EFFECTS ON THE MEASUREMENTS OF THE TERRESTRIAL LASER SCANNER HDS 6000 (LEICA) CAUSED BY DIFFERENT OBJECT MATERIALS

T. Voegtle, S. Wakaluk

Institute of Photogrammetry and Remote Sensing (IPF), Universitaet Karlsruhe (TH), Germany -
thomas.voegtle@ipf.uni-karlsruhe.de

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ABSTRACT:

One of the main aspects of terrestrial laser scanning (TLS) is data quality. In the literature a lot of publications concerning this topic can be found. Several authors included also different materials into their investigations to analyse the influence on the measurements of a terrestrial laser scanner. In this paper the results of systematic test series with planar plates of different materials will be discussed. Besides targets of defined reflectivity, the choice of materials has been concentrated on those common for building facades. For quality assessment the following parameters have been selected: range correction value, standard deviation of range measurements, mean intensity value and its standard deviation. These parameters have been calculated systematically for different distances (5m to 25m), incidence angles (0^{gon} to 90^{gon}), reflectivity (5% to 98%) and ambient lighting and wetness conditions. The results show that the range correction value is not constant but increases with longer distances (non linear) and lower reflectivity of the surface material. The standard deviation of range measurements also increases with longer distances (about a factor of two at 25m) and reduced reflectivity (about a factor of four at 5%) but decreases with wider incidence angles, which confirms the results of other research groups. The intensity values are quite constant for different distances but decrease with wider incidence angles. Standard deviation of intensity increases with higher reflectivity. Problems occurred with concrete (extreme variation of parameter values) and metal plates (saturation effects).

1. INTRODUCTION

Nowadays, terrestrial laser scanning (TLS) is one of the most important standard methods for 3D data acquisition. It is used in numerous application fields, e.g. for building reconstruction in architecture, archeology or cultural heritage, forestry or industrial applications to name only a few.

One of the main aspects of 3D object capturing and modelling based on TLS is data quality to assess the suitability for specific applications. The resulting quality depends not only on the measurement devices of the laser scanner itself but also on the reflectance characteristics of different object materials. Due to the fact that increasingly laser intensities will be used for classification and matching purposes (e.g. Pfeifer et al. 2007), radiometric aspects should be also investigated together with geometric parameters like range offset or point accuracy.

This contribution is a continuation of previous research based on a pulsed scanner (time of flight measurement) (Voegtle et al. 2008). Now a phase shift scanner (Leica HDS 6000) is applied to an extended selection of materials and test configurations. Therefore, some comparisons can be drawn between the main characteristics of these different types of measurement principles. A lot of systematic test series had been carried out, however, only some main results can be presented here.

In the next chapter the work of some other research groups concerning data quality is discussed. The main specifications of the laser scanner applied in these test series (Leica HDS 6000) are sampled in chapter 3. Subsequently the chosen quality parameters and test configurations as well as the selected materials are presented in chapter 4 and 5 respectively. The main results of our investigations with grey scaled and coloured material, with building materials and metal plates are described in chapter 6 to 9. Finally the main results are outlined and discussed as well as further investigations are proposed.

2. RELATED WORK

In the literature several publications can be found concerning general accuracy tests of TLS. A detailed explanation of the different principles and error sources of range measurements are given by Thiel and Wehr (2004), e.g. detection errors of backscattered pulses dependent on the signal level, background illumination or the effects of different heights inside a laser spot. This knowledge helps to understand some specific laser scanning effects. Pesci and Teza (2008) also investigate the backscattering and receiving process of laser signals, especially for retro-reflective targets which are often used for registration and georeferencing of point clouds due to their easy recognizability. The authors have detected anomalous effects on the TLS measurements and other phenomena like a halo: the errors of range measurements are dependent on the distance, to short for near distances (e.g. 10m and 60m) but too long for larger distances (e.g.160m) but these offsets were the same for all high-reflectance points at the same range. The extreme reflections lead to a saturation of the signal into the internal sensor and therefore to a specific deformation of the laser pulse, but the transferability of these results to phase shift scanners has to be further investigated. Boehler et al. (2003) describe a comparison of different TLS by means of a special test site. Besides geometric accuracy tests based on targets of different reflectivity the characteristic of scanned edges was investigated ("Boehler star"). It can be proven that dark surfaces introduce
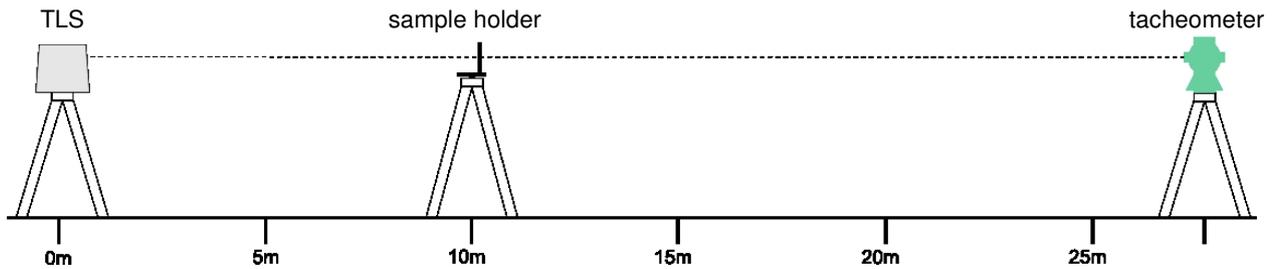
Figure 1. Test configuration TLS, sample holder and tacheometer (reference measurements)

