Influence of the Incidence Angle on the Reflectorless Distance Measurement in Close Range

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Abstract

The reflectorless distance measurement is supported by many geodetic instruments. In this measuring mode the laser beam is directly reflected from the measured surface. Thus, new influences due to the measured surface have to be taken into account when specifying the quality of the measurement. One important influence factor is the incidence angle of the laser beam on the surface. As a matter of principle it can influence the type and magnitude of the measurement noise and/or systematically corrupt the distance. Therefore, it is necessary to deal with, in order to describe the quality of the measurements and propagate it to estimated measures.

In this paper the influence of the incidence angle of the laser beam is experimentally investigated. The focus is set on the error charactersitic of this factor in close range from 3.5 to 5.2 m. Distinct from previous investigations we analyse the measured distances. This novel approach is enabled by the merge of scanning and total station into a single instrument. Single points were scanned under different incidence angles, staked out and measured by theodolite measurement system (TMS). By the comparison of the scanned distances with the TMS reference measurements a systematic variation from -4.0 to 2.1 mm with respect to the incidence angle could be detected. Is is caused by the influence of the incidence angle and by another systematic effects in close range.

Key words: Reflectorless measurement, incidence angle

1 INTRODUCTION

The incidence angle of the laser beam belongs to often mentioned error influences on the reflectorless distance measurement (Joeckel et al., 2008). It occurs in measurements by hand-held distance meters, total stations and terrestrial laser scanners (TLS). Despite the numerous studies on this source of error a generally accepted model is not available yet.

A systematic effect of the incidence angle on distance measurement was determined for hand-held distance meters by (Kern, 2003) and for total stations by (Runne, 1993, Kuhlmann, 2002, Schäfer, 2011). (Runne, 1993) models the influence as a cotangent function. The influence on 1D terrestrial laser scanner measurements is of stochastic nature (Schulz, 2007). Schäfer (2011, 2014) simulate the influence based on physical principles.

The investigation of single distance measurements during a 3D-scanning is a difficult task due to the fact that the scanned points cannot be reproduced in repeated measurements and are not signalisable on the surface. Therefore, direct distance measurements were not investigated; instead 3D-point accuracy was derived from surfaces. Experimental results obtained by Lindstaedt et al. (2009) shows that the 3D-point accuracy increases with the incidence angle in phase based TLS and is scannerdependent. The 3D-point accuracy is estimated in Gordon (2008) and the dependency is characterised by cotangent and sine function.

This paper aims the experimental investigation of the influence of the incidence angle on distance measurements in the 3D-scanning mode. It focuses on the question whether the effect is of stochastic or systematic nature. The study is restricted to close range (from 3.5 to 5.2 m), which is relevant for indoor and industrial applications. Distinct from previous investigations this study is based on the measured distances to single points instead of 3D-point accuracy. This is possible due to the availability of scanner and tacheometric measurements in a common coordinate system as a consequence of merging a total station and a laser scanner in one instrument. A single point to which the distance in scanning mode is measured can be staked out using the tacheometric features of the instrument and signalised. The distance to this point is determined optically by a TMS. This measuring technique was chosen because the results are not affected by the angle of incidence and are available with higher accuracy compared to the scanner. The differences between the distances obtained from scanning and from TMS is the measure for the influence of the incidence angle.

2 EXPERIMENT

Generally speaking, in the investigation of the influence of the incidence angle two measuring setups can be distinguished – with rotating and fixed object. The one realised in this research uses the fixed object. Different incidence angles are obtained by the rotation of instrument's collimation axis in horizontal and vertical direction. This measurement setup does not require auxiliary constructions.

2.1 MEASUREMENT SETUP

The measurements were performed under laboratory conditions. The realised configuration is shown in Figure 1. The test-object is a board fixed on a vertical wall. It is made of wood, has dark green colour and dimensions of 5 m x 1.5 m x 0.025 m (width x height x depth). The investigated instrument, the Leica MS50, was placed at a distance of ca. 3.5 m from the board. It has an angle accuracy of 0.3 mgon and a distance accuracy of 2 mm + 2 ppm in the reflectorless modus.

