# THE ACCURACY OF THE RESEAU-SCANNING CAMERA (RSC) IN COMPARISON WITH THEODOLITE- AND PHOTOGRAMMETRIC SYSTEMS

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## ABSTRACT

High-accuracy optical 3D measurement techniques have been increasingly applied in the quality control of industrial assembly tooling. While on-line theodolite systems are used operational there is still a lack of such powerful precise photogrammetric systems.
With the realisation of the RSC a efficient high resolution photogrammetric on-line system is available. In order to classify the accuracy of the computer controlled Réseau-Scanning Camera (RSC), a comparison with standard measurement tools is carried out. After a short description of the camera-based and theodolite-based systems used, the results of a test field measurement are presented.

**Key words:** high resolution digital object recording, on-line, comparison of measurement systems

## 1. INTRODUCTION

In the past, measurements and their evaluation did not happen simultaneously. With the introduction of reliable electronic reading devices, the requirement arose for faster preparation of experimental results. Theodolite systems, with their electronically readable graduated circles, were the first automated devices in the field of geodesy.
These were soon used in the design of computer-controlled theodolite systems. These systems are in current use [Kahmen et al. 1984, Gottwald 1987]. The development of CCD-sensors made the first steps towards on-line applications possible in the field of photogrammetry. Besides photogrammetry, other disciplines are also attempting to use these sensors to reconstruct a three-dimensional object (e.g. robotics, machine vision). Precise 3D point determination however remained the domain of photogrammetry. The limited resolution of CCD-sensors considerably reduces the precision attainable in the object space compared to analogue film used in classical photogrammetry. While a precision of 1:100000 or better is attainable by making measurements in the film, object precision of 1:5000 to 1:10000 can be attained by evaluating digital images recorded by CCD-sensors. This assumes a subpixel precision of 1/10 to 1/20 of an image element, which is relevant for practical applications.

The development of the Réseau-Scanning camera makes it possible to record large image formats sequentially in partial digital images, and to perform on-line evaluations e.g. measuring image coordinates. Furthermore, each partial image can be recorded with this camera in a different focus position retaining a constant interior orientation.
A comparison with other on-line and off-line systems from photogrammetry and geodesy was performed in order to classify this new camera.

## 2. A SHORT DESCRIPTION OF MEASUREMENT SYSTEMS USED IN THE COMPARISON

Prerequisite of a precision comparison is all systems being able to measure the same signalized points. Circular points are preferable for optical measurement as their image remains unchanged on rotation and the problem 'point measurement in digital image' is largely independent of scale. That means that if circular marks are used for comparison, tactile measurement systems, e.g. coordinate measurement machines, are unsuitable as comparison systems as they cannot trace the edge of the circle accurately enough. Bearing this in mind, the following brief descriptions of the measurement systems used have been included in the comparison.

## 2.1 SPACE - A Theodolite measuring system

Precise theodolites with photoelectric graduated circle reading form the basis of this system. A beam-splitter makes it possible to project the object onto a CCD-sensor and to make a regular observation using an ocular. Defined points can be targeted under computer control and, providing the system consists of at least two theodolites, their spacial coordinates calculated. The targeting of the theodolite is performed either manually or, given initial values, by computer. The first step in precisely measuring a direction is to align the optical axis of the theodolite so accurately that the point is projected onto the CCD-sensor in the telescope. The second step is to measure the centre of the point in the digitized image using, in this case, an algorithm based on the moment preservation method [Zhou 1986]. The expected accuracy lies in the order of 0.2 to 0.4 mgon for well defined points.

