Measurement Accuracy Assessment for Laser Triangulation 3D Scanning Machine

Khairul Azri Azlan, Mohammad Rafi Omar, Mohamed Saiful Firdaus Hussin, Muhammad Ilman Hakimi Chua Abdullah, Eswaran S. Chinniah

Abstract*: *Laser triangulation 3D scanning machine is one of many types of 3D scanning technologies that are currently available in the current market. It is mainly use to capture object profiles as well as for measurement. Therefore, the measurement accuracy of laser triangulation 3D scanner was assessed and presented in paper. Three solid aluminum calibration block with known dimensions were fabricated by using CNC machine and these samples were named based on its profiles which are round, square and complex. Besides the laser triangulation 3D scanning machine, two more measuring equipment which are Vernier caliper and coordinate measuring machine were used as benchmarks. Three profiles were chose for each calibration block samples that made up of 9 profiles that have been measured and the deviation between the measuring values were analyzed. The results shown that the lowest deviation values for most of the profiles are from coordinate measuring machine and Vernier caliper measurement data. Nevertheless, the measurement deviation for laser triangulation 3D scanner are found to be comparable with other equipment.

Keywords* : *3D Scanner, Measurement Accuracy. Coordinate Measurement Machine (CMM), Vernier Caliper, Computer Aided Design (CAD).

I. INTRODUCTION

One of the powerful ways to capture the shape of an object is by using 3D scanning machine. This machine helps to generate 3D file of the object that can be saved, modified, or can be 3D printed. This is important process to replicate or improvise existing parts in various applications in many fields including reverse engineering, medicine, multimedia, art, architecture, an even in archeology [1]. From many kinds of 3D scanning technologies with various mechanisms, generally it can be classified into two main types which are contact and non-contact scanner. A contact type 3D scanner use a probe to touch the object that they measure and communicate through tactile. Normally the probe is mounted on a -axis or 5-axis machines, attached to a robotic arm or can also be a combination of this two method. It is normally being used to measure object that need high precision, accuracy and consistency. However, contact type 3D scanning have some limitations including very limited measuring range, time consuming process and can cause damage to the to the measured object or its surface due to physical contact that take place [2-3]. One of the common example of the contact type 3D scanner is the coordinate measuring machine (CMM) that typically use probing system with spherical tip stylus. The selection of probe for a specific task is very important as it will affect the accuracy as well as its cost. CMM are quite expensive but slow as the measurement is carried out by displacing point by point. In addition, CMM does not support effective linear or 2D data collection and have some limitation in measuring complex geometry [4-7]. CMM also need to operate in controlled environment such as in metrology laboratory nominally set to 20°C as standard as the accuracy of CMM measurement can be influenced by environment temperature [8]. However, in real application, components that need to be measured by the machine are normally produced in non-controlled environments or undergo several processes that increase or decrease their temperature significantly [9].

A non-contact 3D scanner on the other hand does not require any physical contact with the object that is being measured. It can be further classified into two categories which are passive and active non-contact 3D scanner. A passive non-contact scanner is a scanner that use infrared or fully relying on ambient radiation while scanning rather than emitting its own radiation. It is a quite simple and inexpensive as it does not require special device to operate. Some examples of passive non-contact scanner are stereoscopic, photometric and silhouetted based 3D scanner. In stereoscopic systems for instance, it only requires two video camera that is slightly away from each other recording the same object. Whereas for photometric 3D scanner, it uses only one camera that record multiple shot under several lighting conditions. Silhouetted 3D scanner instead uses sequential outlines generated on a well contrasts background. Nevertheless, passive scanner is relatively less accurate in comparison with active non-contact 3D scanner. An active scanner measure object or environment by emitting radiation such as light, X-ray or ultrasound and detect the reflection of the radiation. Time-of-flight and laser triangulation and are some examples of active 3D scanners.

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The basic principle of time-of-flight is where a pulse of energy is emitted from a laser to the measured object and return back to the laser sensor. The distance from the laser emitter to the object can be acquired by multiplying the speed of light to the time from the emission to sensing. The advantage of time-of-flight are the capability to scan large objects such as buildings or geographic features as it can operate in long distance. However, the accuracy is quite low compared to laser triangulation scanner [10-12]. Laser triangulation scanner uses optical triangulation measuring system. Triangulation is typical method that have been use for land surveying for a long time in geodesy. The scanner consists of two main components which are the laser transmitter and the receiver. A highly collimated laser beam is first projected on the object that is being measured in a pulse or continuous manner, and the reflection of the beam (entirely or defused) will be received and recorded by the receiver (typically one or more cameras) as shown in Figure 1. As the value of the triangle baseline and both angles (emitting and receiving) are known, the position for each points can be acquired [13-15]. In this paper, the focus will be on the non-contact type 3D scanning machine.

