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THE STEKO 1818 FOR ANALYTICAL ON-LINE PHOTOGRAMMETRY

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1. Abstract/Zusammenfassung/Sommaire:

An economical system for ANALYTICAL ON-LINE PHOTOGRAMMETRY based on the STEKO 1818 is presented. The stereocomparator has been equipped with digital components and was connected to a desk-computer of the type TEK 405x. A program was realised which calculates the elements of exterior orientation for a pair of overlapping photographs according to rigurous adjustment; also the subsequent on-line-calculation of object-coordinates is performed. The program is extended for a wide range of graphical outputs which may be presented on the INTERACTIVE GRAPHICAL SCREEN of the TEK desk-computer and/or the connected digital plotter. All data may be stored on magtape or floppy disk resp. may be transfered to a central-computer via TEK in terminal opperation. This efficient system offers a wide range of applications e.g. in the field of ARCHITECTURAL and INDUSTRIAL PHOTOGRAMMETRY as well as in the field of PHOTOGRAMMETRIC EDUCATION. For a great number of cases it is of advantage that the total system is easily mobile and allows photogrammetric on-the-spot-evaluation.

Es wird ein kostengünstiges System für die ANALYTISCHE ON-LINE PHOTOGRAMMETRIE auf der Basis des STEKO 1818 vorgestellt. Der Komparator ist mit digitalen Komponenten ausgerüstet und an einen grafischen Tischrechner Tektronix TEK 405x angeschlossen. Das zum System gehörende Programm bestimmt zunächst für den Allgemeinfall der Photogrammetrie die Elemente der äußeren Orientierung eines Bildpaares, sodann werden die Objekt-Koordinaten im On-Line-Betrieb berechnet. Das Programm ist für einen weiten Bereich grafischer Ausgabe angelegt, die entweder auf dem INTERAKTIVEN GRAFISCHEN BILDSCHIRM des TEK-Rechners und/oder gleichzeitig auf dem angeschlossenen Digital-Plotter erfolgt. Weiter können alle Daten auf Band oder Floppy Disk gespeichert bzw. über das TEK-Terminal mittels Groß-EDV weiterverarbeitet werden. Dieses effiziente System eröffnet einen weiten Bereich von Anwendungsmöglichkeiten auf den Gebieten der ARCHITEKTUR- und INDUSTRIE-PHOTOGRAMMETRIE sowie der photogrammetrischen AUSBILDUNG. Für einige Anwendungsfälle dürfte es von Interesse sein, daß das ganze System leicht transportiert werden kann.

Un système économique pour ON-LINE PHOTOGRAMMÉTRIE ANALYTIQUE sur base de STEKO 1818 sera presenté. Le comparateur est equipé de composantes digitales et connecté a un ordinateur sur pupitre du type Tektronix TEK 405x. Un programme a eté realisé qui determine d'abord en general les élements de l'orientation exterieure d'un couple de cliches, puis s'effectuera la calculation on-line de coordonnées d'objet. Le programme est étudie pour une vaste gamme de sorties graphiques pouvant être presentée soit sur l'ECRAN INTERACTIF GRAPHIQUE de l'ordinateur TEK et/ou en même temps sur le plotter digital connecte. Tous les données peuvent être stockées sur bande magnetique ou floppy disk resp. transferées a un ordinateur central par l'intermediaire du terminal TEK. Ce système efficasé offre une grande portée d'application par exemple dans le domaine de la PHOTOGRAMMETRIE DE L'INDUSTRIE et d'ARCHITECTURE et également dans le domaine d'EDUCATION DE PHOTOGRAMMETRIE. Pour un grand nombre de cas d'application il est d'avantage que tout le système est facilement portatif.

2. Hardware

2.1 Conventional use of the STEKO 1818

The STEKO 1818 is based on the principle of the ZEISS - PULFRICH stereocomparator which dates back as early as 1901. Because of economical reasons the STEKO 1818 has been chosen by many users who had to do stereophotogrammetric measurements rather than photo-interpretation.

Practice has shown that productional work was hardly possible; the instrument was mainly used for demonstrating stereophotogrammetric measuring principles. Photocoordinates have to be read off measuring drums with different graduation, calculation of object coordinates was performed by mechanical calculators. Because of this the widely spread STEKO 1818 had found little practical application.

The situation changed slightly when cheap programmable pocket calculators became available. Now it was at least possible to use the STEKO to a limited extent for practical work and to demonstrate and teach the principles of photogrammetric methods not only to surveying students but also to students in other fields like architecture, civil and mechanical engineering.

But still the situation of doing the stereomeasurements, than reading the scales, typing the data into the pocket-calculator and finally plot the object points - this procedure for a couple of hundred points per model - was demanding and the reason for many gross errors.