A system consisting of two theodolites was provided by the Physikalisch-Technische-Bundesanstalt, Braunschweig for this test.
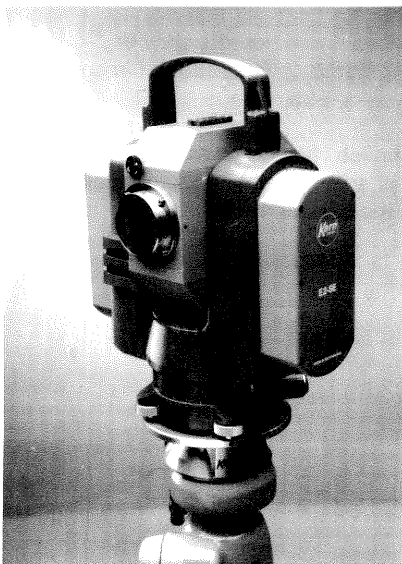


Fig. 1  E2-SE, motorized, electronic theodolite with integrated CCD-sensor

## 2.2 Large Format Camera (LFC)

This system, which was designed for highly accurate industrial photogrammetry, is used primarily for object measurements in which the object can only be recorded for a very short time. Synchronization of several cameras allows the recording of dynamic processes in sections. The LFC combines analogue recording techniques consequentially with the réseau technique. Correction of film unflatness, e.g. using a vacuum plate, is not necessary here. Film unevenness on recording

and film deformations are largely compensated for on measurement with the Réseau- Scanner. Typical measurement accuracy is between 1 - 2 µm.

For safe, reliable identification, the measured points should preferably be made of retro-reflecting material. This method of point targeting has already been successful in many projects [Brown 1984, Dold and Riechmann 1991]. The necessary réseau for optical-numeric transformation is projected onto the film by a pre-exposure unit. Automated image coordinate determination then takes place by means of the Réseau-Scanner RS1 [Luhmann 1988].
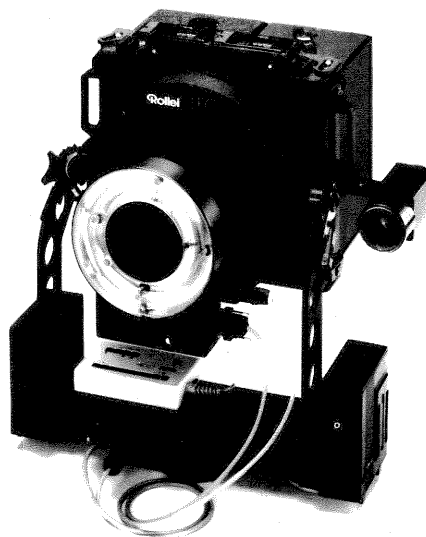


Fig. 2  Large Format Camera (LFC)

## 2.3 Rolleiflex 6008 metric

Building on the positive experiences made with the partial-metric camera Rolleiflex 6006, the successor is equipped with a fine-mesh réseau (1.75 x 2.375 mm²) and a special pre-exposure unit. Film unflatness and deformities can be corrected by this fine-mesh réseau so well that measurement accuracy of 1µm and better is attainable [Suilmann 1992]. A great advantage of this camera is the multitude of electronic aids found in a professional camera, which greatly ease operation. Object lenses with focal lengths ranging from 40 mm to 120 mm and more are available to solve various problems in industrial applications.

## 2.4 Réseau Scanning Camera (RSC)

The RSC was designed for high-resolution on-line object recording using a standard CCD-sensor. The CCD is placed in the image plane of a camera - in this case a mid-size camera. A shifting device is used to move the sensor both within the image plane and perpendicular to

it as shown in Fig. 3. This computer controlled device makes it possible to record the large format sequentially
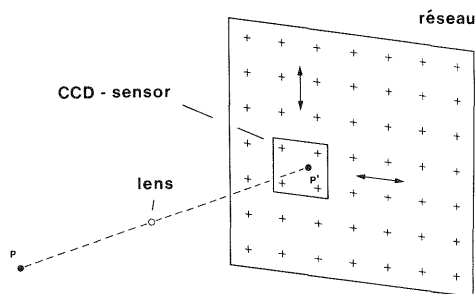


