# A Digital Reseau-Scanning Comparator System

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**Abstract**

A digital mono-comparator system based on the principle of reseau-scanning was first presented in 1986 and has been brought to a fully automated, high-precision image measuring device in the last three years (Rolleimetric RS1).

A CCD camera is used to digitize small image patches with a resolution of less than 8 microns. The camera position within the comparator coordinate system is given by a high-precision reseau grid being in contact with the film. The sensor orientation is found by automatic reseau cross detection and a numerical transformation between sensor plane and film plane. Measurements of a calibrated grid plate lead to a typical precision of about 0.7 microns.

The software system is designed for simultaneous measurement of up to 16 photographs. Automatic point setting of wellknown targets is performed by various methods of structural point detection based on least squares models.

Furtheron the paper will describe some applications in the field of industrial photogrammetry to verify the practical capability of the total system. Final quality assessments will be given by results of bundle block adjustments.

## 1. Introduction

Recent trends in digital close-range photogrammetry can be characterized in two main topics: First, the development of real-time systems by means of at least two digital cameras (e.g. CCD video cameras) for simultaneous object recording. In this field increasing processing speed often leads to decreasing precision of measurements and vice versa [EL-HAKIM 1987, LUHMANN & WESTER-EBBINGHAUS 1986].

Secondly, extended analytical instrumentation is used for digital evaluation of analog metric imagery. Analytical plotters equipped with two CCD-cameras are mainly used in DTM collection in close-range applications as well as in aerial photogrammetry [COGAN & HUNTER 1984, PERTL 1984, SCHEWE 1988]. In these cases the instruments can still function as normal analytical plotters whereas stereomeasurements can be performed automatically.

On the other hand digital mono-comparator systems hve been brought on the market which are especially designed for digital point measurements in the field of industrial photogrammetry [LUHMANN & WESTER-EBBINGHAUS 1986, BROWN 1987]. Close-range applications often require three-dimensional object recordings limited to mesurements of discrete points. In these cases the whole photogrammetric setup can be optimized with respect to following image measurements where special point signalization and a priori knowledge about orientation parameters can lead to a high degree of automization [FRASER & BROWN 1986].

The following paper deals with the development of an automated mono-comparator for digital point measurements of analog photographs. It is based on the principle of reseau-scanning [WESTER-EBBINGHAUS 1984]. Introducing a reseau glass plate as a transparent reference plane into the photogrammetric projection space, it is possible to orientate partial image frames optical-numerically with high accuracy and low mechanical effort.

Fig. 1 shows the principle applied to digital film recording in a reseau-scanner. An image sensor (CCD array) can be shifted parallel to film plane whereas at least four reseau targets are projected onto the sensor plane. Automatic reseau cross detection is performed in order to calculate a rigorous perspective transformation between sensor plane and image plane.

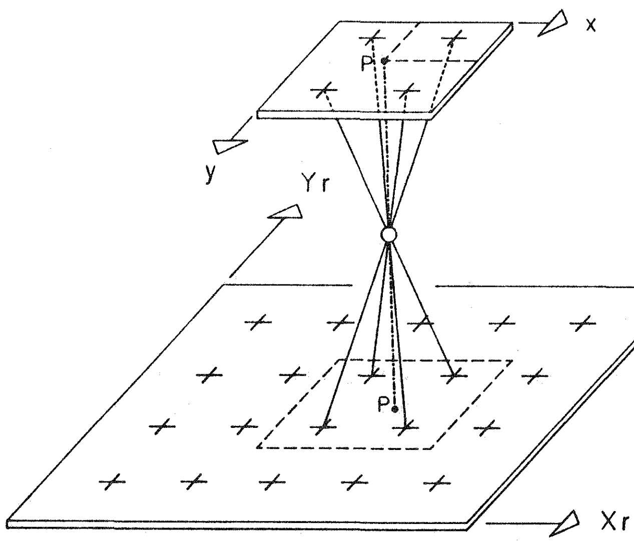


Fig. 1: The principle of reseau-scanning

In cooperation with Rollei Fototechnic, Braunschweig, the Institute of Photogrammetry and Cartography (Technical University Braunschweig) and the Institute for Photogrammetry and Engineering Surveys (University of Hannover) a digital mono-comparator was developed in the last three years (Rolleimetric RS1, see Fig.2) [LUHMANN & WESTER-EBBINGHAUS 1986, LUHMANN & WESTER-EBBINGHAUS 1987, LUHMANN 1988].

