Terrestrial Laser Scanning
Technology, Systems and Applications

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Key words: Terrestrial Laser Scanner, Laser Scanning, Digital Terrain Model, verification of the measurements.

SUMMARY

Terrestrial Laser scanning is a new method for surveying tasks, which allows to acquire easy and fast complex geometric data from buildings, machines, objects etc. Each point is determined by the position (*x*, *y*, *z*) and the intensity (*i*) of the returning signal. This paper describes the technology and summarizes the actual systems on the market. The accuracy of different systems was investigated. The results of the comparisons are presented in a separate chapter.

RESUME

Les nouveaux systèmes 3D Laser permettent la numérisation et la modélisation des objets de grande taille et des scènes entières. Chaque point est déterminé en trois dimensions (*x*, *y*, *z*) et l'intensité du signal de retour. Cet article décrit la technologie et donne une supervision sur des systèmes actuels sur le marché. L'exactitude des systèmes de scannage est déterminé et présenté dans un chapitre

ZUSAMMENFASSUNG

Terrestrisches Laser-Scanning ist eine neue Methode um Gebäude, Maschinen, Objekte usw. schnell und detailliert zu erfassen. Jeder Punkt wird durch dreidimensionale Koordinaten (*x*, *y*, *z*) sowie die Intensität des reflektierten Streckenmesssignals (*i*) beschrieben. In diesem Artikel wird die aktuelle Technologie beschrieben und die aktuellen, kommerziell erhältlichen Systeme werden vorgestellt. Die Ergebnisse von Genauigkeitsuntersuchungen mehrerer Systeme werden in einem eigenen Kapitel vorgestellt.

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1. INTRODUCTION

Terrestrial Laser Scanning is a new and efficient method for digitizing large objects and entire scenes. Since some years several manufacturers offer different systems which are designed and developed more or less for specific tasks. In general each surveying task can be divided in three major steps: data acquisition, data treatment and finally the visualization. For Laser Scanning this categorization is also valid. This paper describes the different systems, available on the market and it will focus on the first two steps.

1.1 Classification of tacheometric Measurements

Tacheometric measurements, this means the combination of measured distances and angles from one station, are today very common. Based on this principle (Fig.1), there is a wide variety of systems on the market. The Laser scanning technology is optimized for a fast and automated data acquisition in a short to medium range (between 1 to 10 m and 1 to 800 m).

tacheometric 3D-coordinates

	Tacheometer	Binocular	Laser Tracker	Laser Radar	Laser Scanner
target cooperative ?	Yes/ No	No	Yes	No	No
range	2 to 5000 m	2 - 5000 m	0,4 - 50 m	1 - 50 m	1 - 800 m
accuracy	> 0,5 mm	> 1 m	> 0,05 mm	> 0,05 mm	> 5 mm
speed [time /Pt.]	0,2 - 10 Hz	3 s	1000 Hz	1s -1 Min[2]	> 1000 Hz
distance meas.	Phase	Puls	Interferom.	Hybrid-M	Puls
applications	well known	GIS	IM[1]	IM[1]	versatile

[1] IM = Industrial Measurements [2] dependant from accuracy

Figure 1. The family of tacheometric measurement systems

1.2 Principle of tacheometric Laser Scanning

Tacheometric Laser Scanners are digitizing the area of interest with a frequency of 1000 Hz or higher. To each point one oblique distance (*s'*) and two orthogonal angles (w_1 and w_2) are measured (Fig. 2).