Fig. 3  The principle of Réseau-Scanning

in partial images. To combine all the partial images in an entire image, a réseau plate placed in front of the image plane is also projected onto the CCD. To ensure that the projected réseau crosses are visible and
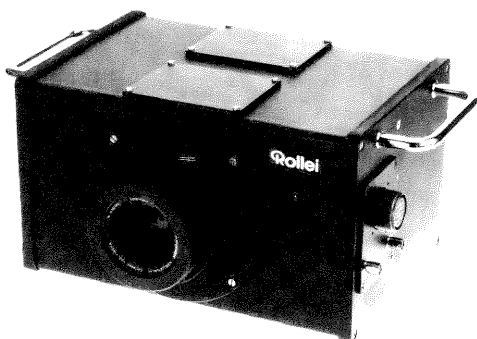


Fig. 4  Réseau-Scanning Camera

measurable, the recording of a partial image is divided into two steps. In the first step the object is projected onto the sensor and in the second step a light emitting diode (LED) mounted in the object lens projects the réseau onto the CCD while the shutter of the camera is closed [Riechmann 1990]. Starting with known coordinates of the projected réseau crosses and the measured sensor coordinates of these crosses, the transformation parameters between these coordinate systems can be calculated. Both absolute and relative distances between réseau and CCD-sensor caused by focussing, are compensated for by this transformation. By transforming the evaluations made in the sensor-system into the réseau-coordinate-system a focusable camera with constant interior orientation is realized.

A measurement system, consisting of 3 RSC and a revolving table is being developed [Godding and Luhmann 1992].

## 3. RECORDING CONFIGURATION AND IMAGE POINT MEASUREMENT

To achieve very high accuracy, the recording positions should be arranged so that the interior orientation of the camera can be determined by means of a simultaneous calibration. The recording configuration corresponds to the spatial multi-image triangulation arrangement shown in Fig. 5. High levels of object point accuracy are achieved by good ray intersection conditions.
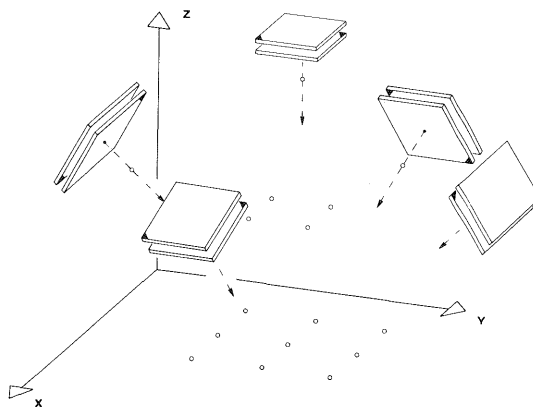


Fig. 5  Geometric configuration of image acquisition [Wester-Ebbinghaus 1987]

A compromise had to be found between test field dimensions and the attainable test field stability in order to realize the test field. The distance between the points in the grid is approx. 14 cm.
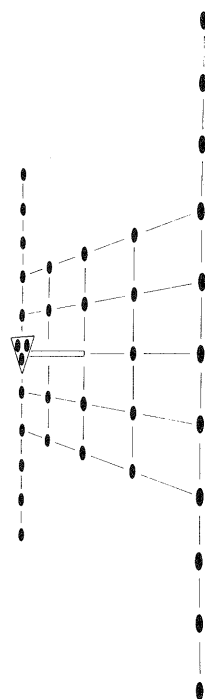


Fig. 6  Schematic representation of the spatial test field [0.60 x 1.40 x 0.25 m$^3$] used

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As the off-line systems Large Format Camera and Rolleiflex 6008 metric are to be included in the comparison, the use of retro-reflecting material is imperative. The projection of these points, which do not have an ideally defined circumference, through the object lens onto analogue film material works like a low-pass filter. However, irregularities in the retro-signals are detectable in the case of direct projection of the points onto the CCD-sensor of the RSC, and this reduces the accuracy of point determination. This effect can be largely corrected by filtering around the measured points with a 3 x 3 low-pass filter. The same point measuring algorithm is used with all three photogrammetric systems. It is based on the convolution of the image function with a gradient operator. It could be shown in various applications that this algorithm is suitable for accuracy of up to 3/100 of the image elements [Bösemann et al. 1990]. The proposition that the ideal centre of the object point and of the measured centre can be equated holds true for the initial approximation, and is sufficient for the evaluation required here.