2.2 STEKO equipped with digital components

Automatic coordinate sensing with digital display and connection to a desk-computer via a standardized interface was the only solution /1/. Efforts in this respect had been carried out by Prof. DEKER, Darmstadt /2/ and Prof. MOLLER, Aachen /3/ as well as by CARL ZEISS Jena Ltd., London*). The STEKO 1818 at TH Darmstadt was equipped with 4 rotational encoders and the STEKO at RWTH Aachen with 3 linear encoders and 1 rotational encoder.

An investigation of the STEKO has shown up the possibility to apply 4 linear encoders of the type MINILID 300 with resolution of 1 micrometer. The encoders have been mounted directly on top of the photocarrier (x', x") and to the moving objectives (y', y") of the measuring optics of the STEKO. The spindles of the instrument are now used only for stereoscopic setting of points. One advantage of the MINILID linear encoders is their facility to realize together with the counter the socalled PRE-/MEMOSET, which allows to fix the point of origin of the photo-coordinate system. The zeropoint once set cannot be lost, even if the system is switched off.

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*) First offered as W.D.S. Digitising System, now as MDR-1, microprocessor based display and recording system.

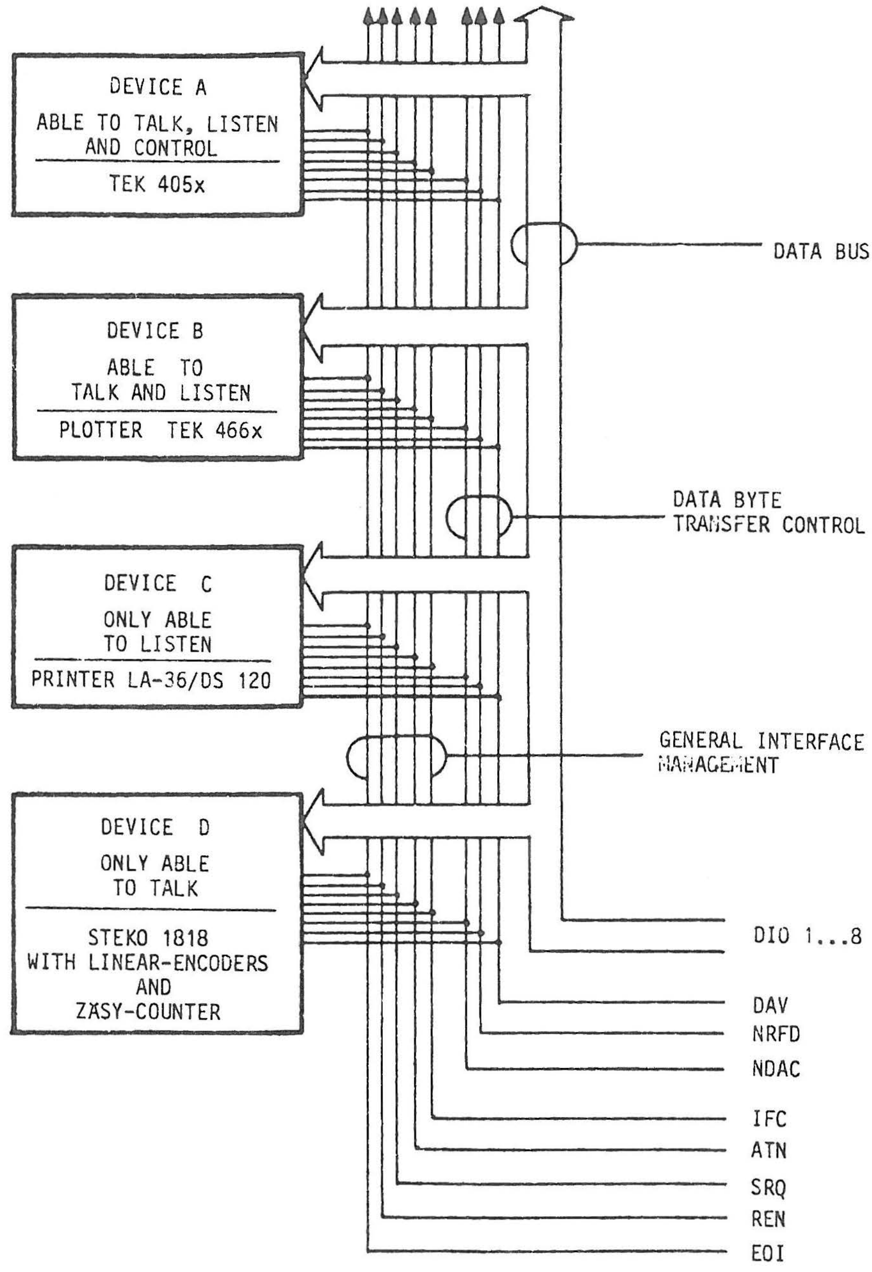

Figure 1. The TEK 405x uses the IEEE Standard Digital Interface for Programmable Instrumentation (IEEE 488-1975; DIN IEC 66.22)