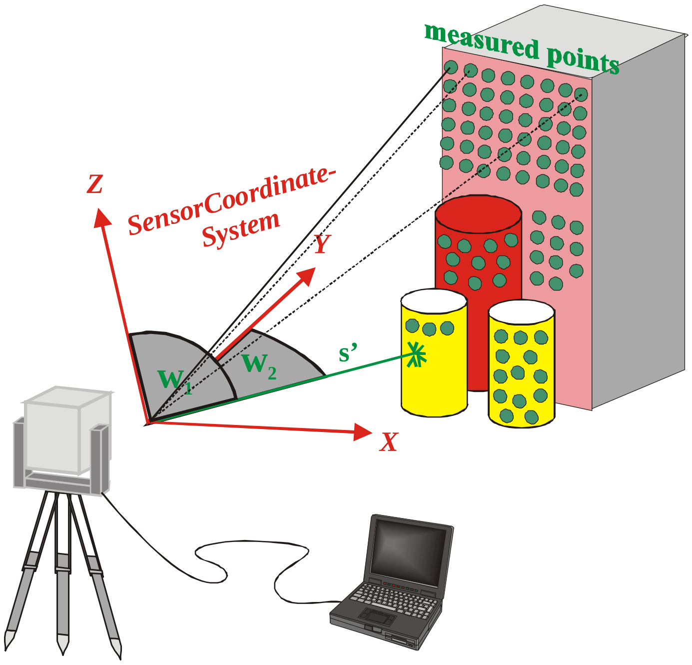
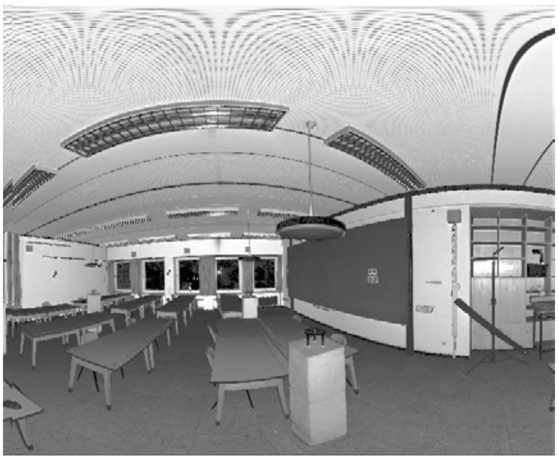


Figure 2. the principle of tacheometric Laser Scanning

Together with the additionally registered intensity (*i)* of the returning distance signal each point is described in a three-dimensional local coordinate system (*SCS*). The intensity - often called the fourth dimension - is very useful for the visualization especially in dense and complex point clouds (Fig.3).



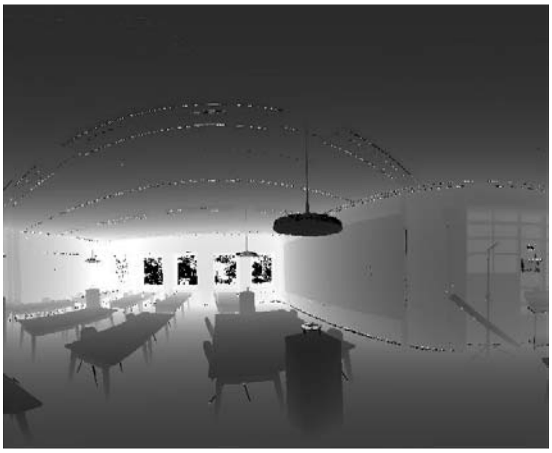


Figure 3a. Point cloud coded by the intensity **3b**. …coded by the range

1.3 Types of tacheometric Laser Scanners

Today the scanner systems on the market can be divided in three different types (Fig. 4):

- Camera Scanner: a limited Field of View (FOW) of e.g. 40x40°, comparable to a Photogrammetric Camera, is scanned. Examples are CYRA 2500 (LEICA) and ILRIS 3D (OPTECH). This type is optimized for a view from outside onto the object(s). Therefore a long range distance measurement device is useful.

- Panorama-Scanner: the field of view is only limited by the base of the instrument (incl. the tripod). This type is designed for indoor purposes, esp. the digitization of rooms, facilities, etc. Examples are Imager 5003 (ZOLLER & FRÖHLICH) or CALLIDUS (CALIDUS PRECISION).

