

INFLUENCES OF DIFFERENT MATERIALS ON THE MEASUREMENTS OF A TERRESTRIAL LASER SCANNER (TLS)

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ABSTRACT:

During the last years terrestrial laser scanning became a standard method of data acquisition for various applications in close range domain, like industrial production, forest inventories, plant engineering and construction, car navigation and – one of the most important fields – the recording and modelling of buildings. To use laser scanning data in an adequate way, a quality assessment of the laser scanner is inevitable. In the literature some publications can be found concerning the data quality of terrestrial laser scanners. Most of these papers concentrate on the geometrical accuracy of the scanner (errors of instrument axis, range accuracy using target etc.). In this paper a special aspect of quality assessment will be discussed: the influence of different materials and object colours on the recorded measurements of a TLS. The effects on the geometric accuracy as well as on the simultaneously acquired intensity values are the topics of our investigations. A TRIMBLE GX scanner was used for several test series. The study of different effects refer to materials commonly used at building façades, i.e. grey scaled and coloured sheets, various species of wood, a metal plate, plasters of different particle size, light-transmissive slides and surfaces of different conditions of wetness. The tests concerning a grey wedge show a dependence on the brightness where the mean square error (MSE) decrease from black to white, and therefore, confirm previous results of other research groups. Similar results had been obtained with coloured sheets. In this context an important result is that the accuracy of measurements at night-time has proved to be much better than at day time. While different species of wood and different conditions of wetness have no significant effect on the range accuracy the study of a metal plate delivers MSE values considerably higher than the accuracy of the scanner, if the angle of incidence is approximately orthogonal. Also light-transmissive slides cause enormous MSE values. It can be concluded that high precision measurements should be carried out at night-time and preferable on bright surfaces without specular characteristics.

1. INTRODUCTION

During the last years terrestrial laser scanning became a standard method of data acquisition for many applications in close range domain. Nowadays an enormous variety of working fields can be observed like industrial production, plant engineering and construction, autonomous car navigation, forest inventories, medical and forensic applications or film industry, to name only a few. One of the most important and extensive fields is the recording and modelling of buildings which is used for instance for 3D city models (e.g. planning of radio networks or infrastructure, tourist guide systems, environmental planning, etc.), architecture, archaeology or cultural heritage.

One main aspect of object capture and modelling based on TLS is data quality to estimate the suitability for a specific application. In the literature some publications can be found concerning the data quality of TLS (e.g. Lichti, Harvey, 2002; Boehler et al., 2004; Clark, Robson, 2004; Amiri, Gruen, 2005; Kersten et al., 2005; Lichti, Licht, 2006; Hanke et al., 2006). In these papers the focus is mostly geometric accuracy or reflectivity of standard targets or colour tables, while in this paper a special aspect of quality assessment – as an extension of previously published investigations – will be discussed, the influence of different realistic object materials and object colours on the measurements of a TLS. Besides the geometric accuracy also the effects on the recorded intensity values have been analysed. Due to the wide field of objects which can be

preferably scanned by TLS the selection of materials was concentrated on those typically for building facades.

2. TERRESTRIAL LASER SCANNER

For these investigations the TRIMBLE GX laser scanner was used. The technical specifications of this scanner are sampled in Table 1.

Measurement principle	Pulsed laser
Wavelength	532 nm (green)
Max. distance	200 m (90% reflect.)
Accuracy	
positioning	± 12 mm (100 m)
range	± 7 mm (100 m)
std. dev. plane	± 1.5 mm (50 m) ± 2.5 mm (100 m)
Point size (footprint)	3 mm (50 m)
Min. point distance	3.2 mm (100 m)
Scan field	360° (H) 60° (V)
Scan rate	< 5000 pts./sec.