decreasing range accuracy. Kersten et al. (2008) created also a test field for different laser scanner types. Amongst others the influence of the distance and incidence angle was investigated. The results corresponded to the manufacturers instructions. Lichti and Harvey (2002) analysed the effects of different natural and arificial materials on range accuracy of a Cyrax 2500. Standard deviations variied between ±5mm and ±9mm but a certain error component was introduced by a weak orientation of the test objects in relation to the scanning direction. Differences between dry and wet conditions were about 3mm.

A couple of authors use test targets with defined reflectivity to determine geometric accuracy parameters as well as radiometric behaviour of TLS. Clark and Robson (2004) applied standard colour tables for a pulse based TLS (Leica HDS 2500). Geometric measurement noise (and point density) decreases with wider incidence angles and depends on the colour of the surfaces. Colours quite different to the colour of the laser produce larger deviations. Kukko et al. (2008) did a comprehensive study on the effects of different incidence angles on the intensity measurements of laser scanners. Besides targets of calibrated reflectance (8% to 70%) also natural and artificial samples like different types of gravel and sand, brick material and clay aggregate have been investigated by means of a goniometer to tilt the samples to defined incidence angles (0º to 70º). A special laboratory laser and a FARO 880 were applied. The results show that incidence angles up to 20º cause nearly no effects on the brightness. Also for natural materials there is no or only a slight decrease up to about 40º probably due to the surface roughness compared to the laser spot size. Using calibrated Spectralon® targets of low reflectance the effect of incidence angle is negligible, but increase significantly with higher reflectance. The results of the laboratory laser are in agreement with those measured with the FARO TLS. The additional investigation of the influence of the wavelength (600-900 nm) demonstrated that the incidence angle effects are consistent between different wavelengths, but shorter wave-lengths lead to a lower levels of intensity.

A very detailed research on the theoretical and real reflection of laser pulses was done by Pfeifer et al. (2007) and Pfeifer et al. (2008). For both pulsed scanners under investigation the behaviour of intensity vs. range deviated strongly from the pure Lidar equation having a minimum resp. a maximum at a range of about 20m. The standard deviation of intensity increases with higher intensities significantly by a factor of about two. Bucksch et al. (2007) use a Z+F IMAGER5003 and a FARO880 for Esser test tables. Dark colours (low reflectivity) caused a significant decrease of range accuracy, best results were not obtained with high but with mean reflectivities.

3. LASER SCANNER HDS 6000 (LEICA)

For the continuation of our investigations a phase shift scanner (Leica HDS 6000) was used. The main technical specifications of this scanner are sampled in Table 1.

Measurement principle	phase shift (cw)	
Wavelength	670 nm	
Accuracy		
Positioning	± 6 mm	(25 m)
Range	± 4 mm (90% alb., 25 m)	
	± 5 mm (18% alb., 25 m)	
Point size (footprint)	8 mm	(25 m)
Scan field	360º	(H)
	310º	(V)

Table 1. Technical specifications of HDS 6000 scanner

4. QUALITY PARAMETERS AND TEST CONFIGURATION

For the investigation of the effects of different object materials and colours on the measurements of a TLS the following quality parameters had been selected:
- correction value d for range measurement
- standard deviation σ_R of range measurements
- mean intensity I and its standard deviation σ_I

These parameters had been determined in dependence on different distances (5m to 25m in steps of 5m), incidence angles – i.e. the angle to surface normal – (0^{gon} to 90^{gon} in steps of 10^{gon}, where $100^{gon} = 90º$) and ambient lighting and wetness conditions. Therefore, a special test configuration was generated in defined environment (sub-terranean laboratory with constant climatic conditions, no influences of ambient illumination). To determine a distance correction value (offset) a high-precision tacheometer was included opposite to the TLS (Fig.1). After measuring the reference distance to the TLS the sample holder with the regarded material was aligned and orthogonally oriented by means of collimation. For this purpose a mirror was temporarily fixed on the backside of the sample holder in the height of the laser beam of the tacheometer which was still oriented to the TLS station (cf. Fig. 1). Now the sample holder was rotated till the laser beam of the tacheometer was reflected back to the center of its optics (autocollimation). For each range and material correction values and their accuracy can be estimated (addition of both measured ranges plus thickness of the material incl. sample holder compared to the reference distance). The standard deviation of the range measurements is calculated by means of an adjusted plane through the laser points of each test sample, where the surfaces of the materials

have to be strictly planar. To determine the effects of different incidence angles the sample holder was rotated around the vertical axis in defined steps of 10^{gon} (related to the 0^{gon} - direction by autocollimation) which are realized by engraved marks on the horizontal plate of the sample holder (Fig. 2).

