# The Geometrical Quality of Terrestrial Laser Scanner (TLS)

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**Key words**: Terrestrial Laser Scanner (TLS), Laser Scanning, Geometrical Quality, Accuracy, Verification of the Measurements, Optical Perturbations

## SUMMARY

Terrestrial Laser Scanning is a new and efficient method to digitize large objects and entire scenes. As a result of the data acquisition the customer obtains a point cloud for each scan representing the scanned area. In general the point clouds are very big, full of detail and each single point is the result of a not-over determined measurement (in contradiction to the well known tacheometry!). Therefore it is very important to investigate the scans (resp. the scanners) with regard to the geometrical quality.

In a first step the technical specifications, given by the manufacturers, are summarized and discussed. Useful types of specifications for point clouds are suggested additionally. Finally the principal methods to investigate Laser Scanners are described and discussed with regard to their geometrical quality. The different strategies are additionally illustrated by several practical examples. Finally, the performance of the whole measurement system is derived under realistic conditions, by a comparison with tacheometric measurements

## ZUSAMMENFASSUNG

Terrestrisches Laserscanning ist eine neue Methode um Gebäude, Maschinen, Objekte usw. schnell und detailliert zu erfassen. Als Ergebnis der Datenerfassung erhält der Anwender eine Punktwolke, welche den gescannten Ausschnitt numerisch repräsentiert. Die Punktwolken sind in der Regel sehr groß und detailreich; jeder Einzelpunkt ist das Ergebnis einer unkontrollierten, nicht-überbestimmten Einzelmessung (im Gegensatz zur bekannten Tachymetrie). Deshalb ist es sehr wichtig, die geometrische Qualität der Scans zu kennen, bzw. diese auf ihr Qualität zu untersuchen.

Zunächst werden die verschiedenen Herstellerangaben zusammengefasst und diskutiert. Sinnvolle Spezifikationsangaben werden zusätzlich vorgeschlagen. Die verschiedenen Ansätze zu Qualitäts- und Genauigkeitsuntersuchungen werden vorgestellt und verglichen. Die unterschiedlichen Vorgehensweisen werden zusätzlich anhand mehrerer praktischer Beispiele verdeutlicht. Abschließend wird die Genauigkeit des ganzen Messsystems unter realistischen Bedingungen, durch einen Vergleich mit tachymetrischen Messungen, abgeleitet

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## 1. INTRODUCTION

Terrestrial Laser Scanning (TLS) is a new and efficient method for digitizing large objects and entire scenes. The geometrical quality of the derived objects depends directly from the quality of the raw data (x, y, and z coordinates from each point). In contradiction to tacheometric measurements there is no overdetermination and no validation for single points. The real performance of a TLS is influenced by numerous parameters (Fig. 1).

