A DIGITAL THREE LINE STEREO SCANNER SYSTEM

Otto Hofmann
Messerschmitt-Bölkow-Blohm GmbH
D 8000 Muenchen 80, P.B. 80 11 09
Federal Republic of Germany
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1. The Problem

Digital photogrammetry up to the present time is actually "digital assisted analogical photogrammetry". Photogrammetric images are generated by a photographical process and must be measured and interpreted visually. A direct digital and automatic compilation and evaluation is therefore not possible. This problem can be optimally solved by the immediate survey of digital pictures. Photogrammetrists may dream of CCD-arrays with 20.000 by 20.000 pixels, but technical obstacles and immense costs prevent the realisation of such wishes in the near future, and it will be doubtful whether it is really reasonable.
The well-known push-broom scanner principle (Fig. 1) solves the problem of the generation of digital imagery, but it produces image strips line by line. Each line has its own set of orientation parameters, but no spatial bundles of rays with central perspectivity exists. Consequently, the fundamental basis of stereophotogrammetry is lost. Many proposals in the past tried to overcome this difficulty, but up to now no really practicable process for rectification and three dimensional compilation of scanner-imagery was found.

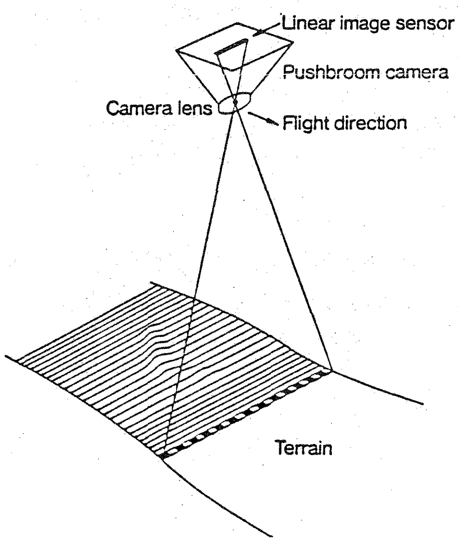

Fig. 1 Push broom scanning principle

2. The Solution

The author proposed to solve this problem by the arrangement of three sensor lines A, B, C in the focal plane of a push broom camera (Fig. 2). Alternatively, three telescopes whose optical axes are convergent, each with one sensor line can be used.
During the flight, these sensors A, B, C scan the terrain according to the push broom principle simultaneously by the synchronized image cycle N from different perspectives (Fig. 3), thereby producing three overlapping image strips A_s, B_s, C_s (Fig. 4).