The most important criteria in evaluating measuring device performance is its accuracy and precision. To check that, a calibration is needed. Calibration is a process of comparing a measuring device against a standard instrument of higher accuracy to detect, correlate, adjust, rectify, and document the accuracy of the device being compared [16]. Some of 3D scanning devices that are available on the market currently especially the low cost devices are sold without calibration procedure. In fact, since long time there are no international standard for 3D scanner calibration. Therefore, several calibration methods have been propose by some researchers. Genta et al. for instance have proposed the use of a reference ball plate that are measured by CMM as reference standard in order to evaluate the accuracy of Vi-900 Konica-Minolta laser triangulation 3D scanner. The result shows that by implementing a calibration procedure that identify and corrects systematic errors, the metrological performance of the instrument can be greatly improved as well as reducing the device's measurement uncertainty. [17]. Tóth and Živčák have tested the accuracy of two 3D scanner types which are the Steinbichler Comet L3D optical scanner and the Creaform EXA Scan Laser Scanner by comparing the measurement data from of a specimen. The specimen that have been design does not contain complicated shapes or parts that are not possible to scan by using the chosen technologies and satisfies scanning criteria that are needed by both scanner [18]. Bernala et al. have conducted a calibration of Steinbichler Comet L3D scanner that use structured light technology. The equipment calibration was done by using calibration plate and a few gauge blocks with different sizes. The accuracy range of the scanner has been established through multiple digitization showing the dependency on influential factors such as the characteristics of the object and scanning procedure [19]. Gapinski et al. have carried ot comparative tests between computed tomography (CT) scanner, GOM ATOS II optical scanner, and coordinate measuring machine (CMM) by conducting measurement on a calibration block that is made of aluminum. The results shows that computed tomography are able to produce comparable measurement results with CMM and the GOM ATOS II optical scanner [20]. Therefore, the same principle will be implemented in this research whereby three calibration block samples with known dimensions were produced and named based on its profiles which are round, square and complex. The three calibration block samples were then measured by a laser triangulation 3D scanning machine and the results were compared with CMM and Vernier caliper. The objective is to evaluate the accuracy of the laser triangulation 3D scanning machine by comparing the measurement date with two other measuring equipment. It is hypothesized that laser triangulation 3D scanner will show a comparable reading accuracy compared to the others.

II. METHODOLOGY

A. Sample Selection

To evaluate the capabilities for each measuring equipment, three fabricated solid aluminum calibration block with different shapes were used as measuring samples. Sample 1 is in rectangular shape, sample 2 in circular, and sample 3 is a complex shape. Sample 1 were choose mainly to test distance measurement between flat surfaces, sample 2 to for round surfaces and sample 3 for complex curvature. Holes diameter were also measured for each of the samples. Fig. 1 shows CAD drawing for sample 3 (complex shape).

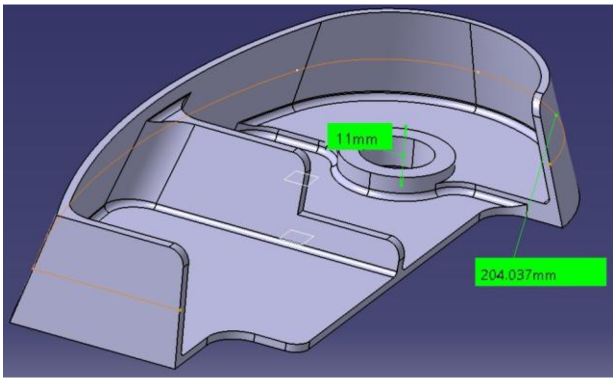


Fig. 1. CAD drawing for sample 3 (complex shape).