Table 1. Technical specifications of TRIMBLE GX scanner

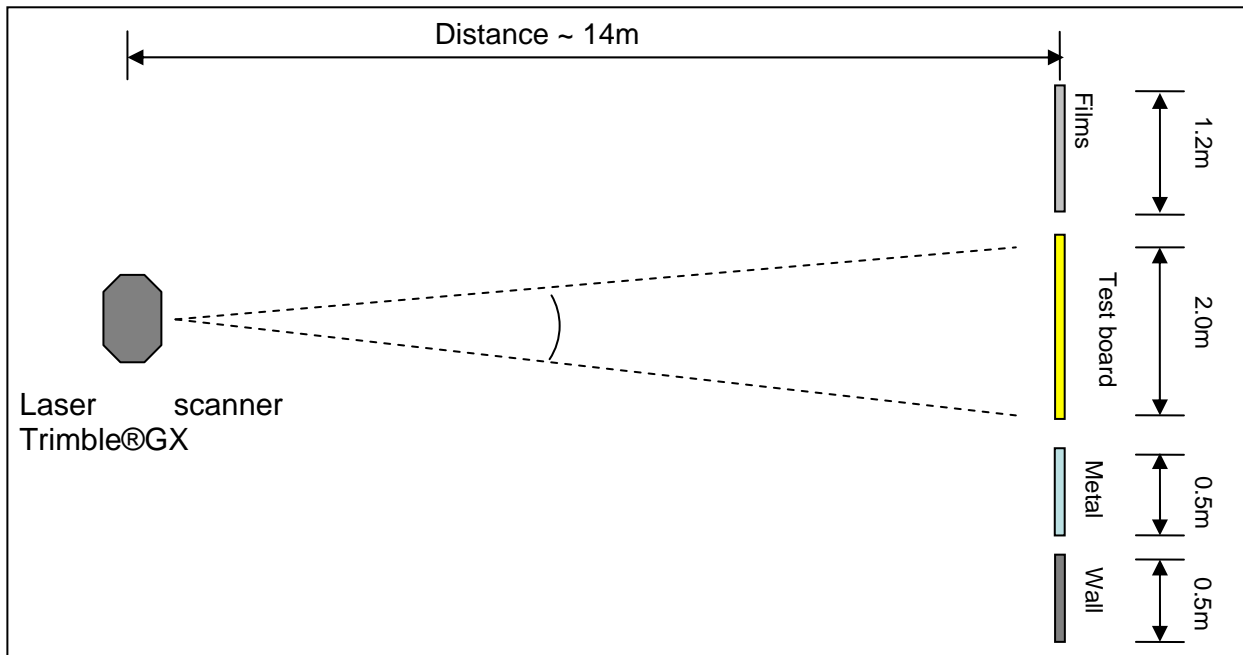


Figure 1. Principle of the test configuration

3. TEST CONFIGURATION AND TEST BOARDS

For the investigation of the effects of object materials and colours on laser scan measurements special test boards had been constructed where several test plates of different materials were mounted. Figure 1 illustrates the configuration of the tests. It has to be taken into account that the board under investigation had been positioned in the centre, in order that the laser rays hit the board orthogonal. The distance of 14 m had been chosen due to a typical range for building acquisition. All main investigations have been carried out at day and night-time to estimate the influences of surrounding lighting conditions.

To analyse the accuracy of the range measurements an adjusted plane (best fit) has been calculated for all laser points of the same plate and the mean square error (MSE) was derived based on the point distances (residuals) to this plane. For the analysis of the recorded intensities the mean value has been computed.



Figure 2. Colour sheets red, green, blue, light red, light green, light blue

4. ANALYSIS OF GREY SCALED AND COLOURED MATERIALS

In order to test the effects of different grey levels of an object on the laser scan measurements, several sheets with b/w patterns and a sheet with a grey wedge was used. To assess the quality of measurements on coloured surfaces, four sheets in red, green, blue and black had been mounted on the main board. Also three sheets in light red, light green and light blue were supplemented (Figure 2).

4.1 Geometric accuracy

The range measurements on our grey scaled test sheets have proven a significant dependence between the brightness of the object and the obtained accuracy and therefore, confirm previous results of other research groups (e.g. Hanke et al., 2006). Figure 3 shows the results of the recording of the grey wedge. For dark areas an error of about $MSE = \pm 5$ mm and about $MSE = \pm 2.5$ mm for bright parts was estimated. Unexpectedly the MSE value for white is a little bit higher than the minimum at green (colour of laser light).

The analysis of the colour sheets leads to similar results, i.e. the range errors decrease from black over red, blue and green (colour of the laser light) to the light colours. Again the MSE value for white is higher than the minimum of the light coloured sheets. Besides this the most significant feature is the enormous difference between measurements at day and night-time (approx. a factor of 2). So the range error for black lies about $MSE = \pm 5.1$ mm at daytime and about $MSE = \pm 2.4$ mm at night-time. These values decrease to the light colours with a MSE of about ± 2.2 mm (daytime) and $MSE = \pm 1.4$ mm (night-time) (Figure 4). Again the MSE for the white sheet lies above the minima with only a slight difference between night and day.