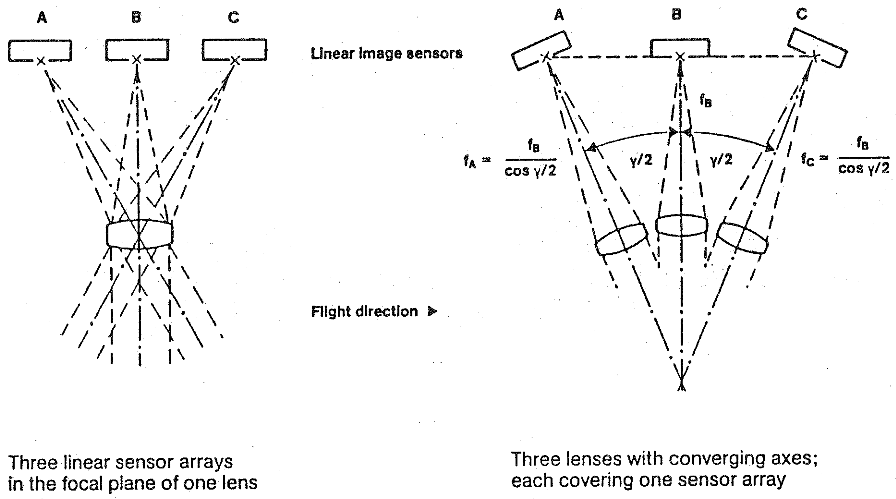

Fig. 2 Three line camera

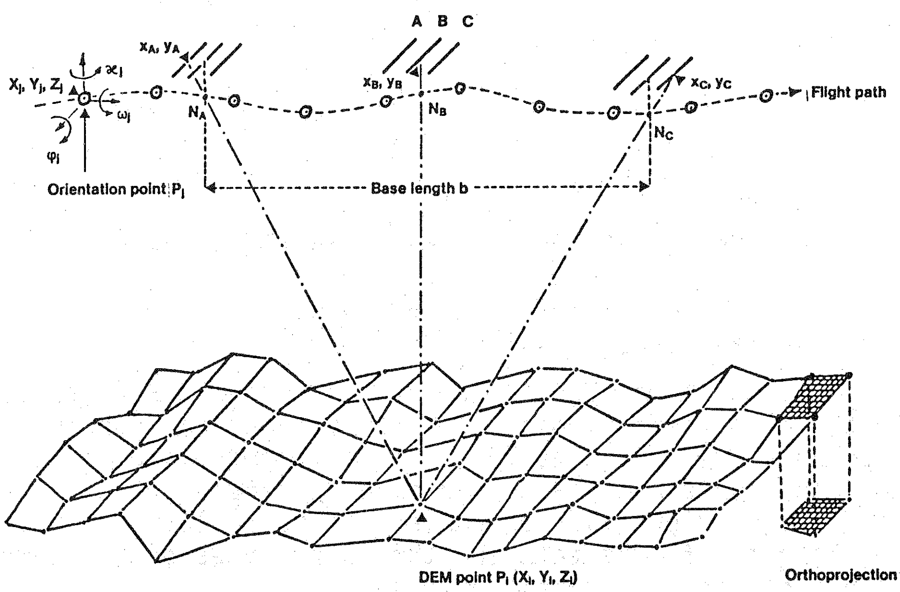

Fig. 3 Strip model generation with three line camera

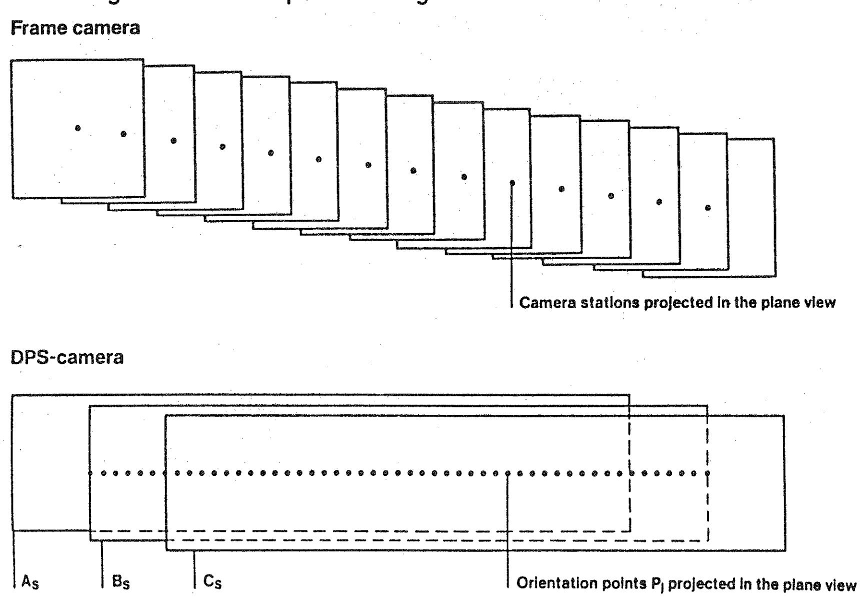

Fig. 4 Overlapping image strips

Each terrain point P_i (X_i, Y_i, Z_i) is imaged in three different image cycles(N_A, N_B, N_C)on the sensors A, B, C in the pixel numbers m_A, m_B, m_C. As the positions of the linear arrays and the pixel intervalls are calibrated the image coordinates x_A, y_A, x_B, y_B, x_C, y_C of any imaged and identified terrain point P_i can be determined.
This imaging process can be explained as the travelling of an imaged terrain point across the image plane crossing the line sensor arrays A, B, C in the pixels m_A, m_B, m_C during the image cycles N_A, N_B, N_C (Fig. 5).

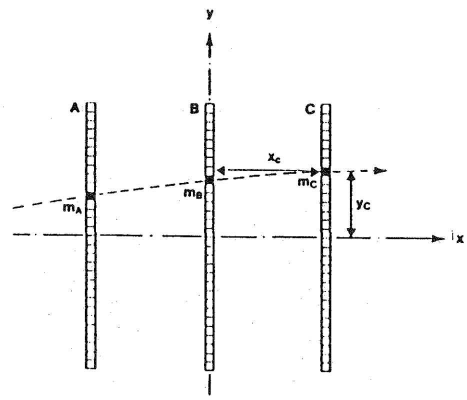

Fig. 5 Trace of a terrain point in the image plane

The compilation process for the rigorous reconstruction of the strip model now consists of two main procedures:

a) Determination of the homologous image points in the three strips belonging to the same terrain point P_i by an automatical sophisticated multistep process (Fig. 6). The result is a computer stored list of corresponding image coordinates x, y and image cycles N.
b) Computation of the orientation parameters of so called "orientation points" P_j along the flight path and the coordinates of the terrain points P_i in a closed analytical process.

