# STUDIES ON OBJECT RECONSTRUCTION FROM SPACE USING THREE LINE SCANNER IMAGERY

Heinrich Ebner and Franz Müller
Chair of Photogrammetry
Technical University of Munich
Arcisstr. 21, D-8000 Munich 2
Federal Republic of Germany

Senlin Zhang
Departement of Photogrammetry
and Remote Sensing
Wuhan Technical University of
Surveying and Mapping
Lo-yuroad 23, Wuhan
People's Republic of China

Commission I

**Abstract**

The paper investigates the capability of object reconstruction from space for two specific projects. Both of them are based on the use of three line scanner systems allowing for simultaneous digital image recording from three different angles. An efficient model for combined point determination is proposed, considering the digital image data as well as orbit information, GPS and INS observations. The resulting accuracy is estimated from project oriented simulations.
Finally the possibilities for DTM generation, orthophoto production and stereo compilation from three line scanner imagery are discussed.

## 1. Introduction and Review

A line scanner or opto-electronic camera allows for digital image recording line by line according to the push-broom principle. A three line scanner records the object simultaneously in forward, downward and backward looking direction. The threefold coverage makes a rigorous reconstruction of the object possible (Hofmann et al., 1982).
Three line scanner systems shall be used from space in conjunction with the MEOSS experiment (Lanzl, 1986) and the MOMS-02/D2 project (Ackermann et al., 1988).
The paper first describes the proposed mathematical model for combined point determination using three line scanner imagery and general control information.
Then accuracy estimations for the space projects MEOSS and MOMS-02/D2 are performed by means of computer simulations.
Finally the possibilities for DTM generation, orthophoto production and stereo compilation from three line scanner imagery are discussed.

## 2. Combined Point Determination Using Three Line Scanner Imagery

A three line scanner contains in the focal plane of the objective three linear CCD-sensors, which are oriented perpendicularly to the direction of flight. During the flight the shutter of the objective is open and the sensors are read out with constant frequency. Within each read cycle a digital image is recorded, consisting of only three lines. If read cycle frequency, speed of flight, image scale and size of sensor elements are in proper relation to each other the terrain is scanned with nearly square shaped object surface elements (Figure 1). Generally each object point is imaged three times, first by the forward looking sensor a, then by the downward looking sensor b and finally by the backward looking sensor c. So, classical frame photography with proper longitudinal overlap is replaced by a composition of a large number of successive three line images. Basically, each of them has its own exterior orientation.

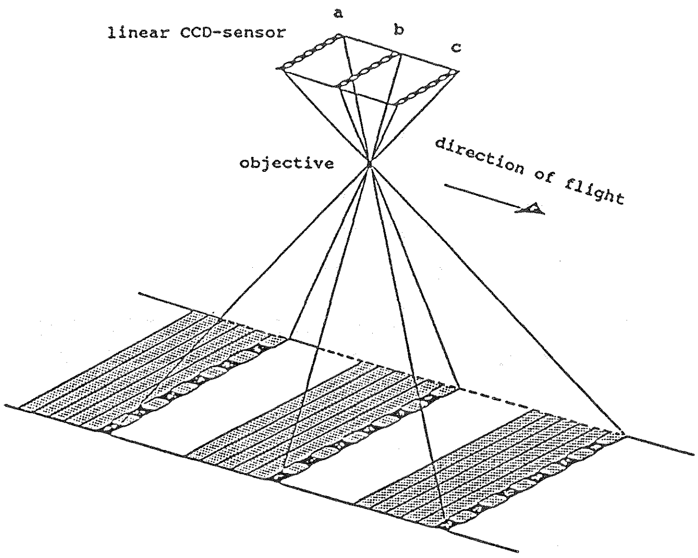


Fig. 1: Image recording using a three line scanner

Consequently the mathematical model for the reconstruction of the exterior orientation should use 6 unknown parameters for each three line image $I_j$. In practice, however, there is not enough information to determine such a large number of unknowns. A solution to this problem can be found by the introduction of a proper functional model for the variation of the exterior orientation parameters. In the simplest case piecewise linear functions can be used. Then so-called orientation images $I_k$ are defined for which the parameters of the exterior orientation are unknown and the 6 parameters of an arbitrary image $I_j$ are represented by linear functions of the 12 unknown parameters of the two nearest orientation images $I_k$ and $I_{k+1}$. For details see (Ebner and Müller, 1986).