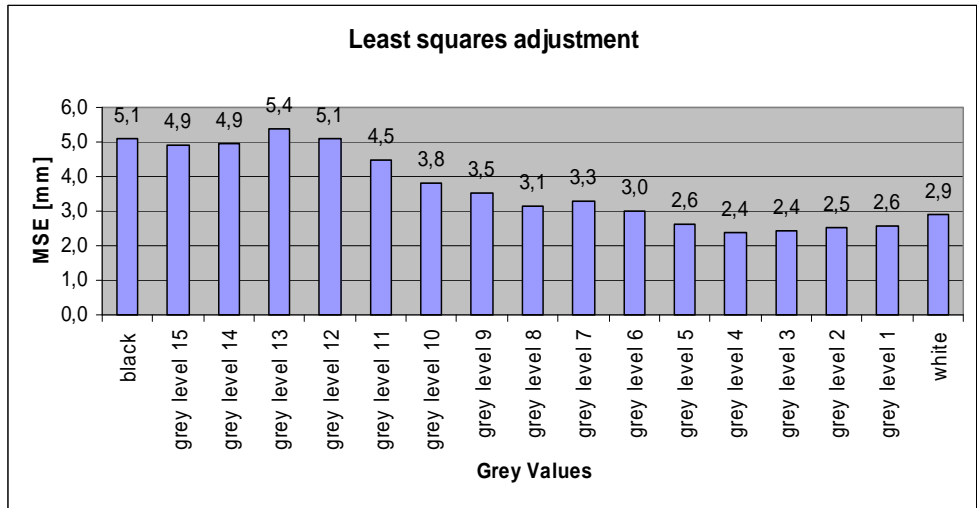


Figure 3. Range accuracy for different grey levels (grey wedge)

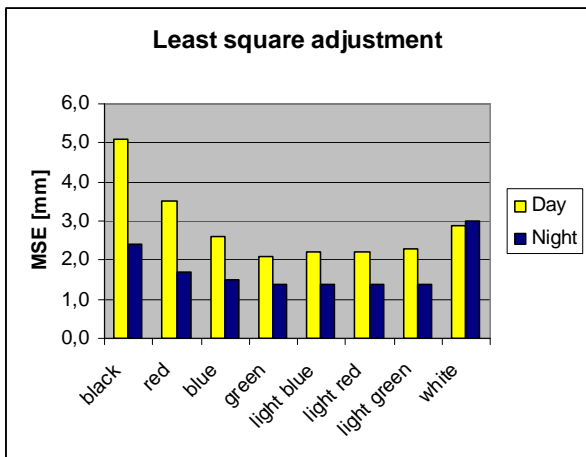


Figure 4. Range accuracy at day and night-time for different coloured sheets

4.2 Intensity analysis

The analysis of the intensity values has been based on the same measurements as those carried out for the geometric accuracy assessment (sect. 4.1). The results for the grey wedge clarify that the recorded laser intensity values – as expected – increase systematically from black to white but a certain non-linearity can be observed (Figure 5). The related standard deviations of the intensities also increase from black (MSE about ± 8 grey values) to white (MSE about ± 14 grey values) and therefore, show an opposite characteristic compared to the MSE of the range measurements.

A similar behaviour can be obtained from the measured intensity values of the coloured sheets. The means increase from black, red, blue to green with somewhat higher values for night-time measurements (Figure 6). Also the MSE of the intensities (Figure 7) increase from black (MSE about ± 7 grey values) to green (MSE about ± 15 grey values) and confirm the results from the grey wedge

