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Accuracy Analysis of a 3D Scanner on Small Dimension Object

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Abstract

3D scanning technology is vital for engineering, manufacturing and quality control for larger object with less time require, but it can fail to capture fine detail or scan small object from big object, that can affect simulation accuracy, leading to uncertainty in the reliability of the data .This study investigated the accuracy of the GOM II ATOS Triple Scan 3D scanner in measuring small dimension objects. The scanner was compared with a conventional Vernier caliper and five scans and measurements were taken on three different sized metal blocks. Measurement deviations were analysed using absolute error, percentage error standard deviation and root mean square error (RMSE). The results showed that all the 3D scan measurements deviated from the manual readings, with the largest error for the medium-sized metal blocks. It was found through standard deviation statistical analysis, although the Vernier calipers were consistent across all sizes, the 3D scanning was more affected by the size and complexity of larger objects and therefore less stable for small and medium sized metal blocks. The RMSE values for small metal blocks were generally lower, indicating better stability of the measurements. Large metal blocks had the highest RMSE values in some areas, suggesting greater variability, while medium-sized metal blocks showed a similar trend but with slightly lower errors. This study confirms that although the GOM ATOS triple scanner is an important tool for engineering applications, it still has limitations when measuring small objects with complex details. This study makes an important contribution to metrology by identifying the key factors affecting the accuracy of 3D scanning and suggesting ways to optimise the scanning procedure to improve the reliability of precision measurement tasks.

1. Introduction

This research presentation focuses on the accuracy analysis of a 3D scanner when measuring small metal objects. It emphasizes the importance of accurate 3D models in simulation and testing, as errors in the scanned data can lead to unreliable results. The study aims to compare the digital measurement accuracy of the GOM ATOS Triple Scan 3D scanner with conventional Vernier caliper measurements. The study discusses factors that affect scanning accuracy such as surface reflectivity, scanner resolution and environmental conditions. Objectives included evaluating the accuracy of the scanner, identifying sources of error, and determining the effect of material and scanning angle on measurement reliability. This research is expected to provide valuable insights to engineers and manufacturers in high-precision applications.

2. Literature Review

2.1 3D Scanning in Reverse Engineering

Engineering involves the development, manufacturing, assembly, and maintenance of products and systems. It can be divided into forward and reverse engineering. Forward engineering involves the development process from a product's concept to operational outcomes, while reverse engineering involves a detailed study of the product's design, ability, and individual elements. Both approaches can be used in developing, analyzing, or replicating products or systems, with the difference being whether the process starts with a finished product or a design concept. This chapter discusses computer-aided reverse engineering (CARE), an automation of reverse engineering (RE) that uses computer-aided design (CAD) to create 2D or 3D models of products before production. CARE involves digitizing an object, processing data, and recreating it into a CAD model [1].

2.2 Factors Affecting Accuracy

3D scanning technology uses methods like laser scanning, structured light, and photogrammetry to create accurate 3D models of objects and surroundings. However, factors such as the type of scanner, environment, object surface, and data processing can affect the accuracy of these models. Resolution refers to the ability to detect small objects or features in a point cloud. Surface characteristics like reflectivity, color, and texture also impact 3D scanning accuracy [2]. Surface roughness and tilt can significantly affect data acquisition and measurement noise [3]. Weather analysis is crucial for 3D laser scanning accuracy, as changes in temperature can affect the laser beams travel and accuracy [4]. Temperature sensitivity affects calibration quality of structured light 3D scanners and suggests temperature correction procedures [5]. Vibration is another challenge to 3D scanning systems, affecting accuracy and image quality. A study on a system for 3D scanning marine propeller blades using an industrial robotic 3D camera uses vibration cancellation and input shaping techniques to minimize vibration, increase accuracy, and improve scan quality [6].

