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The influence of the incident angles variation on the accuracy of TLS point cloud based on surface reflectivity and roughness

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ABSTRACT

The accuracy of measuring TLS point clouds depends on the measuring travel time, range detector, and surface properties. TLS conducted interesting experimental tests to examine the effect of different scanned materials in terms of reflectivity and surface roughness on the quality of the measured TLS data at different incident angles. Different types of materials specifically (wood, glass, steel, Ekoplast, and adhesive total station target) were selected for this purpose. During the experiments, 24 scans were measured as the selected four materials scanned at six incident angles (0˚, 15˚, 30˚, 45˚, 60˚, and 75˚) while the range was fixed to about 5m. The experiment's results reveal that smooth surfaces are more highly affected by the accuracy of the measured 3D point clouds than rough surfaces at different incident angles. At 0˚ incident angle, the total station target reflects about 20cm closer to the scanner than the other materials; this difference decreases with increasing incident angle. At 75˚ incidence angle, the difference decreases to become approximately 2mm in comparison to the other materials. The maximum RMSE of rough materials is less than 1cm except for wood material at 30˚, while the Maximum RMSE for smooth materials reaches 4cm in 45˚ glass material. Furthermore, different materials have different intensities, both smooth materials, glass and steel, have different levels of accuracy due to different properties. The minimum RMSE in glass is 1.47cm, and the maximum RMSE for steel reaches 1.17cm.

KEYWORDS: Different Materials; Incident Angle; Point Cloud Quality; Reflectivity; Roughness; and Terrestrial Laser scanner

1 INTRODUCTION

Laser scanner systems basically conduct two-way travel times (Time of Flight TOF) to measure the range/distance (ρ) from the scanner to the scanned objects. Usually, reflector-less scanner systems are preferred in the scanning procedure as it means that there is no need to place the targets on the surface of the objects to be measured. Hence, The range depends on the amount of sufficient returned signal from the object to the scanner's photo-detector. So, the material's properties have an impact on the amount of reflecting signal to the scanner range finder.

To create an accurate 3D model of the objects, there aremany techniques various between the traditional method and modern methods. The most common and new techniques are image-based and laser-based techniques using a camera and sensor (T. On Chan & Lichti, 2012). Terrestrial Laser Scanning (TLS) is the most recent and accurate technique that is used in this field.

Interestingly, many factors affect measured point clouds, such as instrumental effects, weather condition effects, the geometry of the measurement, and properties of materials. High measuring data, high spatial density data, and accuracy of reflector-less natural scanning system are some of the attractive properties of the scanners. However, it was influenced by some effects that are considered a real problem like the geometry of the instrument (Tan et al., 2018), oscillating mirror problem (Bae & Lichti, 2007), beam divergence (Soudarissanane et al., 2009), incident angle (Soudarissanane & Ree, 2007), calibration process (Abbas et al., 2014) and (Ting On Chan et al., 2015), and instrument type based on the manufacturing company like Faro, Leica, Topcon, and Trimble.

On the other hand, scanning geometry is one of the major factors that affect the quality of the measured point clouds, such as distance and incident angle (Amer et al., 2018), (Soudarissanane & Ree, 2007), (Derek D. Lichti & Harvey, 2002). While there were many other problems during the processing of data in the registration and georefrecessing process, targets method process and some software obstructions (Bae & Belton, 2012), (Murtiyoso & Grussenmeyer, 2018),(Abdurrahman Farsat1* et al., 2014), (Abbas et al., 2014), (Date et al., 2019), (Steinvall, 2007) (Jr et al., 2017). Documenting and applications of some materials were made from different materials scanned for different purposes such as deformation monitoring (D. D. Lichti et al., 2000), (Hartmann & Alkhatib, 2023) assessment of the bridge structure (Gordon et al., 2000), and measurement building facades (Balzani, n.d.), (Helios-Rybicka & Förstner, 1986). Obviously, Scanning these kinds of objects provides different accuracies due to color's effects, quality of the surface and its materials type. (Huang et al., 2023), (Julin et al., 2020) (Huo et al., 2023).

This research focuses on conducting different scans with particular specifications for different materials in the same weather conditions. It aims to examine the effects of scanning different material surfaces in terms of smoothness and roughness on the quality and accuracy of the measured point clouds at different incident angles with a fixed range between the TLS and objects.

2 MATERIALS AND METHODOLOGY

2.1 Materials

Surface reflectivity and roughness are two significant material properties that possibly have a significant effect on the quality and accuracy of the measured point cloud (Derek D. Lichti & Harvey, 2002) regardless of its nature whether artificial or natural materials.

In this research methodology, four different materials were selected and then prepared for the scanning process. Their selection criteria were based on two main factors: firstly, the most usable material in artificial objects, such as buildings or towers. Secondly, significant variation in the material's surface in terms of reflectivity and roughness. Hence, the selected materials were Glass, steel, wood, and Ekoplast. All of these materials are mostly used in artificial constructions and have a significant variation in their surface roughness.

Prior to the scanning procedure, the characteristics of all selected materials were studied, and all required information was determined, such as the dimensions of the material's sample as follows: glass material used is mackle to reflect the laser beam to the scanner and avoid noises on this material with 6mm thickness and (80cm x 80cm) size dimensions.

In terms of Steel material as it is one of the materials that are mostly used in constructions such as buildings and bridges. Steel's sample has 1.8mm thickness and (80cm x 80cm) size dimensions.

Wood material is also mostly used in construction, such as buildings, doors, bookcases, and lockers. Its sample has only 8mm thickness and the same (80cm x 80cm) size dimensions; it was pure wood material without any painting or covering. Lastly, EkoPlast material is usually used in plastering buildings façade in order to isolate and deposal heat, cold and sound from the building. This kind of material needs to be mixed with water to produce stucco, gypsum and parget products. In addition, it contains some other materials that work as a filtration of heat and cold weather from outside to inside the building and vice versa. Hence, an Ekoplast sample has been prepared for this research with 20mm thickness and also (80cm x 80cm) size dimension.

On the other hand, Glass and Steel materials are considered smooth materials according to the size of the laser scanner beam. At the same time, wood and Ekoplast are two materials considered a rough

surface according to the footprint area of the beam and the Bidirectional Reflectance Distribution Function (BRDF). All of these selected and prepared material samples for this research are shown in
Figure 1

Figure 1.

Finally, for all of the selected materials, five total station targets were fixed on each material's sample in order to examine the effect of the highest reflective and smooth surface materials on the quality of measured point clouds at different scan angles. The type of total station target is a Geoleni Reflective Adhesive sheet target with a size of (4 x 4 cm), and its thickness is about only 1 mm. These targets are totally smooth, and they have the highest reflectance level.

Figure 1: All materials used for scanning in different angles using ScanStation2 materials from left to right are Glass, Steel, Wood, and Ekoplast

2.2 Methodology

PA methodology process of this research was conducted under three main steps: The first step is selecting and preparing a material's samples with required dimensions and manufacturing a required stand for holding the material's sample properly in order to meet the requirements for correct scanning procedure. The second step is the configuration setting of the TLS and fixing range between the stand holder of materials and the scanner station. Finally, as a third step, perform the process of scanning the material's sample with different scan angles. Figure 2 below shows the methodology flowchart conducted to achieve this research aim.