### 1.1 Parameters influencing the Quality of the Scans

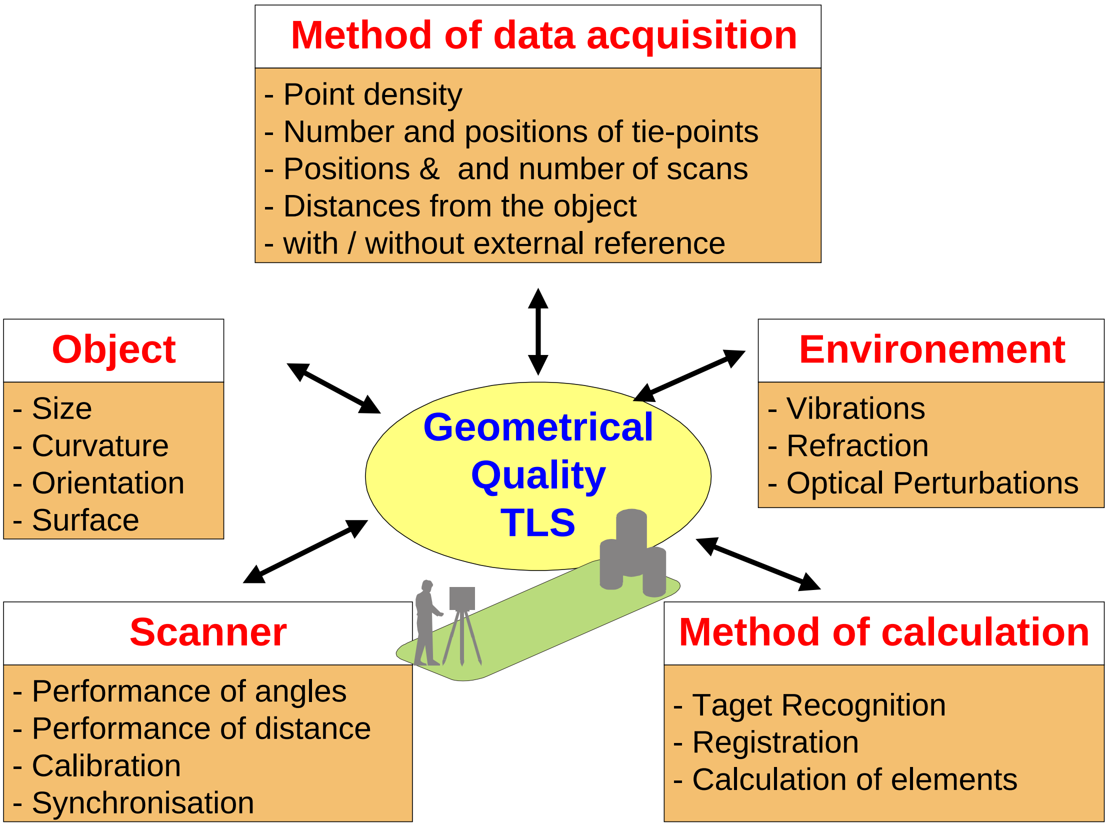


Figure 1. the dependence of the performance of TLS-measurements

It is obvious, that the quality of an entire scene (one or several scans) cannot be described by a single value. The user is only able to derive the achieved accuracy or repeatability by using additional information from known points, objects or independent measurements.

## 1.2 Specifications given by the manufacturers

In this context it is interesting to analyze the specifications, given by the manufacturers and to compare them.

| Manu-facturer | System | Angle | Distance | Position | Element |
|---|---|---|---|---|---|
| Callidus | CP 3200 | ***A***: 0,009°(V)<br>***A***: 0,005°(Hz) | ***A***[2]: 5 mm | | ***A***: ±2,5 mm (planes[3]) |
| Cyra | HDS 3000 | ***A***[1]: 60 µrad | ***A***: ±4 mm | ***A***: 6 mm @ 50 m | ***A***: 2 mm (plane)[7] |
| Iqsun | iQsun 880 | ***R***: 0,0011°(V)<br>***R***: 0,00076°(Hz) | ***U*** [4] :3mm @10m | | |
| Mensi | GS 200 | ***R***: 32 µrad | ***U*** [5,6] :1,4–6,5mm<br>***T*** [5,6] :3–10mm | ***R***: 3 mm @100 m | |
| Optech | ILRIS-3D | | | ***A***: 10 mm | |
| Riegl | LMS Z 420i | ***R***: 0,0025° | ***A***: 10 /5 mm[6] | ***R***: 5 mm | |
| Z & F | IMAGER 5003 | ***R***: 0,018°(V)<br>***R***: 0,01°(Hz) | ***L***: 5 mm | | |

[1]Horizontal and Vertical [2]typical accuracy [3]depends on averaging
[4]with reflectivity of 84% [5]between 5 and 100 m [6]average [7]CYRA 2500

Meaning of the indicator: ***A:*** Accuracy ***L:*** Linearity ***P:*** Precision ***R:*** Resolution ***U:*** Uncertainty ***T:*** Tolerance

Table 1: The specifications from the manufacturer ( October, 2004)

Analyzing Table 1, it is important to keep in mind, that in general we form geometrical elements like planes, spheres, cylinders, etc. out of a huge number of points. Single points are - in contradiction to classical surveying - not treated individually. It can be stated:

- The performance-values itself are not comparable, because the manufacturers are using different indicators like Resolution, Precision, Accuracy, Tolerance or Uncertainty.
- The final result for the customer are xyz-coordinates for each point. As a single point is not reproducible the given indicators for distances, angles or single positions are not of real interest. Additionally the named indicators can only be proofed by wasteful and special measurements.
- Only the indications in the last row (->elements, green row!) are directly linked to the standard results, which are calculated from a subset of the scanned point cloud.
- Only two manufacturers give useful information regarding the geometrical quality of their scanners.

For practical purposes future specifications should be object- and not point-related under well-defined conditions. Otherwise these parameters are not really useful, objective and cannot be used for the comparison of different systems.

