DEVELOPMENT OF A 4 x 5" RÉSEAU CAMERA FOR HIGH PRECISION INDUSTRIAL PHOTOGRAMMETRY

Jürgen Peipe
Universität der Bundeswehr München
Institut für Photogrammetrie und Kartographie
D-8014 Neubiberg, Fed. Rep. of Germany

Günter Suilmann
Rollei Fototechnic GmbH & Co KG
D-3300 Braunschweig, Fed. Rep. of Germany

Wilfried Wester-Ebbinghaus
Technische Universität Braunschweig
Institut für Photogrammetrie und Bildverarbeitung
D-3300 Braunschweig, Fed. Rep. of Germany

ISPRS Commission V

ABSTRACT

Réseau cameras are approved tools for high precision three-dimensional coordinate determination of industrial objects. Measurement accuracies of 1 part in 100,000 of the object dimension and even better can be achieved by photogrammetric systems consisting of large-format cameras, special targeting techniques (use of retro-reflecting targets), digital monocomparators, and bundle triangulation software.

In order to provide a relatively handy and light-weight imaging system offering a sufficiently large photo format, the 4x5" réseau camera Linhof METRIKA was further developed in cooperation with Rollei Fototechnic. The new camera R_METRIKA offers some special features such as vacuum system, close-meshed réseau plate, pre-illumination of réseau crosses, and ring flash. With this camera incorporated in the RolleiMetric industrial measurement system, a measuring accuracy of 1 μm and better can be obtained for image coordinates.
The paper outlines the design of the camera and first test results.

KEY WORDS: Camera, Close-Range, Industrial Photogrammetry.

1. INTRODUCTION

Over the last decade photogrammetric methods have gained more and more significance in industrial mensuration technology (Fraser, 1988). Key industries are aircraft and automobile manufacturers, aerospace companies, and shipbuilders. The quality control of components of different size and shape and the periodic inspection of tools are to be mentioned as important applications. Measuring task is the three-dimensional coordinate determination of object points. Competitive techniques are based on e.g. three-axis coordinate measuring machines or theodolite systems. However, photogrammetry offers facilities for quick on-site data acquisition which can be flexibly adapted to various production processes (Heister and Peipe, 1990).

Photogrammetric systems tailored particularly for high precision applications in industry yield measurement accuracies of 1 part in 100,000 of the object dimension and even better (Fraser and Brown, 1986; Wester-Ebbinghaus, 1990; Dold and Riechmann, 1991; Fraser, 1992). Such systems consist of large-format analog cameras, they apply digital monocomparators for automatic film measurement, and use the multi-station, multi-photo approach of bundle triangulation for the 3-D reconstruction of discrete object points. The combined adjustment also allows for simultaneous determination of image space parameters, i.e. the elements of interior orientation of the camera.

In order to meet the precision required in object space ($\leq 10^{-5}$), the image coordinate measurement is to be performed with an accuracy of 1 μm or better. Automatic monocomparators in which digital image processing has replaced human interpretation fulfil these accuracy demands (e.g. AutoSet from GSI (Brown, 1988) and Rolleimetric Réseau-Scanner RS1 (Luhmann, 1988)). A special signal recording technology using retroreflective targets facilitates both detection and measurement of image points (Brown, 1984).

At present, large-format analog cameras cannot be replaced by CCD cameras due to the small image area of the electronic sensors. Thus, photographic data acquisition combined with off-line, but automated film mensuration is still essential if high precision photogrammetric surveys are to be carried out.