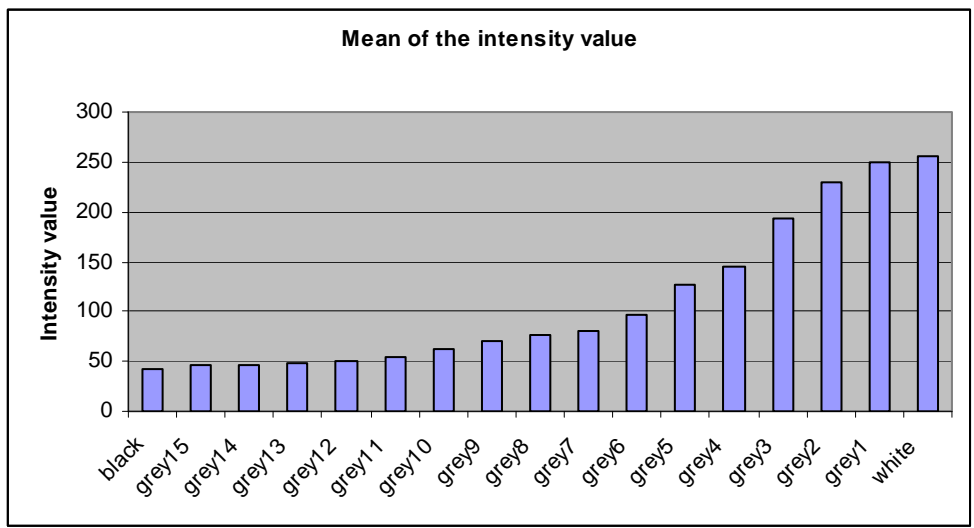


Figure 5. Mean intensity values of different grey levels (grey wedge)

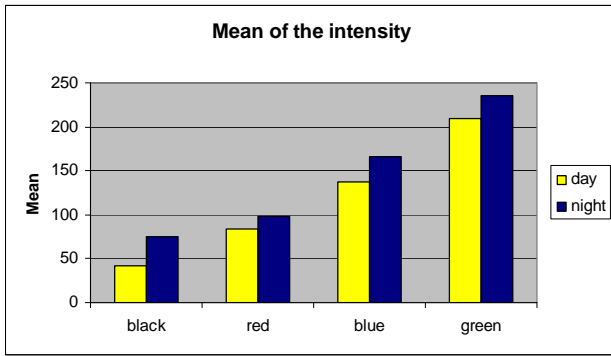


Figure 6. Means of intensity values for different coloured sheets

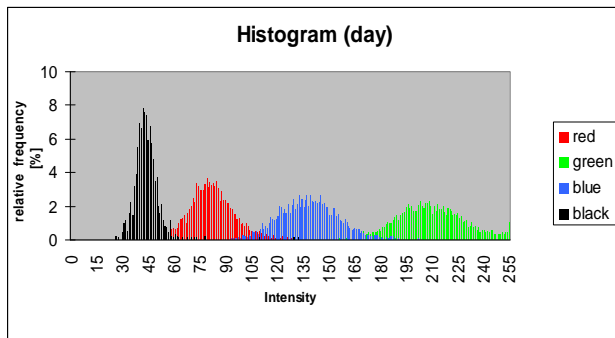


Figure 7. Histograms of the intensity values for different coloured sheets

5. ANALYSIS OF DIFFERENT TYPES OF WOOD

At one area of the main test board five different species of wood had been positioned: pine, fir, beech, oak and spruce. All pieces are of the same roughness.

5.1 Geometric accuracy

The MSE values of range measurements lie nearly in the same domain and vary only between $MSE = \pm 2.5$ mm for pine and $MSE = \pm 3.3$ mm for spruce (Figure 8). Therefore, no significant effect of the species could be verified.

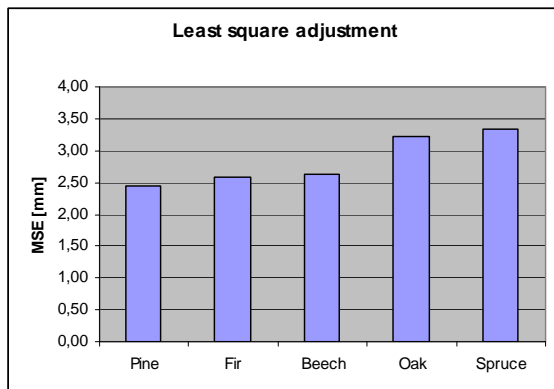


Figure 8. Range accuracy for different species of wood

5.2 Intensity analysis

Due to the specific characteristics of natural material like wood, remarkable colour discrepancies occurred with regard to the different species. The lowest intensity values were obtained for oak (about 140) with increasing intensities for beech, pine, fir and spruce with the highest values (about 220). Compared to the differences of the mean intensities the MSE values are quite high (Figure 9) and therefore, it can not be distinguished between these species by analysing the intensity values.

