Quality Assessment of 3D Point Clouds on the Different Surface Materials Generated from iPhone LiDAR Sensor

Razali, M I.,[1] Idris, A. N.,[1]* Razali, M. H.[1] and Syafuan, W. M.[2]
[1]Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
E-mail: ahmad_norhisyam@uitm.edu.my*
[2]Department of Civil Engineering, National Defence University of Malaysia, 57000 Kuala Lumpur, Malaysia
**Corresponding Author*

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Abstract
Terrestrial Laser Scanning (TLS) is a powerful device that can capture 3D reality faster than ever before. For more industry nowadays, this equipment assists a lot in analyzing issues from artifacts, structures, buildings, and landscapes at required accuracy and precision depending on the applications. Nonetheless, the costs and complexity of TLS in many fields remain high. With the invention of the iPhone 12 Pro's new Light Detection and Ranging (LiDAR) sensor, and the increased capability of the iPhone's camera array system, the generation of 3D point clouds using this sensor led to several studies on their capability and resulting accuracy for some applications in Architecture, Engineering and Construction (AEC) industries, especially in planning and decision-making purposes towards 3D reconstructed model. Generally, this 3D model is incorporated from different surface materials which have different results when scanning via laser scanning platform. Therefore, several tests were conducted on the iPhone 12 Pro at different surface materials (e.g., plywood, aluminium, canvas, plastic board, and ceramic tile), where the density of 3D point clouds and accuracy of distance measurements generated by iPhone 12 Pro were used as the parameters of quality assessment while comparison to TLS served as reference data. The 3D scanning sessions on different object materials were carried out in a small classroom, approximately 100m^2 where each object has its specific dimension and being placed side by side with each other. According to the test outcomes, the LiDAR sensor of iPhone 12 Pro was able to generate a good density of 3D point clouds which produced proximate value of actual object dimensions using meshing process in CloudCompare Software. Therefore, it can be seen that the output of 3D model generated from iPhone LiDAR Sensor is sufficed to replicate the 3D indoor building environment at small coverage area.

1. Introduction

Laser scanning is a common land surveying tool for accurately measuring and collecting data from artifacts, structures, buildings, and landscapes. This emerging instrument is incrementally used in the AEC industries which improve the productivity and management efficiency of several field disciplines (Telling et al., 2017). The principle of laser scanning was defined by Böhler and Marbs (2002) in which the laser lights are used to measure distance from the sensor to the object. It operates by pulsing a ray of light that rotates vertically 270 degrees and horizontally 360 degrees. The light shall be mirrored backwards when any surface touching and registered as a data point that assigns a reflection of colour and surface. To be able to read the data, the 3D point clouds which are composed from millions of 3D coordinates (XYZ coordinates) could be used to provide a precise and detailed image of the environment.

In this study, two datasets were applied from Terrestrial Laser Scanning (TLS) and iPhone LiDAR sensor. Generally, TLS is a well-established method for collecting 3D data on a small scale (Jaboyedoff et al., 2012, Riquelme et al., 2021, Suchocki and Katzer, 2018 and Wu et al., 2021). TLS, also known as terrestrial LiDAR, determines the XYZ coordinates of numerous locations on the ground by delivering laser pulses to all spots while measuring the distance between instrument and the target. Classifying terrestrial laser scanner is possible on the basis of the measuring concept (i.e. triangulation, step, pulse) or the technical criteria obtained (Frohlich and Mettenleiter, 2004). For all possible uses, there is no universal laser scanner.

Certain scanners are well-suited for use in indoor as well as medium-sized operations. Other scanners with a longer range (up to 100 m) are more suited for outdoor use, although close-range scanners with excellent precision are also available (up to a few metres). Multiple geodetic measurements are the most popular use of the models generated with TLS (Spreafico et al., 2021).

