TOWARDS AN AUTOMATED DATA FLOW IN DIGITAL CLOSE RANGE PHOTOGRAMMETRY

Dieter Fritsch and Günter Strunz
Chair of Photogrammetry
Technical University of Munich
Arcisstrasse 21, D-8000 Munich 2
Federal Republic of Germany

Commission V

Abstract

In digital close range photogrammetry the data flow in data preprocessing and data analysis should be fully automated to have the most profit of the digital data acquisition for example by the use of CCD-sensors.

In order to realize this idea sequential algorithmization must be performed considering problems such as data compression, filtering, edge detection, image matching, bundle block adjustment and object reconstruction. The paper discusses the use of tuned systems in data preprocessing, heuristic procedures in image matching and the integration of object reconstruction into bundle block adjustment.

The reconstruction of a cube demonstrates the application of the methods proposed.

1. Introduction

With the use of CCD-sensors close range photogrammetry can be fully automated. This implicates a chain of algorithms ranging from sensor calibration to object reconstruction (A. Grün, 1987). Especially with regard to real-time applications the algorithmization should be fast and robust using adequate hardware architecture such as image processors and most recently transputers.

Although camera calibration remains an object to be investigated furthermore in detail (H.A. Beyer, 1987, R. Lenz/D. Fritsch, 1988) main interest of photogrammetrists is directed to the data flow in data preprocessing and data analysis. Data preprocessing should contain mainly grey value manipulation whereas in data analysis grey value evaluation predominates.

Some methods on both steps will be demonstrated by the following task: reconstruct a cube of 20 (cm) side length by means of three digital (synthetic) images generated by a CCD-sensor of 245 H x 319 V picture elements and with a focal length c=15 (mm). First results have been given by D. Fritsch/G. Strunz (1987) using edge information only; thus the methods applicated and the complete results will be reviewed in the following.

2. Data Preprocessing

In data preprocessing some steps have to be performed to lead the digital images (digigrams) to the final data analysis. Above all the preprocessing must be fast which can be guaranteed by operators with short point spread functions.

Let be

$$y(m,n) = \Phi(x(m,n)) \qquad \forall m=0,1,2,\ldots,M-1 \quad n=0,1,2,\ldots,N-1 \tag{1}$$

in which Φ characterizes the system being used for the preprocessing. Its design may result from heuristic and analytic procedures respectively, depending on the problem to be solved.

With the use of linear time invariant systems in data preprocessing the grey value manipulation is represented by the convolution

$$y(m,n) = \sum_{k=0}^{K-1} \sum_{l=0}^{L-1} h(k,l)x(m-k,n-l) = h(m,n)*x(m,n) \tag{2}$$

whereby $h(k,l)$ is the 'kernel' (point spread function or impulse response) of the system being applied. Some experience has shown that the length K and L of the kernel should not be greater than 5 for many manipulations of the data. To provide for linear phase it is recommended to use operators with K and L odd resulting into

$$y(m,n) = \sum_{k=-(K-1)/2}^{(K-1)/2} \sum_{l=-(L-1)/2}^{(L-1)/2} h(k,l)x(m-k,n-l) \tag{3}$$

otherwise the preprocessed pixel $y(m,n)$ is not defined at the original location of $x(m,n)$ but shifted $\pm m/2$ and $\pm n/2$ respectively.

For the computation of the kernel $h(k,l)$ frequency considerations are often helpful and, in some cases, necessary. Especially, when using selective systems (D. Fritsch, 1984) like filters, noise eliminators, contrast amplifiers etc. the impulse response has to take care for precise geometry. For that reason a comprehensive program package is used in our application in which a quadratic programming algorithm provides for sub l_∞ approximations within the frequency domain (D. Fritsch, 1987, 1988). The following example demonstrates the optimization strategy:

Design a circular shaped amplifying highpass with K=L=15 as well as stop- and passband frequencies $w_s=0.07\pi$, $w_p=0.16\pi$ within $w\in(0.,0.5\pi)$. The approximation should make use of 14400 sample points within the frequency domain.

In Fig. 1 the results of a least squares approximation and a sub l_∞ approximation are represented. While the least squares residuals (b) amount to maximum values of $\max(v_i)=0.104$ leading to a shifted geometry of about 10%, the optimized frequency response (c) has only $\max(v_i)=0.07$ reducing the error behaviour (d) to 7%. Thus it is important to tune the systems such that the errors one has to pay for in data preprocessing are kept to minimum.