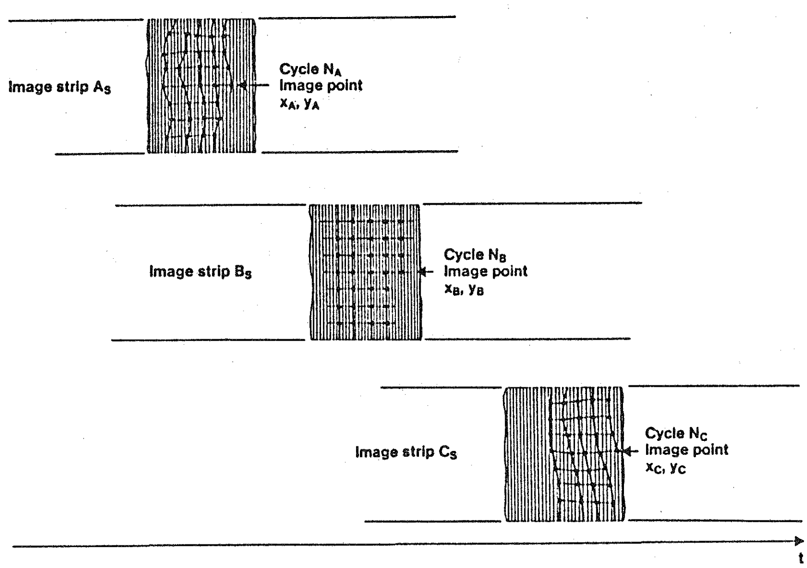

Fig. 6 Homologous image points in the image strips

The latter will be explained briefly: The fundamental geometrical condition imposed is the requirement that the rays through the three corresponding image points and the corresponding perspective centers intersect in the terrain point P_i. This requirement is implemented by the well known collinearity equations. They are established for each correlated terrain point. The corresponding observation equations have the following form:

$$x_{i,N} + v_{x,i,N} = c\,\frac{a_{11}(X_i-X_N) + a_{21}(Y_i-Y_N) + a_{31}(Z_i-Z_N)}{a_{13}(X_i-X_N) + a_{23}(Y_i-Y_N) + a_{33}(Z_i-Z_N)} \qquad (1)$$

$$y_{i,N} + v_{y,i,N} = c\,\frac{a_{12}(X_i-Y_i) + a_{22}(Y_i-Y_N) + a_{32}(Z_i-Z_N)}{a_{13}(X_i-X_N) + a_{23}(Y_i-Y_N) + a_{33}(Z_i-Z_N)} \qquad (2)$$

Here c is the focal length of the camera and a_{11}, ... a_{33} are the coefficients of the matrix of the camera rotation:

$$a = f\,(\omega_N, \phi_N, \varkappa_N) \qquad (3)$$

On the left side of these observation equations (1), (2) the observed image coordinates x, y and their corrections v_x, v_y are arranged, the right sides of the equations contains

a) the unknown coordinates k (X_i, Y_i, Z_i) of a terrain point P_i and

b) the actual unknown orientation parameters p $(X_N, Y_N, Z_N, \omega_N, \phi_N, \varkappa_N)$ at the image cycle N. These are expressed as functions of the orientation parameters of the neighboring orientation points P_j to be determined. In the case of linear interpolation between P_j and P_{j+1} each observation equation contains 12 orientation parameters.

For each terrain point P_i three pairs of these observation equations (1), (2) are set up.

These nonlinear observation equations are solved in the well known method by a Taylors expansion, and the direct setting up and solution of the normal equations. Approximations for the orientation parameters p and the terrain point coordinates k are determined from the known flight parameters, the correlated image coordinates x, y and their corresponding cycle numbers N. The unknowns are determined in two steps. At first, the orientation parameters p of the orientation points P_j are computed from the reduced normal equations, and then the coordinates k of the terrain points P_i are compiled by reinsertion. Because of the non-linearity of the problem, several iterations are necessary.
The image observations x and y may be complemented by additional observations, e.g., control points and measured orientation parameters. These algorithms have been coded and computer simulations are implemented and successfully tested by MBB.