The intensity values I are measures of the electronic signal strength obtained by converting and amplifying the back-scattered optical power (Pfeifer et al. 2007). For HDS6000 the original backscattered signal power is received by the sensor detector which has normally a non-linear response curve. These "intensity" values are then transferred into the interval [0,1] by a linear function (Cyclone software) based on the absolute maximum and minimum defined by the capability of the detector. For our investigations these stored intensity values are used to calculate mean intensities I (arithmetic average of the intensity values of the laser points inside a sample) and their standard deviations σ_I.
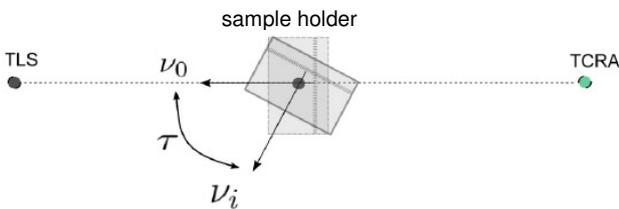

Figure 2. Top view of the test configuration. Rotation of the sample holder in defined angles τ to realize different incidence angles (related to the 0°-direction v_0)

5. SELECTION OF TEST MATERIALS

Out of the multiplicity of possible materials those which are common for building facades had been selected. Nevertheless, the first test series were carried out with targets of diffuse and calibrated reflectivity (Spectralon® tables, Lambertian reflector, 20cm × 20cm, reflectivity: 5%, 20%, 50%, 90% and 98%). Furthermore, eight uncalibrated colour tables had been included (red, green, blue, black, light red, light green, light blue, white). From the group of building materials concrete, brick, sandstone, granite and marble, from the group of metals iron, copper and aluminium had been chosen.

6. ANALYSIS OF GREY SCALED MATERIALS

The above mentioned test targets of defined reflectivity were scanned with the HDS 6000 at distances from 5m to 25m, common for building recordings. At each position the sample holder was rotated stepwise by means of precise marks engraved on the horizontal plate (cf. Fig. 2) to obtain different incidence angles of 0^{gon} to 90^{gon} with an accuracy of $\pm 1^{gon}$ (estimated). In order to test the effects of ambient lighting conditions, the orthogonal scan was repeated with and without ambient illumination (mixture of neon and bulb lights of the laboratory).

6.1 Geometric aspects

The range correction values d show a certain dependence on the measurement distance, i.e. an increase of about 2mm between the near (5m) and far distance (25m) can be observed (Fig. 3). Higher reflectivity causes similar tendencies but at lower correction values. The standard deviation σ_R of range measurements increases by a factor of about two between 5m

and 25m (Tab. 2, Fig. 4). The values decrease with increasing reflectivity significantly by a factor of four. Both observations confirm the results of other research groups (e.g. Hanke et al. 2006; Kersten et al. 2008) as well as the manufacturer's instructions.
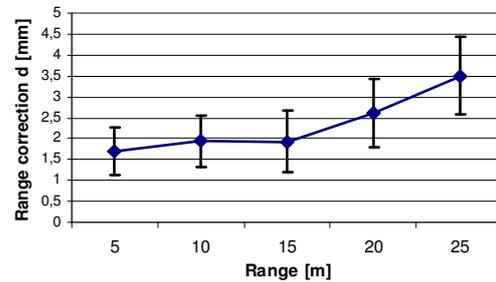

Figure 3. Range correction value d and its uncertainty in dependence on distance (target of 50% reflectivity)

Reflectivity	5m	10m	15m	20m	25m
5 %	± 1.9	± 2.6	± 3.3	± 4.5	± 5.3
20 %	± 0.9	± 1.2	± 1.5	± 1.9	± 2.0
50 %	± 0.7	± 0.8	± 1.0	± 1.2	± 1.4
90 %	± 0.6	± 0.6	± 0.8	± 0.9	± 1.0
98 %	± 0.5	± 0.7	± 0.7	± 0.9	± 1.0