Recently, the generation of 3D point clouds using smartphones have been introduced since the last decade. According to Sirmacek and Lindenbergh (2014), the production of point clouds using iPhone 3GS smartphone sensor data might be a quick, low-cost, and less complex as compared to TLS, which then could enhance 3D reconstructed model by incorporating a smartphone-generated point and conduct several assessments on the quality of 3D point clouds in terms of density, point-to-point distance and local roughness values between iPhone and TLS. In our study, the focuses are on the evaluation of the density of 3D point clouds and the accuracy of distance measurement from mesh 3D point clouds at different surface materials generated from the iPhone LiDAR sensor and comparison to TLS was for a reference data.

2. Methodology

The general methodology for this research starting from the planning and area selection, data collection and processing, result and analysis until to conclusion and recommendations. Figure 1 shows the general methodology for this study.

2.1 Project Planning

In this stage, the selection of study area, materials, instruments, processing software and research design were decided to ensure the study run smoothly. Such conditions on study area, types of instruments and surface materials plus the software selection have been considered for an ideal condition at the standard operating procedure when conducting the laser scanning task.

2.1.1 Study area

An indoor environment of small classroom area was selected to carry out the tests. This classroom is located in Universiti Teknologi MARA (UiTM) Shah Alam, Malaysia and labelled as B516 due to the block name and level. The area of this classroom is approximately at $100m^2$ and can accommodate 60 people at one time. There is sufficient lighting in this space which suitable to scanning the objects using TLS and iPhone 12 LiDAR sensor. Therefore, all the object materials were arranged in this classroom side by side for a better scanning scenario. Figure 2 shows the view of B516 classroom and the arrangement of the object materials to be tested.

2.1.2 Instruments

For the data capture, the Leica RTC 360 (TLS) and iPhone 12 Pro (iPhone LiDAR sensor) were selected. For Leica RTC 360, it can apply a real time registration by using its high-speed 3D laser scanner with integrated HDR spherical imaging system and Visual Inertial System (VIS).

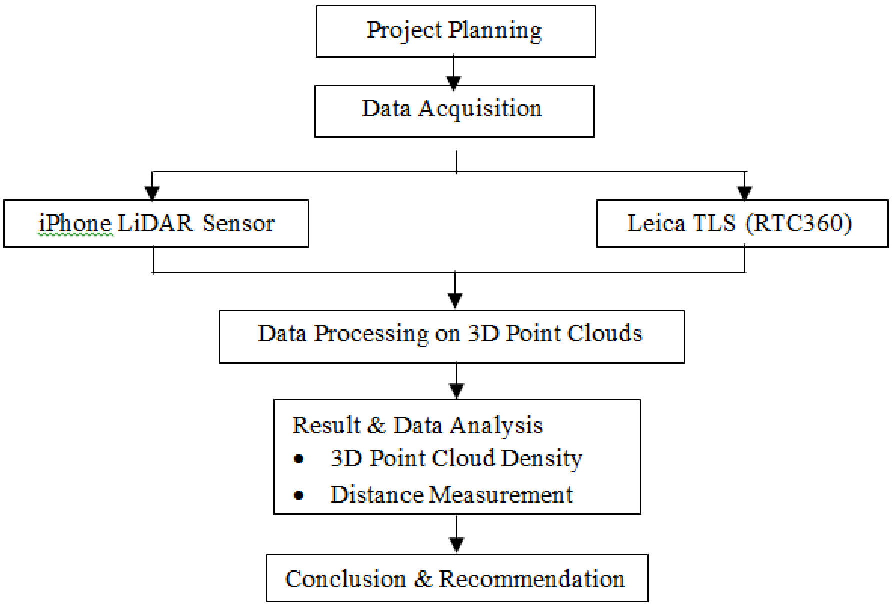

Figure 1: General methodology

Figure 2: The view in B516 Classroom

This device is able to capture 3D point clouds up to 2 million points per second at the range accuracy of 1.0 mm + 10 ppm. Also, this scanning device has different 3D point accuracy which are divided into three classes ranging from 10m, 20m and 40m at 1.9mm, 2.9mm and 5.3mm respectively.