In order to detect the edges of a digigram a differentiator must be applied to provide for the gradient of the image. Among well-known dif-

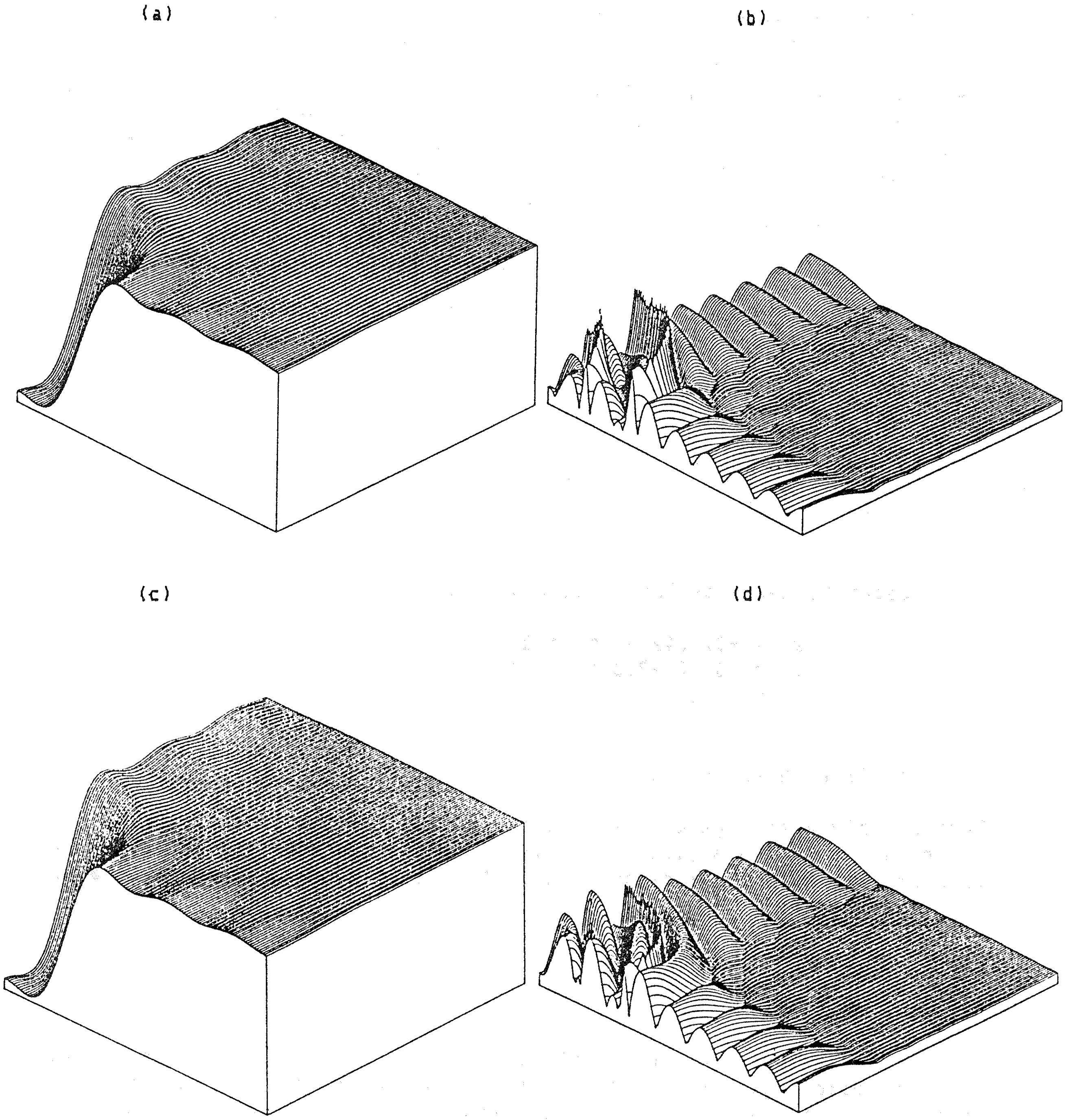

Fig. 1: Design of a circular shaped amplifying highpass
(a) least squares frequency response
(b) least squares residuals (Dim: db)
(c) sub l_∞ frequency response
(d) sub l_∞ residuals (Dim: db)

ferentiator templates in digital image processing the question arises, which operator can be used in digital photogrammetry and of which length should its impulse response be.