Table 2. Standard deviation σ_R [mm] of range measurements in dependence on distance and surface reflectivity
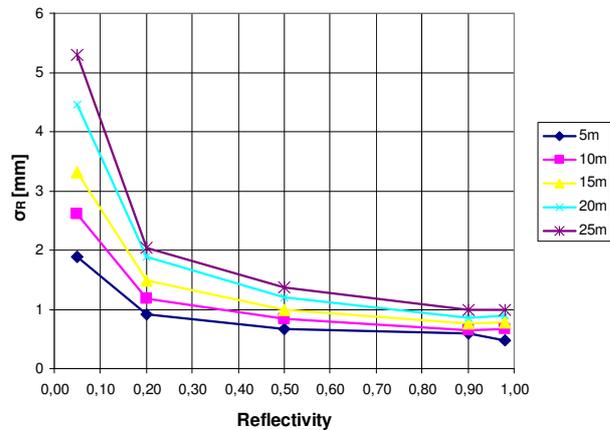

Figure 4. Standard deviation σ_R [mm] of range measurements in dependence on reflectivity

The dependence on the incidence angle is illustrated in Fig. 5. There is a clear tendency of decreasing values of σ_R (about 0.4mm) with larger angles of incidence, a phenomenon also reported by other research groups (e.g. Clark and Robson 2004) which is not easy to explain. One hypothesis may be that the laser scanner has a considerably higher accuracy for angle than for range measurements which is confirmed by the manufactu-rer's instructions where the main error component is caused by the range measurement (Tab. 1). For large incidence angles the range component has a smaller effect on the standard deviation derived from the residuals orthogonal to the adjusted plane.

For all distances the range accuracy was determined with and without ambient illumination. In contrast to results obtained

with pulsed laser scanners (e.g. Voegtle et al. 2008) with differences about a factor of two, no significant deviations could be proved for this phase shift scanner, even for lowest reflectivity of 5% (Fig. 6), which confirms the physical theory concerning the synchronous demodulation techniques of phase shift scanners (Thiel and Wehr, 2004).
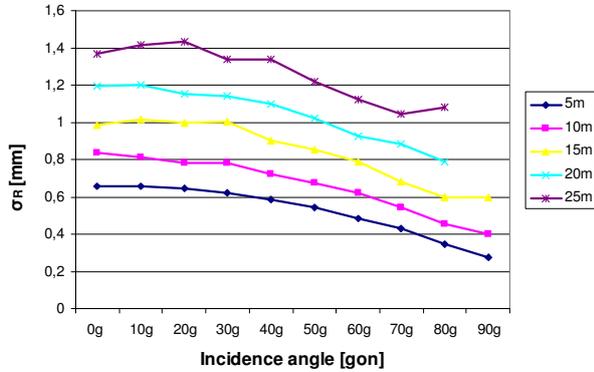

Figure 5. Standard deviation σ_R [mm] of range measurements in dependence on incidence angle (reflectivity 50%)
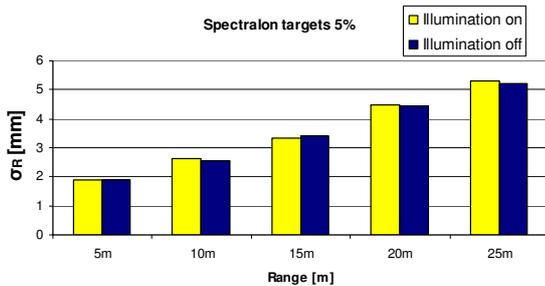

Figure 6. Range accuracy σ_R in dependence on ambient lighting conditions (reflectivity 5%)

6.2 Radiometric aspects

At first the relation between the calibrated reflectivity of the Spectralon® targets (by means of a broadband spectro-photometer) and the recorded intensity values had been tested (Fig. 7). The calibrated values related to the wavelength of the HDS 6000 could be taken from the protocol of the spectro-photometer calibration measurements of the targets, where for each Spectralon® target the reflectivity values in dependence on the wavelength are sampled. It can be seen that the relation is nearly independent of the distance. For low reflectivities the values coincide well with the calibrated ones (near the diagonal). For higher reflectivity values, slight deviations (reductions) of the recorded laser intensities compared to the calibrated values (diagonal) can be observed (loss of about 10%). Obviously, the target of highest reflectivity (98%) caused measuring errors (cf. Pesci and Teza, 2008) – a problem which also occurred for other materials of high reflectance (e.g. granite, metal plates). Now, for each test target and position the average of the intensity values and the related standard deviations σ_I have been determined using all laser points inside the target (without regarding points near the edges). Only a slight decrease for distances up to 25m can be recognised with very small standard deviations σ_I (Fig. 8) although there is no range-dependent amplification of the laser signal (manufactorer's instructions).
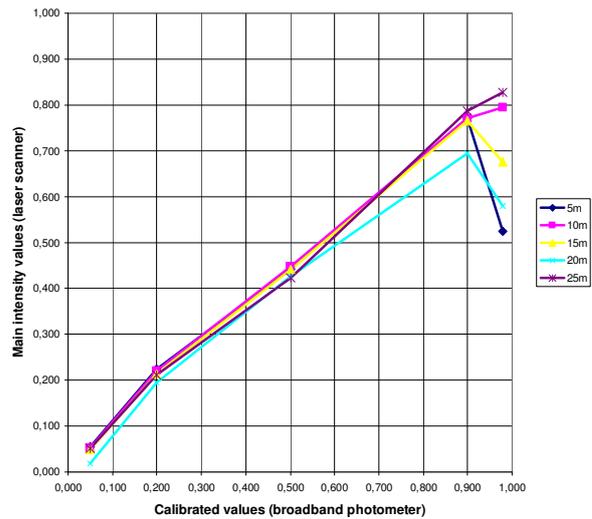