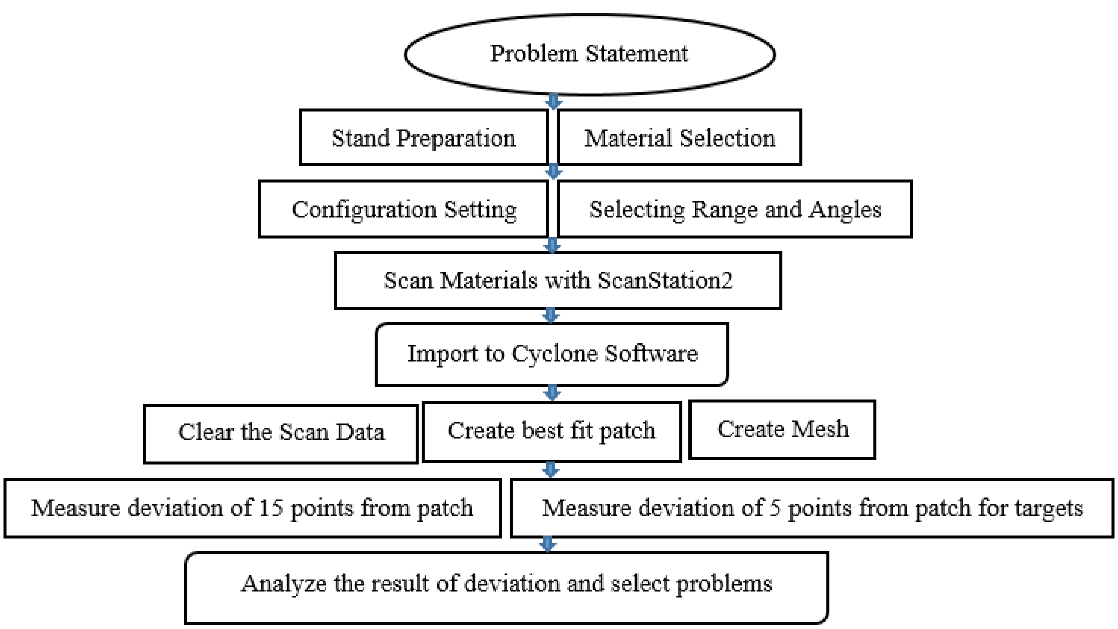


Figure 2: The diagram shows the procedure for measuring and analyzing data

It is important to mention that manufacturing a stand is required in order to achieve good and correct scanning of the material's samples, as it is necessary to control the variation of the scanning angle, keep the material's sample fixed vertically during the scanning process and fixed the range between scanner instrument and material's sample as an observed target. This stand was manufactured from wood material due to its cheap cost and lightweight when it needs to transfer from one place to another. It is designed and structured as two separate parts: The first part (upper), which is a frame (1 x 0.8m) dimensions that is used to insert and fix the material's sample inside it. Interestingly, this frame has been designed to be a removable part from the structure body in order to make the operation of removing or changing, then inserting another material's sample easy and quick. In term of the second part (Lower) is a circular shape stand made from wood material also Figure 3. The height of this part is 50cm from the earth. This part of the structure has two circular bases (up and down); at the center of these two circular bases, two central wholes lie on one vertical line, as shown in Figure 3, in order to achieve the verticality of the removable frame. To control this verticality, the centering laser beam of Topcon total station instrument was used. Also, scan angles were controled by a sharp nail near the edge of the top circular part.

Figure 3: Test the verticality of the stand using the centering vertical laser beam of the total station instrument, two right photos for verticality test, and left image shows the controlling scan angle

2.3 Scanning the Materials

All prepared elected material's samples were scanned at six different incident angles as : (0˚, 15˚, 30˚, 45˚, 60˚, and 75˚), with a fixed distance between the instrument and the material's stand to be about 5m. It means that 24 scans were performaed. Some examples of scanned data are shown in Figure **4**

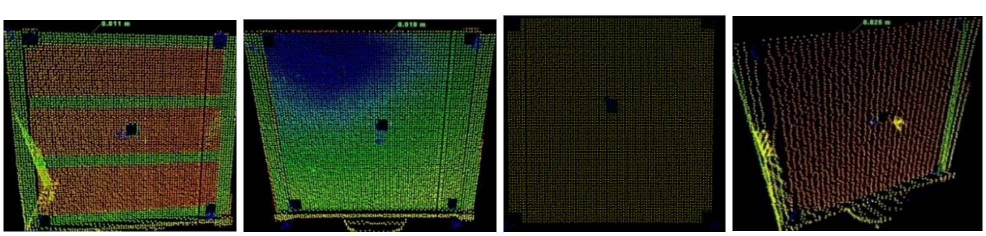


Figure 4: From left to right: Glass, Steel, Wood, and Ekoplast are scanned materials

The ScanStation2 TLS instrument was used for the scanning purposes as its specification prsented in Table 1 below. In addition, Leica license cyclone software were used for storing and analyzing the scanned data that is directly transferred into the connected PC via ethernet cable.

Table 1: ScanStation2 laser scanner specifications

Names	Specifications
Instrument name	ScanStation2, Leica Geo-system, class 3R
Field of view	V. and H angles are 270˚ and 360˚, respectively
Two Scanning window	First, w. -45˚ to 32˚ and second w. 23.5˚ to 90˚
Beam divergence	After 20m from the scanner
Beam diameter	2mm
Scanning model	Pulse-based method
Accuracy of a single measurement	Position 6mm and 4mm distance
Maximum Range	300 m
Scanning rate	Up to 50000 points per second

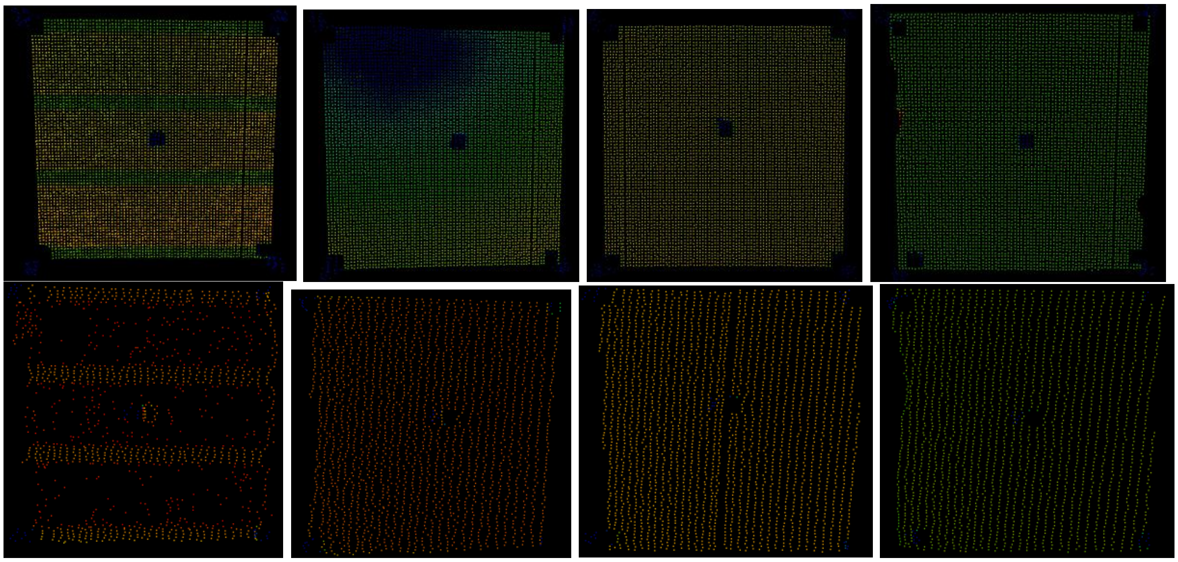
Interesetingly, five adhesive total station targets were fixed on the corners and center of the surface scanned material’s sample in order to examine the effect of highist reflective and smooth sufrace materials on the quality of measured point clouds at different scan angle.