- Hybrid Scanner: One rotation axis is without restrictions (often the Horizontal Movement) the second rotation axis is – due to the use of mirrors - limited, e.g. to 60°.
  GS 200 (MENSI) and LMS Z 360 (RIEGL) represent this group.

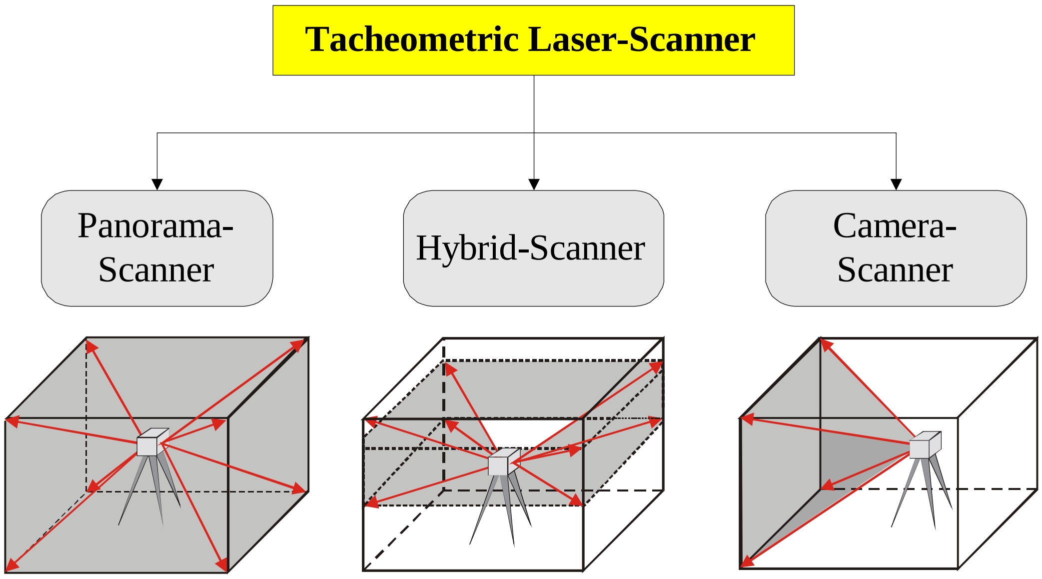


Figure 4. The different types of tacheometric scanners

1.4 Software

Each manufacturer offers product-specific software for the acquisition of the data. The point clouds are stored in an internal data format. Therefore the customer needs special software which allows to read and treat the data afterwards for the treatment.

The data acquisition with the IMAGER 5003 from Z& F is realized with the LRC-SERVER-program running under MS-WINDOWS®. Each single scan creates a data file in the (internal *zfs*-format) with a maximal file size of 1 GB (highest resolution, full panorama). The scan itself can directly be controlled visually with LR-VIEWER (see Fig. 3).

Before the modeling the data has to be transformed (LARA-KONVERT) in the ZFC-Format. The Modeling is accomplished with the powerful LFM- Light- Form-Modeler module.

The general philosophy of LFM can be seen in Figure 6. The customer selects a subset of points (right side), which are transferred to the 3D CAD-window (left side). There, all the desired operations can be performed (calculation, combination, export, etc.).

