PERFORMANCES AND EXPERIENCES IN TERRESTRIAL LASERSCANNING

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ABSTRACT

In this paper, the results of the investigations and lab tests at the ETHZ with the Cyrax, Callidus and Zoller+Fröhlich scanners, their various functionalities and specific parameters are presented and compared.
In particular, the Zoller+Fröhlich Scanner is examined. The main focus lies on the investigation of the "technical" parameters representing the mechanical-optical stability such the geometry of the axes, eccentricity, and addition constant. On the 52 m interferometric test line, lab tests were carried out and thus enabled a comparison of the resolution and accuracy, both in static and in kinematic mode with continuously changing distance. Other experiments will demonstrate the performance of the different scanners in different applications as the interior geometry capture of the Monastery Einsiedeln, Switzerland with respect to high-precision applications in engineering geodesy.

1. INTRODUCTION

The diverse scanners, which are offered by the several manufacturers, can be categorized according to their technical performances such as accuracy, distance range, angle of view, scanning speed etc. Basic features of terrestrial scanners are the distance measurement technologies, the beam deflection techniques which have a strong relation to maximum scanning angle and the resolution of the encoders.
The distance measurement technologies follow, in principle, the known EDM technologies as time of flight detection, phase measurements and high-frequency modulation of the carrier (Leica Laser radar). Until now the phase-measurement technology, as used in geodetic instruments, was stated to be slow but accurate. The time of flight measurements are regarded to be fast but restricted to a cm-accuracy level. During the last years, the distance technology showed a progress in phase measurement technologies by multi-modulation techniques. The Zoller+Fröhlich scanner uses a bi-modulation technology including a simultaneous coarse frequency to determine the ambiguities in a range of 53.5 meters and the fine frequency for the accurate measurements (Fröhlich, 1996). The main techniques of the laser beam deflection are mirror-rotation systems and sweeping mirrors.
Additionally, all scanners determine the reflected intensity of light where the resolution depends on the depth of A/D conversion.

2. PHYSICAL LIMITATIONS IN LASERSCANNING

In all reflectorless laser technologies - including laser scanners - the performance is affected and limited by the physical laws of reflection, optical properties of materials and including refraction and inner reflection effects. The surface reflection of monochromatic light normally shows reflected beams in many directions. This type of isotropic reflection can be described by Lambert's cosine law.

$$I_{reflected}(\lambda) = I_i(\lambda)\ kd(\lambda)\ \mathrm{Cos}(\theta)$$

$I_i(\lambda)$ I= the incident light intensity as a function of wavelength (colour)
$kd(\lambda)$ = diffuse reflection coefficient which is also a function of wavelength
θ = angle between the incident light and the normal vector to the surface.

Directed reflections occur when the roughness of the surface is small in comparison with the wavelength of the reflected radiation. Additional speckle effects affect the image of intensity which is used in laser scanner postprocessing software packages.

As known from experiments with reflectorless tacheometers, the properties of the surface, as reflectance of the surface, affects the distance determination also. The reflectance, defined as the relation of the reflected radiation power to the incident radiation power, gives the signal-to-noise ratio and influences systematically the distance measurement. In addition, several materials are penetrated by the laser beam and the ray is also refracted and reflected in the material itself. This causes an addition constant in distance measurements, which has to be regarded in the computation. Experiments at the ETHZ and other geodetic institutions (Godin et al., 2001; Schwarz, 2001; Ingensand, 1999) have shown a dependence on these superimposing effects which generate a material-related variance of distance of about 1cm.

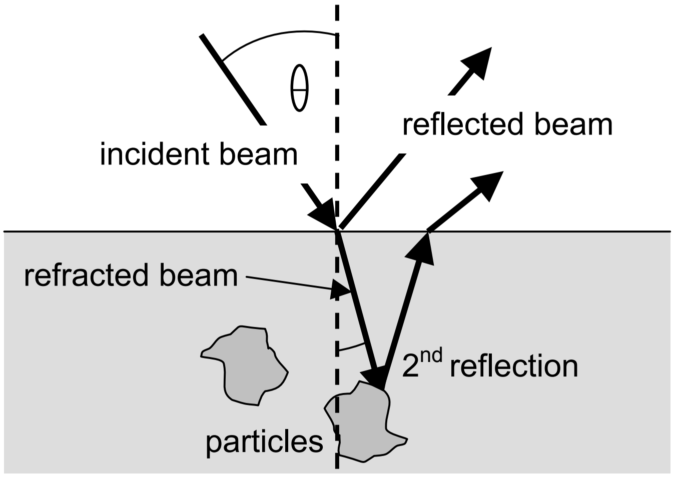


Figure 1: Reflections and refractional effects in inhomogeneous semitransparent materials (Styropor, wood, marble)

From these effects we can state that the physical threshold in accuracy in laserscanning is in the range of a few millimetres.