3 RESULTS AND DISCUSSION

TLS is an instrument recently used in many different fields such as monitoring, documentation, building, oil tank calibration, and many other different fields, due to its high accuracy level in scanning objects. However, like other instruments it has no exception form error occurance in measured point clouds. Hence, four different materials (in terms roughness and reflectivity) were scanned at different incident angles in order to examine the extent of their effects on the quality and accuracy of the measured point clouds.

As it has been mentioned before, (glass, steel, wood, and Ekoplast) were selected material’s sample that have been used for conducting experimental tests. It is important to mention as it is noticed that numbers of reflected point clouds are changed according to the heating, roughness, and property of each material. For example, the number of reflected point clouds from glass material was smaller than the number of point clouds reflected from the wood at the same incident angle and distance, due to the significant difference in surface roughness of both materials. In addition, it is obviously noticed that the number of reflected point clouds are dramatically decreases from (glass and steel) materials and gently decreases from (wood and ekoplast) materials when incident angle increases as it can be seen from

Figure **5**. Accordingly, obtained results of each scanned material’s surface are presented and discussed below separately:



A B C D

Figure 5: Scanned Materials at 0˚ and 60˚ scan angle: first row results at 0˚ and second row results at 60˚ scan angle: (A: Glass material, B: Steel material, C: Wood material, and D: Ekoplast material)

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3.1 Scanning Results from Glass Material

Usually, normal mesh grid is created for the collected point clouds from the glass surface. As the main aim of this research is to determin the accuracy of measured point clouds, a best fit patch has been created and then applied on all scanned collected data from the glass surface in order to examin to what extent these collected point clouds in terms of its density are located on the same patch surface and how much of them are located far from this patch suface which in turn translated the accuracy of scanned data from smooth surface (glass). As a result, the effect of incident angle variation on the scanned smooth materials such as glass are highly appeared on the accuracy measured point cloudsin terms of point clouds density then its impact on the quality and accuracy of measuring single points. The density of point clouds decreases dramatically when incident angle increased. This is happend because the intensity of the returned signal decreases and also projected scan surface (field of view) decreases. Figure 6 shows that at 60 degree incident angle (third image to the right), the density of the reflected point clouds from glass surface were obviously decreased in compare with first and second image (at 0˚, 30˚ degree respectively), this is because that most of these point clouds were closed to zero value.

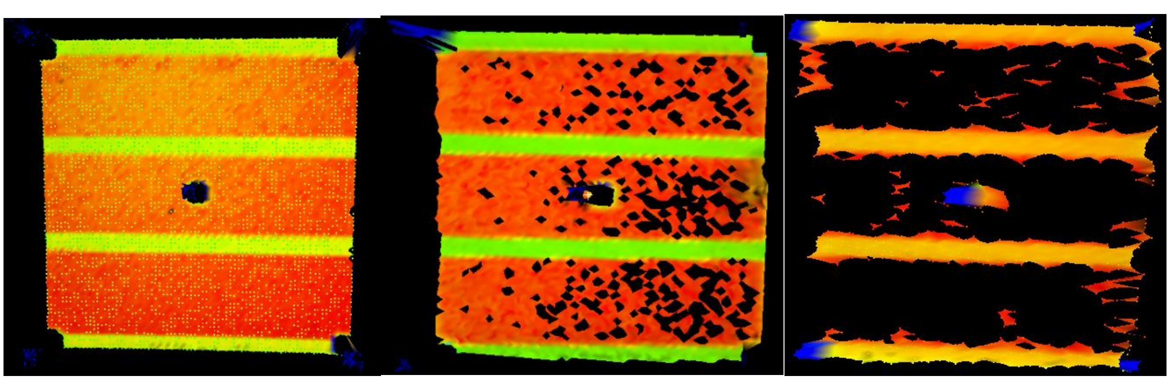

Figure 6: Creating meth for glass material from left to right 0˚, 30˚, and 60˚ incident angle

On the other hand, when the best fit patch created for the reflected point clouds, its become easily to notice that most of the reflected point clouds appears as a wide strips on the image plane. It means that all of the collected point clouds on these strips are located behind the fitted patch, which in turn means those points were needed more travel time to reach the scanner range find detector. This is happaned because a part of the laser beam transmitted through the glass and strike the stand behind the glass means that laser beam is actually reflected from the stand surface rather than the glass surface itself. It became easily to seen that most of the reflected points are actually reflected from the stand bar behind the glass sample rather than from the glass surface itself Figure 7.

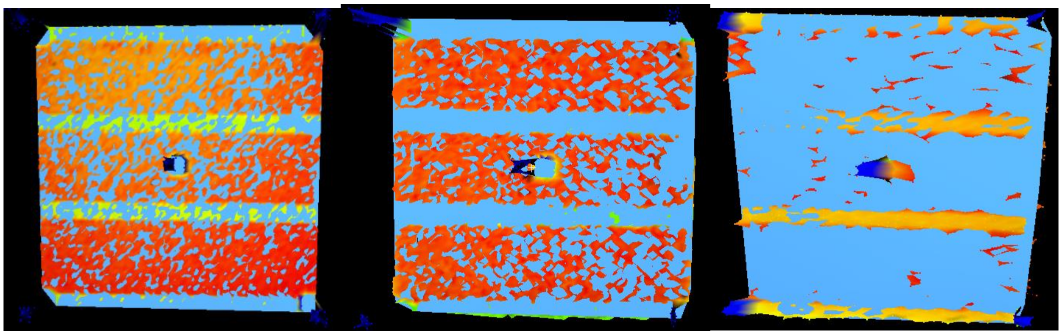

Figure 7: Creating mesh with best fit patch for point clouds reflected from glass sample at 0˚, 30˚, 60˚ incident angle from left to right respectively

To examine the effect of glass material on reflected data accuracy, a diviation value in the location of point clouds from the best fitted patch has been calculated. Hence, 15 point clouds that distributed on the surface were selscted randomly with 5 additional points on the total station target (adhesive sheet) at each incident angle scan data from zero to 75 degree. The result of the calculated deviation can be seen in Figure **8** for those 15 points and five points on the targets.

