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Assessment of Terrestrial Laser Scanning (TLS) Behavior against Material and Color for Short Range Applications

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Abstract

Terrestrial laser scanners provide high spatial resolution and high accuracy three-dimensional (3D) data where data collection does not necessitate physical contact with the object of interest. For these reasons, point-cloud coordinate information acquired is widely utilized in a variety of surveying and civil engineering applications, in addition to many applications in the close-range domain. Some of these applications incorporate the scanning of building facades of different materials, and are concerned with reliable measurements, which may then affect the quality of laser scanned data. Several publications have investigated the quality of the data to ensure the achievement of high accuracy and examine the several factors influencing it. As one important feature of TLS-based object acquisition and modeling is data quality, which is used to determine the compatibility for a specific application. Some publications on the data quality of TLS are mainly concerned with geometric accuracy, reflectivity of standard targets, or the influence of different realistic object materials and object colors on TLS range measurements and recorded intensity values. Another aspect was investigated in this paper regarding the effect of two distinct materials with different colors on taking actual linear measurements from the acquired point cloud data. The materials chosen were of the most commonly used building facades materials. Measurements were taken at different distance intervals, and results show that different scanning materials produce point clouds of varying quality and even various colors within the same material results in various effects among the measurements.

Keywords: Terrestrial Laser Scanning (TLS), Lidar, Target Color, Target Material

1. INTRODUCTION

Terrestrial laser scanners produce high spatial resolution and accuracy three-dimensional (3D) data where physical contact with the object of interest is not required. As a result of these factors, acquired point-cloud coordinate information is widely used in a variety of surveying and civil engineering applications, such as monitoring bridges, dams, and buildings.

In addition to the aforementioned fields, terrestrial laser scanning has recently become a common method of data collection for many close-range applications. Industrial production, plant engineering and construction, autonomous vehicle navigation, forest inventories, and medical and forensic applications are just a few examples. One of the most important and wide-ranging fields is building recording and modeling, which is used for 3D city models (e.g., radio network planning or infrastructure design, tourist guide systems, environmental planning, etc.), architecture, archaeology, or heritage documentation. Some of these applications involve scanning building facades made of various materials, which could have an impact on the accuracy of the laser scanned data.

Due to the recent great importance of TLS-based measurements, several publications have investigated the data quality to ensure high accuracy and examined the different factors influencing it. One important feature of TLS-based object acquisition and modeling is data quality, which is used to determine the compatibility for a specific application. Some publications on the data quality of TLS, mainly concerning geometric accuracy or reflectivity of standard targets or color tables, are found in the literature; e.g., Lichti and Harvey, 2002 investigated range measurement distribution and return intensity of several dry and wet samples of construction materials and rocks having various surface roughness and mineral composition and traditional survey targets, while Boehler et al., 2004 discussed angular and range accuracies and surface reflectivity of 7 different spray painted surfaces using 7 distinct instruments.

Whereas Kersten et al., 2005 tested the trunnion axis error, the dispersion of points, and its correlation with the intensity and object surface characteristics of RAL (Reichs-Ausschuss für Lieferbedingungen) colors and the geometry recognition of selected objects. On the other hand, Clark and Robson, 2004 investigated the data and noise distributions with rotation and changes in range or intensity of return signals of color patches and building materials having various colors and textures and scanned at varying ranges and angles, the same as Hanke et al., 2006 who tested the correlation between the bias of the individual color planes as well as the noise of the point measurements with the resulted intensity values of 192 different RAL colors.

Whereas others discuss a different aspect of quality assessment - as an extension of previously published investigations - the influence of different realistic object materials and object colors on TLS range measurements. While Amiri, Gruen, 2005 and Lichti and Licht, 2006 discussed sensor model self-calibration and error modeling to calibrate the resulted 3D coordinates.