Figure 7. Relation between calibrated values (photometer) and recorded intensity values by HDS 6000
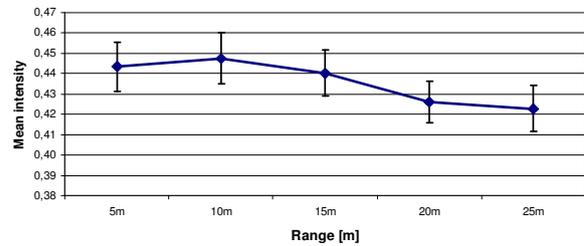

Figure 8. Mean intensity I and its standard deviation σ_I in dependence on the distance (reflectivity 50%)

However, a significant reduction of the mean intensity is caused by increasing incidence angles (Fig. 9). An interesting phenomenon is a certain increase of the values up to 20^{gon} before they approximately follow the expected cosine-law (Pfeifer et al. 2008). Again, no significant differences could be detected between the intensity values captured with and without ambient illumination.
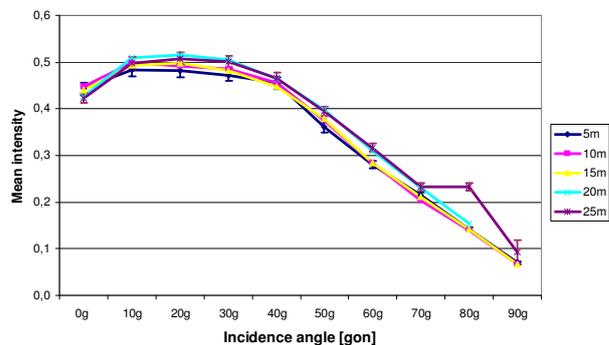

Figure 9. Mean intensity in dependence on incidence angle (reflectivity 50%)

According to previous investigations with a pulsed laser scanner the standard deviation σ_I increases from ±0.003 (reflectivity 5%) to approximately ±0.014 (reflectivity 98%). Due to the absence of an amplification this is not really reasonable.

7. ANALYSIS OF COLOURED TEST PLATES

Several coloured, diffuse reflecting test plates were included in the series of observations. Here no calibrated standard colour tables known from photographic laboratories have been used but simple, customary colour plates at which the red one should approximately correspond to the (red) colour of the HDS 6000. Three basic colours (red, green, blue) and three reduced colours (light red, light green, light blue) were selected, additionally black and white.

7.1 Geometric aspects

The range correction values d_i show a similar behaviour as the grey scaled test targets. They were approximately constant up to 20m distance (2mm (red) / 3mm (black)) and begin to increase beyond 20m to 3.5mm (red) / 4.5mm (black). This implies the necessity to extend the measurement distances up to 50m in future test series.

Colour	5m	10m	15m	20m	25m
black	± 1.1	± 1.4	± 1.7	± 2.1	± 2.5
blue	± 0.6	± 0.8	± 0.9	± 1.1	± 1.3
green	± 0.6	± 0.8	± 0.9	± 1.1	± 1.3
red	± 0.5	± 0.6	± 0.7	± 0.9	± 1.1
light blue	± 0.5	± 0.6	± 0.8	± 0.9	± 1.2
light green	± 0.5	± 0.6	± 0.7	± 0.9	± 1.0
light red	± 0.5	± 0.6	± 0.7	± 0.8	± 0.9
white	± 0.5	± 0.6	± 0.7	± 0.8	± 1.0

Table 3. Standard deviation σ_R [mm] of range measurements in dependence of colour and distance