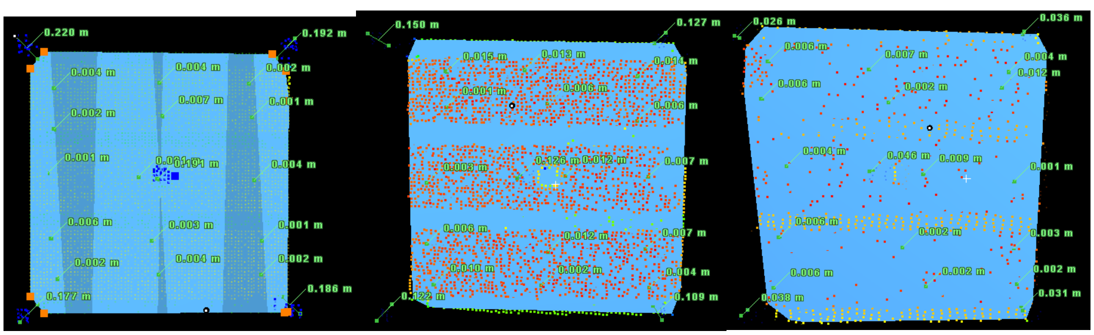

Figure 8: Randomly select 15 points + 5 target points to examine the deviation from the patch for glass sample at: 0˚, 30˚, and 60˚ incident angle respectively

Table 2: Deviation from the patch for glass material

0d	15d	30d	45d	60d	75d
0.004	0.007	0.015	0.014	0.006	0.003
0.004	0.004	0.013	0.016	0.007	0.004
0.002	0.007	0.014	0.017	0.004	0.005
0.002	0.002	0.001	0.006	0.006	0.002
0.007	0.004	0.006	0.012	0.002	0.005
0.001	0.005	0.006	0.014	0.012	0.003
0.001	0.003	0.003	0.007	0.004	0.003
0.001	0.003	0.012	0.015	0.009	0.003
0.004	0.002	0.007	0.002	0.001	0.005
0.006	0.004	0.006	0.009	0.006	0.004
0.003	0.001	0.012	0.009	0.002	0.002
0.001	0.003	0.007	0.005	0.003	0.006
0.002	0.004	0.01	0.005	0.006	0.002
0.004	0.006	0.002	0.004	0.002	0.004
0.002	0.008	0.004	0.002	0.002	0.003

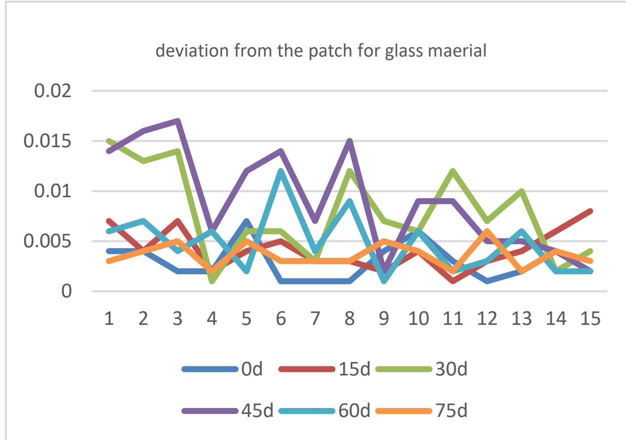

Figure 9: Deviation from the patch for glass material using 15 points

Table 2 and Figure 9, illustrate the deviation of the selected point clouds from the best fit patch surface. The maximum deviation appeared at incident angle 30 and 45 closed to be 16mm, while the overall deviation reduced for other incident angles such as 6mm in 75 degree.

In another hand, parallel to the scanning glass, the five adhesive sheet targets were fixed on the glass sample exactlyon four corners and center. On each target one point cloud selected to find its deviation from the patch. As shown in Table 3 and Figure 10 the deviation results of those points gradually decreases when incident anlge increases from zero to 75 degree. The deviation value about 20cm when the incident angle is zero degree, while the deviation decreases to 1cm at 75 degree.

Table 3: Distance from target sheet to patch for glass material

Series	0d	15d	30d	45d	60d	75d
1	0.191	0.161	0.15	0.095	0.026	0.014
2	0.192	0.163	0.126	0.098	0.046	0.01
3	0.177	0.157	0.127	0.096	0.036	0.012
4	0.186	0.154	0.122	0.086	0.038	0.025
5	0.22	0.146	0.109	0.067	0.031	0.014

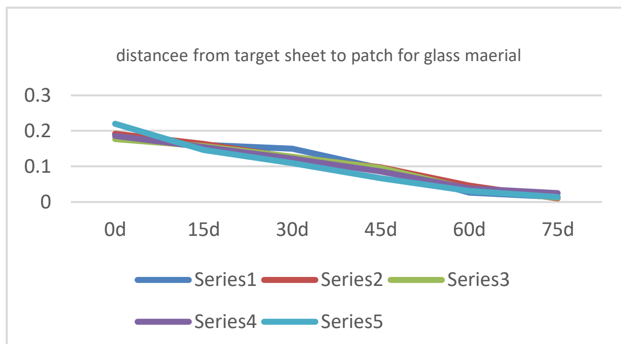

Figure 10: Distancee from target sheet to patch for glass maerial, first series refered to deviation first targt from 0 to 75˚ scan angle and so on

3.2 Scanning Results from Steel Material

Similar to glass material steel is consider as another smooth surface material. The effect of the incident angle variation on the smooth materials are highly appeared on the reflected point clouds in terms of their density and the accuracy of measuring single points. The density of point clouds decreases when increasing the incident angle. a mesh grid also is created for reflected point clouds
Figure **11**.

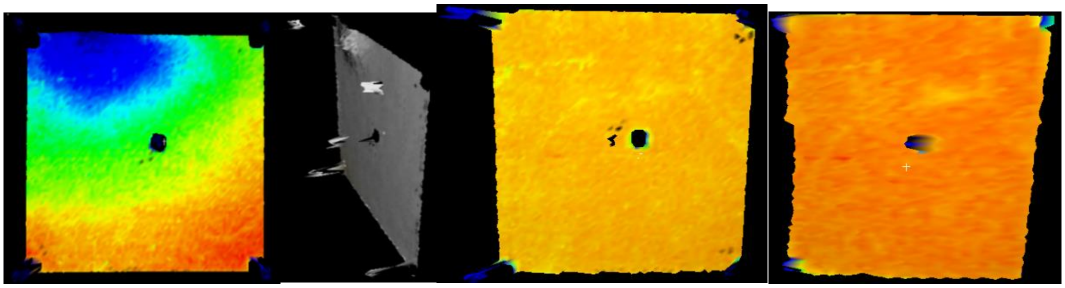

Figure 11: Creating mesh for steel sample from left to right at 0˚, 30˚, 60˚ incident angle respectively

Followed by applying best fit patch for all scans based on reflected point clouds

Figure **12** it can be seen easily that all reflected points from the steel surface have different reflectivity at each incident angle. for example, at zero degree incident angle upper-left part of the steel surfaces has shown a significant problem that refers to a certain deviation of the reflected point clouds from the fitted patch.

Figure **12** clearly shows the deviation of point clouds from the patch.

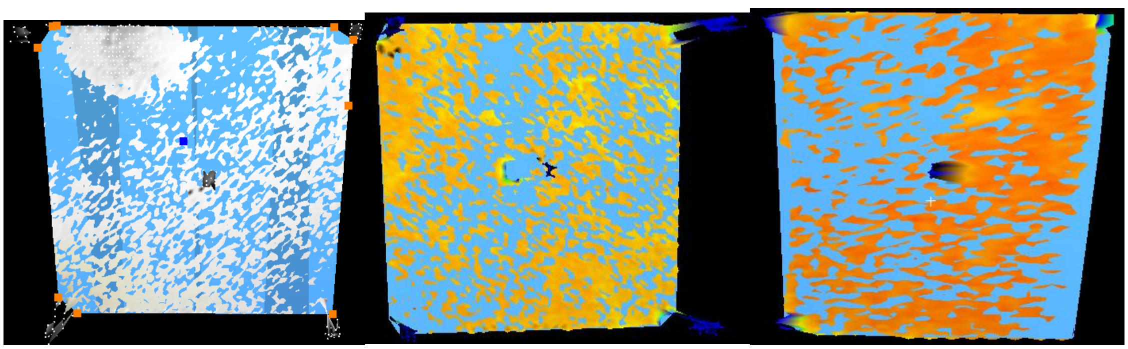

Figure 12: Creating mesh with best fit patch for steel material at 0˚, 30˚, 60˚ incident angle from left to right respectively

To assess the occured deviation from the fitted patch, 15 point clouds that distributed on the surface were selscted randomly with 5 additional points on the total station target (adhesive sheet) at each incident angle scan data from zero to 75 degree. The result of the calculated deviation can be seen in Figure **13**.