3. Accuracy

It must be emphasized that the strip model is form-invariant and stable even without any control points or other external orientation measurements. Without them, the strip model could be computed in any scale and orientation within a local system. The insertion of external measurements, control points

and orientation parameters, establishes the absolute orientation and possibly improves the accuracy of the strip.
The accuracy of each computed unknown X can be expressed by the equation

$$\sigma_X = \sigma_0 \sqrt{Q_{XX}} \tag{4}$$

σ_0 is the standard error, which can be replaced by the image error in the focal plane. Q_{XX} is the appropriate diagonal element of the cofactor matrix, the inverse of the normal equations. It is influenced by the camera-, flight- and strip parameters. With these tools, simulated strip models and the least square adjustment, general valid forecasts of accuracy can be made for each application.
Fig. 7 shows the elevation errors σ_z of the terrain points in the middle axis of a long strip (86 km). Only four control points in the corners at the beginning and the end of the strip are arranged. The accuracy is remarkable.
These results of a simulation relates to a normal flight configuration with a wide angle camera, mounted in an aircraft.
Spacecraft configurations with high pixel resolution on the ground cause small image angles and sliding intersections of rays. Consequently the accuracy of the reconstructed strip is affected. Remedial measures can taken by the extension of control points and measurements of orientation parameters, e.g. by the GPS and inertial platforms.

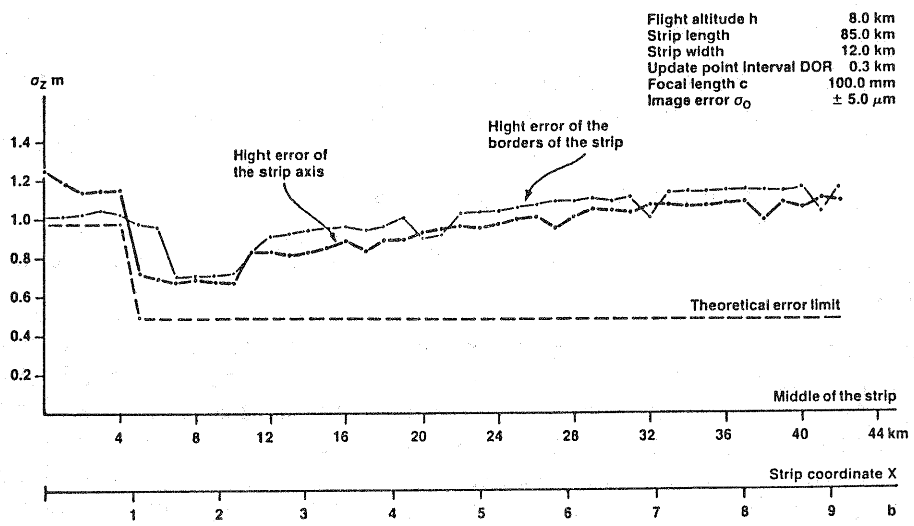

Fig. 7 Terrain elevation errors of a long strip

4. Hardware

On the basis of the described solution a whole system, comprising hard- and software components, can be joined together. It is called "DPS = Digital Photogrammetric System".
Fig. 8 shows the system with the most important components of the hardware. The image data of the three line camera, supplemented by a spectral module with several bands (Fig. 9) are stored in a special code on a High Density Digital Tape (HDDT).