## 2. PRACTICAL TESTS FOR THE QUALITY OF POINT CLOUDS

Each Laser Scanner shows different properties, which can be of importance for a specific task:

### 2.1 Resolution Test

BÖHLER (2003) introduced a target for resolution tests (Fig. 2). The front panel has slots which were about 30 mm wide at the perimeter. They are becoming narrower towards the centre. There should be reflections not only from the front panel but also from the solid surface approximately 60 mm behind. With a high resolution scanner the reflections from the bottom surface should not only be present in the wider slotted areas near the perimeter, but also close to the centre where the slots are narrow. The point clouds shown in Fig.3 were acquired at a distance of 3m.

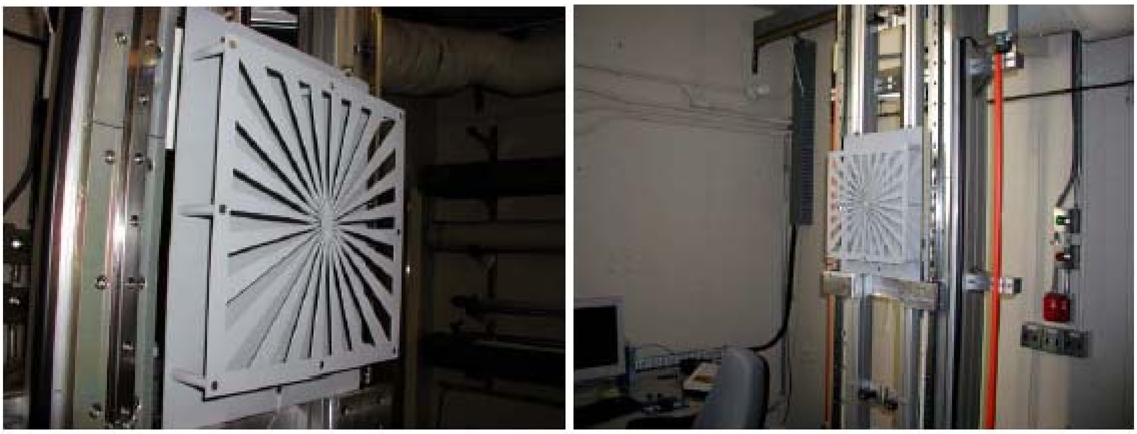

Figure 2. Target for Resolution test

In such a difficult test the perturbations of mixed pixels, “comet” tails, total reflections, multipath, and more are expected. The second pair of images (Fig. 3b) from iQvolution’s IQSUN 880 shows a lot of virtual points (probably created by multipath effects). The third pair (Fig. 3c) from Trimble’s GS 200 has missing data in the middle area and high noise between the planes. In Fig. 7c Z+F’s IMAGER 5003 generates very few points between the two planes. The middle “star” area with the tightest openings is clearly visible indicating good resolution and low noise.