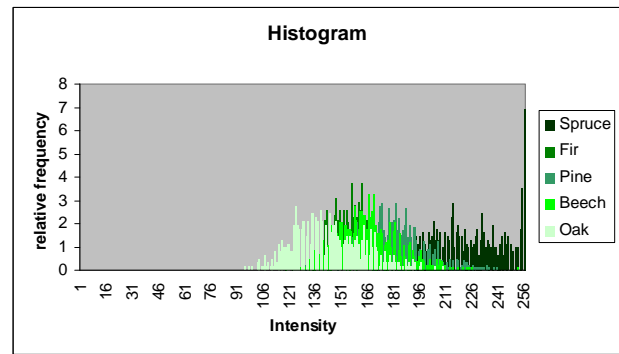


Figure 9. Histograms of five different species of wood

6. ANALYSIS OF METAL PLATE

Since metal is also a possible material covering building façades, a metal plate was centred in front of the laser scanner in order to keep an incidence angle normal to the object surface in the first status. Due to the fact that metal is not a Lambertian reflector, the board has then been rotated stepwise (in increments of 10 gon) around the vertical axis to study the influence of different incidence angles.

6.1 Geometric accuracy

For every rotation angle of the metal plate – as mentioned before – an adjusted plane has been estimated and the residuals of the original laser points have been used to determine the MSE values. The results for every incidence angle are compiled in Table 2.

Incidence Angle [gon]	MSE [mm]	Number of points
100	± 7.0	63 602
90	± 4.3	72 086
80	± 3.1	66 779
70	± 2.4	65 247
60	± 1.9	56 756
50	± 1.6	51 783
40	± 1.4	44 214
30	± 1.2	33 791
20	± 1.0	23 424
10	± 0.9	11 009

Table 2. MSE values of the metal plate for different incidence angles

The obtained values of Table 2 show a dependence on the incidence angle: with smaller angles also the MSE values

decrease, from MSE = ± 7.0 mm at 100° (orthogonal direction) to MSE about ± 1.0 mm below 20°. However, it has to be taken into account that in the same way as the MSE values also the number of points decrease and therefore, the estimations may be too optimistic. Another interesting aspect is the dimension of the MSE for orthogonal data acquisition or large incidence angles. These values of about ± 7.0 mm to ± 4.3 mm lie significantly above the general accuracy of this laser scanner which had been confirmed by the other tests during these investigations.

6.2 Intensity analysis

The acquired mean intensity values for every incidence angle are assembled in Table 3. Due to the high reflectivity of metal applying orthogonal scanning direction total reflection occur and the intensity values lie in the saturation domain. Expectedly the values decrease drastically with smaller incidence angles.

Incidence Angle [gon]	Mean Intensities [grey values]	Number of points
100	253.8	63 602
90	231.4	72 086
80	149.7	66 779
70	99.3	65 247
60	68.2	56 756
50	49.8	51 783
40	36.8	44 214
30	28.8	33 791
20	16.6	23 424
10	9.1	11 009

Table 3. Mean intensity values of a metal plate for different angles of incidence

7. ANALYSIS OF PLASTER MATERIALS

For analysing the reflection characteristics of plasters some typical types had been provided. Therefore, several plates of plasters with known particle sizes were available. Four types with particle sizes of < 1.5 mm, 1.5 mm, 2-3 mm and 3 mm had been used for these investigations. Due to the same colour of all test plates (white) only the range measurements are of interest. Again the measurements have been executed by day and night-time. The obtained results are depicted in Figure 10.

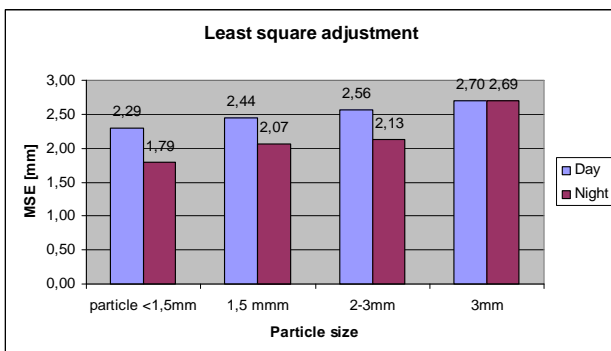


Figure 10. Range accuracy for different types of plaster

Certain differences can be recognised between the measurements of day and night-time where the MSE values captured at night-time are again somewhat smaller and show more significantly a dependence on the particle sizes, i.e. the particle sizes affect the measurements systematically which is predominantly caused by the varied roughness of the structured surfaces. The MSE values for day time increase with the particle sizes only from ± 2.3 mm (particles < 1.5 mm) up to ± 2.7 mm (particles of 3 mm) but from ± 1.8 mm – which corresponds to the basic accuracy of the laser scanner – up to ± 2.7 mm for night-time acquisition. Therefore, it can be distinguished between the plaster types by analysing the range measurements and their MSE values.