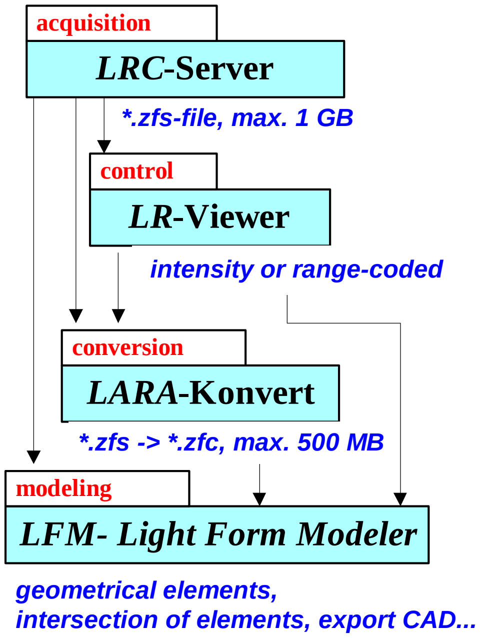
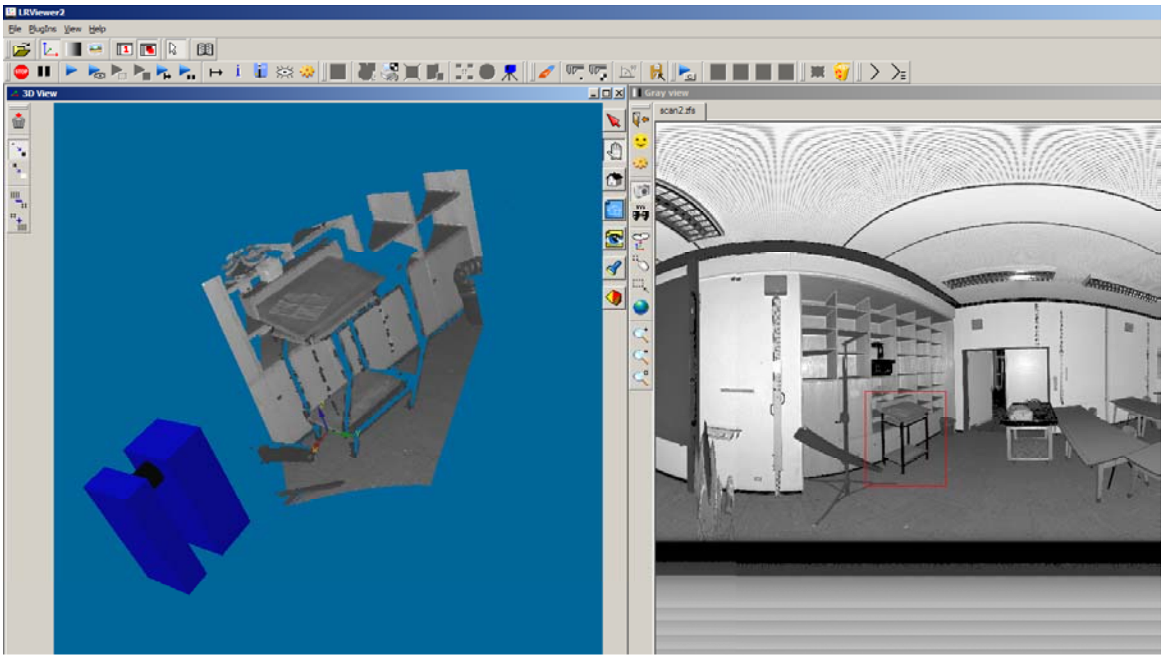


Figure 5. Software for IMAGER 5003



3D-CAD-window point cloud-window

Figure 6. LFM-Software

2. PHASES OF A PROJECT

Each surveying project can be divided in three major steps: the data acquisition, the data treatment and the visualization.

2.1 Data Acquisition

The data acquisition itself consists of several steps. The area of interest will be scanned in one or more scenes. The immediate result is a point cloud, in which each point is represented by 3D-coordinates (x, y, z) and the intensity of the reflected signal (i). The fusion of several point clouds in one (global) coordinate system (often called "registration") is realized either with pass points or with natural structures in the point clouds. The method with pass points is the most precise one. The use of a tacheometer in conjunction with pass points offers several advantage:

- no overlapping areas in the scans are necessary
- the scan is geometrically controlled
- a transformation into a geodetic coordinate system or into a local, gravity related system is possible.