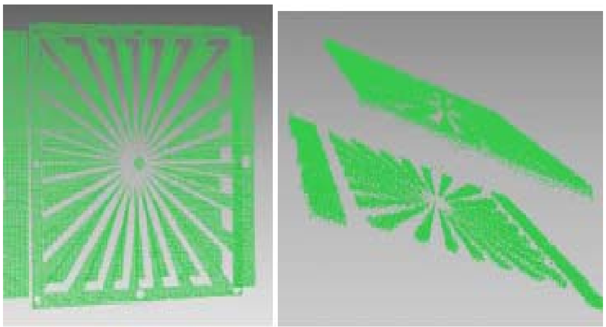

Fig. 3a: HDS 4500

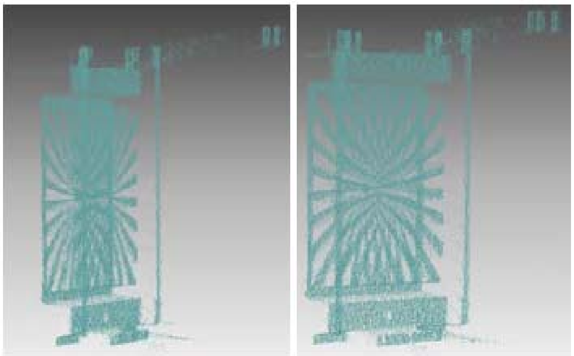

Fig. 3b: IQSUN 880

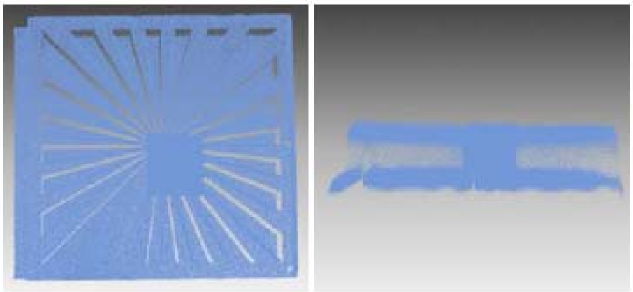

Fig. 3c: MENSI GS 200

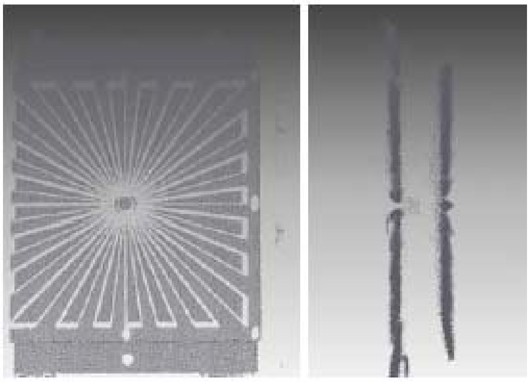

Fig. 3d: IMAGER 5003

## 2.2 Noise Test

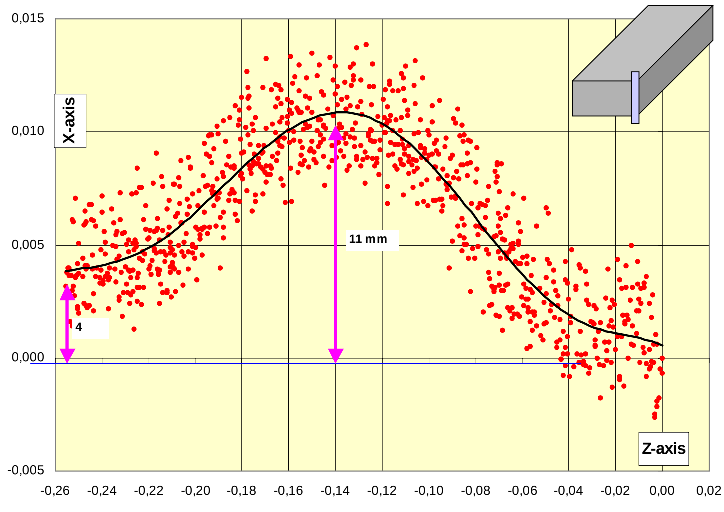


Fig. 4: Noise-Test

“Noise” describes the unavoidable small deviations from the nominal values. For digitizing surfaces it is crucial to have small noise. Fig. 4. shows the curved edge of a piece of hot metal scanned with a CYRA 2500 (Leica). The data allows the calculation of the real contour line (red), but due to the high noise it is not possible to create a smooth surface.

### 2.3 Accuracy-Test

In general the accuracy of a measurement system can be evaluated by applying two different strategies:

- The Component Calibration method: Only one “isolated” component of the entire system, e.g. the distance measurement device of the scanner is regarded. The final result is the accuracy (Precision, Resolution, etc. for the specific component (STAIGER, 2002).
- The System Calibration method: The entire measurement system is considered. The final result are deviations from the nominal values, which are necessary. In a lot of cases objects (planes, spheres, cylinders, etc.) or special targets (Tie-points, Reference points) are used for this type of investigations. As result deviations from nominal values express the “overall performance” of the entire system (Fig. 1). It is impossible to derivate the influence of single components.

## 3. SYSTEM CALIBRATION TEST

### 3.1 Description of the Test

In order to determine the overall performance of a typical As-Built-Documentation, we scanned with an IMAGER 5003 (Zoller & Fröhlich) an area of 1200m$^2$ (Fig.5) in a building from 10 different positions. The 10 different point clouds (Fig. 6) were tied together with the standard chess-board-targets suggested by the manufacturer.