In that way point determination using three line scanner imagery can be performed similar to classical photogrammetric point determination. Based on the bundle method collinearity equations are formulated for the image coordinates $x_{ij}$, $y_{ij}$ of the object points $P_i$ in the images $I_j$. The exterior orientation parameters $\hat{x}_j\ \hat{y}_j\ \hat{z}_j\ \hat{\omega}_j\ \hat{\phi}_j\ \hat{\kappa}_j$, however, are replaced by the unknown parameters $\hat{x}_k\ \hat{y}_k\ \hat{z}_k\ \hat{\omega}_k\ \hat{\phi}_k\ \hat{\kappa}_k\ \hat{x}_{k+1}\ \hat{y}_{k+1}\ \hat{z}_{k+1}\ \hat{\omega}_{k+1}\ \hat{\phi}_{k+1}\ \hat{\kappa}_{k+1}$ of the neighbouring orientation images $I_k$ and $I_{k+1}$.

All relevant image coordinates $x_{ij}$, $y_{ij}$ are considered as observations in a least squares adjustment. Further observation

equations are formulated for the control point coordinates. Unknowns of the adjustment are the coordinates of the object points $P_i$ and the parameters of the orientation images $I_k$.
This concept can easily be generalized to combined point determination, if instead of or in addition to control points general control information is available, e.g. direct geodetic observations, measured orientation parameters or DTM data.
In conjunction with the planned space project MOMS-02/D2, GPS and INS observations are of particular interest. With the MEOSS experiment where such data are not available orbit information can be used.

## 3. Accuracy Estimations for the Space Projects MEOSS and MOMS-02/D2

### 3.1 MEOSS Experiment

The Monocular Electro-Optical Stereo Scanner (MEOSS), which has been designed and manufactered by the Institute of Optoelectronics at the 'Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V.' (DFVLR) will be the first three line camera in space (Lanzl, 1986). The mission is planned for 1988 on the SROSS satellite provided by the Indian Space Research Organisation (ISRO).
Besides thematic applications relating to cartography, meteorology and geosciences, MEOSS offers the first possibility of three dimensional photogrammetric object reconstruction based on spaceborne three line imagery. Although the ground resolution is limited to 52 m by 79 m, the MEOSS image data may be used for basic investigations and tests of photogrammetric compilation methods for threefold stereo scanner data.
The intention of this paper is to give an à priori estimation of the accuracy of point determination using MEOSS imagery. By means of computer simulations with project oriented camera- and flight parameters, the theoretical standard deviations $\sigma_{\hat{x}i}$, $\sigma_{\hat{y}i}$, $\sigma_{\hat{z}i}$ of the unknown coordinates $\hat{x}_i$, $\hat{y}_i$, $\hat{z}_i$ of object points $P_i$ have been calculated. In (Hofmann and Müller, 1988) the principle of this method is described in detail.
The simulations point out:
- the advantages of a simultaneous adjustment of two overlapping strips versus single strip adjustment and
- the possibility of the integration of orbit models, which provide information about the satellite position with limited accuracy.

The first item has to be seen in conjunction with the important feature of the MEOSS mission, that areas of interest can be recorded twice from different orbits, providing sixfold overlap. The advantages of such a block adjustment of three line imagery have been demonstrated in (Ebner and Müller, 1987).
Figure 2 shows an example for 5 consecutive orbits in the course of the MEOSS experiment representing the coverage of one day.
The rastered areas have been arbitrarily selected to investigate the accuracy of the object reconstruction from MEOSS imagery:
- area A represents a single strip,
- area B represents a block, consisting of two strips, which intersect at an angle of approximately 22 grad,
- area C represents a block, consisting of two strips, which intersect at an angle of approximately 61 grad.