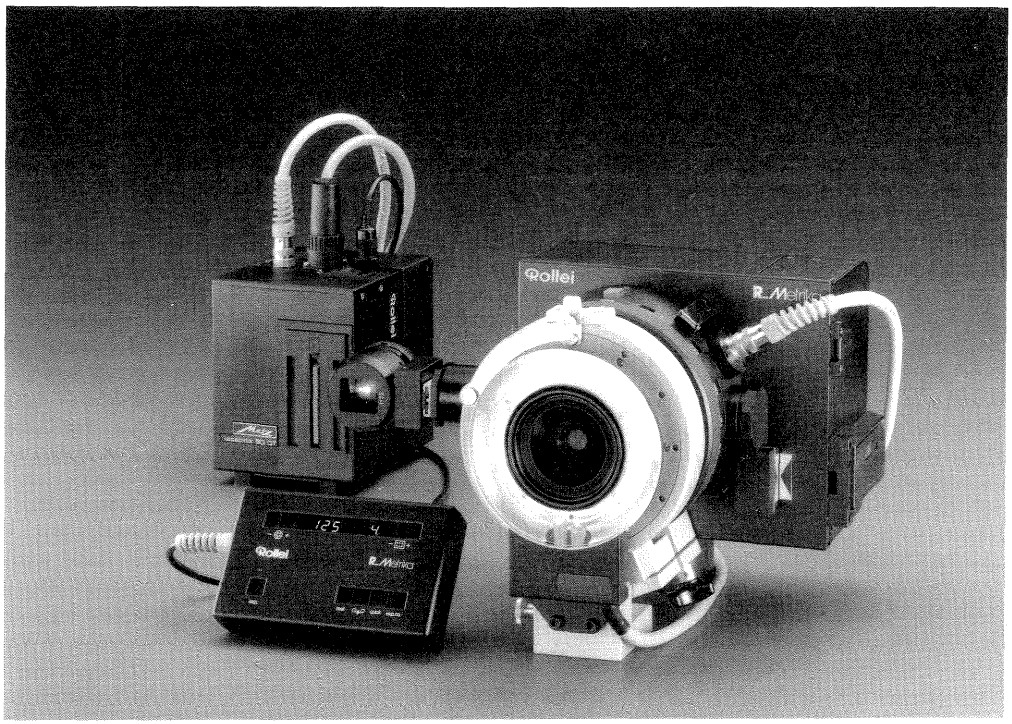

Fig. 1 The R_METRIKA consisting of camera body with lens and film magazine, rotation ring with flash, power supply unit, and control panel