3. CYRAX 2500 DISTANCE MEASUREMENTS AND PRACTICAL TESTS

In winter 2001/02 a Cyrax 2500 Laserscanner was tested in the laboratory of the Chair of Geodetic Metrology (geomETH). Using the setup of the 52 m calibration track, distances to specific Cyra-targets were measured in a range of 5 to 50 m and compared with the values of a HP-Interferometer.

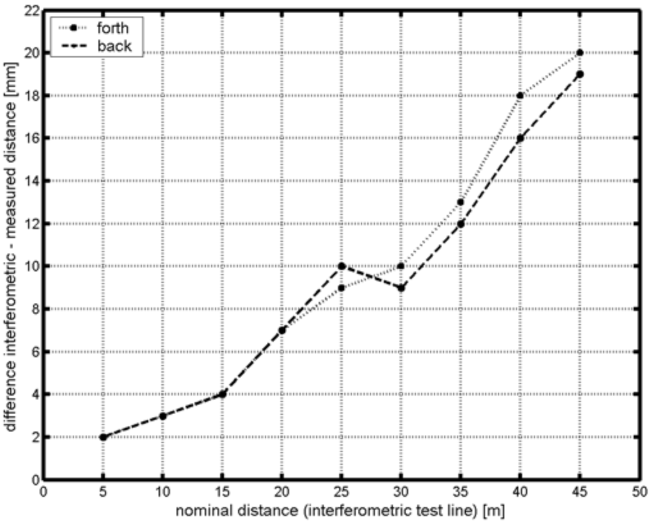


Figure 2: Comparison of CYRAX 2500 with HP-Interferometer distances

The repeat accuracy between the forth and the back measurement was 1 mm. The detected scale factor of about 400 ppm exceeds the indicated instrument specifications (6 mm single point accuracy) for distances above 20 m.

To verify the practical capabilities of the Cyrax 2500, the new chemistry building of the ETH campus was scanned from different views. Several Cyra-targets were used for the combination (registration) of the scans and the geo-referencing of the object with the Cyclone-software.

The versatile features and the high user-friendliness of the software made it easy to produce high quality views of the building.

4. EXPERIENCES WITH THE CALLIDUS LASERSCANNER

Thanks to the generous support of the allnav gmbh in Zürich tests with the Callidus Laserscanner could be carried out in the laboratories of geomETH. Moreover, two students had the opportunity of scanning the front side and the inside of the impressing church of the famous Benedictine Abbey of Einsiedeln.

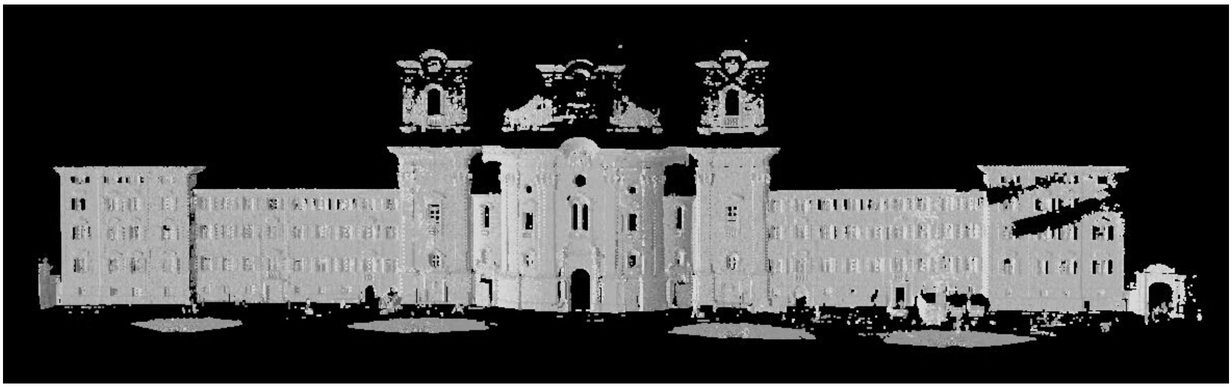


Figure 3: Facade of the Benedictine Abbey of Einsiedeln, scanned with Callidus

The combination of different Callidus-scans in the 3D-Extractor-Software is simplified thanks to the close affinity of the scanner to a total station. The position of the scanner can be determined putting a prism on the respective adapter on the top of the scanner. Thanks to the biaxial compensator the point-clouds are referenced to the horizon. A rough orientation of the cloud is done by the integrated compass, the precise orientation can be realized with an automatically detected prism on a known point. Distances of 10 to 20m between scanner and prism resulted as ideal values for the orientation. However, more than one detected prism in a scan does not agree with the software and makes the orientation impossible. Hence, special attention is required to cover objects like mirrors that might be interpreted as prisms. Tests in a reference network resulted in a repeat accuracy of 6 mgon for the orientation parameter, which is 6 mm / 60 m in the transverse direction.