The slope distance D_{scan} between the zero point of MS50 and the scanned point is our investigated measure. To signalise a subset of the scanned points, these were staked-out from the MS50 by means of their coordinates obtained from scanning. Reference distances D_{TMS} from the instrument to the signalised points were determined by TMS, where the MS50 was one of the two used theodolites. The other one was a Leica TCRP1201 with angle accuracy of 0.3 mgon. The 3.5 m-long basis between the theodolites was determined by means of a 0.8 m long reference scale solving the Hansen problem (Witte et al., 2011).

The TMS-configuration was optimised a priori by simulation studies. The lines of sight from the optimised locations of the instruments intersect in an angle of 45-58 gon. The attainable point accuracy expressed as Helmert point error is 0.2 mm. The corresponding distance accuracy of TMS is 0.2 mm and thus, it conforms to the requirements for the reference measurement.

To proof the stability of the instruments five prisms were distributed in the room and repeatedly measured with both total stations. The entire measuring process was controlled via the serial interface GeoCOM from MATLAB.

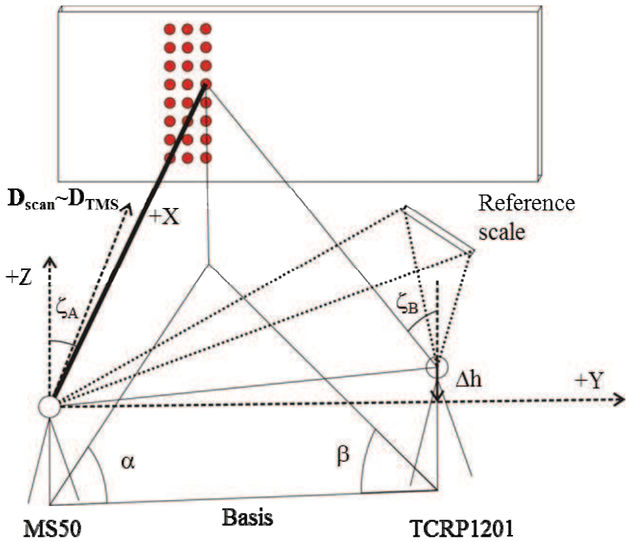

Figure 1 Measurement setup

2.2 MESURING PROCESS

The results of the scanning and TMS-measurements are available in the same coordinate system. Its origin lies in the zero point of MS50, the Y-axis coincides with the basis (MS50 - TCRP1201), the Z-axis is the local plumb line and the X-axis completes a left-handed system.

The mutual orientation of the two theodolites in the TMS was done by collimation in two faces. Afterwards the azimuthal directions $t_{MS50\text{-}TCRP1201}$ = 100 gon, $t_{TCRP1201\text{-}MS50}$ = 300 gon were set at the two instruments. The distance between the theodolites was determined by Hz-angle measurement in two faces to the endpoints of the reference scale (measurement accuracy $\sigma_{Hz,\ MS50}$ = 0.3 mgon and $\sigma_{Hz,\ TCRP1201}$ = 0.7 mgon, empirical standard deviation from 10 measurements). The reference scale was measured with the laser interferometer Agilent 5530 with $\sigma_{ref.\ scale}$ = 0.4 ppm.

The board was scanned in one face, with a resolution of 0.37 gon and a scan velocity of 62 points/s. The point space of 0.020 m at 3.5 m and of 0.030 m at 5.2 m was chosen in accordance to the manufacturer information for the spot size of 8 x 20 mm at the distance of 50 m in order to ensure uncorrelated distance measurements. A section of the point cloud within a vertical angle of ±5 gon (corresponds to a height of ± 0.27 m on the board) was used in the subsequent analysis. The angle of incidence for every point in this section is obtained as angle between the sighting line and the normal vector of the best approximating plane. Afterwards, the point cloud was segmented in eleven zones corresponding to incidence angles of 45 to 100 gon. In each zone seven points were selected to be determined by TMS. The points were identified from a plane adjustment in each zone, as having residuals corresponding to the locations of -3σ_e, -2σ_e, - σ_e, 0, σ_e, 2σ_e, 3σ_e (see Figure 2). Thus, the following analysis accounts for a predominant part of the measurement noise spectrum.