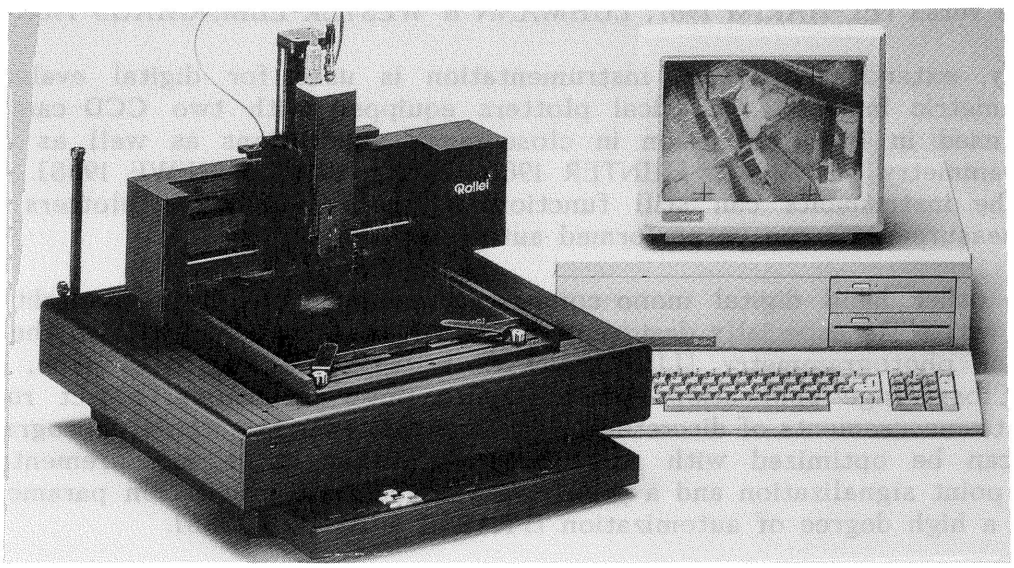


Fig. 2: Digital mono-comparator Rolleimetric RS1

## 2. Hardware Configuration

The mono-comparator system consists of the following hardware components:

a. Reseau-Scanner Rolleimetric RS1
   - CCD-array camera: Valvo NXA 1010 sensor, 604 x 576 elements (10.0 x 7.8 μm) internal or external synchronization, CCIR video standard
   - reseau plate: 2 mm grid spacing, measurement area 230 x 230 mm
   - interface: Centronics 8 bit parallel
   - controlling: focus, light intensity, color filters, camera movement
   - pixel size: 7.7 x 5.3 μm on film plane
b. Micro-computer TANDON PCA 40 (AT-compatible)
   - processor: Intel 80286/80287
   - disk: 40 MB
   - operating system: MS-DOS 3.10
c. Frame grabber Imaging FG-100-AT
   - frame buffer: 1024 x 1024 x 12 bit
   - scanning rate: 10 MHz
d. Digitizing tablet Aristo GRD 122
   - resolution: 25 μm
e. video monitor

The resulting pixel size related to the film plane depends on the projection scale of the optical system (1.5 : 1) and the scanning rate of the video A/D-converter (10 MHz). Different pixel sizes can be obtained if the optical magnification changes with respect to the corresponding grid spacing of the scan-reseau.

## 3. Geometric Accuracy

The geometric accuracy of the comparator system is influenced by the quality of
- sensor system
- video processing and digitization
- optical system
- scan-reseau plate
- sensor orientation
- digital point measurement

Due to system complexity it is difficult to separate single effects responsible for the total sysetm accuracy. The following chapters summarize some important investigations dealing with sensor system and optical effects in order to test the possible precision under laboratory conditions.