8. ANALYSIS OF LIGHT-TRANSMISSIVE MATERIAL

A special aspect of these investigations was the characteristic of light-transmissive materials (films) where different levels of transparency were used. Three slides had been centred in front of the laser scanner with a larger distance of about 3 m to the wall in the background in order to be able to exclude reflections from the background. The three slides had a transparency of 5%, 20 % and 35% respectively. As in the case of plasters only the range measurements can be reasonably analysed. Figure 11 illustrates the MSE values for these slides.

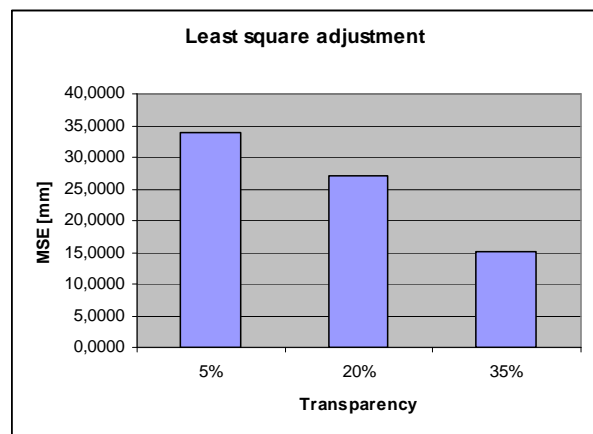


Figure 11. Range accuracy for slides of different transparencies

Even after elimination of outliers (e.g. from the background) the MSE values of range measurements are worse about a factor of 20 compared to the results for non-transparent materials, an effect which can be explained by the noise which may be probably introduced by transparent materials. Furthermore a strong correlation between MSE value and transparency can be observed. The slide with 5% causes the highest values of about ± 34 mm which decrease to ± 15 mm at 35% transparency.

9. ANALYSIS OF THE INFLUENCE OF WETNESS

Since wetness as well as roughness are known to be important disruptive factors for active systems, their influence on laser beams has been investigated. The effects of wetness has been analysed with regard to two materials, wood and concrete wall.

As expected, the tests confirm that wetness of wood leads to a significant decrease of the obtained intensity values. While the

dry piece of wood has a mean intensity of about 160 the same piece in wet condition delivers a value of about 75. Nevertheless the MSE values of range measurements don't differ significantly and approve the independence on wetness conditions. Similar results can be obtained by the test with concrete walls, but in contrast to wood material the change of the mean intensity values was not relevant (Figure 12). The MSE value for wet condition was determined as ± 1.37 mm and the one for dry condition as ± 1.31 mm.

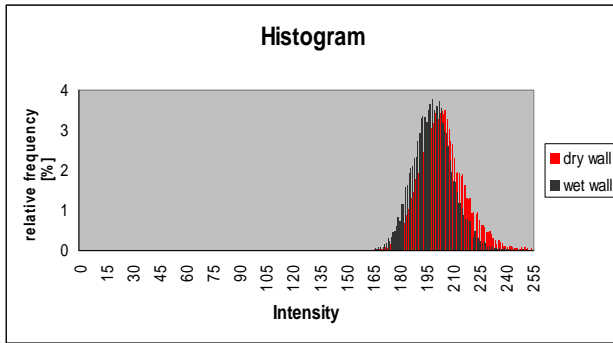


Figure 12. Histogram of intensities of dry and wet concrete wall

10. CONCLUSION

A special aspect of quality assessment – the influence of different materials on the measurements of a terrestrial laser scanner – was presented in this paper. Besides the geometric accuracy of the range measurements for different materials also the simultaneously recorded intensity values have been an integral part of our investigations. For the test series grey scaled and coloured sheets, different species of wood, a metal plate, plasters of different particle size, light-transmissive slides and objects in different conditions of wetness have been scanned. The selection was based on those materials commonly used at building façades.

The analysis of our results led to some general statements. First of all the producer's specification concerning the range accuracy of an extracted plane could be verified. An interesting aspect was the increase of measurement accuracy at night-time and on bright materials. The influence of different wood species and of wetness seems to be marginal while light-transmissive material and metal plates induces enormous MSE values much higher than the general range accuracy of the laser scanner.

In the future these test series should be repeated with other types of terrestrial laser scanners, especially with systems based on phase measurement principle. Furthermore additional materials should be included like surfaces of industrial and cultural heritage objects. The presented results emphasize the need for such investigations.

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