2.3 Error Measurement Technique

Evaluating the accuracy of a scanner involves comparing scanned data to reference measurement results from traditional tools like Vernier calipers and micrometers. Error analysis measures the deviation of scan data from conventional measurements to determine the level of accuracy [7]. A reference model is also used to assess fidelity and accuracy, as in a study comparing a reference model of a titanium alloy scanned with different scanners [8].

The study about evaluates the accuracy of an optical 3D scanner using calibration objects or standard geometries. The results show that after calibration, the values are closer to the nominal dimension, with deviations of sphere diameter and spacing being twice as large in the non-calibrated system. Therefore, frequent calibration is crucial for optimal performance and accuracy in various applications [9].

Statistical methods like analysis of variance (ANOVA) and post hoc tests are used to assess the accuracy of scanning data. For example, comparing three-dimensional models with conventional calipers found discrepancies in data accuracy [10]. Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) are metrics used to assess model performance. RMSE is more suitable for normal Gaussian errors, while MAE is better for Laplace distributions [11][12]. Both metrics have advantages and disadvantages, and their choice depends on the error propagation and analysis requirements. Combining them can provide a more comprehensive understanding of model performance [13][14].

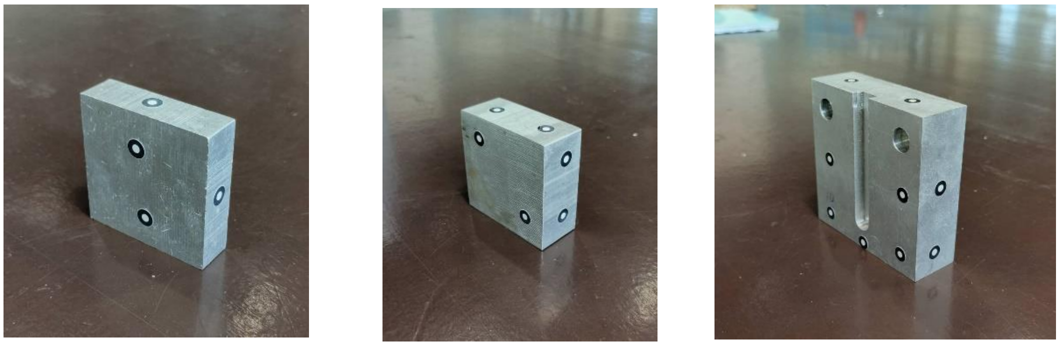
3. Methodology

3.1 Experimental Setup

For this experiment, metal block is chose as test specimen because metal blocks only have basic geometric form. Three different sizes small, medium and big metal blocks will be use for testing shown in Table 1 and Fig 1.

Table 1: Dimension Measurement for Three Metal Block Sizes

Block Sizes	Material	Length (mm)	Width (mm)	Height (mm)
Small	Aluminium	51.00	15.00	51.00
Medium	Aluminium	51.00	21.00	51.00
Big	Aluminium	75.00	25.00	75.00



(a) **(b)** **(c)**

Fig. 1: Actual Test Specimen (a)Small Metal Block (b) Medium Metal Block (c) Big Metal Block

Table 2 and Figure 2 show The GOM ATOS II Triple Scan is a high-precision noncontact optical laser 3D scanner used in this study to accurately capture detailed geometric information of metal blocks.

Table 2: Specification of GOM II ATOS Triple Scan

Descriptions	Values
Camera Pixels	2 x 5MP
Minimum Measuring Area	38 mm x 29 mm
Maximum Measuring Area	2000 mm x 1500mm
Working Distance	490 mm-2000 mm
Cable Length	Up to 30m
Sensor Controller	Integrated
Operating Temperature	5 °C – 40 °C
Power Supply	90 V – 230V AC

Fig. 2: GOM ATOS II Triple Scan

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Vernier calliper is one of precision measuring instrument use by many applications and industries. It very suitable tool for measuring metal blocks because it more precise compare to ruler and used to measure linear dimensions, such as the length, width, and thickness of objects.