Similar to the results from grey-scaled tables σ_R increases with larger distances about a factor of two from 5m to 25m (Tab. 3). The colours blue and green have slightly worse range accuracies compared to red (colour of the laser). All light colours show results similar to white (comparable to the values of the Spectralon® tables of 90% and 98% reflectivity). Also the effect of different incidence angles is nearly the same (Fig. 10). Ambient lighting conditions have no significant influence on the accuracy values. Overall it can be stated that the specific influence of colour on the geometric quality is quite limited.
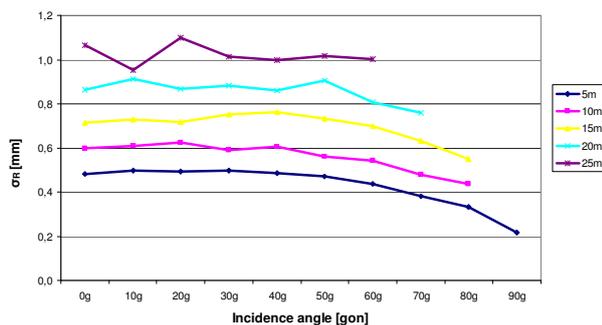

Figure 10. Standard deviation σ_R [mm] of range measurements in dependence on incidence angle (colour red)

7.2 Radiometric aspects

The maximum intensity values (about 0.82) are obtained by the white, red and light red colour tables, followed by light green (0.79), light blue (0.66), green / blue (0.5) and black (about 0.15). There is only a slight reduction of I for longer distances up to 25m of approximately 5% to 10% (Fig. 11). In this figure

it can also be seen that ambient lighting conditions have no remarkable effects on the acquired intensities.
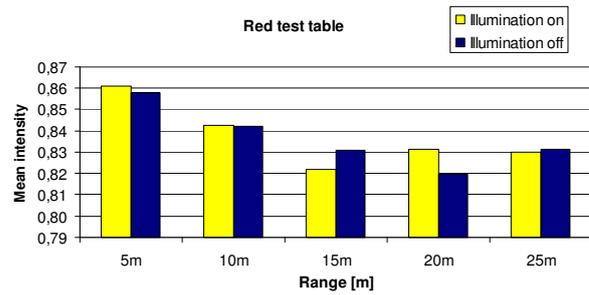

Figure 11. Mean intensity values (red test table) in dependence on distance and ambient lighting conditions

Increasing incidence angles lead to expected reductions of the recorded intensity values. In contrast to Spectralon® tables no increase occurs and the values follow the cosine-law quite well.

The highest standard deviations σ_I of the intensity values were caused by bright colours (especially white: $\sigma_I = \pm 0.023$) and the colour of the laser itself (red: $\sigma_I = \pm 0.019$), followed by green and blue (about ±0.013), while the lowest values were obtained for black surfaces (about ±0.006). This characteristic proves to be contrary to the range accuracy – a phenomenon which can be also observed for a pulsed laser scanner (Voegtle et al. 2008). Therefore, on the one hand bright surfaces generate high intensity values, but on the other hand introduce the highest standard deviations.

8. ANALYSIS OF BUILDING MATERIALS

As mentioned above several materials common for building facades had been selected: concrete, sandstone, brick, granite and marble. Main problems occurred by scanning granite and marble where measures could be obtained only for a distance of 5m (orthogonal scan) and incidence angles of 10^{gon} to 70^{gon}. Due to the specific structure of the surfaces wetness conditions were analysed only for concrete, sandstone and brick. For this purpose these samples were scanned at first in dry condition, afterwards the sample was sprayed with water by a squirt bottle.

8.1 Geometric aspects

The determination of range correction values d_i showed high variations, especially for concrete where values between 0.4mm and 10.1mm had been calculated. Repeated measurements led to quite different results. The reason for this phenomenon could be the specific surface structure of the material as Thiel and Wehr (2004) observed anomalous effects for phase shift scanners at micro structures of a quarter of the wavelength within the instantaneous laser spot. Therefore, additional test series with other test plates of concrete have to be carried out. The estimated range correction values for the other materials are sampled in Tab. 4. An error propagation confirmed that there is a great uncertainty for these values.

The results for the standard deviations σ_R of range showed an expected characteristic, i.e. increasing with larger distances (Tab. 5). In spite of a certain roughness of those building materials the obtained values are quite small (comparable to Spectralon® tables).

Material	5m	10m	15m	20m	25m
Sandstone	0.8	1.2	1.7	1.9	3.2
Brick	2.1	1.9	1.4	1.9	3.3
Granite	2.2	---	---	---	---
Marble	3.3	---	---	---	---

Table 4. Range correction value d [mm] for building materials in dependence on distance

Material	5m	10m	15m	20m	25m
Concrete	0.6	0.7	0.9	1.4	1.2
Sandstone	0.9	1.2	1.3	1.6	2.0
Brick	0.8	1.0	1.3	1.5	1.6
Granite	0.6	---	---	---	---
Marble	0.6	---	---	---	---

Table 5. Standard deviation σ_R [mm] of range measurements for building materials in dependence on distance

The influence of incidence angles is similar to the other test tables. The values of σ_R for concrete decrease from ±0.75mm (0^{gon}) to ±0.35mm (80^{gon}), for sandstone from ±1.2mm to ±0.75mm, for brick from ±1.0mm to ±0.5mm and for marble from ±1.1mm to ±0.8mm. An exception is granite where the values are nearly constant about ±1.2mm.