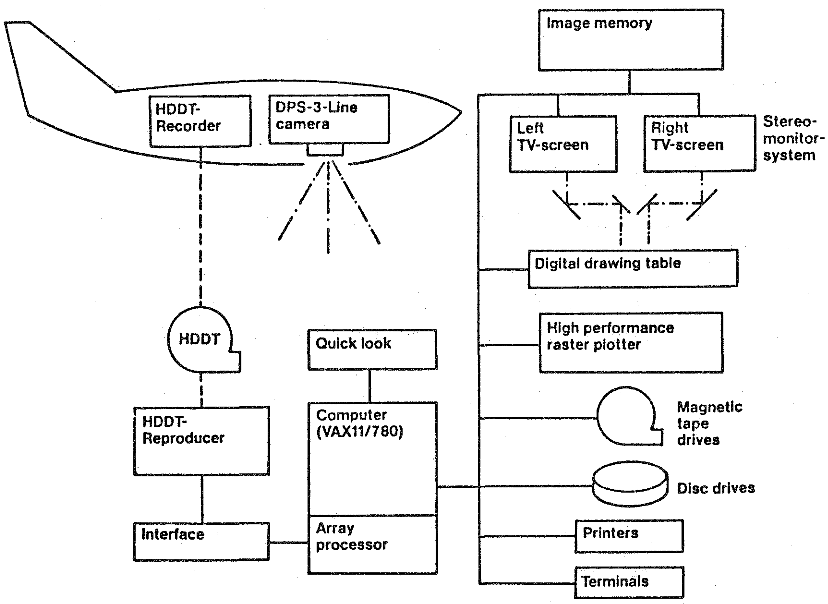

Fig. 8 Hardware system

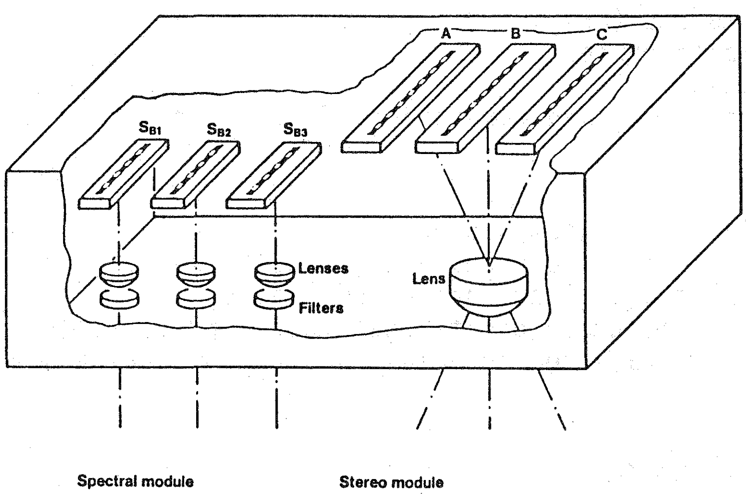

Fig. 9 Three line stereo module and spectral module

The heart of the compilation and evaluation process on the ground station is a powerful 32-bit Minicomputer, e.g. a VAX. The image data stored on the HDDT are decoded via a special interface to computer compatible storage devices, discs and tapes. A quick-look device, a fast plotter and/or a video terminal permits the operator to make a preliminary inspection of the image strips. Beside peripheral computer devices

a) an image processing system with an integrated interactive work station and stereo monitor system

b) high performance raster plotters

c) and digital drawing tables

are important components of the whole system.
The stereo monitor and the interactive workstation has the same function as the viewer of an analytical plotter, but it can dispense with measuring de-

vices. The operator need not work "blind". This fact is very important and the stereo monitor performs the following tasks and functions:

a) Visual selection and manual setting of the first point(s) of correlation;

b) Identification and setting of control points;

c) Correction and supplements within the correlation process and measurement of terrain points;

d) Interpretation, evaluation and measurements for topographic line map production, insertion of legends, coordinates, symbols, etc.

In general the stereo monitor in combination with the main computer and the image processing system will become the analytical plotter of the next generation.

5. Possibilities of application

The DPS is applicable in a wide range of scales for photogrammetry and remote sensing from aircraft and spacecraft. Nearly all evaluations for topographic and thematic map production can be delivered automatically or semiautomatically by this system:

- Strip and block triangulations,
- Digital elevation models (DEM),
- Ortho- and stereo-orthophotos,
- Line map evaluations,
- Support for map production and generation of Geo-Information-Systems and data banks,
- Spectral classifications.

The DPS will be applied advantageous specially in those cases where large areas have to be surveyed for map production, update and revision in a short time and multi-temporal imaging for change detection.
It may be pointed out, that these digital generated and by raster plotters reproduced images can be evaluated in detail in conventional analytical plotters.

6. Advantages of the solution

What are the advantages of the DPS compared with the "classical" photographic photogrammetry and what will the user gain? Only some highlights may be mentioned:

a) The DPS realizes the idea of a full digital and rigorous photogrammetric process. The generation of images as well as the compilation and evaluation process is digitally. It has the power and capability of automatic and computerized evaluation and lies completely in the trend of the general technological evolution.

b) Reduction of costs and time of map production. Automation of time consuming manpower.

c) Combination of photogrammetry and remote sensing, if wanted.

d) No reduction of image quality in the course of evaluation. The original surveyed image quality is preserved.

e) Reduction of errors.

7. Outlook

Messerschmitt-Bölkow-Blohm develops two three line cameras,corresponding data storage systems and ground segments by order of the government of the Federal Republic of Germany. One camera system, MOMS 02, is assigned for the planned space craft mission D2 on the spaceshuttle at the beginning of the nineties.
The other three line camera will be the prototype of an operational system for aircraft applications, mainly for map production and revision in the scale 1 : 50 000. In both cases the cameras contain a three line stereo module and a multispectral modul with several bands.
The future will reveal, whether the expectations and hopes in this new digital photogrammetrical system can be fullfilled.

8. References

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