On the other hand, the iPhone 12 Pro uses a scanner-type LiDAR sensor which applied flash illumination and no scanning method for data acquisition. With the integration of 8XX nm wavelength, Photon Counting detectors or known as SPADs or Single Photon Avalanche Photodiodes, plus the Vertical Cavity Surface Emitting Lasers (VCSELs), this device is able to capture point clouds in a short period of time, but has a limited Field of View (FoV) which at ~ 5m range distance between sensor and object and perfectly adequate for the types of consumer applications. Due to these specifications, it is a good thing to have several tests on the quality obtained from the 3D reconstruction at different surface materials within 5m range of scanning scenario where the main focuses are given to the density and the accuracy of distance measurement gathered from the 3D point clouds.

2.1.3 Surface materials

Several different surface materials were selected in this study. The selections are made up among the most often used in construction materials. Plywood, aluminium, canvas, plywood board marker, plastic board and ceramic tile were being used for scanning sessions. Table 1 shows the object materials used with their chracteristics.

2.1.4 Software and applications

During the fieldwork session, the Leica Cyclone FIELD 360 was used as the software to run the scanning session by the TLS.

For the post-processing session, the Leica Cyclone REGISTER 360 was utilized for reconstructing the 3D model which replicating the real environment of B516 classroom. Meanwhile, the 3D Scanner Apps was used for data capture using iPhone LiDAR sensor. For the result and analysis to achieve the objectives, the CloudCompare software was applied to the 3D point clouds generated from both TLS and iPhone LiDAR sensor in terms of point density and accuracy of distance measurements.

2.2 Data Acquisition

For TLS, two scanning stations were applied to get the 3D reconstruction environment in B516 classroom. Meanwhile, for iPhone LiDAR sensor the scanning sessions were made within 5 metres from each of surface materials due to the best scanning distance as suggested by the manufacturer. All the fieldwork setting parameters in both instruments were set as default for obtaining the standard results.

2.3 Data Processing

For the TLS, the Leica Cyclone FIELD 360 software was used on-site to connect direct 3D data acquisition inside the line of work with the RTC360 laser scanner where it can capture, register, and assess the scans as well as image data automatically on-site. Next, at the office, the Leica Cyclone REGISTER 360 was applied for data processing where it can automatically place project data on real-world coordinates with complete registration process. For iPhone LiDAR sensor, it started with 3D Scanner Apps to capture and view 3D point clouds as scanned at on-site and converted them into various formats depending to the analysis software of 3D point clouds to be used.

Table 1: Types of object materials

Types of Object Surfaces	Dimension	Characteristics
1. Plywood 	1m x 1m	Low reflectivity with dull in colour and high absorption material.
2. Aluminium 	1m x 1m	High reflectivity with smooth and shiny surface.
3. Canvas 	0.3m x 0.3m	The surface is thin and dry, with a high absorption strength and reflective material.
4. Plywood Board Marker 	0.6m x 0.6m	Hard and medium rough surfaces. Low reflectivity and high absorption by its dull surface.
5. Plastic Board 	1m x 1m	High transparency which good for light scattering.
6. Ceramic Tile 	0.3m x 0.3m	Medium reflectivity, glossy and iridescence.

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Lastly, all the datasets output from both scanning sensors were uploaded into CloudCompare software which was used to view the point cloud datasets from both sensor in one screen as well as creating 3D reconstruction model, cropping process, obtaining point cloud density and measuring the distance lines for each surface material.

3. Result and Analysis

3.1 Point Cloud Density for Aluminium

Referring to Figure 3, the 3D reconstruction object for aluminium on both instruments produced an actual shape after the mesh process applied. The mesh of 3D reconstructed model from TLS produced a real good surface while some black spots were presented in iPhone LiDAR sensor which indicates some missing point clouds that did not reflected back to the sensor. The density of point clouds using TLS and iPhone LiDAR sensor was measured at 469,856 points and 9745 points respectively in $1m^2$ of dimensional area.