2.3 Analytical on-line system based on STEKO 1818

To achieve analytical on-line processing the digitized STEKO must be interfaced directly to a computer; graphical as well as gigital output should be possible. For this purpose the BASIC-desk-computer Tektronix TEK 4051*) was attractive. Only this desk-computer had a graphical screen and two standardized interfaces, one V-24 (RS 232 C) and the IEC-bus (IEEE 488-1975) also known as HP-IB-bus system. The IEC-bus has the advantage to add - without extra efforts - other peripheral equipment like plotter and printer to the system (s. fig. 1).

In cooperation with the corporation IGI Ltd.**) the 4-channel counter ZÄSY I has been developed. The ZÄSY has got the PRE-/MEMOSET facility together with a 90-day-memory and an IEC-bus interface.

The TEK 4051 may be operated in terminal mode via the V-24 interface for data transfer to a central computer.

The possibilities of source collection of data preparation and data transfer to a central computer made the TEK computer especially suitable for an integration into the STEKO analytical system.

On the base of the STEKO 1818 it has been possible to develop an ANALYTICAL PHOTOGRAMMETRIC SYSTEM (s. fig. 2) of the type "image space plotter" /4/.

Nevertheless two disadvantages of the STEKO 1818 are to be pointed out:

1. the limited max. photo format of 18x18 cm^2 and
2. the limited range of movement of the right photograph with respect to the left one.

On the other hand the system-components have been selected in such a way, that any other stereocomparator - like CARL ZEISS, Oberkochen, PSK; VEB CARL ZEISS, Jena, Stekometer; etc. - may be integrated into the system.

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*) Since 1979 the more powerful types TEK 4052 and TEK 4054 with a 19" graphical screen are available.