### 3.1 Sensor System

The sensor system consisting of CCD camea, optical system and video processing unit is rather complex, so that the geometric behaviour is affected by different errors.

a) video processing:
   The recorded image signal on the CCD array is transformed into an analogue video signal, which has to be digitized in a separate hardware unit (frame grabber). Analog and digital video processing leads to systematic and non-systematic errors, which partly can be corrected [BEYER 1987, LUHMANN & WESTER-EBBINGHAUS 1987]. Nevertheless line shift errors of up to 0.4 pixel might occur in the digitized video image.

b) lens and sensor distortion:

The optical and electronic sensor distortion was investigated by partial camera calibration resulting form bundle triangulation over planimetric test field (calibrated 1 mm grid plate). Thus functions describing image distortions can simultaneously be determined in bundle adjustment [MAUELSHAGEN 1977]. Summary of results:

| | |
|---|---|
| number of images | 24 |
| points per image | 12 |
| $\sigma_o$ | 0.08 pixel |
| $\sigma_{xyz}$ of object points | 1.1 µm |

Although the bundle adjustment shows highly accurate and reliable results significant optical lens distortion does not exist. On the other hand Fig. 3 shows the distribution of residuals on sensor points. Local systematic effects can be detected with maximum distortion of 0.2 pixel. This result is only caused by internal sensor errors since warm-up effects as well as line synchronization errors could be avoided.

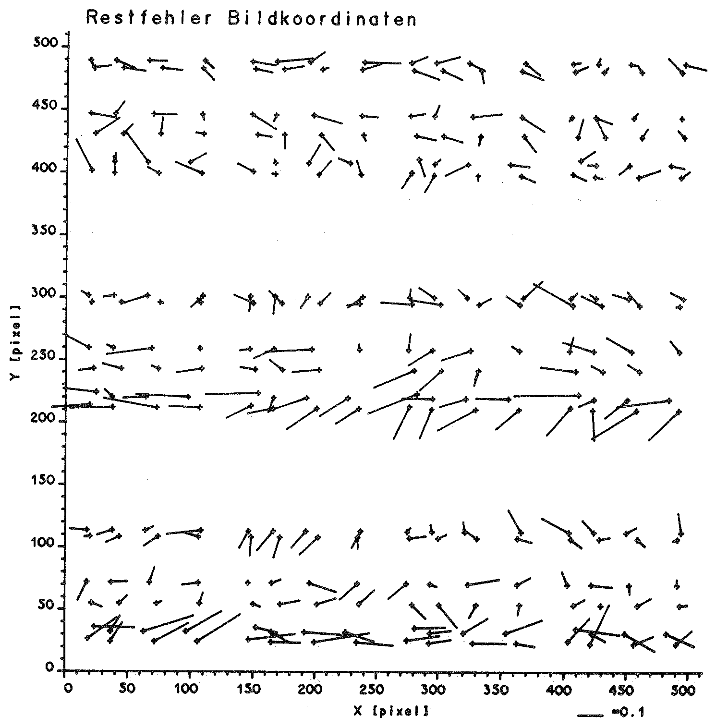


Fig. 3: Sensor distortion (residuals of image points)

### 3.2 Scan-réseau

In principle reseau-scanning allows the transformation of each pixel of an entire image frame into the reseau coordinate system. This requires a plane sensor surface as well as plane reseau grid and film. In order to achieve a measurement accuracy of less than 1 µm film and scan-reseau have to be plane within a tolerance of less than 20 µm. Otherwise each single measuring point has to be located in or close to the optical axis of the compartor sensor system [LUHMANN 1988]. The available ccomparator system (prototype version) only guarantees a reseau flatness of 100 µm so that the following investigations are performed with a centered-point strategy.

### 3.3 Repeated Measurements

Repeated measurements of an optimal point signal are used to investigate the local inner accuracy of the comparator system. Furtheron typical warm-up effects can be observed.