Apart from geometric accuracy, the effects on recorded intensity levels have also been investigated. For example, Voegtle et al., 2008 examined the effect of different realistic objects (colored sheets, five different wood species having the same surface roughness, same color plaster materials with 4 different particle sizes, light transmissive materials having different transparency levels, metal plate (acquired at different incidence angles) and finally the influence of the wetness of wood and concrete wall) on the range measurements and intensity values at daytime and night-time.

While Schwartz, 2017 investigated the influence of other materials (nine distinct glass samples, two plastic samples, steel perforated plate, clear glass, opaque plastic, and cardboard), each measured at different distances with different incidence angles, on the standard deviations of the range measurements obtained from the fitted plan for each sample.

Besides, Bolkas, 2017 did not only analyze the plane residuals of different colored industrial particle boards but also having different sheens at different distances, incidence angles, and lighting conditions (indoor and outdoor) using two distinct laser scanners. Furthermore, Sabiha, 2022 due to the purpose of autonomous vehicles, was mainly concerned with the intensity values of two distinct materials (orange PVC cone and brown cardboard), each painted with two colors and detected at different distances.

Apart from all the mentioned methods, the paper addresses a different aspect of determining the effect of different colored materials on the measurements obtained from TLS.

2. DATASETS and INSTRUMENTS

Six blocks (each is approximately 10 cm * 10cm) were used in order to examine the effect of different materials, or even different colors within the same material, on the measurements obtained from laser Scanning, three of them made of wood and the other ones were made of iron (as shown in figure 1), as they are of the most common realistic materials found profusely in nature, as used for buildings facades, while data acquisition. Measurements were investigated on the raw material and the same material after being painted with white and black colors.

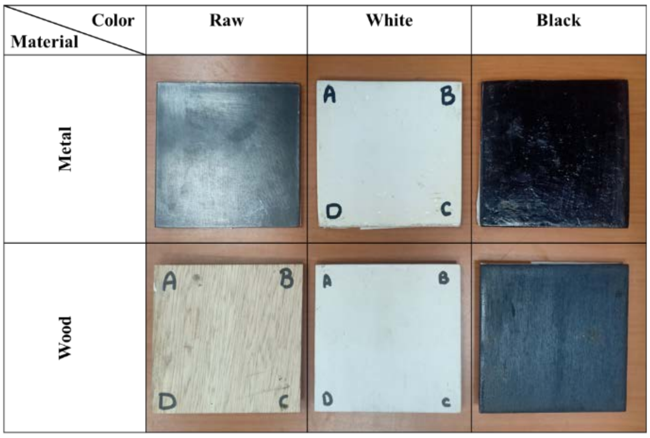

Figure 1: The six wooden and metallic blocks used (RGB).

The TLS used is FARO S-150 plus having an angular accuracy of 19 arcsec for vertical/horizontal angles and the laser is of class 1. The scanner is designed to scan objects in a distance range between 0.6 meters and approximately 150 meters and the speed is up to 2 million points per second. The instrument is integrated with multi-sensors which are GPS, compass, height sensor, dual axis compensator, a built-in 8 mega-pixel, HDR-camera which captures detailed imagery providing a natural color overlay.

Figure 2: Faro S150 Plus Laser scanner.

Table 1: Technical specifications of Faro S150 Plus laser scanner.

Measurement principle	Phase-based
Wave-length	1550 nm
Spot size at front window	2.12 mm
Highest resolution	1.5 mm (10 m)
Max. distance	150 m (90% reflectivity)
Accuracy Positioning Range	± 2 mm (10 m), ± 3.5 mm (25 m) ± 1 mm
Scan field	360° (H) 300° (V)
Scan rate	Up to 2 million pts/sec

3. METHODOLOGY

In contrast to previously mentioned papers, another aspect was concerned where the effect of two different materials with different colors on the lidar measurements was investigated.

Six Scans were acquired using Faros 150 Plus laser scanner, which was the most suitable one to be used according to the test requirements, where each block of material scanned was found in only one scan, for each distance, and all acquired at the same intervals (at 1m, 5m, and 10 m from the scanner), with laser being fired in orthogonal direction, with respect to the targets being scanned, and indoor while ensuring the same lighting and weather conditions and the resolution used in acquisition is “1/2”.