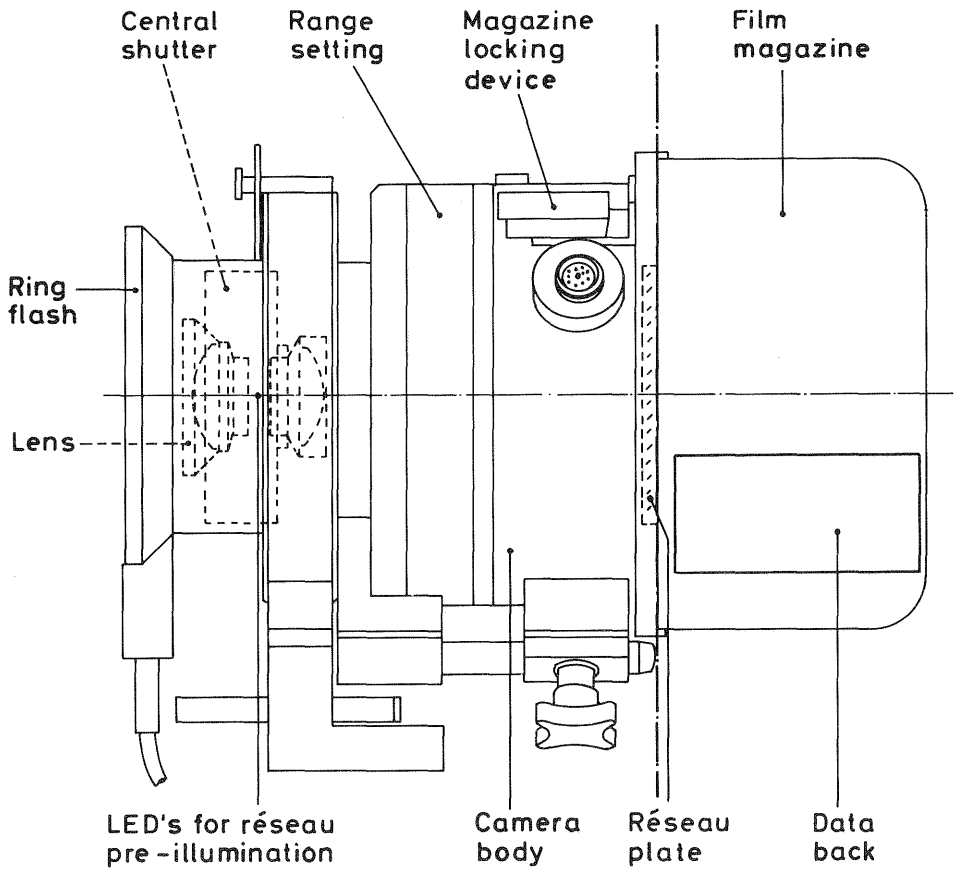

Fig. 2 Design and features of the R_METRIKA

2. RÉSEAU CAMERAS

The mathematical model of photogrammetric object reconstruction presumes the images to represent a perfect plane. When using a camera with rollfilm as the photographic medium, film flatness must be assured at the instant of exposure. This can be achieved mechanically by flattening against a vacuum plate or numerically by means of réseau techniques (Wester-Ebbinghaus, 1989). In addition, film deformation also may arise after exposure, e.g. as result of the development or adverse storage conditions.

The geometric effect of film unflatness and any other deformation can be determined if the camera is equipped with a réseau plate as reference system, i.e. a glass plate with cross-shaped marks mounted in front of the film surface. The réseau is recorded onto the film by perspective projection together with the object. The cross positions can be measured and compared with their precisely calibrated counterparts on the grid plate. Displacements indicate the influence of film deformation to be eliminated by a meshwise numerical transformation of the image into the réseau plane. The smaller the mesh size, the higher will be the accuracy to determine local deformations. In general, the four adjacent réseau crosses are to be measured in addition to one object point. An automatic measurement is therefore advisable.

Réseau cameras available on the market are listed in Table 1.

The Linhof METRIKA 45 (Peipe, 1990) is a ruggedly built, compact camera for universal photogrammetric applications which, in spite of the relatively large 4x5" format remains rather handy and fully portable. A réseau plate is integrated into the camera body forming a rigid unit with the lens barrel. Precise click stops on the focusing mount determine reproducibly a (calibrated) set of interior orientation parameters. Film flattening is provided by combining the vacuum system installed in the rollfilm cassette with the réseau technique. Daylight loading cartridges accept approximately 5 m of 5" rollfilm, that corresponds to about 50 exposures.

To incorporate the METRIKA into the RolleiMetric industrial measurement system, a number of modifications were realized in cooperation between Rollei Fototechnic and Linhof. The principle idea was to enable the use of retroreflective targets in combination with high precision automatic image coordinate measurement employing the Rollei Réseau-Scanner RS1. The joint efforts resulted in the R_METRIKA, a camera which is especially adapted to industrial applications.

3. R_METRIKA

The camera (Figs. 1 and 2, Tab. 2) is fixed to a rotation ring and can be continuously turned about its axis by ± 180°. The integrated ring flash assures the ideal illumination of retroreflective targets (Fig. 3). The photographs then contain the images of the retrotargets clearly visible and detectable as dots of high contrast and sharpness. The photographic image itself with all the other object information is deliberately underexposed to create an optimum background for digital automatic point determination. For this reason, the amount of light coming from the object through the lens does not suffice to record the fine réseau crosses with high and uniform quality. Therefore, an active réseau illumination is achieved in the R_METRIKA by means of light-emitting diodes (LED's) built into the lens (Figs. 2 and 4). This pre-illumination method, also used in the Rollei Large-Format Camera LFC and the Réseau-Scanning Camera RSC (Wester-Ebbinghaus, 1990; Dold und Riechmann, 1991) has proved very effective.

Two lens systems, 75 mm wide angle and 150 mm normal lens are available (Tab. 2). They are equipped with an electronically driven, microprocessor-controlled shutter. To the back of the lens cone, a close-meshed réseau plate (2 mm grid spacing) is fixed (Fig. 2). In addition to the vacuum system which yields mechanical film flattening, the réseau serves for numerical correction of film deformation as mentioned above. On the other hand, the calibrated grid crosses of the camera form the reference system for the sensor orientation within the automatic image coordinate measurement process of the Réseau-Scanner RS1.