The characteristic data for the MEOSS simulations are listed in table 1.
Concerning the chosen distance between orientation images, a remark is necessary: 16 km is probably a too pessimistic value, because the variations of the parameters of the exterior orientation might be small. Therefore, the changes in the parameters could be described using longer intervals without increasing the interpolation errors.

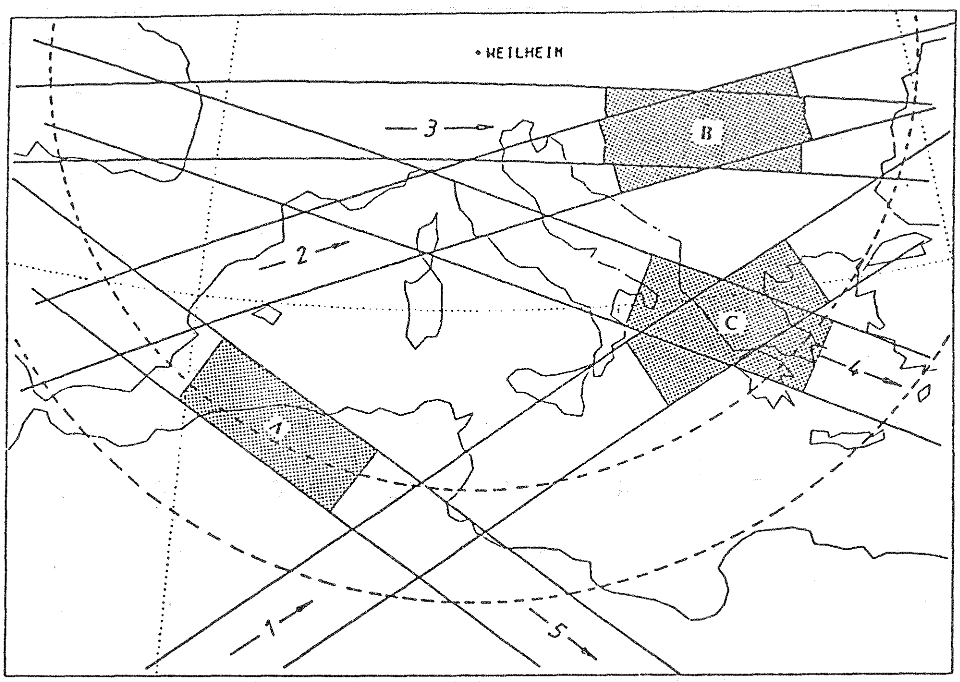


Fig. 2: Example for 5 consecutive orbits in the course of the MEOSS experiment (taken from Lanzl, 1986)

| | |
|---|---|
| <u>camera parameters</u> | |
| calibrated focal length | 61.10 mm |
| spacing forward/vertical sensor and vertical/backward sensor | 26.69 mm |
| standard deviation of image coordinates $\sigma_0$ | 5.0 $\mu m$ |
| <u>flight parameters</u> | |
| flying height | 458 km |
| baselength between forward/vertical look and between vertical/backward look | 200 km |
| strip length | 600 km |
| strip width | 240 km |
| distance between orientation images | 16 km |
| <u>object point distribution</u> | |
| distance in flight direction | 5 km |
| distance across flight direction | 60 km |
| height of all object points | 0 km |

Table 1: Characteristic data for the MEOSS simulations

The following simulations have been performed:

- strip / block adjustment for A, B and C assuming error-free parameters of the exterior orientation (accuracy limits),
- strip / block adjustment for A, B and C using four error-free ground control points (GCP) for each strip,
- strip / block adjustment for A, B and C assuming given position parameters for the orientation images $I_k$ with $\sigma_{xk} = \sigma_{yk} = \sigma_{zk} = 100$ m (orbit information) in addition to the GCPs.