Fig. 4 shows the results of repeated measurements within one hour whereas the CCD camera was switched on just before the first point measurement. The dashed lines indicate the raw pixel coordinates, while the continuous curve shows the results after transformation into the scan-reseau. In x-direction (line direction) one can observe a shift of more than 8 pixels within the first 30 minutes while the y-coordinates are rather constant. Using reseau transformation almost all global shift errors are compensated. The idea of reseau-scanning can be applied to normal CCD array cameras if at least four fiducial marks are projected onto the sensor plane.

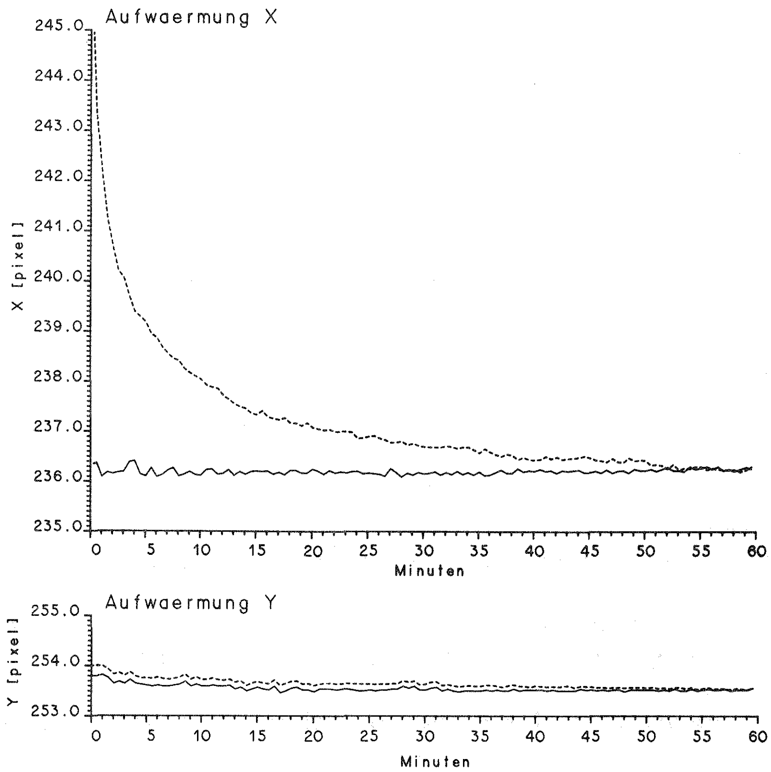


Fig. 4: Repeated measurements and warm-up
dashed: raw pixel coordinates
continuous: transformed into scan-reseau

### 3.4 Grid Measurements

The global measurement precision is tested with a calibrated glass grid plate. Automatic detection of 121 grid points (5 mm spacing) leads to a RMS of

$$\sigma = \pm\ 0.7\ \mu m$$

Fig. 5 shows the residuals after conformal Helmert transformation with maximum errors of 1.8 μm.

With respect to these results the digital monocomparator system can be classified as one of the most precise instruments on the market.

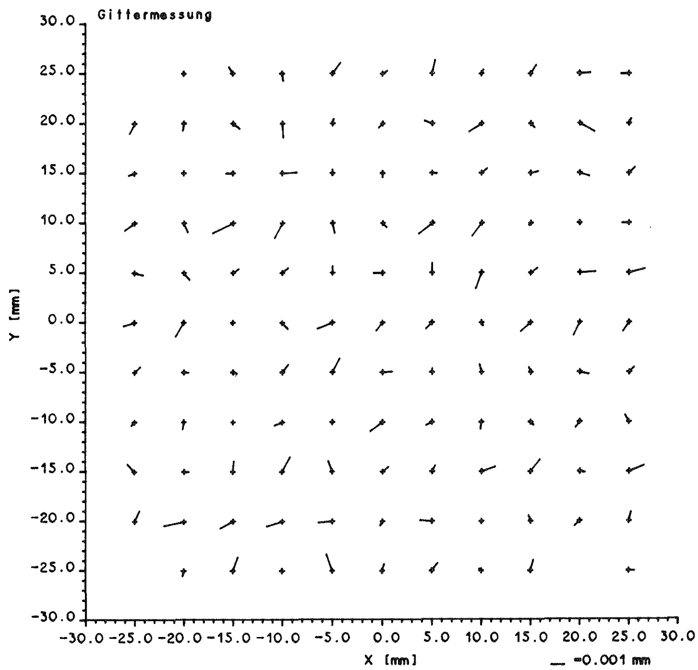


Fig. 5: Measurement of a calibrated grid plate

## 4. Automatic Point Measurement

There are three categories of precise point loction methods implemented in the system:

1. center-of-gravity operators: weighted averaging of pixel coordinates using grey values or gradients.
2. correlation operators: cross correlation of (synthetic) reference image and search image
3. structural operators: extraction of line or edge elements of a known pattern and point modelling by means of least squares adjustment.

Automatic point location methods should satisfy following requirements:

1. precise point determination with sub-pixel accuracy
2. reliable pattern recognition if points are affected by noise, perspective deformations and background information
3. calculation of parameters describing precision and reliability of point determination for automatic measurement control.

These conditions are widely fulfilled by structural point location operators. Separating background and point pattern by classification of edge and line elements combined with rotation, shift and scale invariant procedures leads to flexible and reliable point detection. Since desired structural point elements (e.g. bars of a cross target, border of a circle-shaped point) are extracted they are modelled in a least squares adjustment (e.g. curve approximation) [LUHMANN 1986]. Using robust estimation gross errors are detected.

Furtheron standard errors can be used as test values for automatic measurement control. This enables the automatic separation of good and bad points either for iterative parameter adjustment or following interactive control measurements.

Fig. 6 shows examples of typical digital point measurements of cross-shaped and circle-shaped signals. Point detection is calculated in a defined image window so that sufficient approximate coordinates are required. Depending on the quality of approximate values it might be necessary to improve these positions. An automatic improvement can easily be performed by center-of-gravity operators. Especially the operator of FÖRSTNER & GÜLCH is suitable for detection of cross-shaped and circle-shaped targets [FÖRSTNER & GÜLCH 1987], if the pattern is not disturbed by background information.

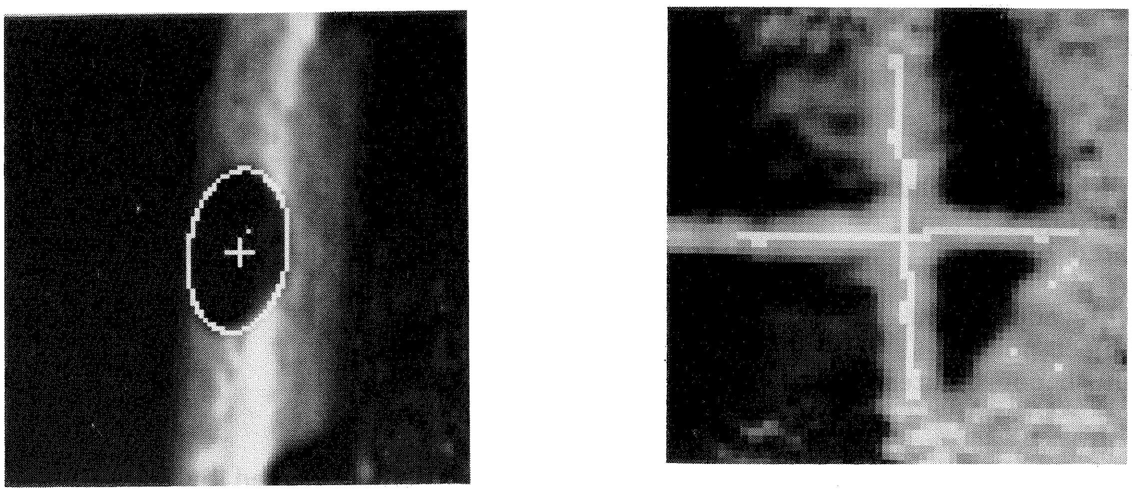

Fig. 6: Examples of digital point measurements

## 5. Applications

Two applications of close-range photogrammetry should verify the capability of automatic point setting. Fig. 7 shows examples of photographs once for test field triangulation in order to test a photogrammetric system (a) and once for photogrammetric vehicle deformation analysis (b). Both objects were recorded with a partial-metric camera Rolleiflex 6006 reseau.