A comparison between a simple analytical (3x3) operator, the heuristic Sobel operator and a designed (5x5) operator (D. Fritsch, 1987) gives advantages for the benefit of short (3x3) operators. The operators used can be seen in Fig. 2.

(a) simple analytical

$$\begin{bmatrix} 0 & -1/2 & 0 \\ 0 & 0 & 0 \\ 0 & 1/2 & 0 \end{bmatrix} \qquad \begin{bmatrix} 0 & 0 & 0 \\ -1/2 & 0 & 1/2 \\ 0 & 0 & 0 \end{bmatrix}$$

(b) Sobel operator

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

(c) Design by means of the REMEZ algorithm

$$h(-2) = -0.1042030 = -h(2)$$
$$h(-1) = 0.2212293 = -h(1)$$
$$h(0) = 0.0$$

Fig. 2: Differentiator templates

Particularly with regard to the vectorization of the image gradient it is better to have a smaller bandwith of pixels representing an edge than to work with more coefficients within the differentiator leading to more emphasized edges.

3. Data Analysis

The data analysis in digital close range photogrammetry is consisting of image matching, point determination and object reconstruction. The integration of these steps is most recently topic of contributions on digital photogrammetry (B. Wrobel, 1987, H. Ebner et al., 1987). But regarding close range applications it is more appropriate using fast methods (S.F. El Hakim, 1986, H. Haggreen, 1987) leading to heuristic procedures which may depend on the problem to be solved. This implicates for image matching not to use image correlation and least squares matching respectively, but to apply robust procedures detecting target locations and to solve target matching.

3.1 Image matching

The procedures for fast target location mostly depend on the target pattern. When circular targets are used two main strategies lead to the center of targets

(i) estimation of the center of gravity
(ii) calculation of best-fit ellipses within the original image or the image gradient

But first of all, targets must be located automatically. For that reason some operators can be used to search for a target pattern represented by a grey value mountain and valley respectively. For the example below the following operators are used within the convolution (3)

$$h_1 = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} , \qquad h_2 = \frac{1}{5}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{bmatrix} \qquad (4)$$

both kernels are capable to reduce the noise level on the targets if any. The final centering may be supported by a recursion algorithm using a window of nxn in which for each recursion k=1,2,....,K the center is computed. This value has to be compared with the proceeding center; if

$$m_K, n_K - m_{K-1}, n_{K-1} \le 1 \text{ pixel} \qquad (5)$$

the optimum center is found (see Fig. 3).

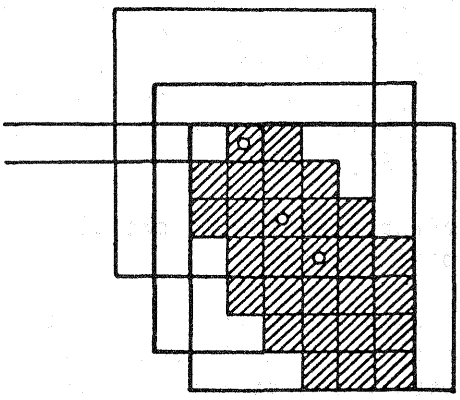

Fig. 3: Window centering

In some cases the center calculation is not satisfactory because changes of imaging conditions cause variable results. For that reason it is more reliable to compute real ellipse centers (G. Zhou, 1986). In our application best-fit ellipses are derived from the constraint

$$a(x_i - x_o)^2 + 2b(x_i - x_o)(y_i - y_o) + c(y_i - y_o)^2 = 1 \qquad \forall i=1,2,.... \qquad (6)$$

whereby x_i, y_i represents the pixel location at the corner of the ellipse being computed. The parameters a,b,c as well as the exact position x_o, y_o are obtained by a least squares parameter estimation using the center coordinates as approximate values. Another strategy for the derivation of ellipse centers is to find two diameters and then calculate their intersection which is the center of the ellipse; but this will not be commented on in the paper.

The target matching problem may be solved using the collinearity equations or the coplanarity condition. Each point in one image (master) has to be matched with its corresponding point taken by another camera (slave image). Using known exterior orientation parameters the result is a straight line (epipolar line)

$$y_2 = ax_2 + b \qquad (7)$$

in which the parameters a and b are given by the image perspectives. All coordinates of the slave image can be introduced into (7) and compared with a threshold Δ_T. If

$$\Delta = ax_2 + b - y_2 \leq \Delta_T \tag{8}$$

the points match each other. Occasionally more than one target will satisfy (8) therefore the strategy may be reversed to match a point in the slave image with its corresponding point in the master image.