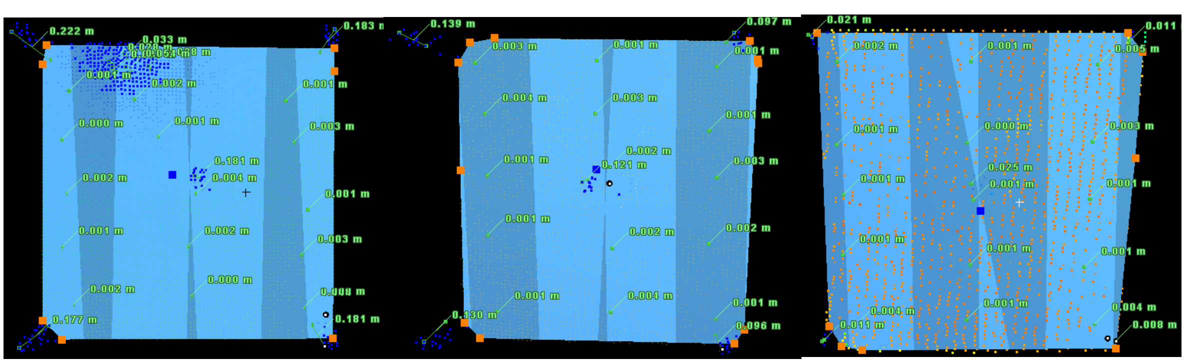

Figure 13: Randomly select 15 points to validation the deviation from the patch of steel sample at: 0˚, 30˚, and 60˚ incident angle from left to right respectively

Table 4: Deviation from the patch for steel material

0d	15d	30d	45d	60d	75d
0.001	0	0.003	0.005	0.002	0.001
0.002	0.002	0.001	0.001	0.001	0.002
0.001	0.002	0.001	0	0.005	0.001
0	0.001	0.004	0	0.001	0.001
0.001	0	0.003	0.001	0	0.003
0.003	0	0.001	0.002	0.003	0.001
0.002	0.001	0.001	0.001	0.001	0
0.004	0.001	0.002	0.009	0.001	0.001
0.001	0.003	0.003	0.002	0.001	0
0.001	0.002	0.001	0.001	0.001	0.003
0.002	0.004	0.002	0.001	0.001	0.002
0.003	0.001	0.002	0.002	0.001	0.001
0.002	0	0.001	0	0.004	0.002
0	0.003	0.004	0.003	0.001	0
0.008	0.004	0.001	0.002	0.004	0

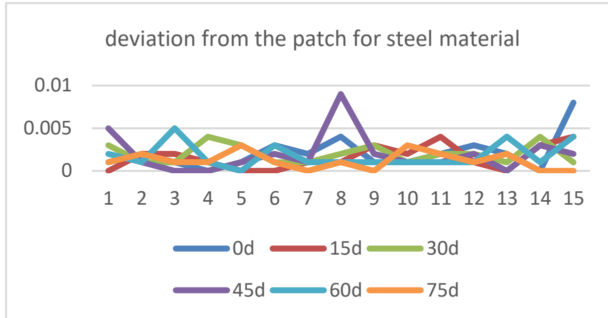

Figure 14: Deviation from the fitted patch ofsteel sample based on selected 15 points

Table 4 and Figure 14, illustrate the deviation values of the selected point clouds from the best fitted surface patch. The maximum deviation found at zero and 45 degree incident angle which is about 8 to 9mm.While the overall deviation reduced for other incident angles such as 3mm at 75 degree.

Furthermore, five fixed adhesive total station sheet targets are fixed on the steel surface. One point cloud selected on each target to find its deviation value from the fitted patch as well. As shown in Table 5 and Figure 15 the deviation values of the points gradually decreases at zero to 75 incident angle degree. When incident angle is equal to zero, the deviation was about (18 to 22 cm), while it is decreased to less than 1cm when the incident angle reaches 75 degree. It means that the scanner cannot recognize the effect of the material properties when the incident angle increases.

Table 5: target sheet on Steel 5m from 0d to 75d

series	0d	15d	30d	45d	60d	75d
1	0.222	0.174	0.139	0.059	0.021	0.001
2	0.181	0.163	0.121	0.079	0.025	0.001
3	0.183	0.154	0.097	0.05	0.011	0.009
4	0.177	0.191	0.13	0.068	0.011	0.005
5	0.181	0.15	0.096	0.049	0.008	0.001

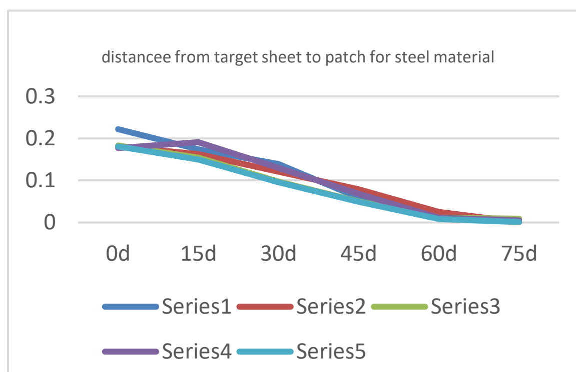

Figure 15: Deviation from target sheet to fitted patch of steel sample, first series refered to the deviation of the first targt from 0 to 75˚ scan angle and so on

Intrestingly, it is important to mention that a significant problem was occurred when diviation from the fitted pathch has been calculated as it can be seen in

Figure **12** previously. It showed at the upper–left corner of the image plan a full white area which is scientifically means a very high intensity reflection. This is happened due to coincidency of the sun light that hits steel surface with the incident angle of scanner which in turn will increase the intensity of the scanned laser beam and make the reflected point clouds returned to the scanner faster than other parts. Figure **16** shows steel sample scanned at zero degree incident angle. It can be seen that the sun light effect is calculated as a diviation value which is about (3 to 5 cm) at the range of 5m distance from the scanner to the object.

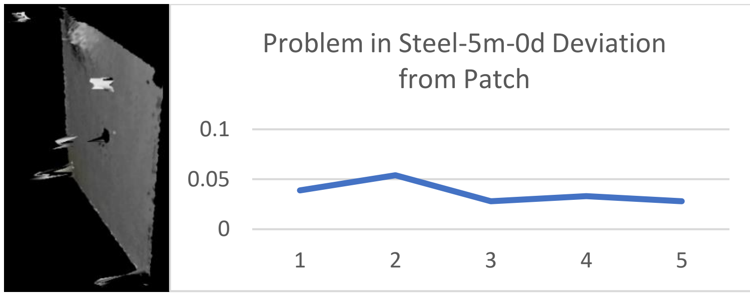

Figure 16: Problems in Steel material in 5m range and 0˚ when it is shine by the Sun light

3.3 Scanning Results from Wood Material

Wood is the third material sample that has been conducted for this research purpose. It is consider as a rough material. Similar to both glass and steel, The density of reflected point clouds decreases when increasing the incident angle as it can be seen Figure 17. Additionally, it is noticed that the effect of the incident angle variation on the rough sample is less than its effect on smooth sample. This is because that the laser beam reflected from the micro-facets on the rough surface that cause a reduction of the incident angle variation. Also when increasing incident angle the intensity of the laser beam on the rough surfaces decreases less than the intensity on smooth surfaces.