Wetness introduces only small differences. While the values for concrete increase slightly for wet conditions (about 0.4mm), they decrease for sandstone and brick (about 0.2mm to 0.4mm). Again, due to the above mentioned reasons, illumination differences caused no significant changes of the results.

8.2 Radiometric aspects

Marble had the highest mean intensity (0.66), followed by granite (0.49), concrete (0.32), brick (0.21) and sandstone (0.14) – all at a distance of 5m. Beginning at 10^{gon} the influence of incidence angles on the mean intensity is comparable to the other materials, i.e. a decrease by a factor of two according to the cosine-law. Differences in wetness conditions cause – as expected – big changes of recorded intensities, dependent on the material. While concrete delivers remarkable lower values (factor of two) in wet condition, the values for sandstone and brick increase about a factor of two.

9. ANALYSIS OF METAL PLATES

Three different types of metal had been used in these test series: iron, copper and aluminium. These materials introduced extreme problems because a lot of measurements could not be carried out (no data recorded) – especially the orthogonal scans, probably due to saturation effects caused by high energy backscattered from the shiny surfaces. The sensitivity of this laser scanner seems to be too high which may cause anomalous effects (Pesci and Teza, 2008).

9.1 Geometric aspects

Due to the problems mentioned above no range correction values could be determined. The range accuracies σ_R could be acquired only for incidence angles greater than 10^{gon} (Tab. 6).

The values for copper and aluminium are quite small (comparable to Spectralon®) and a little bit higher for iron.

Material	5m	10m	15m	20m	25m
Iron	1.0	1.2	---	1.6	1.5
Copper	0.7	0.9	---	1.1	1.2
Aluminium	0.5	0.6	0.8	0.9	1.0

Table 6. Standard deviation σ_R [mm] of range measurements for different metal plates in dependence on distance (incidence angle: 10^{gon})
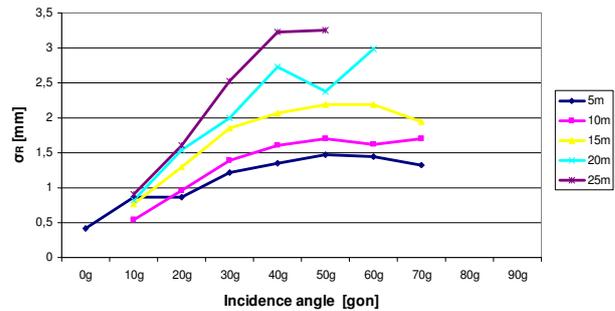

Figure 12. Standard deviation σ_R of range measurements for aluminium in dependence on incidence angle
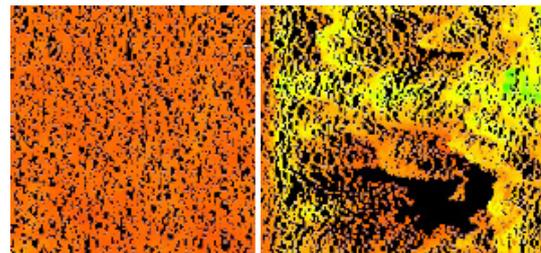

Figure 13. Oblique view on the point cloud acquired from a aluminium plate (left part) and a copper plate (right part)

In contrast to all other materials of these test series, the range accuracy for metal plates decreased with greater incidence angles (Fig. 12). Especially for copper an increase of significant deviations could be observed (Fig. 13), may be due to problems with micro structures of a quarter of the wavelength.

Due to the mentioned problems of data capture, no useful and comprehensive analysis of the radiometric parameters could be carried out for metal plates.

10. CONCLUSIONS

Our systematic test series have proven that different materials – especially building materials – may have significant influences on the measurements of terrestrial laser scanners, partly higher than the basic accuracy of the scanner itself. Some general conclusions can be drawn: No constant or functional relationship for the range correction value d for all materials could be found. It varies – according to Clark and Robson (2004) – dependent on distance and reflectivity about 1mm – 3mm, so a range correction seems to be appropriate only for applications of high accuracy requirements. The standard deviation σ_R of range measurements increases systematically according to the

distance, for most of the used materials from about 0.5mm – 0.8mm (5m distance) to 1mm – 1.5mm (25m distance). A stronger impact on σ_R is caused by the reflectivity of the materials. The differences of σ_R due to low and high reflectivity have proven to be up to a factor of four. An interesting phenomenon for all materials – except metal plates – is the decrease of σ_R with increasing incidence angles which should be investigated further on in more detail. While different wetness conditions have marginal effects on the geometric data quality (10%-20%), ambient illumination has no (significant) influence on the measurements of this phase shift scanner – in contrast to the results for a pulsed scanner. To obtain suitable results the objects should have surfaces of high reflectivity and should be scanned with wider incidence angles.