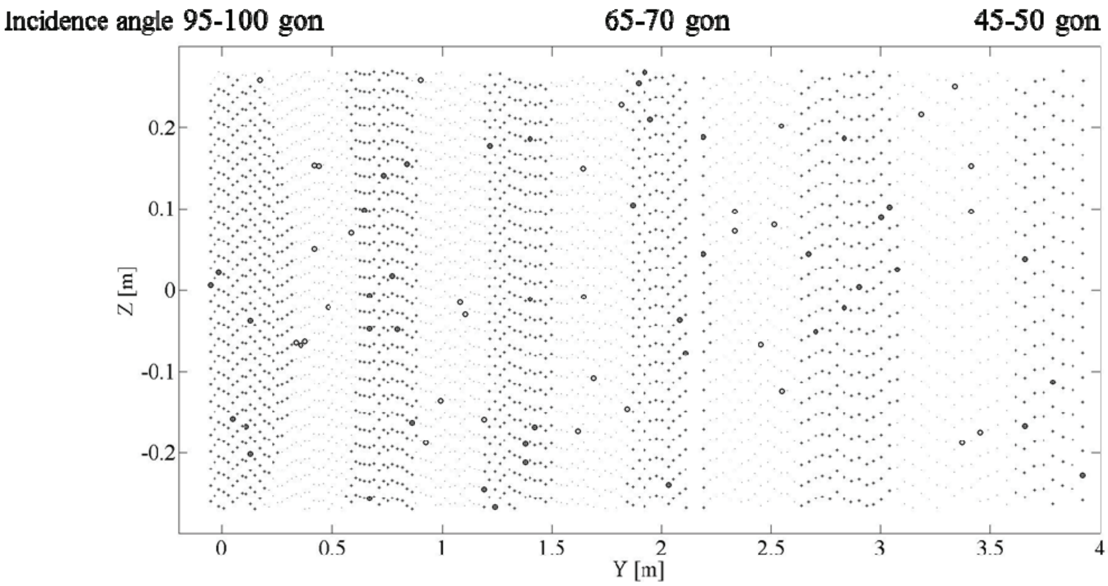

Figure 2 Point cloud of the measured object, segmented zones and points selected to be determined with TMS (circles)

For the TMS measurement every selected point was staked out with the MS50 and signalised on the board. The determination was done in two faces. For reliability reasons, the points in the first zone were measured twice, at beginning and at the end of the TMS process. During the whole campaign the stability of the measuring arrangement was checked at regular time intervals. Thereby, the orientation of the theodolites (max. deviation of 1.5 mgon), the basis (max. deviation of 0.3 mm) and point stability (max. coordinate difference of 0.4 mm) were checked. During the measurements we accounted for the variation of the environmental influence factors temperature, air pressure and humidity.

3 DATA PROCESSING AND RESULTS

The investigated distance was determined by scanning and TMS-measurements. In scanning modus the distance D_{scan} was calculated back from the coordinates. In case of the TMS the distance D_{TMS} was calculated from coordinates determined by spatial intersection. This type is regarded as the reference distance. The a priori accuracy of 0.2 mm was confirmed by the measurements. The maximum deviation between different determinations was 0.4 mm.

The obtained differences between the reference distances D_{TMS} and the corresponding distances resulting in scanning modus D_{scan} are related to the angle of incidence in Figure 3.

The illustrated differences vary systematically with the angle of incidence. The scanned distances are up to 4.0 mm longer than D_{TMS} in two intervals: 100-65 gon and 50-45 gon. In contrast, the distances are up to 4.4 mm shorter within the interval 65-50 gon. A good agreement is obtained at 100, 65 and 50 gon respectively. We assume that the systematic component of the difference results due to an overlap of the influence of the incidence angle and of other effects in close range.