**) IGI - Ingenieur-Gesellschaft für Interfaces mbH, Schwarzwaldstrasse 6, 7858 Weil 4, W.-Germany

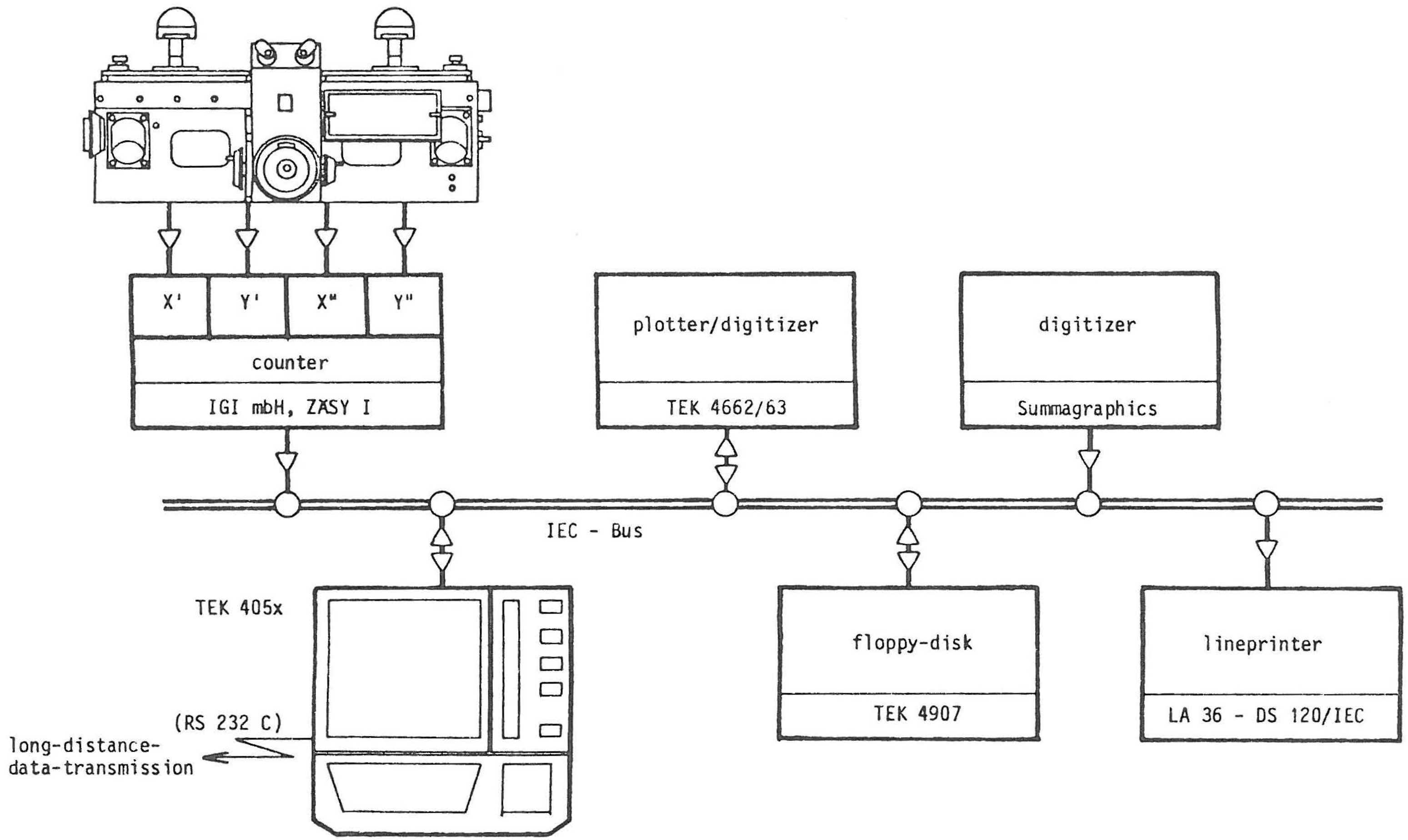

Figure 2. The STEKO 1818 Analytical Photogrammetric System

3. Software

All programs are written in Tektronix Basic.

3.1 Simultaneous determination of all orientation elements

Applying the well known collinearity condition according to figure 3

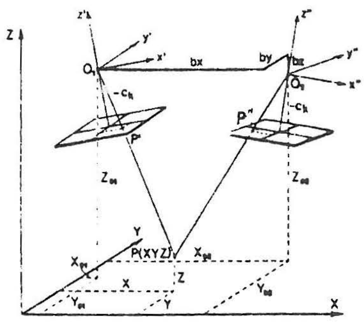

Figure 3

Photo- and objectcoordinate system

the following correction equations are obtained for photo points with given object coordinates (control points) :

$$x' + v_{x'} = \frac{\begin{bmatrix} a_{11} & a_{21} & a_{31} \end{bmatrix} \cdot \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix} \cdot c}{\begin{bmatrix} a_{13} & a_{23} & a_{33} \end{bmatrix} \cdot \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix}}$$

$$y' + v_{y'} = \frac{\begin{bmatrix} a_{12} & a_{22} & a_{32} \end{bmatrix} \cdot \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix} \cdot c}{\begin{bmatrix} a_{13} & a_{23} & a_{33} \end{bmatrix} \cdot \begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix}} \qquad (1)$$

Applying the two equations for corresponding photo points in the left and right photograph means that 4 correction equations are obtained per one control point.

Linearization is achieved according to the software friendly method of calculating the quotients of differences /5/.
The program allows for a maximum of 10 control points.

Applying the coplanarity condition the following correction equation is obtained for points of which object coordinates are not given :

$$
\begin{aligned}
V = \; & b_x \cdot \left\{ [a'_{21}\; a'_{22}\; a'_{23}] \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} [a''_{31}\; a''_{32}\; a''_{33}] \cdot \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} - [a'_{31}\; a'_{32}\; a'_{33}] \cdot \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} \cdot [a''_{21}\; a''_{22}\; a''_{23}] \cdot \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} \right\} + \\
& b_Y \left\{ [a'_{31}\; a'_{32}\; a'_{33}] \cdot \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} \cdot [a''_{11}\; a''_{12}\; a''_{13}] \cdot \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} - [a'_{11}\; a'_{12}\; a'_{13}] \cdot \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} [a''_{31}\; a''_{32}\; a''_{33}] \cdot \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} \right\} + \\
& b_Z \left\{ [a'_{11}\; a'_{12}\; a'_{13}] \cdot \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} \cdot [a''_{21}\; a''_{22}\; a''_{23}] \cdot \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} - [a'_{21}\; a'_{22}\; a'_{23}] \cdot \begin{bmatrix} x' \\ y' \\ c \end{bmatrix} \cdot [a''_{11}\; a''_{12}\; a''_{13}] \begin{bmatrix} x'' \\ y'' \\ c \end{bmatrix} \right\}
\end{aligned}
\quad (2)
$$

V is a correction which may be assigned to the function which results from the coplanarity condition. Linearization again is achieved by the method of calculating the quotients of differences.
This "function correction equation" may be introduced into the adjustment process applying the following weight factor /6/:

$$
P = \frac{1}{\left(\frac{\Delta V}{\Delta x'}\right)^2 + \left(\frac{\Delta V}{\Delta y'}\right)^2 + \left(\frac{\Delta V}{\Delta x''}\right)^2 + \left(\frac{\Delta V}{\Delta y''}\right)^2} \quad (3)
$$

The program allows for a maximum of 10 non - control points.