Also influences on the intensity values and their standard deviation could be detected. In contrast to the theoretical $1/r^2$, the mean intensities decrease only slightly with longer distances (up to 25m). A stronger decrease is caused by increasing incidence angles, most materials approximately according to the cosine-law with exception of the Spectralon® targets where an increase up to 20^{gon} can be observed. Wetness condition has a strong effect on the received intensities for building materials (about a factor of two). Therefore, a classification of objects or object parts based on intensity values seems to be difficult – especially for surfaces with unknown reflectivity. Such tasks may be suitable for industrial applications in defined environment. The standard deviation σ_I of intensity values increases with higher reflectivity. Therefore, white surfaces and surfaces in the colour of the laser deliver highest σ_I values.

Compared to a pulsed scanner metal plates and surfaces of high reflectivity caused even more scanning problems for the HDS 6000, probably due to saturation effects. Other phenomena like dependency of σ_R on distance and incidence angle or increase of σ_I with higher reflectivity are comparable for both types of scanners.

Further investigations have to be carried out for concrete and metal plates to detect the reasons for such enormous deviations and the impossibility of data acquisition for specific configurations. Another necessity is the enlargement of measuring distances up to 50m and the inclusion of additional materials into future test series – especially from industrial productions.

The current discussion should lead to a standardisation of such test configurations for terrestrial laser scanners to make the results comparable.

REFERENCES

Amiri Parian, J., Gruen, A. 2005. Integrated Laser Scanner and Intensity Image Calibration and Accuracy Assessment. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 36, Part 3/W19.

Boehler, W., Bordas V., M., Marbs, A., 2004. Investigating Laser Scanner Accuracy. In: *Proceedings of XIXth CIPA WG 6,* International Symposium, Antalya, Turkey, 30. September– 4. October, pp. 696 -702.

Clark, J., Robson, S., 2004. Accuracy of measurements made with CYRAX 2500 laser scanner against surfaces of known colour. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science*, Vol. XXXV, Comm. IV, Part B4, pp. 1031-1037.

Hanke, K., Grussenmeyer, P., Grimm-Pitzinger, A., Weinold, T., 2006. First Experiences with the Trimble GX Scanner. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 36, Part 5, ISSN 1682-1750, ISPRS Comm. V Symposium, Dresden, Sept. 25-27, Germany.

Kersten, T., Mechelke, K., Lindstaedt, M., Sternberg, H., 2008. Geometric accuracy investigations of the latest terrestrial laser scanning systems. In: FIG Working Week 2008 – Integrated Generations, Stockholm, 2008

Kukko, A., Kaasalainen, S., Litkey, P., 2008. Effect of incidence angle on laser scanner intensity and surface data. *Applied Optics*, Vol. 47, No. 7, 1 March 2008, pp. 986-992.

Lichti, D., Harvey, B., 2002. The Effects of Reflecting Surface Material Properties on Time-of-Flight Laser Scanner Measurements. Symposium on Geospatial Theory, Processing and Applications, Ottawa.

Lichti, D.D., Licht, M.G., 2006. Experiences with terrestrial laser scanner modelling and accuracy assessment. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 36, Part 5, pp. 155-160.

Pfeifer, N., Dorninger, P., Haring, A., Fan, H., 2007. Investigating terrestrial laser scanning intensity data: quality and functional relations. In: International Conference on Optical 3-D Measurement Techniques VIII, 2007, ISBN: 3-906467-67-8, pp. 328 – 337.

Pesci, A., Teza, G., 2008. Terrestrial laser scanner and retro-reflective targets: An experiment for anomalous effects investigation. *International Journal of Remote Sensing*, Vol. 29, No. 19, 10 October 2008, Taylor & Francis, pp. 5749-5765.

Pfeifer, N., Höfle, B., Briese, C., Rutzinger, M., Haring, A., 2008. Analysis of the backscattered energy in terrestrial laser scanning data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXVII, Part B5, Beijing, 2008, pp. 1045-1052.

Thiel, K.-H., Wehr, A., 2004. Performance Capabilities of laser scanners – an overview and measurement principle analysis. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 36, Part 8, pp. 14-18.

Voegtle, T., Schwab, I., Landes, T., 2008. Influences of different materials on the measurements of a terrestrial laser scanner (TLS). In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXVII, Part B5, Beijing, 2008, pp. 1061-1066.