B. Profile Selection

For each of the samples, three profile have been chosen for measurement. All profiles that were chose can be measured by 3D scanner, CMM and Vernier caliper except for profile 3C. The selected profiles are shown in Fig. 2. For sample 1, the profiles that have been selected is diameter of hole (1A), length of block (1B) and the height of block (1C). For sample 2, the profiles that have been selected are the diameter of the small hole (2A), and the diameter of the center holes (2B), and the outer diameter of the circular calibration block (2C). Finally for sample 3, the profiles that have been selected are the diameter of the center hole (3A), the straight length of the bottom curve (3B), and the outer perimeter of the middle curve (3C). Table 1 shows the nominal dimension for the selected profiles for each samples.

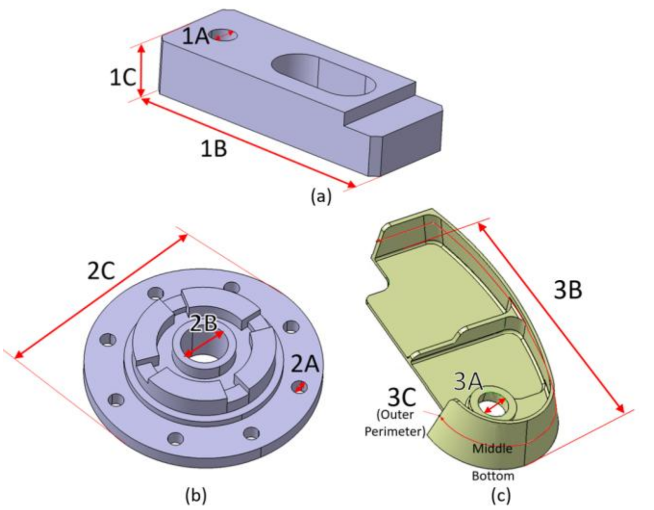


Fig. 1. Three different profiles have been identify for three different samples: (a) Rectangular shape sample (b) Circular shape sample (c) Complex shape.

Table- I: Nominal dimension for the selected profiles for each samples

Sample	Profile	Profile Type	Nominal Dimension
Samples 1 (Rectangular)	1A	Inner Diameter	10.00
	1B	Length	100.00
	1C	Height	20.00
Samples 2 (Circular)	2A	Inner Diameter	10.00
	2B	Inner Diameter	30.00
	2C	Outer Diameter	150.00
Samples 3 (Complex)	3A	Inner Diameter	13.00
	3B	Curve Length	120.48
	3C	Curve Perimeter	204.04

C. Measuring Equipment Selection.

The 3D scanning machine (3DS) that were selected for this project use laser triangulation technology and are capable to scan wide range of object from small to large objects. This state-of-the-art measuring equipment that is shown in Fig. 3, mainly consist of tracking camera, hand-held scanner and optional touch probe that can acquire rapid 3D data with very good accuracy and data range. However, touch probe was not used in this project.

Fig. 2. Laser triangulation 3D scanner

The second equipment that was used is an entry level coordinate measuring machine (CMM) as shown in Fig.4 that is capable of high-speed scanning with good quality measuring results. The last equipment is an industrial standard digital Vernier caliper. Three readings were taken from each profiles for Vernier caliper (VC) except for profile 3C that cannot be measure by VC.

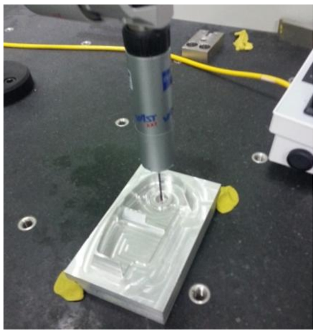


Fig. 3. Measurement of fabricated solid aluminum calibration block by using CMM.

D. Data Analysis.

The data that were measured for each profiles from each samples were compared with the nominal values to get the deviation.

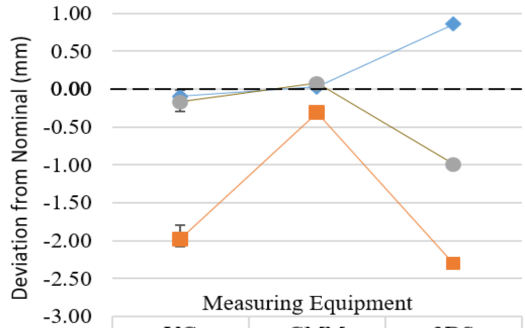
Deviation = Measured Value - Nominal Value *(1)*

Deviation graph for all measuring equipment were then ploted.

III. RESULT AND DISCUSSION

A. Result for Samples 1 (Rectangular Shape)

For sample 1, the measurement result for each profiles were plotted in Fig. 5.