5. INVESTIGATIONS OF THE ZOLLER+FRÖHLICH LASERSCANNER IMAGER 5003

5.1 Introduction

In the following chapter the laserscanner IMAGER 5003 of Zoller+Fröhlich is investigated. The main focus lies on the determination of systematic deviations like eccentricity of the collimation axis and the trunnion axis error. Furthermore, the accuracy of the distance measurement system is examined.

5.2 Instrumental errors

5.2.1 Eccentricity

An eccentricity of the collimation axis is present, if the horizontal axis does not lie in the vertical axis. Due to this error the centre of the geodetic instrument does not fall in the centre of the observing pillar. The result is a offset of all measurements with respect to the coordinates of the observing pillar and its reference frame.

The investigation includes two methods: The first method derives the eccentricity from the base cylinder of the scanner. For that purpose the centre of the base cylinder is determined trigonometrically. In the second method a target in the top of the scanner is observed. The positions of the target are chosen in a way that the distance between two opposite positions can be interpreted as diameter. The average value of these two points has to correspond with the coordinates of the observing pillar.

The results of these investigations are the following: The two experiments revealed an eccentricity of the vertical axis of 0.3 mm with a standard deviation of 0.1 mm. Both determinations provided comparable results.

5.2.2 Trunnion axis error

This instrumental error is caused by mechanical characteristics such as a defective guide away of the axis, a fetch, a defective mould of the contact surface (Deumlich et al., 2002; Matthias, 1961). The trunnion axis error results from the mechanical properties of the instrument. Especially, it is affected by the rotation around the vertical axis. The reasons for the trunnion axis error are manifold. The greatest influence is caused by the bearing of the vertical axis. Various bearings generate various effects.

The examination of the trunnion axis error is carried out by an inclinometer. In the present case, the Nivel 20 of Leica Geosystems is used. This inclinometer provides the inclination in two orthogonal axes. The Nivel 20 was placed with a specific base in the top of the scanner. The inclination of the plane, where the inclinometer is placed, is not of interest. The only requirement is that the sensor is in working range over the full rotation of the scanner (360°). After measuring several full rotations around the vertical axis (0° to 1440°) with several angle increments (5° to 30°), the trunnion axis error can be derived.

At first, a new observation is generated. For each direction, two inclinometer measurements exist. These measurements can be interpreted as two components of a vector, which stands rectangular to the inclinometer plane. The norm of this vector can be calculated and represents the inclination of the vertical axis. If a trunnion axis error is present, the norm of this vector should be constant in each direction. Otherwise, a sine oscillation results. Looking at the amplitude spectrum, the frequency associated with the maximum amplitude represents the most probable frequency of the trunnion axis error.

After measuring several data series, the predominant frequencies varied between a period length of 180 ° and 360 °. The amplitudes of these frequencies are in the range of 0.13 mm/m to 0.21 mm/m. Further, the phase angles of the sine oscillation are different. The used tribrach has three bolts in an interval of 120 ° and could be the reason for the different phase angles. Therefore, new data series were measured, whereby the scanner was rotated in the used tribrach around an angle of 60 °. Two positions of the scanner are exactly at a bolt and the third one is in the middle of two bolts. The assumption is that the phase angle between the data series is 60 °. The results of these three data series are shown in figure 4 and table 1.