3.2 Line Following and Vectorization

The concepts of line following are also very important in digital close range photogrammetry, in particular, when simple objects have to be observed. For example a cube or rhomboid can be reconstructed simply by the use of its corners, whose image coordinates are to determine by line following and simultaneous vectorization within the image gradients. One strategy for line following which is very robust and easy to implement is based on FREEMAN chains (U. Rösler, 1982). Its principle is as follows (Fig. 4):

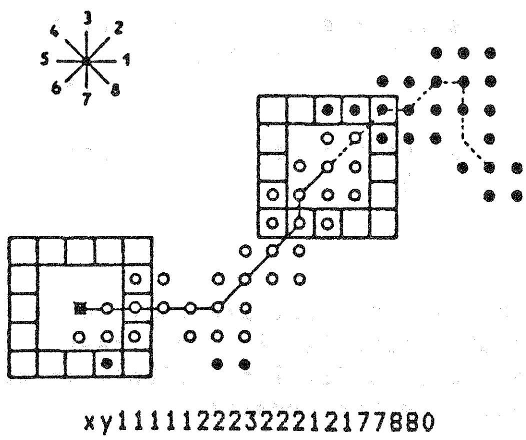

Fig. 4: Line following

(0) define a window of mxm at a point p(x,y)

(1) compare the pixels within the window with a threshold Δ_F and compute the center of gravity

(2) store the pixels representing the edge within the window and delete all grey values

(3) move the window toward the center of gravity and store the FREEMAN number

(4) proceed with (1)

Thus, the window can move along eight possible directions each representing a so-called 'FREEMAN number'. These numbers may also be used for vectorization but in precise applications it is better that all pixels representing an edge contribute to a polynomial approximation. Appropriate functionals solving the approximation problem are splines, however, for simple objects best-fit straight lines are mostly sufficient.

3.3 Combined Point Determination and Object Reconstruction

From the image coordinates the position of points in object space can be derived by bundle block adjustment. Nevertheless, to define the datum parameters or, moreover, to improve the accuracy and reliability of the results and to increase the economy of point determination non-photogrammetric information should be used. General control information, e.g. slope distances, spatial angles and directions, elevation differences, points on a plumb line or any information about the object can be included in a combined adjustment with all available data (H. Ebner, 1984) Especially in close range applications, information about the shape or surface of the object is often given. This can be in form of an analytical description, e.g. by a mathematical function. For complex structures digital surface models can be used to describe the form of the object.

At the Chair of Photogrammetry of the Technical University of Munich a program system for combined point determination has been developed which allows for the introduction of various types of non-photogrammetric information (F.Müller/G. Strunz, 1987). This program system is used in our application.

Because the example below deals with a cube, a best-fit cube of length a is simply to be calculated by the condition equations

$$\left((X_k - X_i)^2 + (Y_k - Y_i)^2 + (Z_k - Z_i)^2 \right)^{1/2} =: |\vec{P_i P_k}| = a \qquad (9a)$$

$$\alpha = \cos^{-1} \frac{\vec{P_i P_j} \quad \vec{P_i P_k}}{|\vec{P_i P_j}| \; |\vec{P_i P_k}|} =: \pi/2 \qquad (9b)$$

whereby $P_i(X_i,Y_i,Z_i)$, $P_j(X_j,Y_j,Z_j)$ and $P_k(X_k,Y_k,Z_k)$ are corners of the cube. Their spatial coordinates can be estimated using its image coordinates which result from line following and vectorization, or by the use of targets in an approximation afterwards.

4. Example

In order to demonstrate the methods above a simple example is treated: reconstruct a cube of 20 (cm) side length by means of three digital images within one quadrant (see Fig. 5). The synthetic CCD cameras used should have a resolution of 245 H x 319 V picture elements; the size of the digital image should be 6.6 x 8.6(mm) leading to a pixel size of about 0.027 (mm). For that reason three synthetic digital images have been generated for a focal length c=15 (mm) and the premise of known camera positions. In order to study the effect of noise the images were blurred by different SNR of 1%, 5% and 10%. The images taken from position (2) are visualized by Fig. 6, whereas Fig. 7 represents the images taken from the three standpoints but already processed by target location algorithms.