From all correction equations

$$
\underline{V} = \underline{B} \cdot \underline{x} + \underline{w}
$$

the orientation elements are obtained according to least square adjustment

$$
\underline{x} = - (\underline{B}^T \underline{B})^{-1} \cdot \underline{B}^T \underline{w} \quad (4)
$$

The advantage of this method is that the matrix $(B^T B)$ is only a 12 x 12 matrix being favourable for small size desk computers.
The adjustment is repeated until the unknowns $\underline{x}$ are below a defined value.
For the TEK 4052/54 one iteration is a matter of seconds, for the TEK 4051 a matter of minutes.

3.2 Computation of object coordinates

Non - corrected image points do not fulfill the coplanarity condition; therefore an object-point-definition is to be introduced. According to the most rigurous method the object point is defined to be in the middle between the two corresponding rays at the place where they come closest together.
From that definition the following formulas can be derived /6/:

$$
\begin{aligned}
X &= \frac{1}{2} \cdot (\lambda \cdot X' + \mu \cdot X'' + X_{01} + X_{02}) \\
Y &= \frac{1}{2} \cdot (\lambda \cdot Y' + \mu \cdot Y'' + Y_{01} + Y_{02}) \\
Z &= \frac{1}{2} \cdot (\lambda \cdot Z' + \mu \cdot Z'' + Z_{01} + Z_{02})
\end{aligned}
\quad (5)
$$

where

$$\lambda = \frac{[b_x\ b_Y\ b_Z]\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix}\cdot[X'\ Y'\ Z']\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix} - [b_x\ b_Y\ b_Z]\cdot\begin{bmatrix}X'\\Y'\\Z'\end{bmatrix}\cdot[x''\ y''\ c]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}}{\left\{[X'\ Y'\ Z']\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix}\right\}^2 - [x'\ y'\ c]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix}\cdot[x''\ y''\ c]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}}$$

$$\mu = \frac{[b_x\ b_Y\ b_Z]\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix}\cdot[x'\ y'\ c]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix} - [b_x\ b_Y\ b_Z]\cdot\begin{bmatrix}X'\\Y'\\Z'\end{bmatrix}\cdot[X'\ Y'\ Z']\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix}}{\left\{[X'\ Y'\ Z']\cdot\begin{bmatrix}X''\\Y''\\Z''\end{bmatrix}\right\}^2 - [x'\ y'\ c]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix}\cdot[x''\ y''\ c]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}}$$

$$X' = [a'_{11}\ a'_{12}\ a'_{13}]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix}$$

$$Y' = [a'_{21}\ a'_{22}\ a'_{23}]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix}$$

$$Z' = [a'_{31}\ a'_{32}\ a'_{33}]\cdot\begin{bmatrix}x'\\y'\\c\end{bmatrix}$$

$$X'' = [a''_{11}\ a''_{12}\ a''_{13}]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}$$

$$Y'' = [a''_{21}\ a''_{22}\ a''_{23}]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}$$

$$Z'' = [a''_{31}\ a''_{32}\ a''_{33}]\cdot\begin{bmatrix}x''\\y''\\c\end{bmatrix}$$

The compentation of object coordinates is for the TEK 4052/54 a matter of a tenth of a second; for the TEK 4051 a matter of half a second.

3.3 Calculation of accuracy values

a) closest distance between corresponding rays

The closest distance between corresponding rays - comparable with residual y-parallaxe in conventional analog restitution - is a good measure for the pointing accuracy in the left and right photograph. It is calculated according to the following formula :

$$\overline{s} = \sqrt{(b_x + \mu\cdot X'' - \lambda\cdot X')^2 + (b_Y + \mu\cdot Y'' - \lambda\cdot Y')^2 + (b_Z + \mu\cdot Z'' - \lambda\cdot Z')^2}$$

The closest distance $\bar{s}$ between corresponding rays may be calculated on-line at any instance.

b) Standard deviation of measured photo coordinates

Corrections for measured photo coordinates of control points can be calculated from equations (1). For corrections of measured photo coordinates of non-control points, "function corrections" have first to be calculated from equation (2); then :

$$v_{x'} = V \cdot P \cdot \frac{\Delta V}{\Delta x'}$$

$$v_{y'} = V \cdot P \cdot \frac{\Delta V}{\Delta y'}$$

$$v_{x''} = V \cdot P \cdot \frac{\Delta V}{\Delta x''}$$

$$v_{y''} = V \cdot P \cdot \frac{\Delta V}{\Delta y''}$$

After that the standard deviation of measured photo coordinates can be computed.