(a) (b) (c)

Figure 3: Scanner positions for three cases studied (a- at 1 m, b- at 5 m and c- at 10 m, respectively).

Figure 4: Measuring the dimensions of each block using the vernier.

After that a vernier, of 0.05 mm least count, was used in order to obtain precise measurements for all the sides of each block and each side was measured again, after processing using the precise measurements for all the sides of each block and each side was measured again, after processing using the available measurement tools in the Faro scene 2019 software to find the differences between the actual measurements by the vernier and those obtained from the processed scans.

4. RESULTS

The tables from 2 to 7 show the dimensions measured by the vernier for each color in both materials, the dimensions resulted from the software used (Faro Scene) and the difference between them which is also specified for each distance interval.

Vernier and software measurements are in centimeters while the differences are shown in millimeters and the figures from 5 to 10 show a better visual interpretation of the results differences compared with others from the same color or material.

Table 2: Dimensions and resulted differences of the raw wooden block.

Raw Wood		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.025	10.05	10.03	10.045
At (1) m	Software (cm)	10.07	10.09	10.08	10.08
	Difference (mm) (software-vernier)	0.45	0.4	0.5	0.35
	Mean Difference (mm)	0.425			
At (5) m	Software (cm)	10.13	10.16	10.06	10.07
	Difference (mm) (software-vernier)	1.05	1.1	0.3	0.25
	Mean Difference (mm)	0.675			
At (10) m	Software (cm)	10.17	10.21	10.12	10.22
	Difference (mm) (software-vernier)	1.45	1.6	0.9	1.75
	Mean Difference (mm)	1.425			

Table 3: Dimensions and resulted differences of the white colored wooden block.

White wood		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.03	10.075	10.035	10.06
At (1) m	Software (cm)	10.05	10.10	10.06	10.08
	Difference (mm) (software-vernier)	0.2	0.25	0.25	0.2
	Mean Difference (mm)	0.225			
At (5) m	Software (cm)	10.18	10.22	10.13	10.23
	Difference (mm) (software-vernier)	1.5	1.45	0.95	1.7
	Mean Difference (mm)	1.4			
At (10) m	Software (cm)	10.18	10.29	10.18	10.23
	Difference (mm) (software-vernier)	1.5	2.15	1.45	1.7
	Mean Difference (mm)	1.7			

Table 4: Dimensions and resulted differences of the black colored wooden block.

Black Wood		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.115	10.155	10.13	10.10
At (1) m	Software (cm)	10.08	10.14	10.1	10.07
	Difference (mm) (software-vernier)	-0.35	-0.15	-0.3	-0.3
	Mean Difference (mm)	-0.275			
At (5) m	Software (cm)	10.04	10.08	10.05	9.92
	Difference (mm) (software-vernier)	-0.75	-0.75	-0.8	-1.8
	Mean Difference (mm)	-1.025			
At (10) m	Software (cm)	9.94	9.95	9.93	9.96
	Difference (mm) (software-vernier)	-1.75	-2.05	-2.0	-1.4
	Mean Difference (mm)	-1.8			

Table 5: Dimensions and resulted differences of the raw metallic plate.

Raw Metal		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.015	10.17	10.02	10.035
At (1) m	Software (cm)	9.94	10.08	9.94	9.95
	Difference (mm) (software-vernier)	-0.75	-0.9	-0.8	-0.85
	Mean Difference (mm)	-0.825			
At (5) m	Software (cm)	9.89	9.91	9.87	9.91
	Difference (mm) (software-vernier)	-1.25	-2.6	-1.5	-1.25
	Mean Difference (mm)	-1.65			
At (10) m	Software (cm)	9.74	9.88	9.73	9.75
	Difference (mm) (software-vernier)	-2.75	-2.9	-2.9	-2.85
	Mean Difference (mm)	-2.85			

Table 6: Dimensions and resulted differences of the white colored metallic plate.