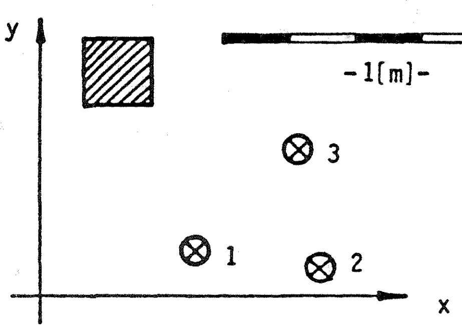

Fig. 5: Location of the (synthetic) CCD cameras

The problem of noise reduction is already treated in D. Fritsch/G. Strunz (1987) and should not be concerned in the following, thus the data preprocessing is restricted on a visual comparison of the differentiators introduced.

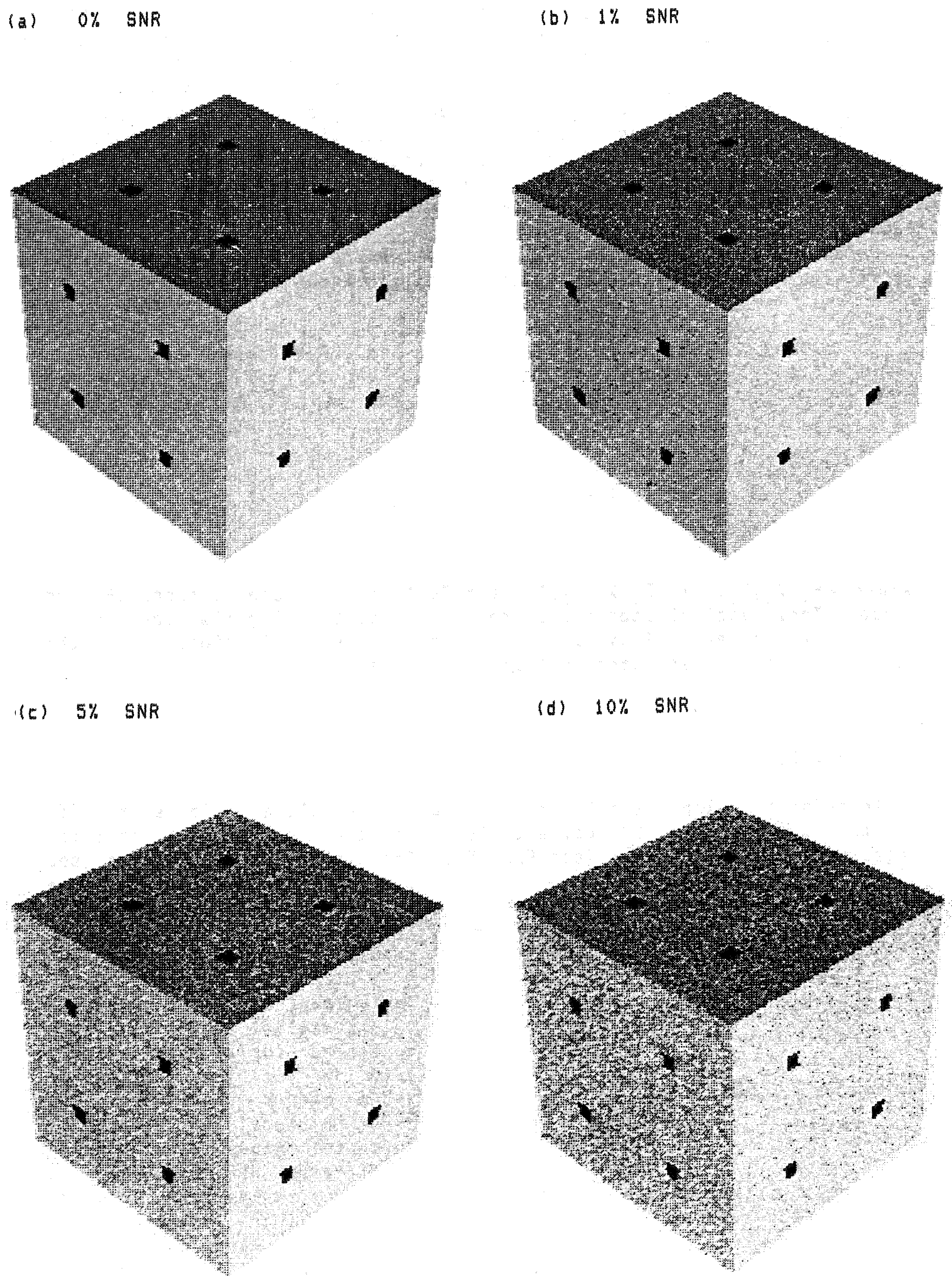

Fig. 6: Digital image at point 2 with 0, 1, 5 and 10% SNR

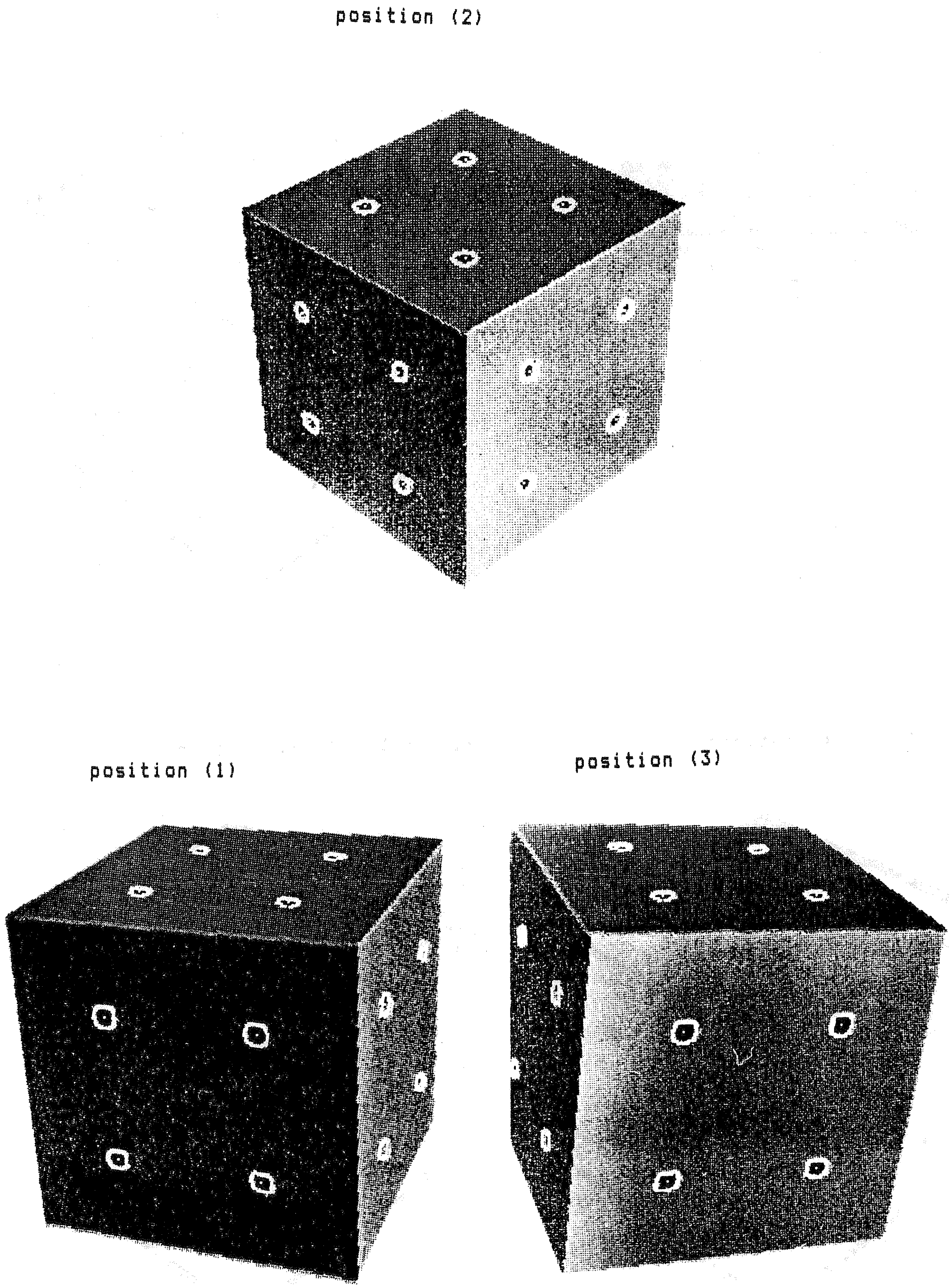

Fig. 7: Digital images with best-fit ellipses (0% SNR)