3.2 Point Cloud Density for Plastic Board

Plastic board is an object that has a low reflectivity, high in absorption, dull in colour and less tough than other surface materials. These made the distribution of point clouds unevenly scattered. It is dull in colour and less tough than other surface materials. As the comparison, the meshing process going smoothly which resulted in almost similar model in both iPhone LiDAR sensor and TLS instrument (Figure 4). All the white lines of reflection can be seen in both images and it is a quite good achievement for the iPhone LiDAR although the black spots can be seen clearly. The point clouds density for TLS is 380,612 while 9928 for iPhone in $1m^2$ of dimensional area.

3.3 Point Cloud Density for Canvas

Referring to Figure 5, the 3D meshes for canvas in iPhone LiDAR was successfully reconstructed at the actual object shape appearance. However, the blurred image of center point mark in the 3D meshes was identified for both datasets, especially for the iPhone LiDAR sensor. This is due to a high absorption surface that resulting to the slower rate of reflected points reached the instrument. Meanwhile, the density of 3D point clouds in the TLS and iPhone were calculated at 112,410 points and 845 points respectively in $0.09m^2$ of dimensional area.

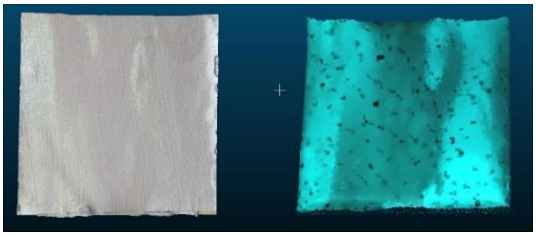

Figure 3: Point clouds distribution for Aluminium using TLS (left) and iPhone (right) in CloudCompare Software

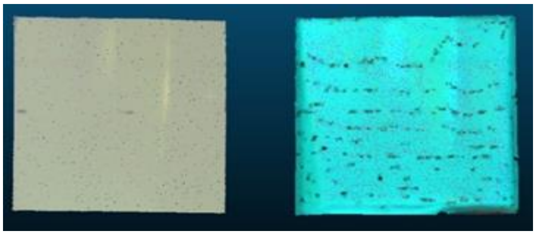

Figure 4: Point clouds distribution for plastic board using TLS (left) and iPhone (right) in CloudCompare Software

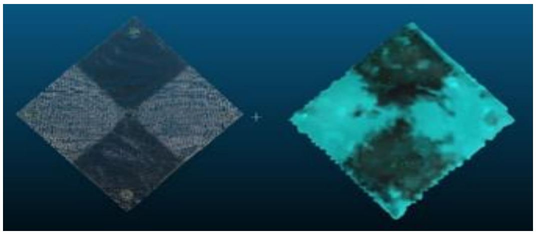

Figure 5: Point clouds distribution for Canvas using TLS (left) and iPhone (right) in CloudCompare Software

3.4 Point Cloud Density for Plywood of Board Marker

Figure 6 showed the object reconstruction for plywood of board marker. It can be seen that the 3D meshes of iPhone LiDAR sensor have a close real shape even there was some black spots representing the missing point clouds. However, most of the point clouds are constantly reflected back to the instrument. For point clouds density, the TLS and iPhone LiDAR sensor were recorded 194,167 points and 3,539 points respectively in $0.36m^2$ of dimensional area.

3.5 Point Cloud Density for Plywood

Referring to Figure 7, the 3D meshes of plywood was closely reconstructed at real shape. It was discovered that the laser beam transmitted precisely on the object surface and reflected well to the sensor. Due to the absence of moisture on this plywood surface, the point clouds were reflected in a consistent direction. The density of 3D point clouds for TLS and iPhone LiDAR sensor was recorded 416,359 points and 10,958 points respectively in $1m^2$ of dimensional area.