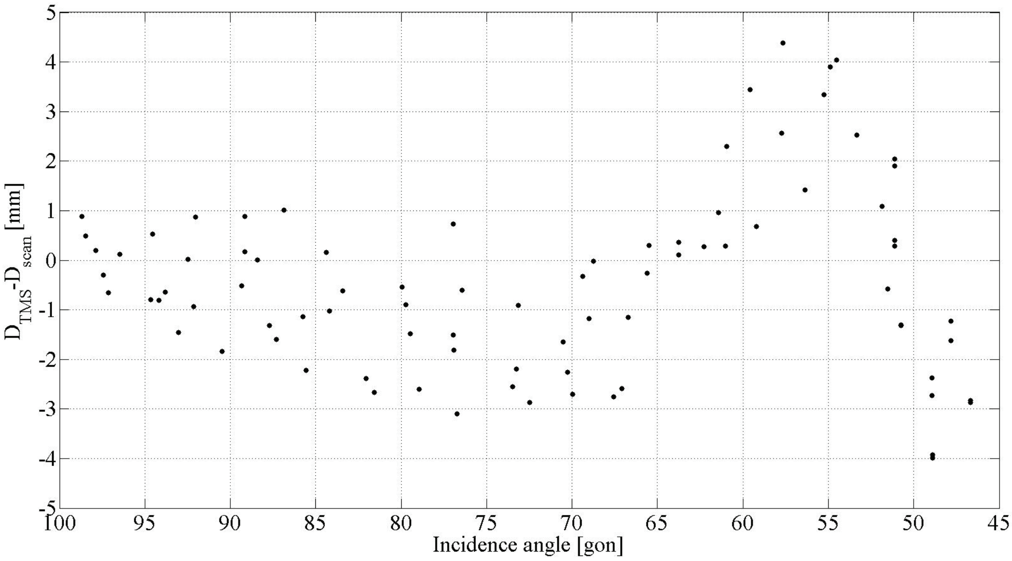

Figure 3 Differences between D_{TMS} and D_{scan} as function of the angle of incidence

Motivated by this assumption we analysed various possible influences on the reference distance determination. The analysed factors and their quantified impact on the determined distance are summarized in Table 1.

Table 1 Influence factors from the reference measurement

Influence	**Quantity/Action**	**Impact**
axes errors of theodolite	2 faces of telescope	eliminated
skewness of the trunnion axis	vertical angles from 95 to 105 gon	minimal
height difference of reference scale	0.5 mm	no influence
collimation	max. 1.5 mgon	max. 0.3 mm
intersection angle	45-58 gon additional measurements with a longer basis	max. 0.6 mm

As can be seen from Table 1 possible influences from the TMS measurement on the systematic variation of the distance differences can be excluded. Furthermore, the influence of the object stability, the pressure on the board during the staking out and the dilatation due to the variation of the temperature are neglected.

In a last step we investigated, whether the influence of the angle of incidence on the measured distances has a stochastic component additionally to the systematic one. Therefore, the systematic component was extracted by a polynomial model from the differences shown in Figure 3. A standard deviation was calculated from the resulting residuals for each zone. The obtained results are shown in Table 2.

Table 2 Standard deviation of distance differences

Incidence angle [gon]	**45-50**	**50-55**	**55-60**	**60-65**	**65-70**	**70-75**
Standard deviation [mm]	1.9	1.4	1.4	0.6	1.1	0.8
Incidence angle [gon]	**75-80**	**80-85**	**85-90**	**90-95**	**95-100**	
Standard deviation [mm]	1.2	0.9	1.0	0.9	0.5	

4 CONCLUSION

The results of this investigation show that scanned distances in close range are systematic distorted with max. 4.0 mm. Implications of the reference measurement for the results were analysed and excluded. It is assumed that the systematic effect is caused by the influence of the incidence angle and other systematic effects in close range. The results of the investigation were confirmed 1.5 months later with another instrument of the same type. A possible effect can be the systematic corruption of absolute distance in scanning mode in close range. Thus, in near future this influence will be experimentally investigated. Additionally to the systematic effect, also a stochastic influence of the angle of incidence on the distance measurement could be detected and needs to be considered in further processing of TLS data.

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