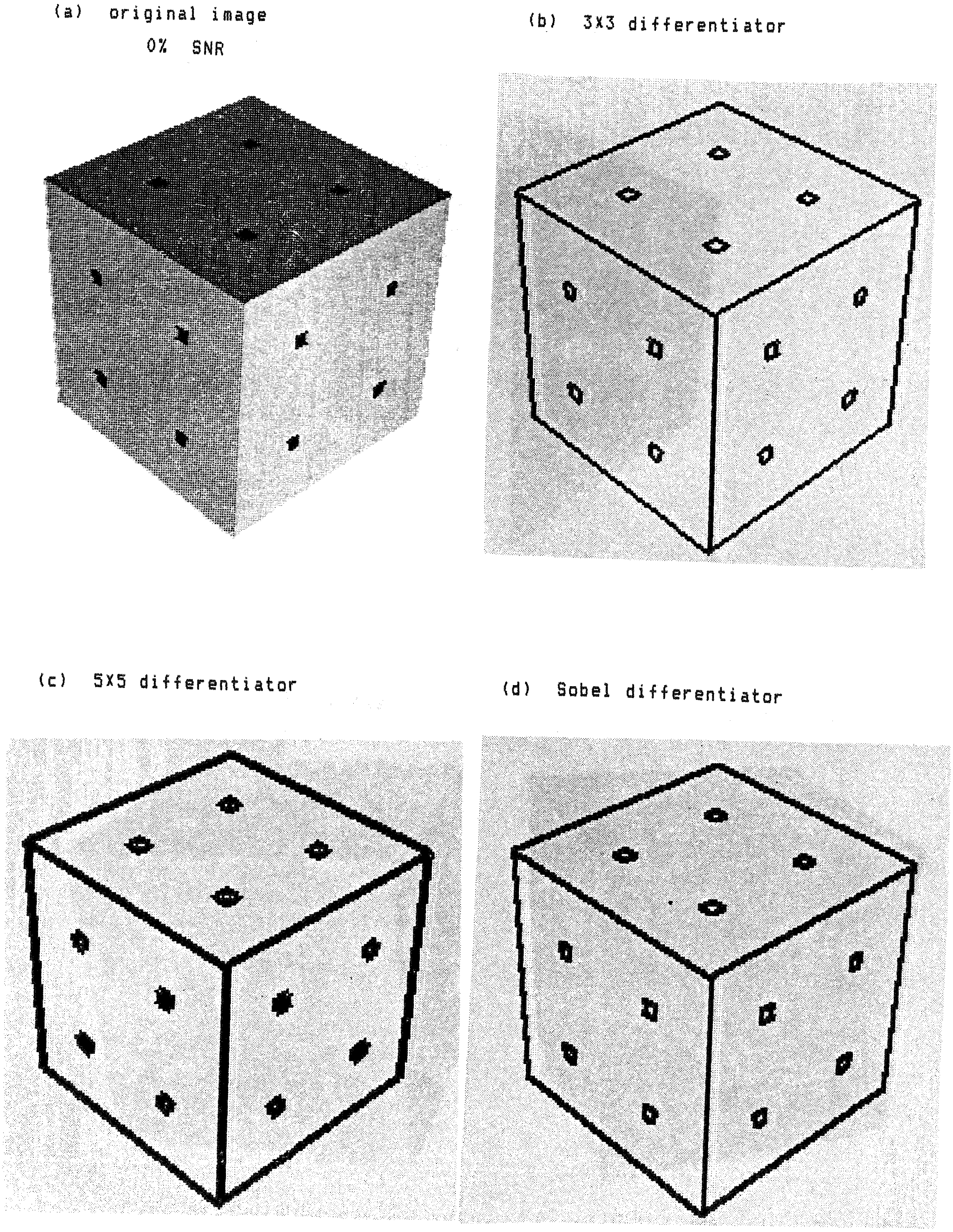

Fig. 8: Image gradients by means of differentiators

For the reconstruction of the cube two strategies are compared with each other: the first one using the image coordinates of the targets and the second one using the image coordinates of corners of the cube. This implicates the algorithmization given by Table 1, in which both the original images and the image gradients are used.

Table 1: Algorithms to reconstruct the cube

step	target information	line information
1	target location by means of convolution operators	vectorization by means of FREEMAN chains and best-fit straight lines (s.l.)
2	calculation of image coordinates of the targets (centers and best-fit ellipses)	calculation of image coordinates of the corners by means of intersections of s.l.
3	image matching using the master and its slaves	image matching using the master and its slaves
4	point determination by bundle block adjustment	point determination by bundle block adjustment
5	best-fit planes, intersection of straight lines and calculation of a best-fit cube	calculation of a best-fit cube

All steps above have been solved by the computer, thus sequential realization leads to an automated data flow in this application.

The cube is reconstructed under different SNR; its side length and corresponding standard deviation can be found in Table 2.