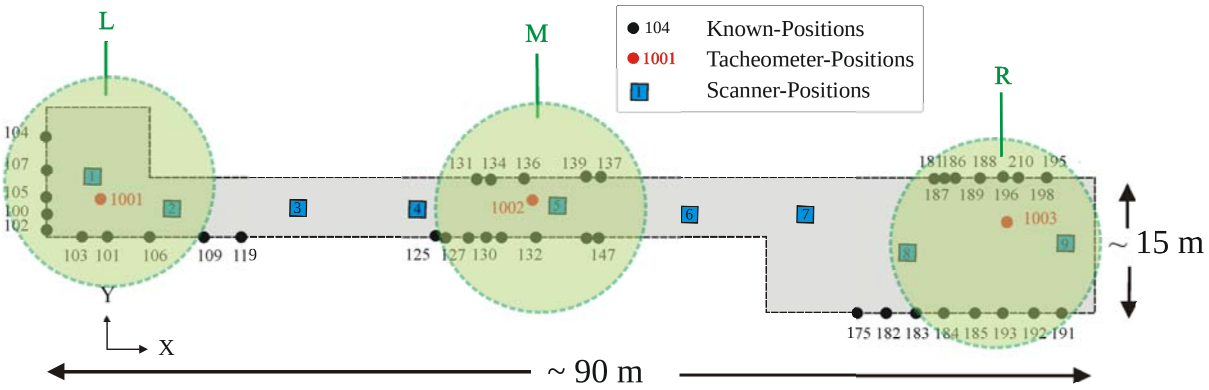


Fig. 5: Overall-Performance-Test

The exact position of the majority of the Tie-Points were additionally determined in the regions L,M and R using a precise total station. The registration itself was realized with the software from Z+F (LRC-Viewer) from “scan- to-scan” with at least 4 Tie-points for each connection. Additionally a subset of known tacheometric points was introduced as additional observations.

