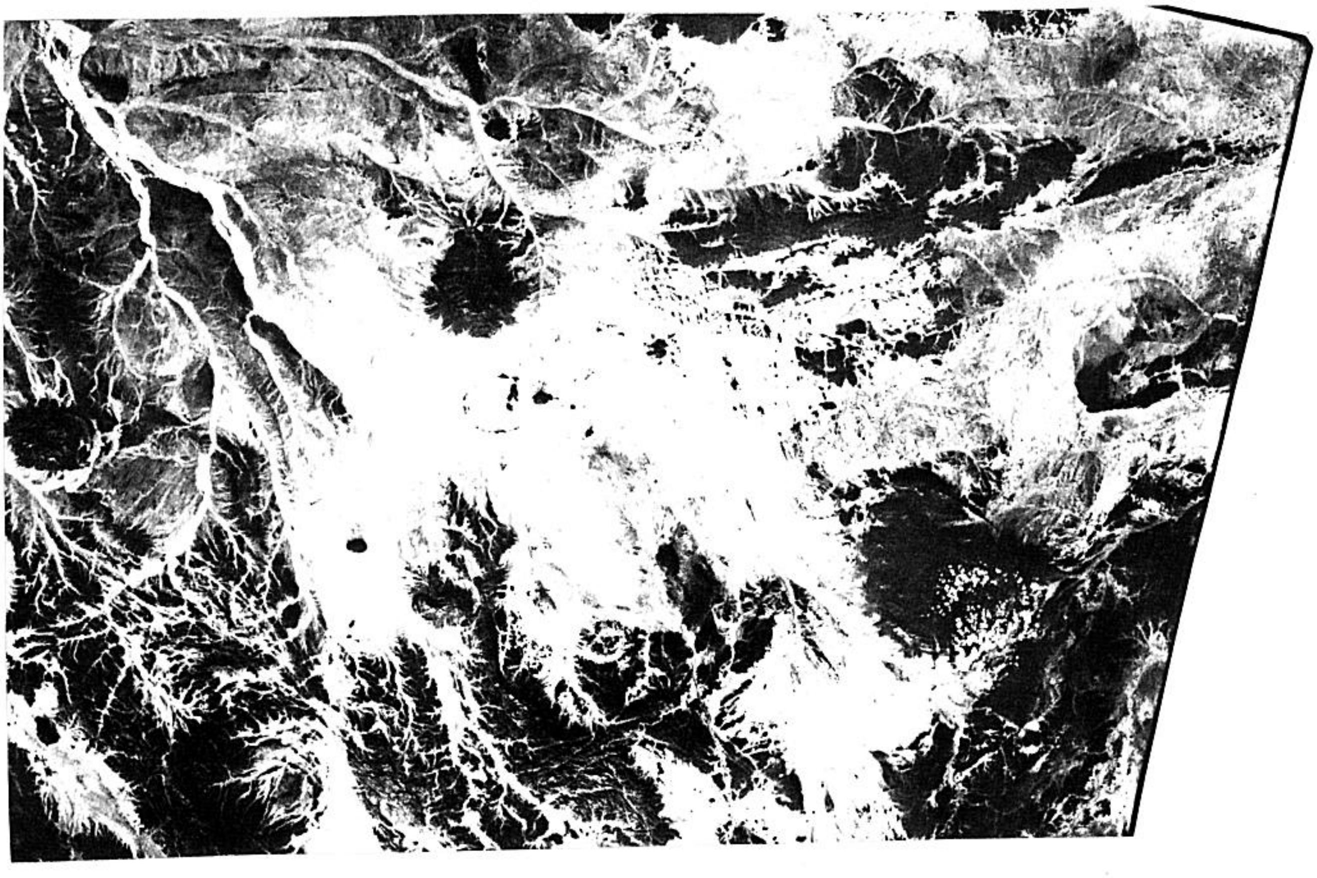

Figure 7: Window of Metric Camera Photograph
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The adjustment will result in the following:

- 6 parameters of exterior orientation X_M, ϕ, ω and κ
- The values of the additional parameters representing the difference between the approximated uniform movement and the reality; redundant parameters are automatically removed.
- The correlation of the additional parameters
- Three-dimensional coordinates of object-points
- Variances and covariances of the unknowns
- The variance components of the observation to check the stochastical model.

5. FIRST PRACTICAL TESTS

This chapter presents first geometric evaluations resulting from a combined bundle adjustment of 3 Metric camera photographs (Spacelab Mission 1 STS 9 1983) and one single image of MOMS (STS 11, 1984). From the images of both missions the region of 'Jabal Todu' in the PR of Sudan was selected. This area was imaged by both sensors and the images are free of clouds. Table 1 summarizes the data of both sensors and Fig. 5 shows the layout of the block on ground.