Table 1 Réseau Cameras

Manufacturer	Type	Format [mm^2]	Lens [mm]
Leica	R5	24 x 36	15 - 180
Rollei	3003	24 x 36	15 - 135
Rollei	35	24 x 36	40
Pentax	PAMS 645P	45 x 60	45
Hasselblad	IDAC	60 x 60	38,70
Rollei	6006 and 6008	60 x 60	40 - 350
Linhof	METRIKA 45	95 x 120	75, 90, 150
GSI Inc.	CRC -2 *	115 x 115	65, 90, 120
GSI Inc.	CRC -1 *	230 x 230	120, 240
Rollei	LFC	230 x 230	165, 210

* with rear-projected réseau marks

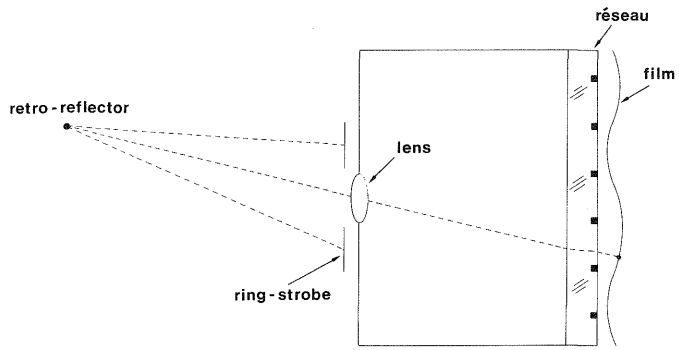

Fig. 3 Illumination and recording of retroreflective targets

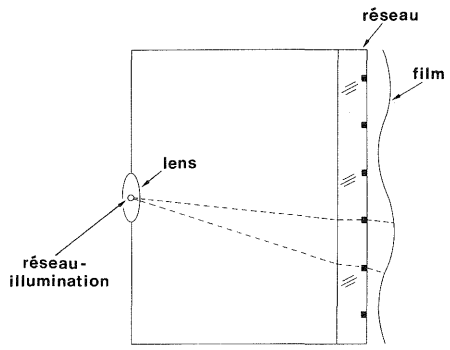

Fig. 4 Illumination for réseau projection

All the camera operations are microprocessor-controlled. Exposure time, réseau exposure level and exposure number can be selected and/or displayed on a remote control panel (Fig. 1). A complete exposure cycle effected by pressing one control key includes film flattening with vacuum pump, réseau illumination and exposure, object illumination with flash light and object exposure, and film transport. The power supply is accomplished by rechargeable batteries.

4. RESULTS OF TEST MEASUREMENTS

In order to prove the practicality of the R_METRIKA and to analyse its accuracy, a test range was photographed several times using both the wide angle and the normal lens cone. The image blocks included 8 photographs taken from 4 camera stations in a convergent imaging geometry. At each station two images rotated about the camera axis by 180° were produced. The photographs then were measured in the Réseau-Scanner RS1, i.e. the target centroids were determined automatically by image processing algorithms (see Luhmann, 1988).

The photogrammetric triangulation performed by self-calibrating bundle adjustment resulted in RMS values of the residuals of image coordinates of 0.8 μm (x) and 0.7 μm (y) for the camera equipped with normal lens. Corresponding values for the wide angle lens amounted to 1.0 μm (x) and 0.9 μm (y). 3-D coordinates of the targets were determined with a standard deviation of $s_X = s_Z = 0.014$ mm and $s_Y = 0.035$ mm (Y perpendicular to the test field wall). In relation to the object diameter of 5.5 m, this means in any case a relative measurement accuracy of clearly better than 1 part in 100,000.