White Metal		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.025	9.985	10.03	10.09
At (1) m	Software (cm)	9.98	9.93	9.97	10.03
	Difference (mm) (software-vernier)	-0.45	-0.55	-0.6	-0.6
	Mean Difference (mm)	-0.55			
At (5) m	Software (cm)	10.07	10.23	10.08	10.39
	Difference (mm) (software-vernier)	0.45	2.45	0.5	3.0
	Mean Difference (mm)	1.6			
At (10) m	Software (cm)	10.29	10.18	10.3	10.2
	Difference (mm) (software-vernier)	2.65	1.95	2.7	1.1
	Mean Difference (mm)	2.1			

Table 7: Dimensions and resulted differences of the black colored metallic plate.

Black Metal		AB	BC	CD	DA
Vernier measured dimensions (cm)		10.125	10.015	10.07	10.02
At (1) m	Software (cm)	10.06	9.95	9.97	9.93
	Difference (mm) (software-vernier)	-0.65	-0.65	-1.0	-0.9
	Mean Difference (mm)	-0.8			
At (5) m	Software (cm)	9.98	9.91	9.96	9.92
	Difference (mm) (software-vernier)	-1.45	-1.05	-1.1	-1.0
	Mean Difference (mm)	-1.15			
At (10) m	Software (cm)	9.8	9.81	9.89	9.92
	Difference (mm) (software-vernier)	-3.25	-2.05	-1.8	-1.0
	Mean Difference (mm)	-2.025			

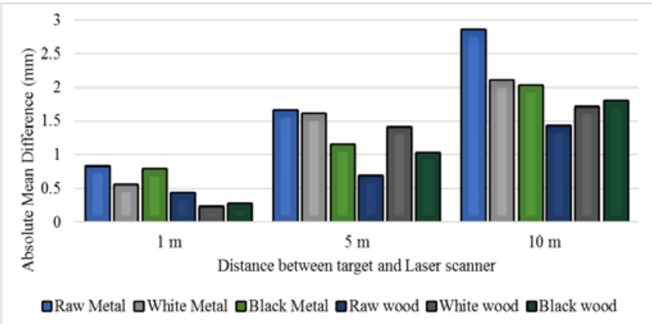

Figure 5: Mean differences for the different colored materials investigated.

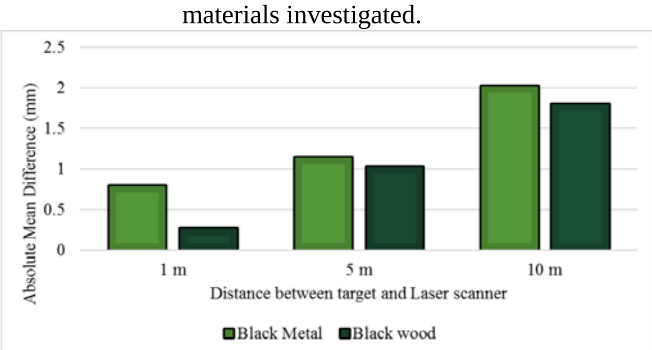

Figure 6: Mean differences for the black colored materials.

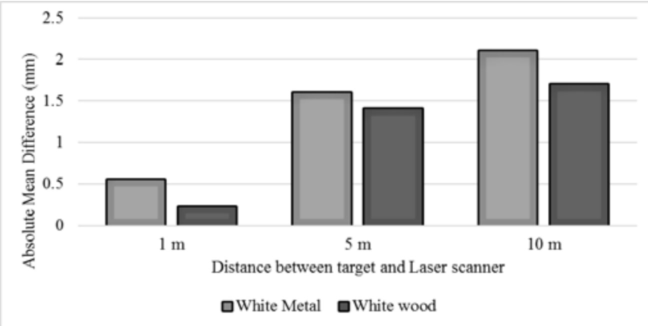

Figure 7: Mean differences for the white colored materials.