Table 2 shows the results of the simulations. Given are the rms values $\mu_{\hat{x}}$, $\mu_{\hat{y}}$, $\mu_{\hat{z}}$ of the theoretical standard deviations $\sigma_{\hat{x}i}$, $\sigma_{\hat{y}i}$, $\sigma_{\hat{z}i}$ for the adjusted object point coordinates $\hat{x}_i$, $\hat{y}_i$, $\hat{z}_i$.

| | accuracy limits | | | 4 GCPs/strip | | | 4 GCPs/strip given pos.param. | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\mu_{\hat{x}}$[m] | $\mu_{\hat{y}}$[m] | $\mu_{\hat{z}}$[m] | $\mu_{\hat{x}}$[m] | $\mu_{\hat{y}}$[m] | $\mu_{\hat{z}}$[m] | $\mu_{\hat{x}}$[m] | $\mu_{\hat{y}}$[m] | $\mu_{\hat{z}}$[m] |
| Strip A | 33 | 32 | 106 | 1219 | 626 | 2780 | 152 | 268 | 309 |
| Block B | 26 | 26 | 84 | 31 | 31 | 200 | 30 | 30 | 91 |
| Block C | 30 | 30 | 98 | 37 | 37 | 176 | 35 | 35 | 109 |

Table 2: Results of the MEOSS simulations

The following conclusions can be drawn from table 2.

- The single strip shows poor geometry. The accuracy could be improved by using a greater distance between the orientation images, if the satellite dynamics allows for this.
- The use of two overlapping strips in a simultaneous block adjustment improves the accuracy of point determination drastically. Especially the achieved planimetric accuracy is close to the accuracy limit.
- The introduction of given position parameters (orbit information) further improves the accuracy, particularly in height.

### 3.2. MOMS-02/D2 Project

The MOMS-02/D2 project, which is also directed by the DFVLR, is based on a panchromatic three line scanner with high ground resolution in connection with multispectral channels (Ackermann et al., 1988). The use of the system is planned for 1991 during the German D2 mission on a NASA Space Shuttle flight.
One of the main tasks of the MOMS-02/D2 project is the rigorous and precise geometric evaluation of threefold stereo data. To secure, that the high requirements of this mission concerning the geometry of object reconstruction are met, comprehensive studies have to be performed.
The simulation results given in this paper show a general trend, but should not be interpreted as final.

There is one characteristic feature of the project, which changes the geometry of photogrammetric point determination for the worse: the ratio of flying height and strip width is approximately 9:1.
Improvements of the geometry may be obtained by using information from navigation systems for the position and attitude parameters.
The following simulations have been performed:

- adjustment of a strip assuming error-free parameters of the exterior orientation (accuracy limits),
- adjustment of a strip using four error-free ground control points,
- adjustment of a strip assuming measured position and/or attitude parameters with different accuracies additionally to four error-free ground control points.

In practice attitude and position information can be derived from Inertial Navigation Systems (INS) and/or from the Global Positioning System (GPS).
Table 3 lists the characteristic data for the MOMS-02/D2 simulations.

| | |
|---|---|
| <u>**camera parameters**</u> | |
| calibrated focal length | 660.00 mm |
| effective spacing forward/vertical sensor and vertical/backward sensor | 300.42 mm |
| standard deviation of image coordinates $\sigma_0$ | 5.0 $\mu$m |
| <u>**flight parameters**</u> | |
| flying height | 334 km |
| baselength between forward/vertical look and between vertical/backward look | 152 km |
| strip length | 606 km |
| strip width | 36 km |
| distance between orientation images | 16 km |
| <u>**object point distribution**</u> | |
| distance in flight direction | 2 km |
| distance across flight direction | 9 km |
| height of all object points | 0 km |