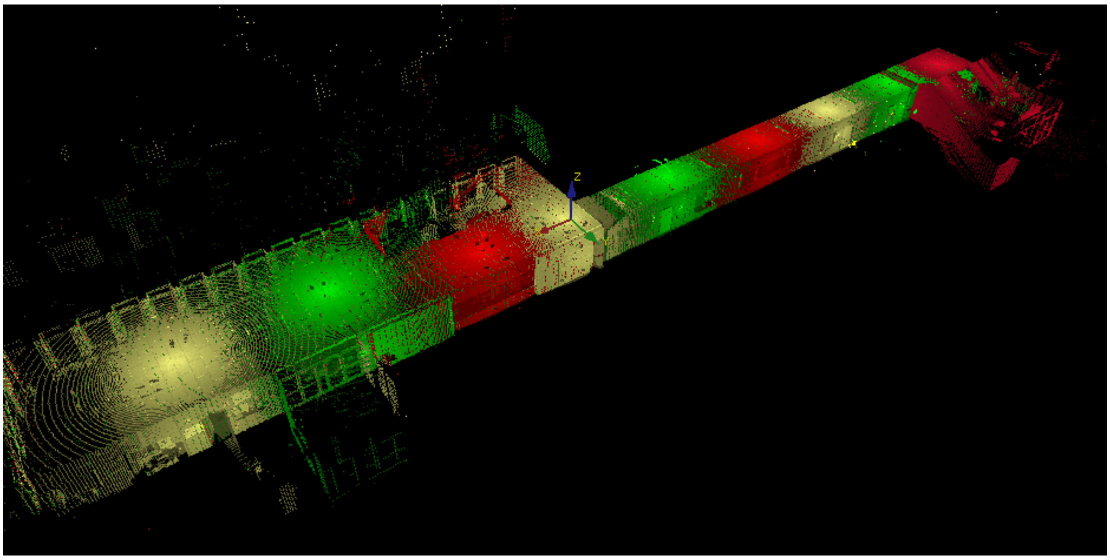

Fig 6a: Image of the entire point cloud

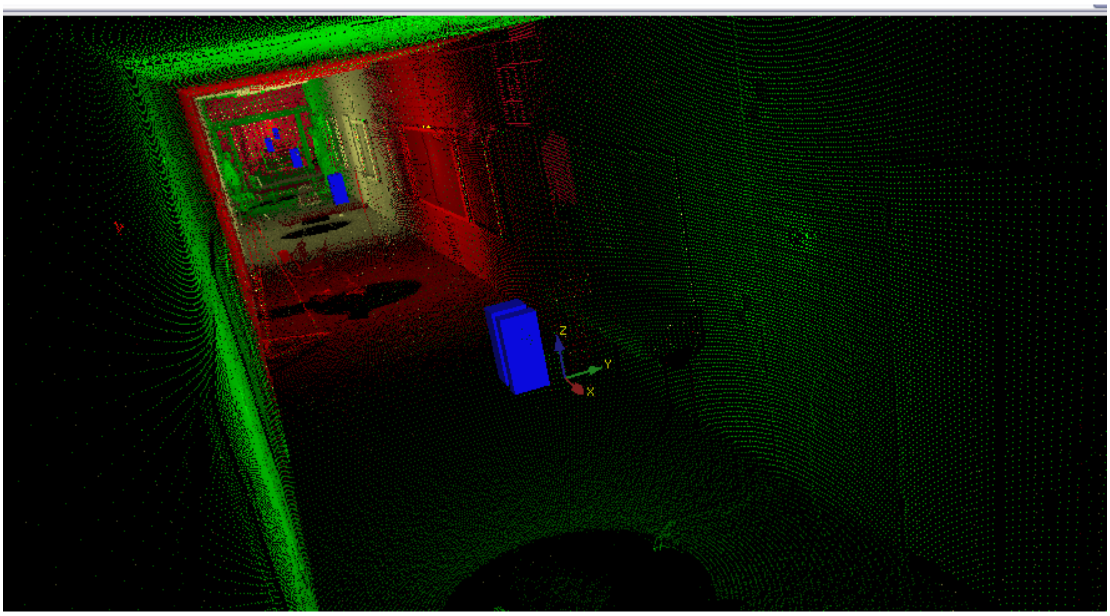

Fig 6b: Image of one section (in blue the scanner positions)

For the analysis the known tacheometric points, which have not served as reference for the registration process are now compared with the coordinates from the point cloud.

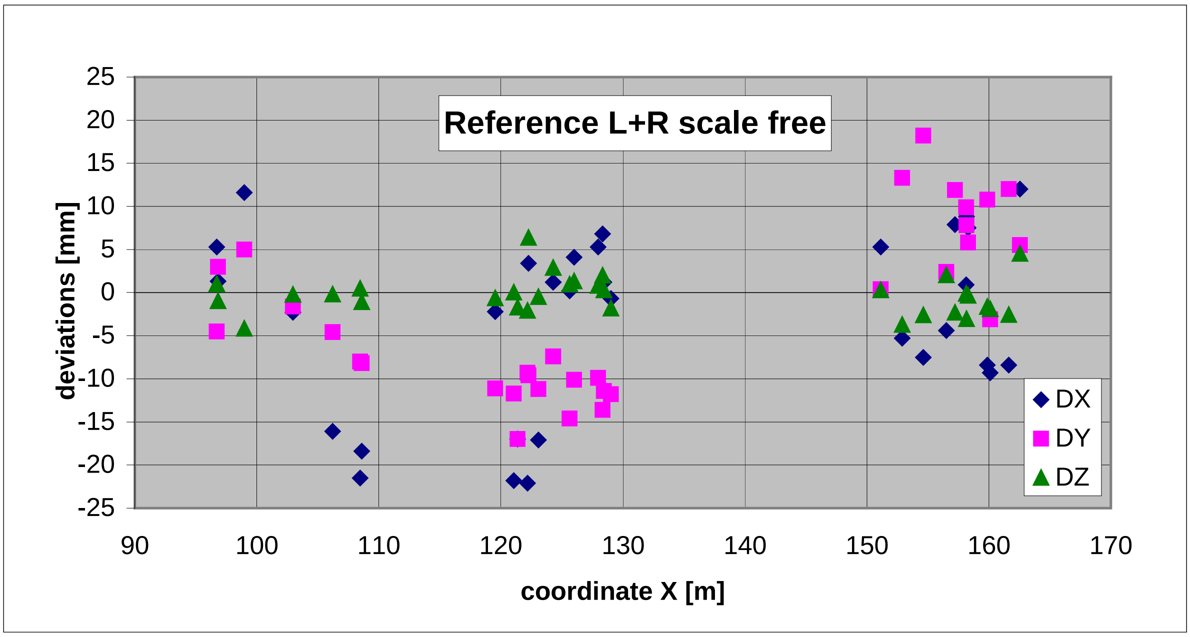


Fig 7a: Deviations of the coordinates. Tacheometric points from the regions L and R are added. The scale of the point cloud is free.