$$m_0 = \pm \sqrt{\frac{[v \cdot v]}{4 \cdot n + k - 12}}$$

n = number of control points

k = number of non-control point which took part in the orientation adjustment process

c) Standard deviation of orientation elements

With m_0 and the weight coefficients from matrix

$$\underline{Q}_x = (\underline{B}^T \cdot \underline{B})^{-1} \qquad \text{(s. equation (4))}$$

standard deviations of elements of exterior orientation are computed.

d) standard deviation of object coordinates

For the computation of standard deviations of object coordinates the following matrix is to be calculated :

$$\underline{Q}_h = \underline{H} \cdot \underline{Q}_o \cdot \underline{H}^T$$

where

$$\underline{Q}_o = \left[\begin{array}{cccc|c} 1 & 0 & 0 & 0 & \\ 0 & 1 & 0 & 0 & \underline{O} \\ 0 & 0 & 1 & 0 & \\ 0 & 0 & 0 & 1 & \\ \hline & & \underline{O} & & \underline{Q}_x \end{array}\right]$$

and

$$\underline{H} = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,16} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,16} \\ h_{3,1} & h_{3,2} & \cdots & h_{3,16} \end{bmatrix}$$

The coefficients of matrix $\underline{H}$ are calculated according to the method of quotients of differences from equations (5) :

$$h_{1,1} = \frac{\Delta X}{\Delta x'}, \quad h_{1,2} = \frac{\Delta X}{\Delta y'}, \quad \ldots \quad h_{1,16} = \frac{\Delta X}{\Delta \omega''}$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$h_{3,1} = \frac{\Delta Z}{\Delta x'}, \quad h_{3,2} = \frac{\Delta Z}{\Delta y'}, \quad \ldots \quad h_{3,16} = \frac{\Delta Z}{\Delta \omega''}$$

Standard deviations of object coordinates of any object point may be calculated on-line at any instant.

3.4 Choice of plane of projection for graphical outputs

a) horizontal plane of projection

Plotting is done in the X-, Y- plane.

b) vertical plane of projection

This is important e.g. in the field of architectural applications. The program accepts two object points (P_a, P_e), after that any other object point is vertically projected onto the vertical plane which passes through the points P_a, P_e.

c) plane defined by n object points

The best fitting plane of projection is found by adjustment. The program accepts up to 5 points.

3.5 Plumb line references instead of control points

For many applications it is more convenient to establish plumb line references rather than determining control points.
For the case of two plumb lines with marked reference points the program may be applied according to figure 4 and table 1 :

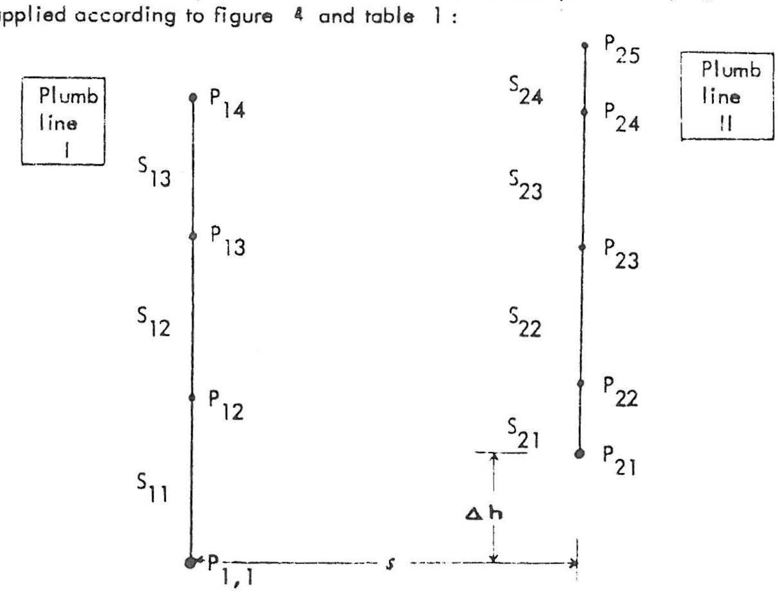

Figure 4

Two plumb lines with marked reference points.
S_{ij} are known, s and Δh are measured in the field.