Figure 17: Creating meth for wood material from left to right in 0˚, 30˚, 60˚ incident angle

Best fit patch was created also for all scans based on reflected point clouds, as it can be seen from Figure 18 that all reflected point clouds from the wood surface have different reflectivity regarding to the incident angle variation. Obviously, In all performed scans the majority of point clouds are located at the center of the material's surface which in turn means that their reflection from the center were faster than those reflected from the edges of the material's surface. This is occurred because the incident angle of scanning at the middle of the surface were less than the edges and the intensity of large incident angle is less than the intensity of small one. Figure 18 below shows the best fitted patch for the scanned point clouds and state that the range of point clouds in the center of the surface is shorter than the points in the edges.

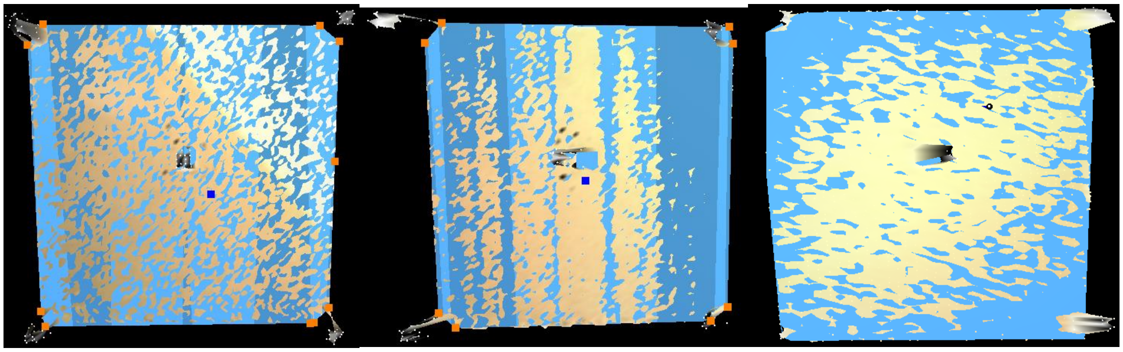

Figure 18: Creating mesh with best fitted patch for wood sample at: 0˚, 30˚, 60˚ incident angle from left to right respectively

Likely to other smooth materials, diviation value of the poin tclouds locations from the fitted patch plane has been examined. So, randomly 15 point clouds on the wood surface image plane have been selected with additional 5 points on the adhesive target sheet at each scan incident angle from zero to 75 degree. Figure 19 shows the diviation results. .

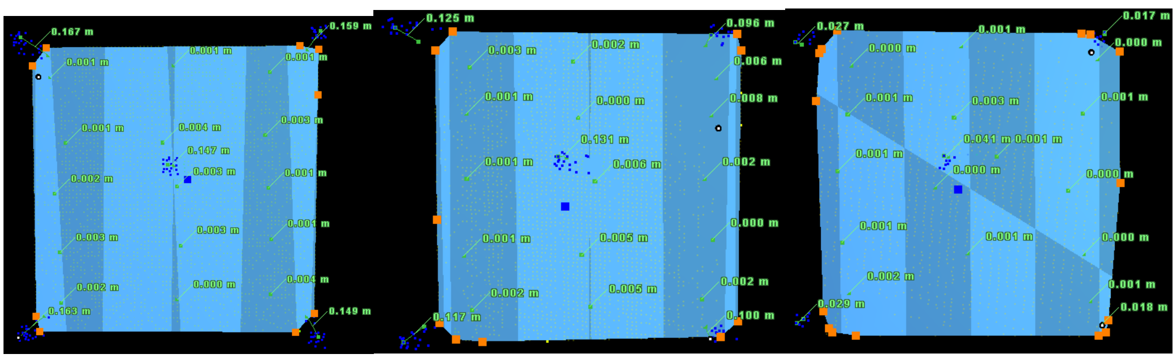

Figure 19: Randomly select 15 points to validation the deviation from the patch for wood material in 0˚, 30˚, and 60˚ incident angle from left to right

Table 6: Deviation of wood material from patch-5m

0d	15d	30d	45d	60d	75d
0.001	0.001	0.003	0.004	0	0.002
0.001	0.001	0.002	0	0.001	0
0.001	0.001	0.006	0.002	0	0.001
0.001	0.003	0.001	0.004	0.001	0.002
0.004	0.003	0	0.002	0.003	0
0.003	0.002	0.008	0.001	0.001	0.001
0.002	0.002	0.001	0.004	0.001	0.001
0.003	0.003	0.006	0	0	0
0.001	0.005	0.002	0.001	0	0.001
0.003	0.003	0.001	0.002	0.001	0.002
0.003	0	0.005	0.002	0.001	0.002
0.001	0.001	0	0.001	0	0.001
0.002	0.001	0.002	0.001	0.002	0.003
0	0	0.005	0	0.001	0
0.004	0.002	0.002	0.001	0.001	0

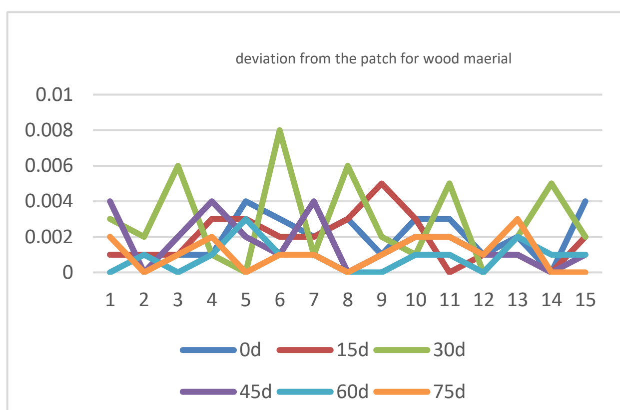

Figure 20: Deviation from the fitted patch of wood sample in 5m range using 15 selected point clouds

Figure 20 and Table 6, show the deviation values of the selected point clouds from the best fitted patch. The maximum deviation appeared at 30 degree scanning incident angle about 8mm, and minimum deviation values were recorded at 60 and 75 degree incident angle about (0 to 3mm). while, the overall deviation reduced at other incident angles.

Furthermore, before scanning fixed five adhesive total station targets on the surface in different positions. On each target one point cloud selected to find its deviation from the fitted patch. As shown in Table 7 and Figure 21 the deviation of the points gradually decreases at incident angle scan from zero to 75 degree. When incident angle is at zero and 15 degree, the deviation about (14 to 18 cm), while the deviation decreases to less than 5mm when the incident angle reaches at 75 degree. It means that the scanner cannot recognize the effect of the material properties when the incident angle increases. Compared to the smooth materials, the deviation of these targets on rough materials is 4cm less than the smooth materials at zero and 15 degrees. Also at 75 degree the deviation is less than from what found from the smooth materials about 5mm.