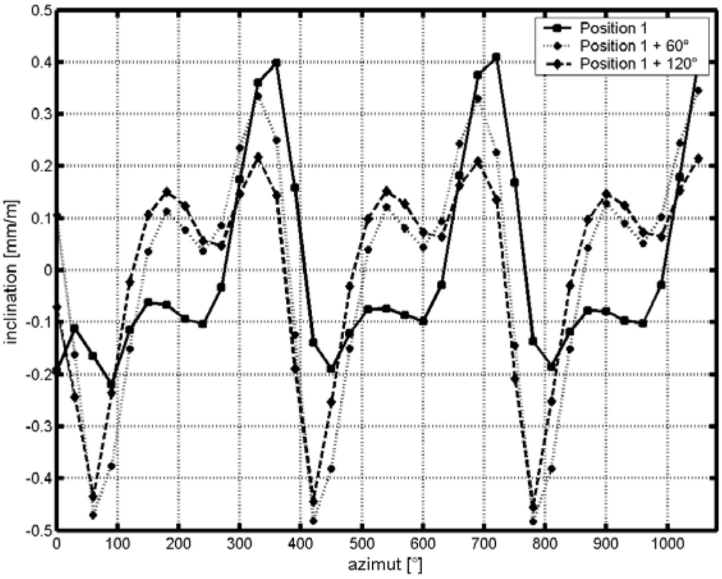


Figure 4: Data series with shifted rotation angles

The three data series with shifted rotation angles of 60 ° allow the following conclusions: The phase angle does not correspond with the carried out rotation. Further, the amplitudes are not constant. In contrast, the lower one increases and the higher one decreases with the rotation angle.
Moreover, the data contain two significant frequencies. This can be attributed to residual levelling effects. The influence of the frequency with a period of 360 ° is predominant. Table 1 lists the parameters of both mentioned frequencies.

A quiet good coincidence between the amplitudes can be found. Further on, the eliminated vertical axis error is identical to each data series. However, no correlations between the phase angels can be seen.

Data series	**Frequency 1**			**Frequency 2**			**Vertical axis error** [mm/m]
	Amplitude [mm/m]	Frequency [1/360°]	Phase angle [°]	Amplitude [mm/m]	Frequency [1/360°]	Phase angle [°]	
Position 1	0.21	1	119	0.15	2	126	1.24
Position 1 +60°	0.26	1	177	0.21	2	131	1.27
Position 1 +120°	0.20	1	199	0.17	2	139	1.26

Table 1: Parameters of the harmonic oscillation

These comprehensive investigations for describing the trunnion axis with a mathematical function failed. For a precise modelling of the harmonic oscillation, the amplitude, the frequency and the phase angle are needed. From the measured data series no conclusions are drawn with respect to these parameters. The data series are not reproducible concerning the phase angle. Reasons for these affects can also be caused by the eccentricity of the balance point. The weight of the laserscanner can affects deformations on the tribrach.

5.3 Distance resolution and accuracy

The distance measuring system applies the phase measurement principle. By means of a coarse frequency an initial distance is determined. Then, a fine frequency measurement resolves the initial distance within a few millimetres.

The following questions are of interest and should to be answered:

- the resolution of the distance measurement
- the accuracy of the distance measurement

The interferometric calibration line at the Institute of Geodesy and Photogrammetry at the Swiss Federal Institute of Technology enables to test both, the resolution and the accuracy of the distance measurement. The laser interferometer yields distances in the micrometer range. The length of the calibration line of 52 m admits calibration measurements within almost the whole measurement range of the scanner.

5.3.1 Resolution of the distance measurement

In order to the resolution of the distance measurement, a small area of the calibration line is chosen. The distance between calibration points has to be smaller than the resolution of the distance measurement.

In this case, the resolution of the scanner is specified as one millimetre. Thus, a 0.01 mm interval was chosen for the setting up the calibration points. A comparison between the nominal and the measured distances will provide a staircase plot, if the resolution of the distance meter is higher than the resolution of the chosen calibration point interval. Otherwise a regression line can be derived (Joeckel et al., 1999). Figure 5 shows the respective results.

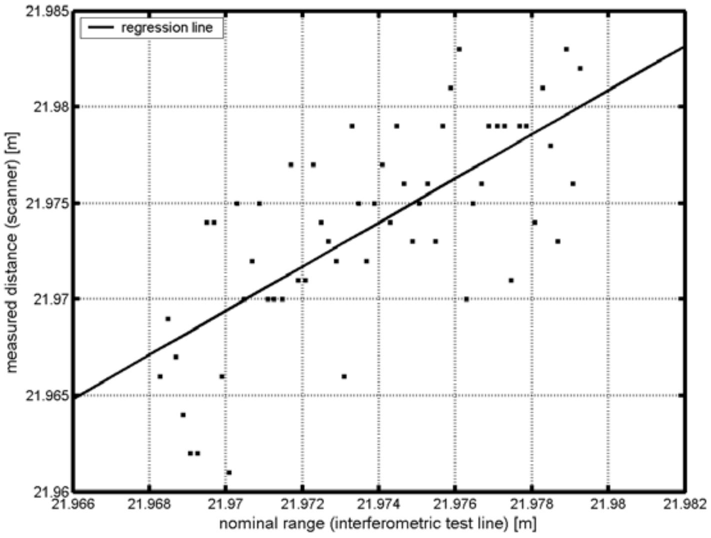
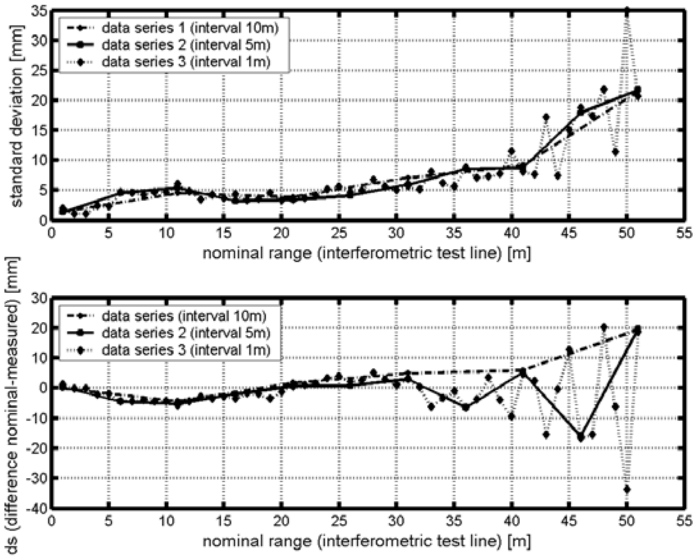