	VC	CMM	3DS
Profile 1A	-0.09	0.03	0.86
Profile 1B	-1.98	-0.31	-2.30
Profile 1C	-0.17	0.08	-0.99

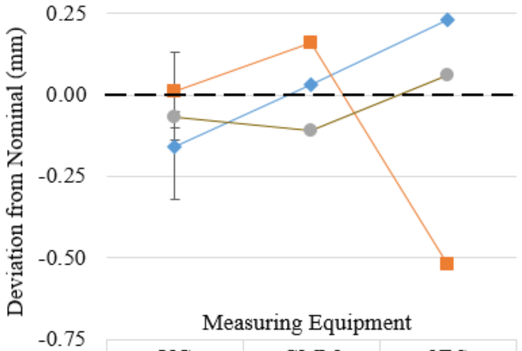
Fig. 4. Deviation from nominal dimension for profile 1A, 1B, and 1C for each measuring equipment measured in milimeters (mm)

It is found that for sample 1, CMM had consistently shown the lowest deviation from nominal values for all profiles that were measured. For VC, the deviation is more than CMM but is less than 3DS.

The deviation for 3D scanner although relatively higher than CMM and VC, still shown deviation reading of less than 1.00 mm for profile 1A and 1 C . The reading for profile 1B shown the highest deviation value for all equipment especially 3DS with a reading of 2.30 mm.

B. Result for Samples 2 (Circular Shape)

For sample 2, the measurement result for each profiles were plotted in Fig. 6.



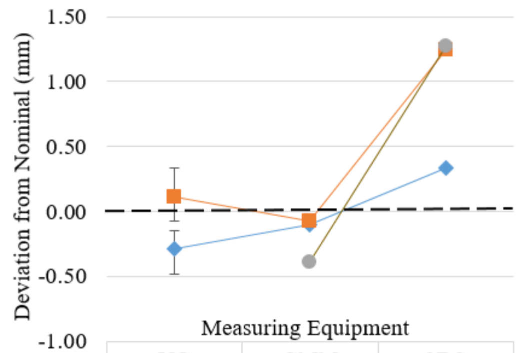
	VC	CMM	3DS
Profile 2A	-0.16	0.03	0.23
Profile 2B	0.01	0.16	-0.52
Profile 2C	-0.07	-0.11	0.06

Fig. 5. Deviation from nominal dimension for profile 2A, 2B, and 2C for each measuring equipment measured in milimeters (mm)

For profile 2A, the lowest deviation is from CMM, followed by VC and 3DS. However, for profile 2B, VC shown the lowest deviation, followed by CMM and 3DS. For profile 2C, the lowest deviation in from 3DS followed by VC and CMM. All measurement values are less than 1.00 mm.

C. Result for Samples 3 (Complex Shape)

For sample 3, the measurement result for each profiles were plotted in Fig. 7.



	VC	CMM	3DS
Profile 3A	-0.28	-0.10	0.34
Profile 3B	0.11	-0.07	1.25
Profile 3C	N/A	-0.39	1.28

Fig. 6. Deviation from nominal dimension for profile 3A, 3B, and 3C for each measuring equipment measured in milimeters (mm).

For sample 3, the lowest deviation is from CMM, followed by VC and 3DS for all profiles (3A, 3B and 3C). Profile 3C however cannot be measured by VC.

The overall results for all profiles and shapes (except for profile 2C) have shown that 3DS have the highest deviation compared to others. The deviation in 3DS might be influenced by the geometry, surface (topology, glossiness, and color), ambient light, scanner resolution, and proper selection of scanned segments. In addition, scanning distance and angle also will affect the scanned results [21-22].

IV. CONCLUSION

Laser triangulation 3D scanner have shown a comparable measurement results with CMM and Vernier caliper for most of the profiles even though CMM and Vernier caliper have shown lower deviation for most of the profile. This is because CMM and Vernier caliper is a contact type measuring equipment that is purposely design for measuring, while laser triangulation 3D scanner is a non-contact scanning tools that is design to capture object profiles. In addition, the accuracy of 3D scanning are also depend on the manpower skills in handling the 3D scanning equipment. The other factor that effects the measurement result is due the shiny surface of the calibration block. To overcome this issue, it is recommended to apply a thin layer of non-destructive and easily removed anti-reflective coating to the scan object before the scanning process take place.

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