2.2 Data Treatment

The scanned point clouds can contain perturbations. "Wrong points" are caused by reflexes from vehicles, animals or persons passing the scene during the scan. Another possibility are total reflexions from the object. They create either a "black hole" (no information) or virtual objects which are not existing. The phase measurement technique for the distances allows very fast measurements (Table. 1).But on non-continuous structures the mix of the different phases of parts of the beam is leading to "intermediate points" (P). This effect is called the "tail of a comet" (Fig. 7).

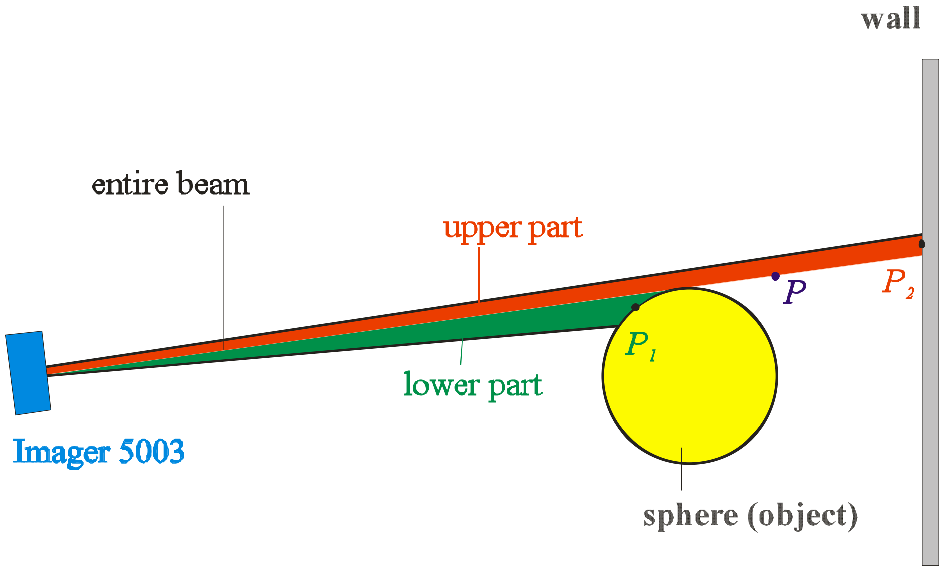


Figure 5: Mix of the Phase-signal

Once the disturbing points are eliminated, the treatment process can be directed into different directions:

- The calculation of geometrical elements from a subset of points, e.g. cylinders, spheres, planes, cones, pipes, etc.
- The intersection of geometrical elements
- The interpolation of a regular grid based on the non-regular point clouds
- The combination of the scanned data with digital images to a “true ortho photo”
- The comparison of a theoretical model (CAD) with the reality (point cloud) in order to predict possible collisions of planned objects embedded in the scanned reality
- The export of the point clouds or of geometrical elements to other programs (CAD, data base,..)

2.2 Visualization

The treated data is visualized in different ways:

- Point clouds in a 3D-projection, with color or greyscale-coded intensity representation, is often used as a first visual check of the acquired data.
- Point clouds can also be combined with derived geometrical elements.
- “True” Ortho-Photos are realized by the fusion of digital images (point information) and the registered point clouds (geometry).
- 3D-Contourplans
- 3D-Models
- “Virtual flights” through the modeled scene.

3. THE GEOMETRICAL QUALITY OF THE MEASUREMENTS

The technical data of the actual scanners are listed in Table 1. The manufacturers give detailed technical information on their systems. But if we are looking at the quality of the measurements itself, this means the accuracy of the 3D-coordinates, respectively the measured elements, it is not easy to find appropriate information.