Figure 5: Resolution of the distance measurement system to a white target

A rough idea about the distance accuracy gives the standard deviation of an adjusted measured distance. A standard deviation of 4 mm was found. However, this distance accuracy is given for ideal conditions. The measurements are made on a white target at a distance of 21.97 m.

5.3.2 Accuracy of the distance measurement.

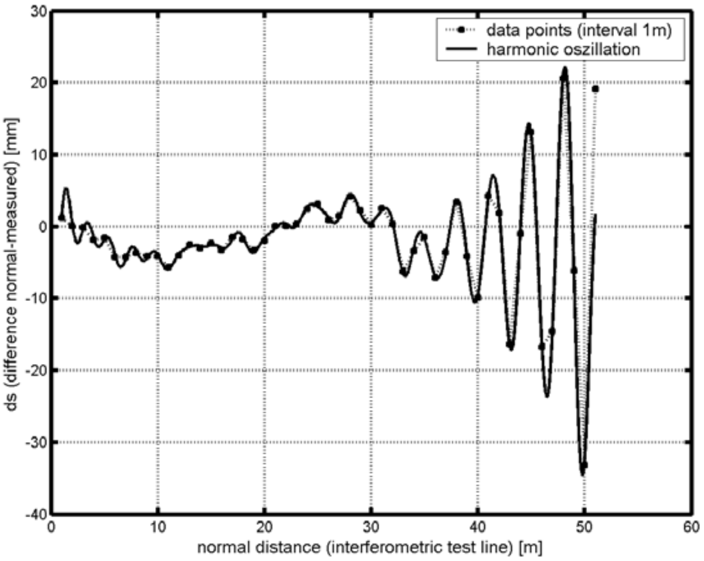
In order to derive the accuracy of the distance measurement, the measured distances are compared with the interferometer distances. The results of the first experiments, with a measurement frequency of 125.000 Hz , are shown in figure 6.



The inhomogeneous accuracy for the distances larger than 28 m shows a periodic curve. The inherent frequency of the obtained standard deviations approximately corresponds to the fine frequency of the distance meter (wave length λ=6.6946 m). The amplitude of this periodic behaviour proportionally increases with the distance. It is possible, that the existence of two targets (the "real" target and a target on the mirror, e.g. dust) causes these effects. But also a correlation between the accuracy and the two different measurement modes is conceivable.

Figure 6: Accuracy of the distance measurement system to a white target

Based on this relation, a calibration curve was derived using harmonics.



Applying the calibration curve to the measured data, subcentimetric accuracies can be reached within the full measurement range apart from the first five metres.

Figure 7: Calibration curve using harmonics for the distance measurement system

6. OUTLOOK

The investigations of the Laserscanner IMAGER 5003 of Zoller+Fröhlich enable the specification of the distance measurement accuracy. Some interesting aspects are derived like a correlation of the distance accuracy with the fine frequency. The eccentricity was investigated and also the trunnion axis error.

Further investigations will regard the distance accuracy in respect to different materials and different incident light ray. Further, the tests will be extended to the kinematic modus. In addition to the distance resolution accuracy, the angle resolution accuracy will be investigated.

The investigations of the high precision scanner of Zoller+Fröhlich have demonstrated the capability of the scanning technique for applications in engineering geodesy applications. This will encourage us to use this technology for kinematic applications with free stationing by the scanner itself.

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