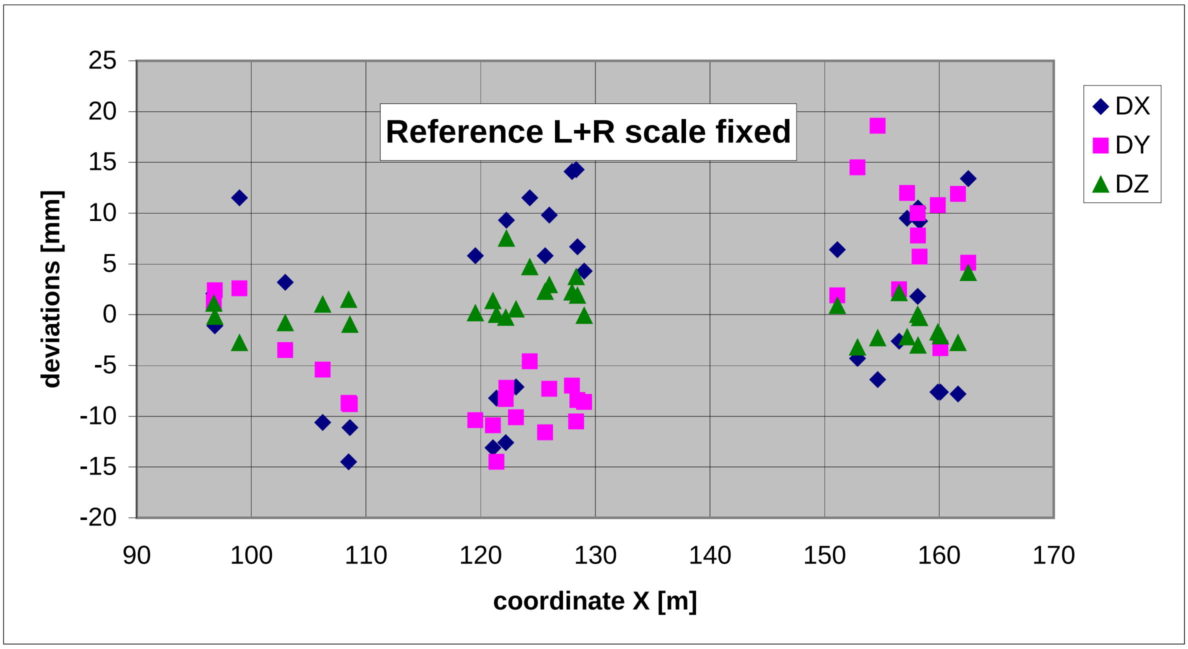


Fig 7b: Deviations of the coordinates. Tacheometric points from the regions L and R are added. The scale of the point cloud is fixed ( m = 1.0000).

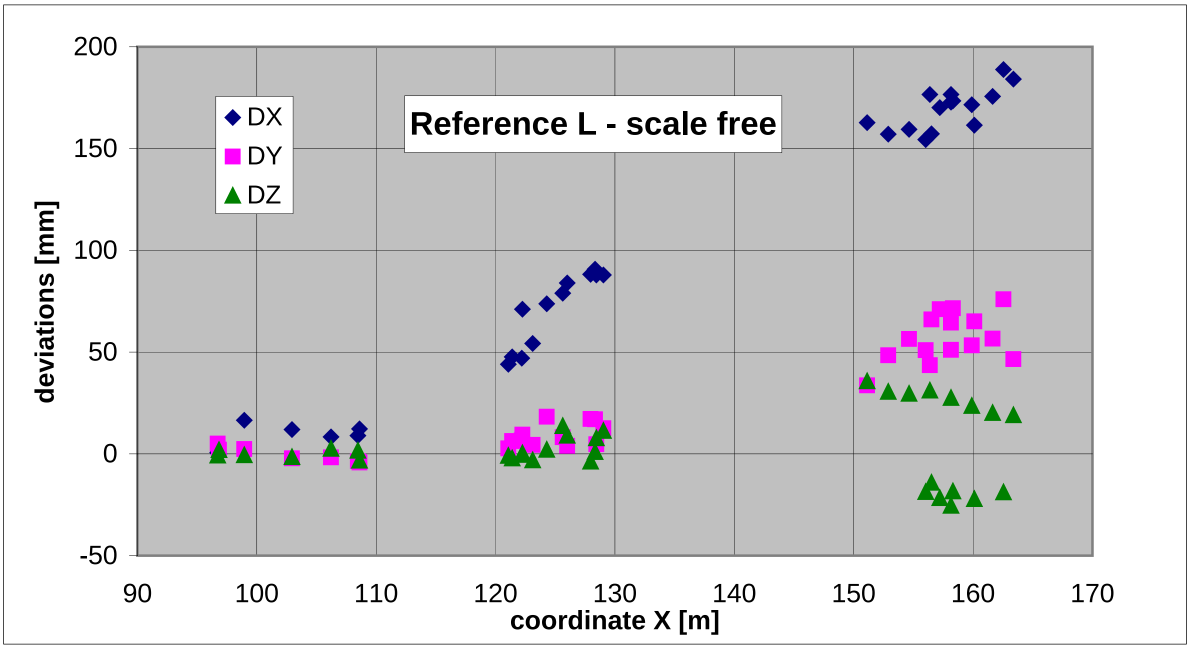


Fig 7c: Deviations of the coordinates. Tacheometric points from the region L are added..
The scale of the point cloud is free.