Table 2: Reconstruction of the cube

SNR	target information		line information	
(%)	$\hat{a}$ (cm)	$\hat{\sigma}_a$	$\hat{a}$ (cm)	$\hat{\sigma}_a$
0	19.989	0.023	20.128	0.027
1	19.990	0.030	20.131	0.029
5	19.991	0.043	20.132	0.032
10	19.977	0.054	20.136	0.036

A comparison of these results gives clear advantages for the benefit of using target information, because the geometry to calculate the corners by means of the image gradients is poor in some cases. Therefore optimization strategies to fix the camera positions are recommended. The estimation of the accuracy of image coordinates a posteriori amounts to $\hat{\sigma}_0$=5.5 x 10^{-4} (cm) and corresponds to about 20% of the pixel size.

5. Conclusions

The aim of the paper is to show up the potential of digital close range photogrammetry. Different strategies can be used to realize an automated data flow, especially for the reconstruction of simple objects; a task often to solve in robotics and machine vision.

First experience has been given using linear operators for data preprocessing, heuristic procedures for image matching, FREEMAN chains for line following and extended bundle block adjustment for object reconstruction. The algorithms developed are robust and very fast; they will be tested in further applications.

REFERENCES

BEYER, H.A. (1987): Some Aspects of the Geometric Calibration of CCD-Cameras. Proceed. ISPRS Intercomm. Conf. Fast Process. Photogr. Data, Interlaken, Inst. Geod., Photogr., ETH Zürich, pp. 142-155, Zürich.

De LAPORTE, K./P. LOHSE (1987): Zur automatischen Erfassung von Bildkoordinaten in digitalen Messbildern. Diplomarbeit Techn. Univ. München, München (not published).

EBNER, H. (1984): Combined Adjustment of Photogrammetric and Nonphotogrammetric Information. Int. Arch. Phot. Rem. Sens., 25, A3a, pp. 130-138, Rio de Janeiro.

EBNER, H./D. FRITSCH/W. GILLESSEN/Ch. HEIPKE (1987): Integration von Bildzuordnung und Objektrekonstruktion innerhalb der Digitalen Photogrammetrie. Bildmess., Luftbildwes. (BuL), 55, S. 194-203.

EL-HAKIM, S.F. (1986): Real-Time Image Metrology with CCD Cameras. Phot. Eng. Rem. Sens., 52, pp. 1757-1766.

FRITSCH, D. (1984): Two-Dimensional Finite Impulse Response (FIR) Linear Systems in Digital Photogrammetry. Int. Arch. Phot. Rem. Sens., 25, A3a, pp. 290-300, Rio de Janeiro.

FRITSCH, D. (1987): On Algorithms Solving the L_∞-Approximation in Geometric Modelling. Proceed. ISPRS Intercomm. Conf. Fast Process. Photogr. Data, Interlaken, Inst. Geod., Photogr., ETH Zürich, pp.142-155, Zürich.

FRITSCH, D./G. STRUNZ (1987): Automatic Digital Reconstruction of Simple Objects by Advanced Photogrammetric Methods. Pres. Paper 41. Photogr. Week, Inst. Photogr., Stuttgart Univ., Stuttgart.

FRITSCH, D. (1988): Design of Two- and Three-Dimensional Selective Systems by Sub L_∞ - Formulations. Proceed. Int. Congr. Optical Science and Engineering, Hamburg.

GRÜN, A. (1987): Towards Real - Time Photogrammetry. Inv. Paper 41. Photogr. Week, Inst. Photogr., Stuttgart Univ., Stuttgart.

HAGGREN, H. (1987): Real-Time Photogrammetry as used for Machine Vision Applications. Canad. Surveyor, 41, pp. 201-208.

LENZ, R./D. FRITSCH (1988): On the Accuracy of Videometry. Int. Arch. Phot. Rem. Sens., 27, Kyoto.

MÜLLER, F./G. STRUNZ (1987): Kombinierte Punktbestimmung mit Daten aus analogen und digital aufgezeichneten Bildern. Bildmess., Luftbildwes. (BuL), 55, S. 163-174.

WROBEL, B. (1987): Digitale Bildzuordnung durch Facetten mit Hilfe von Objektraummodellen. Bildmess., Luftbildwes., (BuL), 55, S. 93-101.

ZHOU, G. (1986): Accurate Determination of Ellipse Centers in Digital Imagery. Proceed. 1986 ACSM - ASPRS Ann. Conv., 4, pp. 256-261, Washington.