Table 7: target sheet on wood 5m from 0d to 75d

Series	0d	15d	30d	45d	60d	75d
1	0.167	0.176	0.125	0.086	0.027	0
2	0.147	0.147	0.131	0.087	0.041	0.004
3	0.159	0.14	0.096	0.064	0.017	0.003
4	0.149	0.174	0.117	0.079	0.029	0.004
5	0.163	0.157	0.1	0.075	0.018	0.002

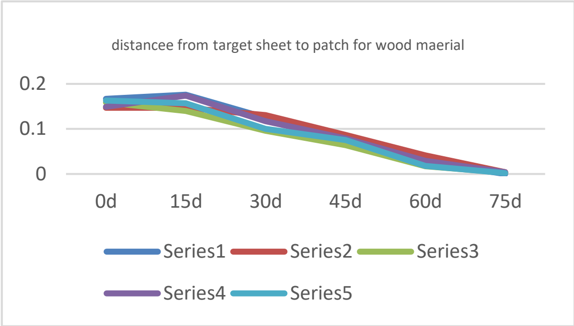

Figure 21: Distancee from target sheet to best fitted patch for wood sample, first series refered to the deviation of first targt at 0 to 75˚ scan angle and so on

3.3 Scanning Results from Ekoplast Material

Another rough material which is the last one conducted for this research purposes which is Ekoplast. Similar procedure that applied on the aforementioned materials, density of the reflected point clouds decreases when increasing the incident angle of scan. Figure 22 shows after creation the proper mesh for the scanned data, the common conclusion in this research that is The effect of the incident angle variation on the rough materials is less than its effect appeared on the smooth material.

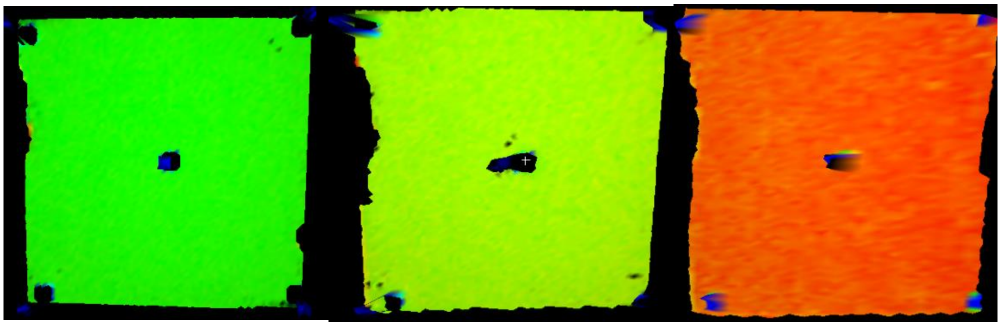

Figure 22: Creating mesh for wood sample from left to right at: 0˚, 30˚, 60˚ incident angle respectively

Best fitted patch was created also for all scans based on reflected point clouds as it can be seen from

Figure **23**. It is obvious that all of the reflected points clouds from the Ekoplast surface have different reflectivity based on the incident angle of scans. Interstingly, most of the point clouds data that already located in the center of the surface reflected faster that the point clouds on the edges. It means that the range of point clouds in the center of the surface is shorter than those points in the edges. On the other hand, at the surface centre, because the incident angle is less than its in edges and high intensity, the point clouds reaches the scanner earlier than the edges.

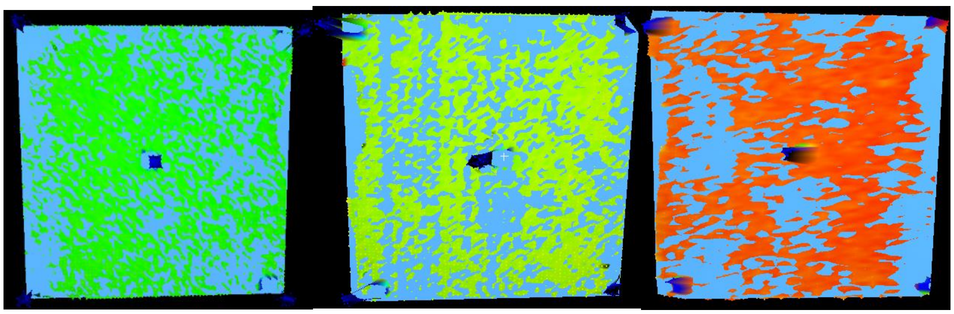

Figure 23: Creating mesh with best fit patch for wood material in 0˚, 30˚, 60˚ incident angle from left to right

To evaluate the incident angle variation effect on this material. The deviation values from the fitted patch is calculated. So, randomly selected 15 point clouds on the surface with additional 5 points on the adhesive arget sheet on the surface is conducted at each incident angle of scan at zero to 75 degree. The result of the deviation from the patch are shown in Figure 24.

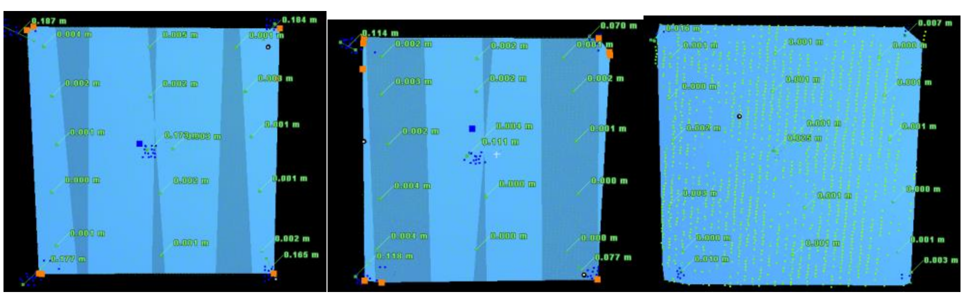

Figure 24: Randomly select 15 points to find deviation from the fitted patch for Ekoplast sample at: 0˚, 30˚, and 60˚ incident angle from left to right respectively

Table 8: Ekoplast material deviations from the patch

0d	15d	30d	45d	60d	75d
0.004	0.002	0.002	0	0.001	0
0.005	0.001	0.002	0	0.001	0.001
0.001	0.002	0.001	0.001	0	0
0.002	0	0.003	0.004	0	0.001
0.002	0.001	0.002	0.001	0.001	0
0.003	0	0.002	0	0.001	0.001
0.001	0.001	0.002	0.001	0.002	0.001
0.003	0.003	0.004	0.001	0.001	0
0.001	0.001	0.001	0.001	0.001	0
0	0.001	0.004	0.005	0.003	0.001
0.002	0	0	0	0.001	0.001
0.001	0.002	0	0.001	0	0
0.001	0.003	0.004	0	0	0.001
0.001	0.001	0	0.001	0.001	0
0.002	0.002	0	0.001	0.001	0

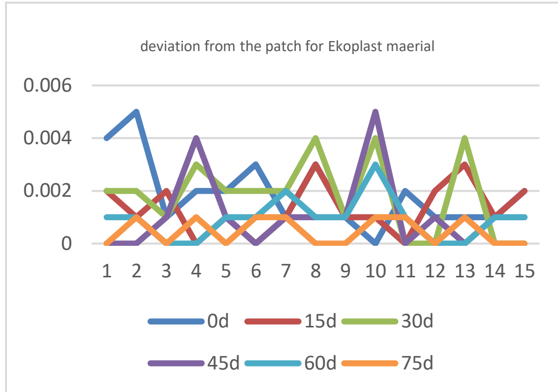

Figure 25: Ekoplast deviation from the fitted patch based on the selected 15 point clouds

Figure 25 and Table 8, shows the deviation values also of the selected point clouds locations from the best fitted patch. The maximum deviation appeared at 0, 30, and 45 degrees incident angle of scans about (4 to 5mm), while the overall deviation reduced at other incident angles. At 75 degree incident angle, maximum and minimum deviation valueabout (0 to 1mm) is recorded. The maximum deviation of reflected point clouds from fitted patch of this material is approximately equal to the minimum deviation of the smooth materials.