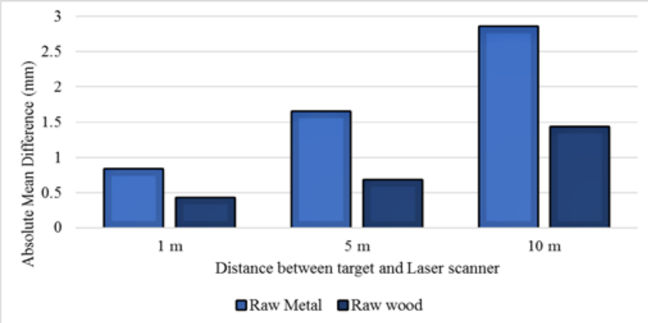

Figure 8: Mean differences for the raw materials.

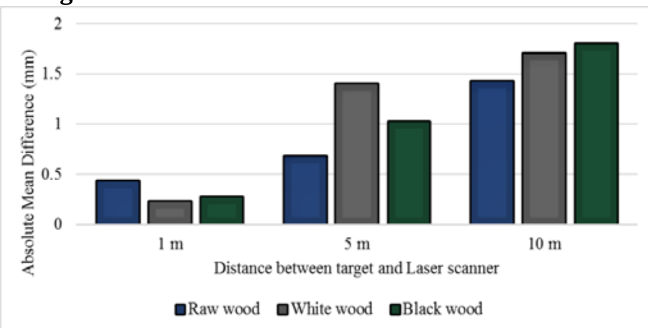

Figure 9: Mean differences for the investigated wooden blocks.

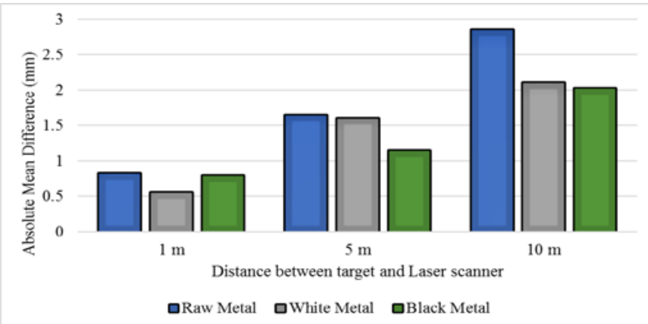

Figure 10: Mean differences for the investigated metallic blocks.

5. CONCLUSION

The quality of the laser scanned data may be impacted by many factors some of them may be materials or even colors within the same material. There are a lot of applications that are concerned with scanning building facades made of various materials which arose the idea of finding these effects to deal with them within this type of applications that discusses reliable measurements.

Our short-range experiments revealed that assessing different colors (raw, black, and white) for wood and metal materials yielded different laser measurement values, which depends on light reflection and radiation absorption. For all experiments, the mean differences show a directly proportional correlation with the scanning distance. While the resulted mean difference of raw metal is significantly larger than that of raw wood as shown in figure8.

The metal experiments for the raw material, despite having the highest absolute mean difference value over the other examined colors, and the black colored one proved that all laser measurements yielded lower values, than that measured by the vernier, while the white one yielded slightly higher values (figure 10). On the other hand, the wooden blocks experiments for raw and white colors revealed that all laser measurements yielded slightly larger (lower accuracy) values than that measured by vernier, while black color yielded slightly less values despite having the highest absolute mean difference value over the other wooden blocks examined (figure 9).

The average differences resulted in all the experiments indicate that the higher values are for metal which means that their resulted measurements are less accurate compared to that from wood as clearly shown in figure 5. As well as the results from the same material, metal, the raw one has the least accuracy while the white one has nearly the highest accuracy. In contrast, the results from the wooden blocks do not indicate a certain accuracy level for each color but the amount of error is randomly found for each distance investigated.

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