Plumb line I				Plumb line II			
Point No	X	Y	Z	Point No	X	Y	Z
P_{11}	0	0	0	P_{21}	S	0	Δh
P_{12}	0	0	S_{11}	P_{22}	S	0	$+S_{21}$
P_{13}	0	0	$+S_{12}$	P_{23}	S	0	$+S_{22}$
P_{14}	0	0	$+S_{13}$	P_{24}	S	0	$+S_{23}$
				P_{25}	S	0	$+S_{24}$

Table 1

Corresponding object coordinates for marked reference points on two plumb lines

3.6 Computation of initial values for the orientation elements

For non - topographic applications the determination of initial values for the unknown orientation elements may be difficult.
Using the DLT (Direct Linear Transfomation) - method /7/, initial values can be calculated in case there are at least 6 control points imaged in each of the two photographs.
The following linear equations are to be fulfilled :

$$X_i \cdot b_{11} + Y_i \cdot b_{12} + Z_i \cdot b_{13} + b_{14} - x_i \cdot X_i \cdot b_{31} - x_i \cdot Y_i \cdot b_{32} - x_i \cdot Z_i \cdot b_{33} - x_i = 0 \quad (6)$$

$$X_i \, b_{21} + Y_i \cdot b_{22} + Z_i \cdot b_{23} + b_{24} - y_i \cdot X_i \cdot b_{31} - y_i \cdot Y_i \cdot b_{32} - y_i \cdot Z_i \cdot b_{33} - y_i = 0 \quad (7)$$

in equation (6) i = 1 6,
in equation (7) i = 1 ....5.

Xi, Yi, Zi are known object coordinates of control points and x_i'; y_i' are the corresponding photo coordinates.
From the resulting 11 linear equations (per one photograph) the values bij are computed.
Initial values are derived from the following equations :

a) for object coordinates of the projection centre X_o, Y_o, Z_o

$$b_{11} \cdot X_o + b_{12} \cdot Y_o + b_{13} \cdot Z_o + b_{14} = 0$$

$$b_{21} \cdot X_o + b_{22} \cdot Y_o + b_{23} \cdot Z_o + b_{24} = 0$$

$$b_{31} \cdot X_o + b_{32} \cdot Y_o + b_{33} \cdot Z_o + 1 = 0$$

b) for angular orientation elements

$$\varphi = \text{arc} \sin\left(-\sqrt{K} \cdot b_{31}\right)$$
$$\omega = \text{arc} \cos\left(-\frac{\sqrt{K} \cdot b_{33}}{\cos\varphi}\right)$$
$$\varkappa = \text{arc} \cos\left(\frac{\sqrt{K} \cdot b_{11}}{c \cdot \cos\varphi}\right)$$

where

$$\frac{1}{K} = b_{31}^2 + b_{32}^2 + b_{33}^2$$

3.7 Interactive graphical software

Here the advantages of the TEK 4054 (with its larger graphical screen and its "refresher" facility)*) in comparison to TEK 4052 and TEK 4051 are to be pointed out.

The special graphical software realized up to now comprises the following possibilities :

a) automatic plotting sheet preparation including grid numbering can be done,

b) plotting of legend is carried out computer supported,

c) points may be connected by different line types,

d) line corrections may be carried out by means of a joystick,

e) exact matching of several lines at one point of intersection may be enforced.

After revision and completion of graphics on the screen data may be stored (on magnetic tape or floppy disk) or direct plotting on a digital plotting table may be carried out.

Because of the fact that the TEK computers also may be run in terminal operation mode data may be transferred to a central computer as well.

3.8 Comparator testing

At present the STEKO is equipped with precision linear encoders. To test the rather rigid adjustmend status of the instrument a computer supported test may be carried out. The test is a modified 9-grid-point-test based on the ZEISS, Jena 25-point-test method /8/. The time needed to carry out the test, takes less than 15 minutes.

The test proved also to be very useful in connection with educational applications.

*) N.B.: The "refresher" facility produces the instant display of graphics up to a number of ca. 900 vectors; this allows partial graphical correction without completely reestablishing the screen content.

4. Examples of application

4.1 Industrial photogrammetry

a) Actual geometry of a spacial steel gurder construction

To compare the actual geometry of a newly designed spacial steel gurder construction with its nominal one under different environmental conditions an efficient survey method had to be established.

The main characteristics of the project are listed below :

- diameter of the construction 50 m, height 13 m, number of reference points at knodal positions ca. 1000
- camera used UMK 10/1318
- lower part of the construction covered by three models, camera axis convergent and appr. 15° upward (b = 8 m)
- upper part of the construction covered by one central model, camera axis appr. vertically upward (b = 4 m)
- permanently marked and signalized control points only at the bottom, rigid part of the flexible construction, four control points per lower - part-model.