Table 3: Characteristic data for the MOMS-02/D2 simulations

In table 4 the results of the investigations are summarized. Again, the rms values $\mu_{\hat{X}}$, $\mu_{\hat{Y}}$, $\mu_{\hat{Z}}$ of the theoretical standard deviations $\sigma_{\hat{X}i}$, $\sigma_{\hat{Y}i}$, $\sigma_{\hat{Z}i}$ for the adjusted object point coordinates $\hat{X}_i$, $\hat{Y}_i$, $\hat{Z}_i$ are listed.
In this case, however, not all points have been used to calculate the rms values, but only the ones, which are located in the threefoldly covered area of the strip.
The obtained results may be analysed as follows.

- Compared to the accuracy limits (Sim. 11) the accuracy of the strip adjustment based on only 4 control points (Sim. 1) is poor.
- The use of measured attitude parameters (Sim. 2 to Sim. 4) improves the height accuracy to some extent. There is no difference, whether 1.0, 0.5 or 0.2 mgrad is assumed.

- Measured position parameters (Sim. 5 to Sim. 7) yield smaller values for $\mu_{\hat{X}}$ and $\mu_{\hat{Z}}$, but there are still significant differences to the accuracy limits.
- Really satisfactory results can only be obtained by the simultaneous use of accurate attitude and position data (Sim. 9 and Sim. 10).

The described studies will be continued. The final goal is a comprehensive analysis of the accuracy properties of combined point determination within the MOMS-02/D2 project.

| | attitude data $\sigma_\omega = \sigma_\phi = \sigma_\kappa$ [mgrad] | position data $\sigma_X = \sigma_Y = \sigma_Z$ [m] | estimated accuracy | | |
|---|---|---|---|---|---|
| | | | $\mu_{\hat{X}}$ [m] | $\mu_{\hat{Y}}$ [m] | $\mu_{\hat{Z}}$ [m] |
| 1 | none | none | 21.8 | 8.0 | 64.1 |
| 2 | 1.0 | none | 21.2 | 6.7 | 35.7 |
| 3 | 0.5 | none | 21.2 | 6.6 | 35.7 |
| 4 | 0.2 | none | 21.2 | 6.6 | 35.7 |
| 5 | none | 25.0 | 11.1 | 7.4 | 24.3 |
| 6 | none | 5.0 | 7.1 | 7.3 | 18.1 |
| 7 | none | 1.0 | 6.7 | 7.3 | 16.6 |
| 8 | 1.0 | 25.0 | 6.7 | 4.4 | 14.1 |
| 9 | 0.5 | 5.0 | 2.6 | 2.1 | 6.2 |
| 10 | 0.2 | 1.0 | 1.6 | 1.6 | 4.2 |
| 11 | error-free orient. parameters | | 1.5 | 1.5 | 3.9 |

Table 4: Results of the MOMS-02/D2 simulations

## 4. Steps of Object Reconstruction and Conclusion

The process of object reconstruction based on digital imagery of three line scanners includes the following tasks.
- Image recording analogous to the push-broom principle (see chapter 2).
- Determination of homologous points by a human operator or by methods of digital image matching.
- Preprocessing of additional control information, e.g. from INS or GPS.
- The main task consists in the reconstruction of the exterior orientation based on the mathematical model described in chapter 2.
- After the reconstruction of the exterior orientation, DTM image points can be determined with methods of digital image matching, yielding DTM object points. Then the DTM surface can be mathematically described by proper models.
- Using the image data of line a, b or c orthophotos and central perspectives may be derived by means of digital image tranfor-

mation methods.

- If an analogue film is produced from the original or transformed digital data, analytical plotters can be used for the evaluation of three line imagery.
- Finally digital mono plotting (compilation of the images generated by sensor a, b or c) and digital stereo plotting (stereoscopic evaluation of the imagery using lines a/b, a/c or b/c) is possible. These methods will play an important role in future photogrammetry.

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