3.6 Point Cloud Density for Ceramic Tile

For this type of surface, the 3D meshes presented from the iPhone LiDAR sensor didn't well reconstructed due to less reflected point clouds similarly to canvas surface (Figure 8). The color of black (low reflectance) and white (high reflectance) in one object surface was also contribute to less quality of 3D point clouds output which deal with 3D point clouds density. For the point cloud density using TLS, it is recorded as much as 42,720 points while 859 points for iPhone in $0.09m^2$ of dimensional area. As overall, the 3D point density for all types of surface materials can be concluded as shown in the Figure 9. Referring to the TLS datasets, the densest point clouds was the aluminium, plywood and plastic board as regard to the $1m^2$ dimensional area, followed by plywood board marker ($0.36m^2$), canvas and ceramic tile for $0.09m^2$. Even tough the difference in dimensional area, the values are still reasonable if equalized with percentage. This result is the benchmark for 3D point clouds dataset as the TLS provides the high accuracy of laser scanning measurement. However, different result has been obtained for the iPhone LiDAR sensor where the densest point clouds was the plywood, plastic board, and aluminium for $1m^2$ dimensional area, followed by plywood board marker ($0.36m^2$), while both ceramic tile and canvas which at $0.09m^2$ dimensional area have a slightly difference of the number of 3D point cloud density.

3.7 Accuracy of Distance Measurements from Different Surface Material

In this stage, several samples of measurement were obtained from different surface materials between the TLS and iPhone LiDAR sensor. The method to measure this distance is by pointing to the corner of the object surface in CloudCompare software on-screen whereby the pick-point is referred to 3D point cloud after meshing process. Two measurements were done for each surface material which labelled as Line 1 (L1) and Line 2 (L2).

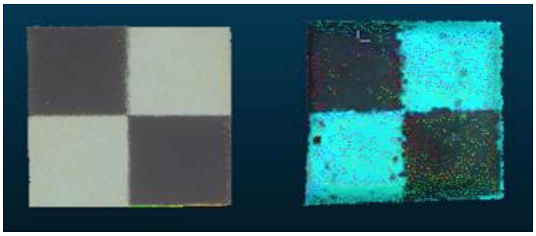

Figure 6: Point clouds distribution for plywood of board marker using TLS (left) and iPhone (right) in cloud compare software

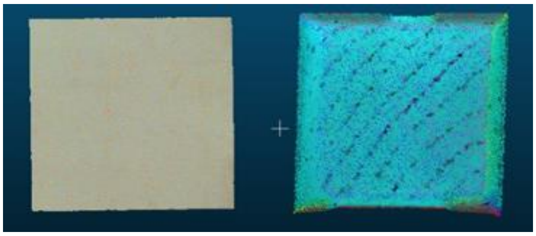

Figure 7: Point clouds distribution for plywood using TLS (left) and iPhone (right) in cloud compare software

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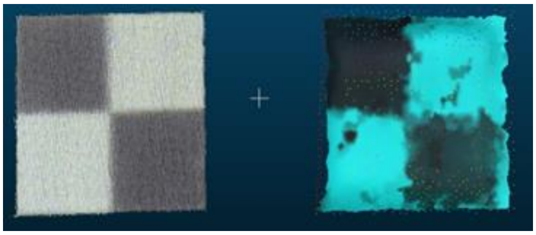

Figure 8: Point clouds distribution for ceramic tile using TLS (left) and iPhone (right) in cloud compare software