Table 2

TECHNICAL DATA R_METRIKA	
Type	Single lens rollfilm camera with viewfinder, film flatness with vacuum pump system and réseau technique, microprocessor-controlled camera functions, user panel, data back, ring flash, réseau pre-illumination, rotation ring
Format	4 x 5"
Film	5" (126 mm) rollfilm
Réseau	mesh width in x and y: 2.0 mm
Lens	1) 75 mm Schneider Super Angulon 5.6 / 75 mm metric (angle of view: diagonal 105 deg.) 2) 150 mm Schneider Apo-Symmar 5.6 / 150 mm metric (angle of view: diagonal 70 deg.)
Weight	camera body with rotation ring and ring flash approx. 9500 g, external accu unit approx. 1000 g
Size	approx. 300 x 300 x 300 mm

5. FIRST APPLICATIONS

The R_METRIKA imaging system is applied at the European Space and Technology Center. The ESTEC is engaged in high accuracy geometric quality control of large spacecraft structures, antenna reflectors etc. These components are tested in a Large Space Simulator (LSS) to examine the influence of space conditions. Measurements in advance and after a test give evidence of non-elastic alterations, e.g. caused by temperature variations resulting from different illumination levels.

In addition, elastic deformations which occur during successive test phases are to be determined by photogrammetric survey in the interior of the LSS. Simultaneous release of three or more cameras is necessary to record the object changes. The cameras are built into protective housings to keep them free from vacuum and simulated space conditions. A front glass plate allows the view inside the LSS. The objects to be surveyed have a diameter of e.g. 6 m. Simultaneous recording of 100 to 500 points is required to yield reliable quality control.

6. CONCLUDING REMARKS

Photogrammetric off-line mensuration technology promotes high-precision quality control in industry. The newly developed R_METRIKA completes the line of film-based réseau cameras to be used within the Rollei industrial measurement system. Thus, a 4x5" camera is now available in addition to the RolleiMetric 6008 (60 x 60 mm image format) and the LFC (230 x 230 mm). Combined with the Réseau-Scanner RS1 a measuring accuracy of 1 μm and better could be achieved for image coordinates.

REFERENCES

Brown, D.C., 1984. A Large Format, Microprocessor Controlled Film Camera Optimized for Industrial Photogrammetry. Presented Paper, XV ISPRS Congress, Commission V, Rio de Janeiro, 29 p.

Brown, D.C., 1988. AutoSet, An Automated Monocomparator Optimized for Industrial Photogrammetry. Proc. Int. Conference and Workshop on Analytical Instrumentation, Phoenix/Arizona/ USA, ASPRS, Falls Church/USA, pp. 292-307.

Dold, J., Riechmann, W., 1991. Industriephotogrammetrie höchster Genauigkeit, ein neues Meßsystem und dessen Anwendung in der Luft- und Raumfahrtindustrie. Zeitschrift für Photogrammetrie und Fernerkundung 59 (6): 221-228.

Fraser, C.S., Brown, D.C., 1986. Industrial Photogrammetry: New Developments and Recent Applications. Photogrammetric Record 12 (68): 197-217.

Fraser, C.S., 1988. State of the Art in Industrial Photogrammetry. Int. Arch. Photogrammetry & Rem. Sensing, Kyoto/Japan, Vol. 27/B5, pp. 166-181.

Fraser, C.S., 1992. Photogrammetric Measurement to One Part in a Million. Phot. Eng. & Rem. Sensing, Vol. 58 (3): 305-310.

Heister, H., Peipe, J., 1990. Zur Interaktion geodätischer und photogrammetrischer Meßtechnik bei der 3D-Erfassung industrieller Objekte. Allg. Vermessungs-Nachrichten 97 (6): 224-240.

Luhmann, T., 1988. Ein hochauflösendes automatisches Bildmeßsystem. Wiss. Arbeiten Vermessungswesen Uni Hannover, Heft 154, Hannover.

Peipe, J., 1990. Eine neue 4" x 5" Aufnahmekammer für die Nahbereichsphotogrammetrie. Int. Arch. Photogrammetry & Rem. Sensing, Zürich/Schweiz, Vol. 28/5.1, pp. 256-263.

Wester-Ebbinghaus, W., 1989. Das Réseau im photogrammetrischen Bildraum. Zeitschrift für Photogrammetrie und Fernerkundung 57 (3): 64-71.

Wester-Ebbinghaus, W., 1990. High Precision Industrial Photogrammetry. Photogrammetric Record 13 (76): 603-608.