The photogrammetric problem was solved in two steps :

α. single model evaluation

Analytical on-line-photogrammetry was applied. - This proved to be very useful to detect gross erros and to find easily good initial values of the orientation elements for the subsequent bundle adjustment. For the single model evaluation 4 control points and 6 noncontrol points were introducted into the adjustment process for simultaneous determination of the orientation elements. -
Control points for the upper central model were taken within the overlapping section from the single model evaluation of the lower part of the construction.

β. bundle adjustment

After single model analytical online evaluation a final bundle adjustment was carried out. Data were transferred from the TEK 4054 in terminal mode operation to the central computer of the Ruhr - University.
The bundle adjustment program used is the program developed by the Institute of Photogrammetry of the University Hannover (Dipl.-Ing. Jacobsen).

The accuracy obtained was $m_{X,Y,Z} = \pm 1,5$ cm.

b) Comparison of actual and nominal positions of anchor holes for a continous casting steel plant for slabs

To ensure the proper positions of ca. 400 anchor holes in the concrete base for a continous casting steel plant for slabs an efficient survey method had to be applied. Up to now the surveys for carrying out the construction work have been performed by the construction engineers and the final acceptance survey was done by the mechanical engineers by means of tape measure and theodolite. Problems occurred regularly when the tremendous machinery had to be brought into position.

By means of analytical photogrammetry the problem of acceptance survey could be solved with a minimum amount of field work and with a minimum loss of time. X,Y coordinates were determined according to the single model on-line method (heights had to be measured by levelling).

The project comprised four models. The number of ground control points was 11. The UMK 10/1318 vertical photos were taken from the crane gantry.

This is another example to demonstrate the efficiency of the method applied, but also indicates the necessity to teach mechanical engineering students the performance and potentialities of photogrammetry.

c) Investigation of deformation behaviour of panels - reflector substructures

For modern communication systems large reflector antennas are of increasing importance. The knowledge of their geometry under different environmental conditions is of vital importance for the quality of signal transfer.

For this, panels (substructures of the reflector antenna) are photographed under different temperature conditions. One panel is covered by one Stereo model - camera used P 32 Wild, camera axis convergent, 6 control points are fixed on a rigid frame, size 2x3 m^2.

The analytical on-line method has proved to be very efficient to precisely survey the approx. 120 signalized panel points.

4.2 Architectural photogrammetry

a) Application of oblique aerial photographs

One example is to be mentioned briefly, that is the survey of the outer facades incl. the roofs of a castle situated on top of a steep mountain. Because of the problem to obtain photographs by terrestrial means oblique colour aerial photographs had been taken with an RMK 21/18 mounted in a Cessna 206 at an oblique angle of 45°. The castle was photographed from three sides; each side couldbe covered by one stereo model with appr. 60% overlap, photo scale being appr. 1 : 1500.

From the geometrical point of view a satisfactory result could be produced which was good for the architects to be completed according to their needs for planning of restauration work. One advantage is to pointed out here that is the fact that camera orientation is independant of planes of projection. Apart from this the STEKO - analytical-on-line method .offers a maximum amount of flexibility with respect to camera focal length, photo format and with respect to general camera orientation.Flexibility is one of the most vital requirements for architectural applications.

b) Terrestial photographs with arbitrary orientation and plumb line reference

For a number of applications in architectural photogrammetry stereoscopic vision is not important because of easy point identification. In such cases camera orientation might be chosen arbitrarily according to local circumstances and accuracy requirements. For the simultanous determination of the orientation elements control points might be determined but the amount of field work can be reduced by using plumb line references (see para, 3.5).

4.3 Education in photogrammetry

a) Introduction into analytical photogrammetry

The STEKO 1818 and other comparators are existing at many universities and other educational institutes and are nowadays nearly useless without digital components. The hardware modification and software package described in this paper is very economical and is therefore extremely suitable for educational applications. Because of its on-line performance it guaranties a very high degree of students' motivation.

b) Computer supported photogrammetry for non-photogrammetrists

Pratice has shown that the system can easily be operated by non-photogrammetry students (architects, civil engieers) after a very short time of instruction because the applicant is softwarewise guided via the screen of the computer.

4.4 Determination of orientation elements of uncomplete models for analog restitution instruments

The method of simultaneous determination of exterior orientation elements proved to be very efficient to find the orientation elements for uncomplete models or in extremely mountainous terrain. For this a comp rator which accepts photos up to the format 23 x 23 cm^2 should be available.

5. Conclusion

Existing stereocomparators may be converted into powerful analytical on-line systems by using digital components and desk-computers. This low cost solution widens the range of photogrammetric application in the field of industrial and architectural applications. Besides this the system is extremely suitable for educational purposes.

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