Table 1: Data of MOMS Sensor and Metric Camera

	Metric Camera	MOMS
Orbit Altitude	254 km	300 km
Focal length	305,1 mm	237.2 mm
Photo Scale	1:830 000	-
Pointing Accuracy	12 μm	1.3 Pixel
Data Product	Film	CCT
Format	23 x 23 cm	4600 x 6912 Pixel
Area Covered	189 x 189 km	93 x 138 km
Resolution	30 lp/mm	20 m (16 μm Pixel size)
Number of photos	3	1
Date	2.12.83	8.2.84
Preprocessing	-	none

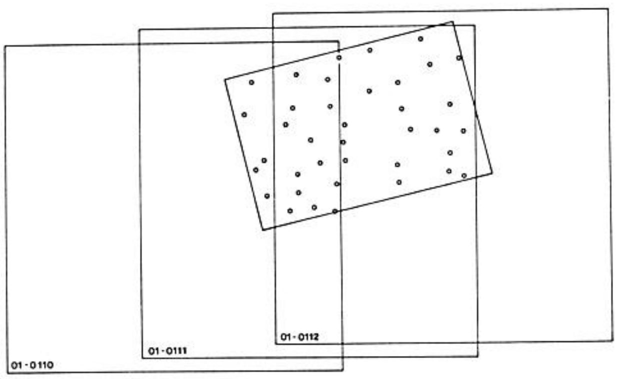

Figure 5: Layout of MOMS and Metric Camera Images

Because maps and control points of that area were not available the bundle block was orientated with minimum constraints using three control points. The pointing accuracy in both image types (MC and MOMS) was not very satisfactory, because real good tie points (Fig.6 and 7) were missing. It is expected that higher accuracies can be obtained in populated areas with a great amount of human made patterns like streets.
Table 2 gives an overview about the results obtained.

Table 2: Overview About Obtained Results

	Metric Camera	MOMS
<u>Standard deviations:</u>		
points planimetric	10-20 m	
point height	40-80 m	
center of projection		
planimetric	250 m	500 m
height	50 m	50 m
image coordinates	12 μm	1,3 pixel
<u>Additional Parameters [Pixel]</u>		
earth rotation		174 (177)*
overscan		25 (95)
other parameters		0,5 (0)

* Values in brackets are predicted by the use of orbital parameters.

The accuracy of the coordinates of the object points is mainly determined by the photographs of Metric Camera. The photographs of the MC have been taken at a lower altitude and the camera has a larger field of view in comparison to the MOMS sensor. This results in a better positioning accuracy for the center of projection of the MC.
It is remarkable however, that the flight attitude of the MOMS system wsa very stable. Time dependant significant variations of the orientation parameters were not detected. This is why BINGO selected only three additional parameters (see Table 2 and Fig.8), out of which the correction of earth rotations, as expected, was of major importance.

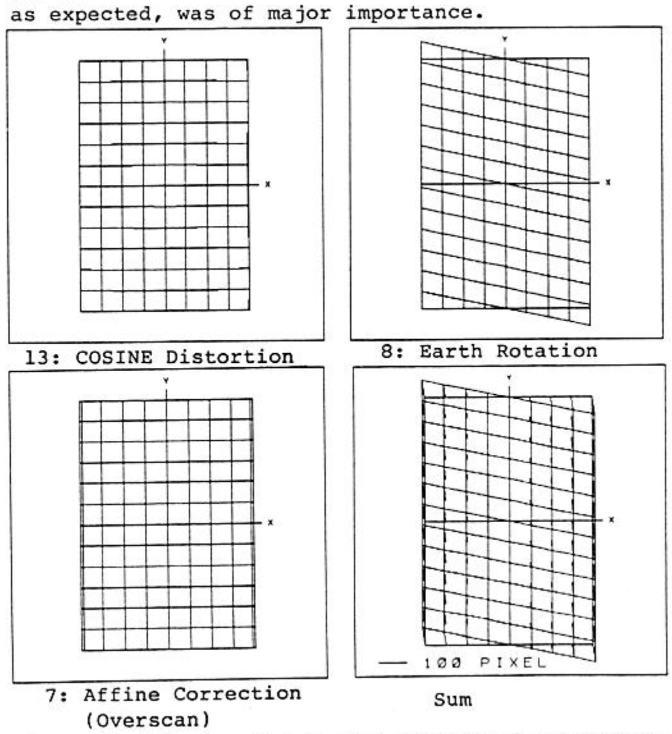

Figure 8: Effects of Selected Additional Parameters

Because the distance S_{AE} as well as the Real Track Heading t_{AE} are fixed adjustment parameters the question arises to what extent a variation of these parameters will influence the results. Fig.9 shows σ_0 as a function of varying t_{AE}. This demonstrates that small changes in the parameter values do not affect the adjustment results.

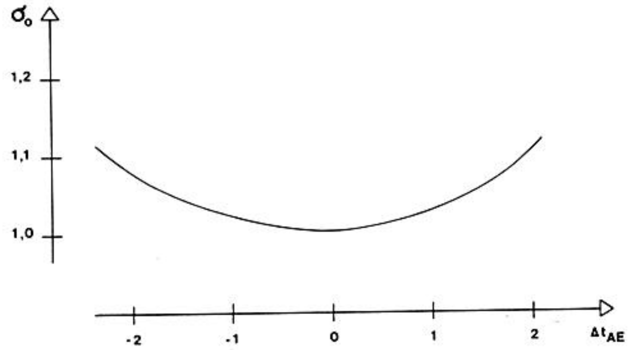

Figure 9: Relative σ_0 as Function of Varying Real Track Heading t_{AE}

The additional parameter to correct overscan effects also compensates small errors in S_{AE} and influences of neglected elliptic or circular orbits. In the same manner the parameter for the correction of earth rotation compensates for incorrect values of t_{AE}.

The software of BINGO is able to generate output files (KONECNY, KRUCK, LOHMANN 1986), which can be used for further image processing like
- online compilation of maps and digital terrain models
- generation of orthophotos by the use of analog orthophoto printers or by the use of digital image processing.

This is ensured by a continuous data flow between BINGO and analytical instruments. The necessary software extentions have already been coded and will soon be presented.

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