Manufacturer	System	3	4	Frequency	Range	Performance
CYRA (USA)	HDS 3000	P	P	1000 Hz	> 100m	*A*: 6 mm @ 50 m
MENSI (F)	GS 200	H	P	5000 Hz	700 m	*R*:3 mm @ 100 m
OPTECH (CAN)	ILRIS-3D	C	P	2000 Hz	800 m	*A*:3mm < 100 m 1-3 cm > 100 m
RIEGL (AUT)	LMS Z 360	H	P	8000 Hz	800 m	*R*: 5 mm
Z & F (GER)	IMAGER 5003	P	A	500 kHz	52 m	*L*: 5 mm

Explanations: row 3: P = Panorama-Scanner, C = Camera-Scanner , H = Hybrid-Scanner
4: P = Pulse-Measurement, A= Phase-Measurement
last row: *A* = Accuracy, *P* = Precision, *R* = Resolution, *L* = Linearity

Table 1: The technical data of the different scanners

The judgment of the quality of the measurements cannot be realized by looking at single measurements (points), as we do for example with tacheometers; here we have to focus on derived elements (spheres, cylinders, etc.).

3.1 Verification of the measured Distances

In order to estimate the achievable accuracy of distances and angles, 7 wooden spheres (with known diameters and known distances in one straight horizontal line) were scanned with a IMAGER 5003 (Z+F). In a first step the spheres and their corresponding center coordinates are estimated in a least-squares-adjustment. The second step is the comparison of the known distance and the calculated distance between two center points. The results of the deviations from the known distances, dependent from the density of the scan, are shown in Fig. 6.

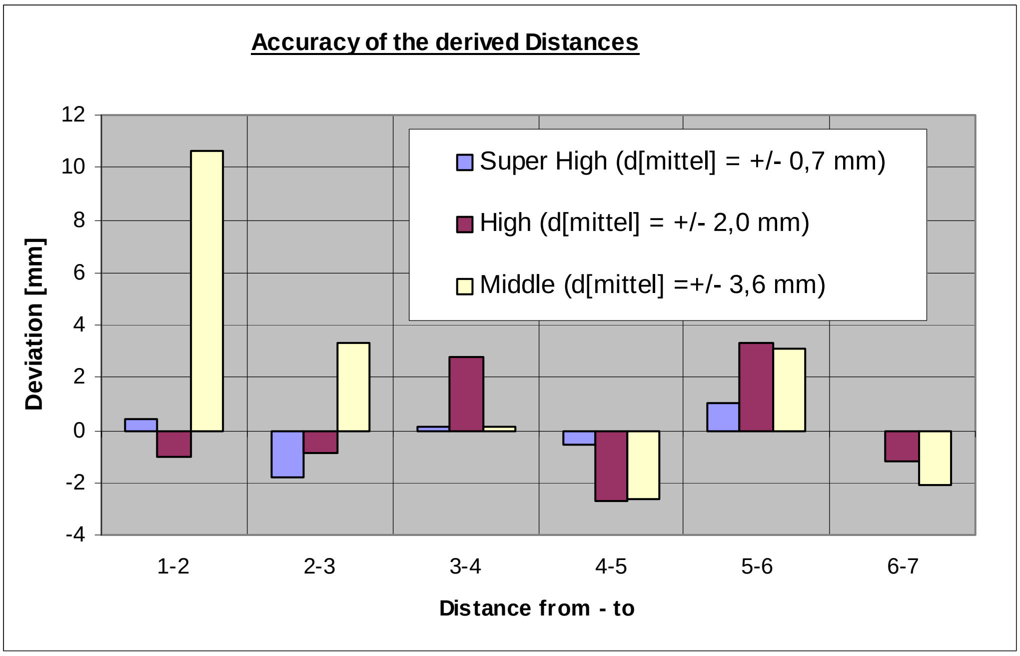


Figure 6: Distances derived from center coordinates of scanned spheres

3.2 Verification of the Parameters of Cylinders

At the University of Essen, there is a work of art, consisting of 32 vertical cylinders (steel, diameter known, approx. 1200 mm, 5 m high) arranged in a square of 30 x 30 m. The cylinders were scanned with different systems and the results are presented for a subset of 10 cylinders in Fig. 7.