On the other hand, five adhesive total station targets were fixed also on the material's surface in different positions. In each target one point cloud selected to find its deviation value from the fitted patch. Hence,Table 9 and Figure 26 shows clearly that the deviation values of the points gradually decreases at zero to 75 degree incident angle. When incident angle is at zero and 15 degree, the deviation value was about (12 to 18 cm), while the deviation value decreases to less than 5mm when the incident angle reaches at 75 degree. It means that the scanner cannot recognize the effect of the material properties when the incident angle increases. In compare to the smooth materials, the deviation of these targets on rough surface materials is 4cm less than the smooth surface materials at zero and 15 degrees incident angle. Also, at 75 degree incident anglre the deviation is less than what is recorded in the smooth materials about 5mm.

Table 9: deviation of sheet target from the patch

Series	0d	15d	30d	45d	60d	75d
1	0.187	0.136	0.114	0.053	0.016	0.002
2	0.173	0.157	0.111	0.068	0.025	0.005
3	0.184	0.126	0.07	0.024	0.007	0.001
4	0.177	0.138	0.118	0.065	0.01	0.002
5	0.165	0.119	0.077	0.024	0.003	0.001

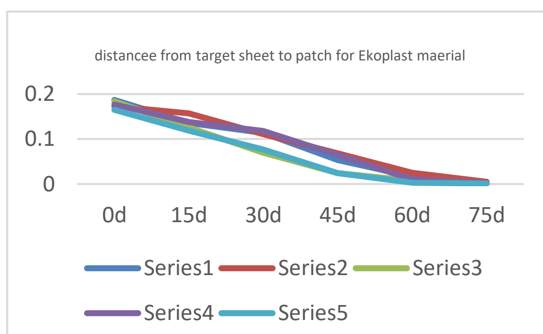

Figure 26: deviation from the patch from zero to 75˚ Ekoplast materials, first series refered to deviation first targt from 0 to 75˚ scan angle and so on

3.4 Overall RMSE of Materials

The overall RMSEs for all of the scans of all selected materials in this research are presented as illustrated in Table 10. The maximum RMSE recorded at smooth materials (Glass and Steel), while the minimum RMSE appeared at rough materials (Wood and Ekoplast). The maximum RMSE reaches 4cm at 45 degree incident angle of the smooth glass surface. And the minimum RMSE appeared in the rough Ekoplast material at 75 degree incident that is 2.6mm. The minimum and maximum RMSE of the smooth materials are 0.6cm and 4cm respectively. In the other side, the minimum and maximum RMSE for the rough materials are 0.26cm and 1.46cm respectively.

Table 10: RMSEs of the selected points on the surface of the materials

RMSE	0d	15d	30d	45d	60d	75d
Glass	0.0133	0.0180	0.0348	0.0403	0.0218	0.0147
Steel	0.0109	0.0081	0.0088	0.0117	0.0089	0.0060
Wood	0.0091	0.0088	0.0146	0.0083	0.0046	0.0055
Ekoplast	0.0090	0.0063	0.0089	0.0070	0.0047	0.0026

Furthermore, Figure 27 shows that the overall deviation from the best fitted patch is at zero degree incident angle for all of the materials approximately equal and this difference increases with increasing the incident angle.

Because the glass material nearly could be considered as a perfect smooth, the surface was highly affected on the accuracy results of reflected point clouds.While Ekoplast material nearly could considered as perfect rough had no more effect on the quality of the reflected point clouds. The main purpose of this difference between rough and smooth surfaces returns to have the micro-facet parts on the rough surfaces that affects on the amount of returned signal and intensity to the scanner in higher incident angles. The Figure 27 shows the effect of the rough and smooth surface on the accuracy point clouds.

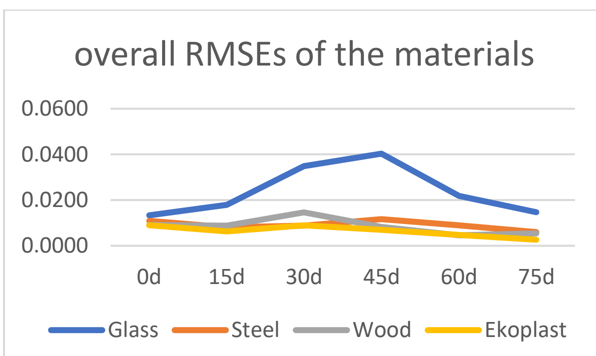

Figure 27: Overall RMSE of the scans for all materials and all incident angles

4 CONCLUSION

TLS is an instrument used in many different fields that need the mill-metric level of accuracy, such as monitoring, documentation of highly expensive heritages, oil tank calibration, and many other different fields, due to the high-performance level of accuracy in the process of manufacturing. However, TLS has not an exception from errors occurance in its data capturing when scanning objects. The accuracy of the measuring data depends mainly on two factors: the performance of the scanner for measuring the time of flight of laser beam, and the property of the scanned surface of the materials. Results obtained from this research practical experiments revealed some significant issues such as Sun shine, surface properties, and scan angle that should be taking into account when looking for very high performance of TLS object scanning.

Firstly, the rough surface materials is higher reflective surface than smooth surface materials. Ekoplast and wood are rough surfaces they have not recorded high diviation values at 0 to 75 degree of incident angle , due to micro-faced parts on the surfaces, while glass and steel smooth surfaces recorded high diveation values at 0 to 75˚ as aformentioned in Figure 6 and

Figure **16**. Maximum RMSE of rough materials is less than 1cm except wood material in 30 degree, while Maximum RMSE for the smooth materials reaches 4cm in 45 degree glass material.

Secondly, different materials have different properties in terms of roughness, absorption, transmission, and reflectance of the reflected laser beam that leads to has different level of accuracy measuring 3D point clouds. Based on that, the accuracy of the point clouds was different from one material to another material. For instance, both smooth materials glass and steel due to having different properties, the minimum RMSE in glass material is 1.47cm. On another hand, the maximum RMSE for steel material reaches 1.17cm.

Thirdly, if the scan angle coincides with the Sun incident angle the laser beam return faster to the scanner and it produce a serious problem in the accuracy of the single point cloud measuring. As it is happened at zero degree incident angle of steel material.

While, when the incident angle reaches at 60˚ or larger, the scanner cannot recognize the properties of the materials. Because the reflectance and intensity of reflected point clouds on all of the performed materials close to each other. As shown for the adhesive total station sheet targets in 60 and 75 degrees' incident angles. Can be supported by (Amer et al., 2018) concluded that the scanning accuracy is directly decreased with the increase of used projection angle.

Finally, if the other side of glass material covered by other material, the laser beam returns to the scanner in longer period of time. It means this part of the laser beam that penetrate the glass material and hit the object behind it, then returns to the scanner as a secondary return signal and provable that the scanner take the average between the primary and secondary return signal. Can easily seen in Figure 7.

It is intended by the authors for the next research, and based on the obtained results from the current study to conduct another set of experiments that will examine another factor which is the distance differentiation between the TLS instrument and object with the variation of the material type.

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