## 4. INTERPRETING THE RESULTS

Besides consideration of accuracy and reliability, derived from excess mesurements a direct comparison of several measuring systems allows an insight into the accuracy of a system.
The essential results of the bundle adjustment are summarized in table 1. Initially, all measured directions and image coordinates, together with the respective apriori standard deviations are adjusted together within the so-called free net. The object point coordinates of this adjustment, considered as datum points, are the basis for the individual adjustments. After individual bundle adjustments some deviations on the datum points exceed the respectiv three-fold standard deviations. The fact that some difference vectors lie outside the three-fold standard deviation indicates that the standard deviation calculated in the free net is a value which must be handled with deliberation. Furthermore, systematic tendencies in the difference vectors between combined adjustment and the individual adjustments are considerable. Thus the vectors near the edge of the test field are larger than those in the centre.

On account of its large image format, the LFC attained the highest accuracy at the testfield. The results of the theodolite measurements do not quite reach this level, as, with the combination of the two theodolite system used here, the configuration of image acquisition indicated in Fig. 5 could not be met exactly. Furthermore, only 6 theodolite positions were taken into account here, as opposed to 10 recording stations on the photogrammetric systems. Evaluation of mid-size images produces, compared to the RSC, which has the same format, object coordinates with inferior standard deviations on the object, in spite of an approximately equal image measurement accuracy. While the Rolleiflex 6008 images could be tilted up to 35 gon due to the depth of field problems, the test field for RSC images could be tilted up to 75 gon to the test field level exploiting the focus function.

| measuring-system | residuals at the image coordinats (RMS) [µm] | | image format [mm] | image scale | relative measurement accuracy in the image | mean standard deviations of the object points (RMS) [µm] | | | mean deviations at the datum points (RMS) [µm] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | x | y | | | | x | y | z | x | y | z |
| combined bundle adjustment | - | - | - | - | - | 2.7 | 2.8 | 5.4 | - | - | - |
| SPACE | 0.38* | 0.40* | - | - | - | 5.9 | 6.4 | 12.2 | 3.2 | 4.8 | 12.0 |
| Large Format Camera (LFC) | 1.13 | 1.21 | 230 x 230 | 1 : 7 | 1 : 200 000 | 2.8 | 2.7 | 5.9 | 3.2 | 4.2 | 5.7 |
| Rolleiflex 6008 metric | 0.91 | 0.97 | 52 x 52 | 1 : 30 | 1 : 55 000 | 8.5 | 7.9 | 14.8 | 17.1 | 18.4 | 19.2 |
| Réseau - Scanning Camera | 0.86 | 0.78 | 52 x 52 | 1 : 30 | 1 : 60 000 | 7.1 | 6.5 | 9.4 | 10.3 | 13.7 | 15.1 |

* measurement accuracy of directions [mgon]

Table 1: Results of combined and individual bundle adjustments

In order to measure the highly tilted test field from a very short distance, each point is to be focused individually for image coordinate measurement. This improves the accuracy of the calculation of object points and especially the accuracy of the interior orientation. All three photogrammetric systems use object lenses whose distortion can be described adequately only using the radially symmetrical parameters. Parameters of tangential distortion could not be determined.

## 5. CONCLUSION

A comparison is made between a new photogrammetric on-line system, on the one hand, and conventional systems designed for highly accurate industrial measurements on the other. Comparison shows that a level of accuracy could be reached with the Réseau-Scanning Camera which up to now appeared to be reserved for analogue mid-size cameras.

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