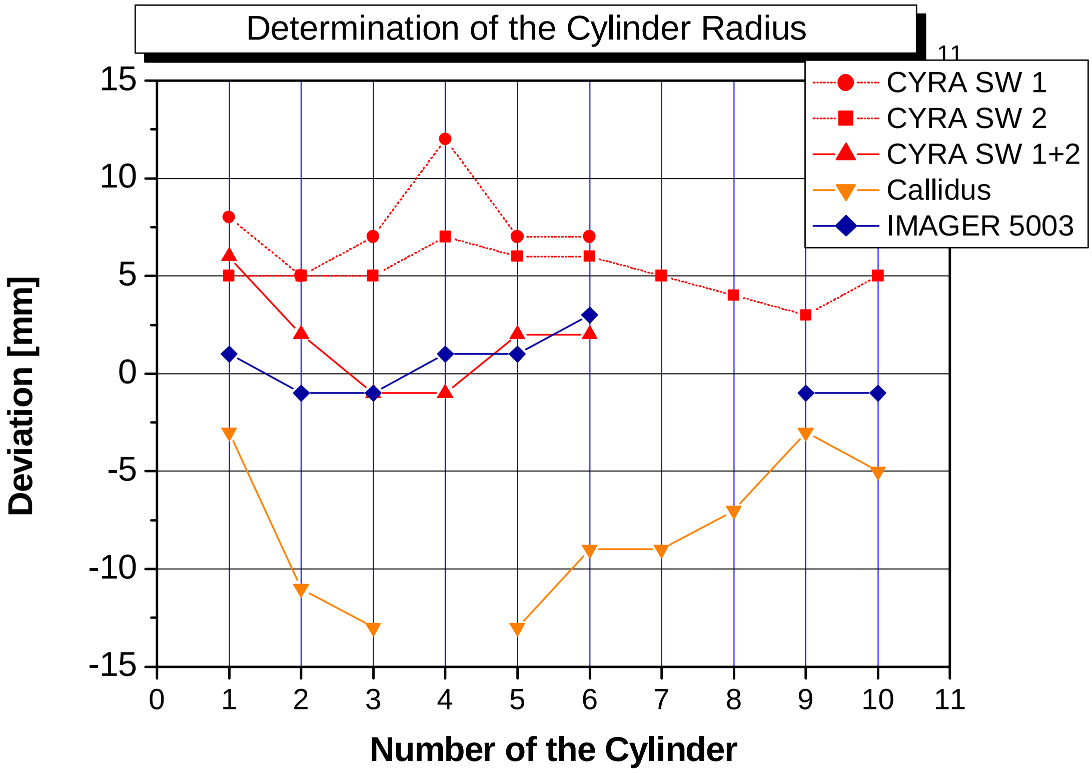


Figure 7: Determination of the determined radius with different systems

4. CONCLUSIONS

The Laser Scanning systems, which are today on the market, are systems with a remarkable performance. The data acquisition is fast and easy to realize. The treatment of the data is still a time consuming process. The customer wishes for this part of the process more automated and faster tools.

The precision and accuracy of the systems was proofed with different methods. The results coincide more or less with the specifications of the manufacturers.

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BIOGRAPHICAL NOTES

1976 –1982 :	studies of geodesy at the University of Karlsruhe (TU) and Paris (IGN)
1983- 1987:	assistant at the geodetic Institute (University of Karlsruhe)
1988:	PhD on the theory of on-line-Triangulation for Theodolite Measuring Systems
1988-1994:	Kern & Co AG, Aarau, Switzerland (later Leica Geosystems), different functions in the Dept. of Industrial Measurement Systems in Marketing and R&D.
Since 1994:	Professor at the University of Duisburg-Essen (Campus Essen), Dept. of Surveying Engineering.
Membership:	Deutscher Verein für Vermessungswesen (DVW) Actual Chair of Arbeitskreis 3 (AK 3) – Methods and Measurement Systems Actual Chair of WG 5.1 - Standards, Quality and Calibration (Comm. 5, FIG)

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