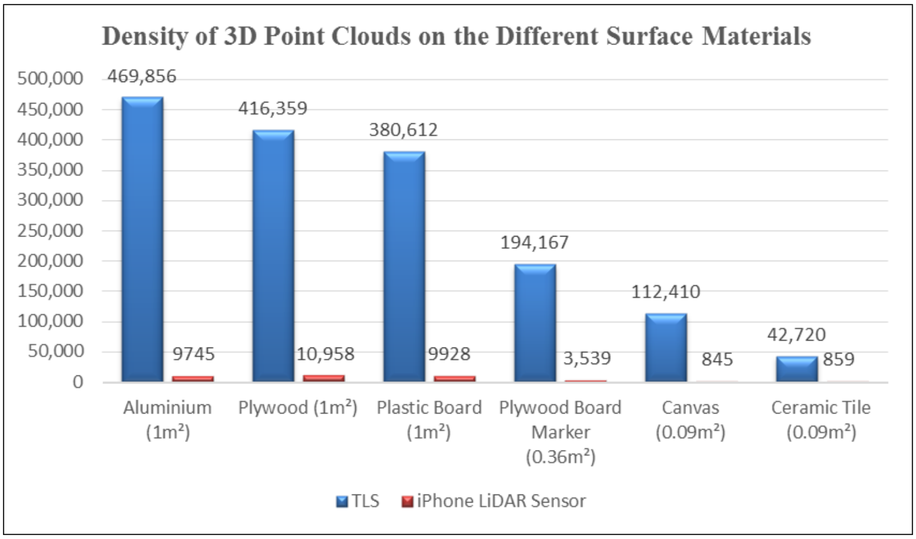

Figure 9: Density of point clouds for each surface material between TLS and iPhone LiDAR sensor

Table 2: Root Mean Square Error (RMSE) for different surface materials

	TLS	iPhone LiDAR Sensor	Difference (±)
Aluminium (L1)	1.004	0.989	0.015
Aluminium (L2)	1.002	0.985	0.017
Plastic Board (L1)	0.996	0.972	0.024
Plastic Board (L2)	0.998	0.981	0.017
Canvas (L1)	0.299	0.267	0.032
Canvas (L2)	0.297	0.271	0.026
Plywood Board Marker (L1)	0.599	0.589	0.010
Plywood Board Marker (L2)	0.602	0.610	0.008
Plywood (L1)	0.998	1.008	0.010
Plywood (L2)	0.999	0.994	0.005
Ceramic Tile (L1)	0.297	0.284	0.013
Ceramic Tile (L2)	0.296	0.279	0.017

Basically, each object surface was cutting into rectangular shape with fix dimension (i.e., aluminium 1m x 1m; plastic board 1m x 1m; canvas 0.3m x 0.3m; plywood board marker 0.6m x 0.6m; plywood 1m x 1m; ceramic tile 0.3m x 0.3m). It can be seen that most the values of different distance measurements at various surface materials were below than 50cm (Table 2). The lowest difference was detected at plywood (L2) with just 5mm, while the highest difference was recorded at canvas (L1) with 32cm. From these results, it can be seen that the iPhone LiDAR sensor could be used for reconstructing 3D environment, specifically for small indoor space within the acceptable accuracy for mapping applications such as *Building Information Modeling (BIM)*. However, the range of distance between sensor and the object surface should be maintained within 5m to ensure the output of 3D model meets the standard quality.

4. Conclusion

As the conclusion, this study managed to compute meshing process in both Leica RTC360 laser scanning and iPhone 12 Pro LiDAR scanner using the suitable software, CloudCompare. By using the result in CloudCompare software, the density histogram of 3D point clouds has been used to get the information of the density of 3D point clouds depending the dimensional area per surface materials. It can be seen that the factors of roughness, reflectivity strength, colors, texture and type of surfaces were influenced the reaction of the 3D point clouds when reaching the surfaces (Hezri Razali et al., 2021). This has been proved from the number of 3D point clouds at each of surface materials as discussed earlier. Next, this study also managed to identify the capability of iPhone 12 Pro LiDAR Sensor in measuring feature dimensions from different object materials as compared to ideal measurement using Terrestrial Laser Scanner (TLS). The RMSE for the data in both instruments have been calculated using the right formula in order to determine the best object surfaces that has the least error which close to 0 value and the denser point clouds has resulted a good accuracy of distance measurements using 3D mesh images. It showed that the iPhone LiDAR sensor is capable to provide a better accuracy of below than 50cm within a small space of indoor environment, approximately at $100m^2$ room area. This research also succeeded in identifying the interaction between point clouds and the properties of the surface materials which influence the diversion of different point clouds emitted and reflected back to the scanning sensor.

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