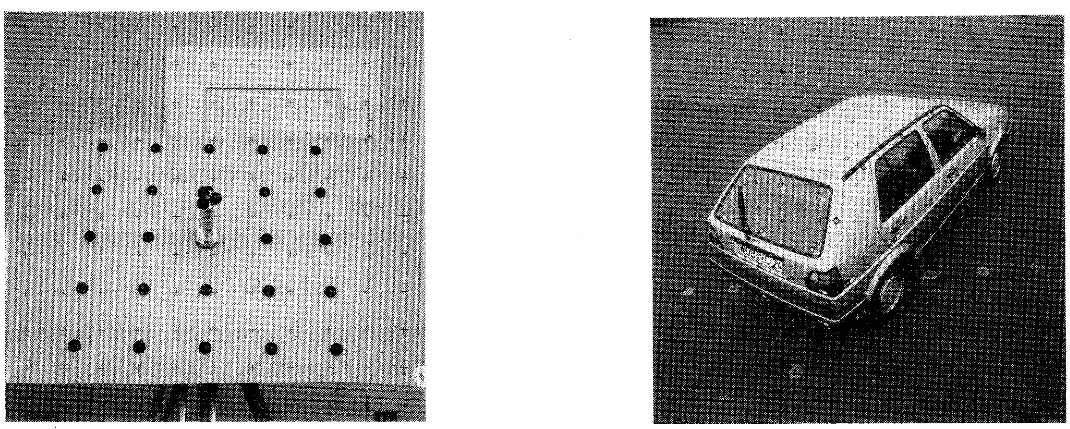

Fig. 7: a) test field triangulation b) vehicle mesurement

Approximate photo coordinates were mesured on a digitizing tablet. They were measured by a combination of center-of-gravity operators and ellipse and cross operators, respectively. There was no parameter tuning during the measurement process.

The following table summarizes the result of automatic point setting and final bundle adjustment:

| | test field | car |
|---|---|---|
| object points | 27 | 78 |
| photos | 10 | 8 |
| mean photo scale | 1:17 | 1:75 |
| measured object points | 262 | 268 |
| blunders ($\sigma_0 > 3$ µm) | 0 | 53 (19.8 %) |
| eliminated blunders | 0 | 33 (12.3 %) |
| measured reseau points | 616 | 344 |
| blunders ($\sigma_0 > 3$ µm) | 16 (2.6 %) | 21 (6.1 %) |
| eliminated blunders | 1 (0.1 %) | 14 (4.1 %) |
| $\sigma_0$ bundle adjustment | 1.5 µm | 3.1 µm |
| $s_{xyz}$ object points | 0.012 mm | 0.25 mm |
| $s_{x'y'}$ photo coordinates | 1.2 µm | 2.0 µm |

The high degree of automation in test field triangulation is caused by an optimized object signalization and bundle configuration. Due to illumination problems and point distortions the number of blunders increases in the case of car measurement. Nevertheless in both projects all blunders were detected automatically. Furtheron the final precision satisfies user requirements.

## Conclusion

The principle of reseau-scanning is a powerful method to achieve high precision in digital image measurement with low mechanical effort. Using this method a digital mono-comparator system was developed, which is controlled by an automatic point setting system. Measurements of a calibrated grid plate lead to a highest possible accuracy of 0.7 µm, so that the system is comparable to other highly precise comparators (e.g. AutoSet-1 [BROWN 1987].

The evaluations of practical applications have shown that precise automatic image measurements without operator control are possible. The strategy of structural point measurement is capable to perform shift-, rotation- and scale invariant point determination combined with an automatic blunder detection. Point signals which are disturbed by noise, background or other effects are automatically seperated and can be measured later under interactive operator control.

Further improvements are required in the field of illumination control and automatic parameter adjustment in order to reduce the number of operator interactions.

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