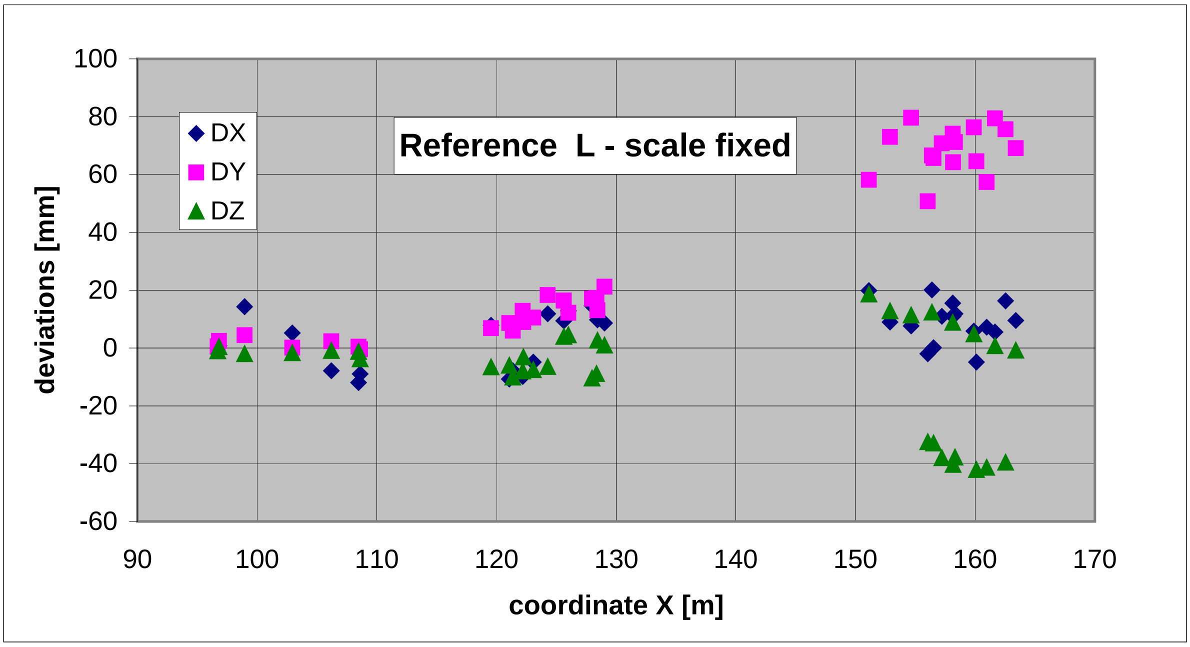


Fig 7d: Deviations of the coordinates. Tacheometric points from the region L are added. .
The scale of the point cloud is fixed ( m = 1.0000).

### 3.2 Analysis of the Results

The calculation has been done in many different ways. In Fig. 7a –d some interesting cases are shown. In the most advantageous cases we strengthen the chained point clouds by introducing known coordinates at the beginning (L) and at the end (R). Having additionally points in the middle (M) does not improve the accuracy. For these cases the handling of the scale (fixed or not) is without influence (Fig. 7a,b). We achieve point accuracy in each coordinate of about 1-2 cm.

If there are only reference coordinates available at one side (L or R) or only in the middle, the accuracy is significantly reduced (Fig. 7c,d). The maximal deviations can achieve 10 cm. Here the handling of the scale is very important. If the scale of the point cloud is treated as additional unknown during the registration process the accuracy can be reduced again (compare 7c and d).

## 4. CONCLUSIONS

- In order to assure that we obtain geometrical "true" information from the point clouds, we have to check and proof the entire measurement system.
- The specifications, given by the manufacturers, are in the majority not useful, because they are not standardized and the indicators are often not reproducible.
- A method for a "System check" is explained and realized. In this realistic approach we achieve a point accuracy of 1-2 cm. The major role of external reference coordinates can easily be deduced: If there are only reference coordinates available at one side of the point cloud, then the accuracy is tremendously reduced, especially when the scale of the point cloud is considered as unknown during the registration process.

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