Table 3: Specification of KENNEDY KEN3302060K Vernier Calliper

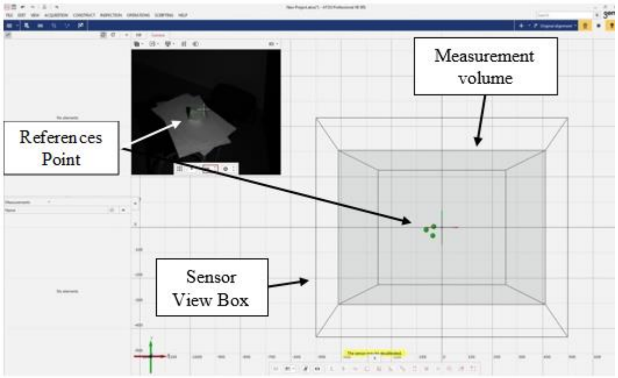
Property	Value
Accuracy	± 0.03
Brand	KENNEDY
EAN13 Barcode	5036140106888
Graduations	0.02 mm
Range	130 mm
Supplier Part No.	3302060K
UNSPSC Code	41111621
Weight	190 g

Fig. 3: KENNEDY KEN3302060K Vernier Calliper

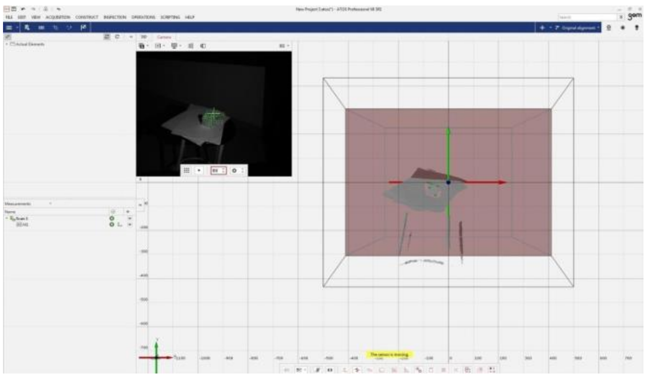
. Developer spray and 3D scanner stickers enhance 3D scanner performance by minimizing surface reflectivity and extracting precise geometric information. The 5mm diameter stickers are applied onto the specimen surface, allowing the scanner to identify and track each sticker. The traditional measurement equipment used to this study is Vernier calliper to study 3D scanner digital measurement effectiveness.3D scanner stickers were strategically placed on the surfaces of each metal blocks. Applying a developer spray before measurement to create a white matte layer for diffuse reflection. The spray is applied at an angle of 45° to 65°, rotating the blocks to ensure complete coverage. The 3D scanning process of small and medium-sized metal blocks with identical flat surfaces was aided by a labelling system, marking the bottoms with alphabetic letters.

3.2 Scanning, Data Processing and Measurement Procedure

Before scanning, metal blocks were positioned on a chair with white paper as a natural background. The front faces of each block were placed towards the GOM ATOS II. The ATOS Professional V8 software was launched, and the 3D scanner was powered on. The scanning process was preheated the scanner and stabilized for optimal performance. To begin scanning, adjust slowly and gradually rotate the 3D scanner or chair to detect 3D scanner stickers on metal blocks, the sensor view box to detect the working area, and the measurement volume to calibrate the area. To start the first scan, the spacebar was pressed, and minor adjustments were made to the scanning setup, such as rotating the chair, adjusting the adjustable sensor, and using an adjustable mounting bracket. These adjustments were detected early to capture the first scan and repeated the rotation of scanner or chair around test specimen, make sure software interface detect sensor view box, measurement volume and reference point (3d sticker on metal block), press spacebar to capture every little movement of them until the 3D model of whole metal blocks was achieved.



(a)



(b)

Fig. 4: Real-time Visualization of the Scanning Process in ATOS Professional V8 (a) Before start scanning (b)After First Scanning

The initial 3D model of each metal block is processed using the Cut Out Point feature to remove unnecessary elements and maintain accuracy, removing any elements below the base, such as paper or chairs. To refine the model, use the Select/Deselect by Surface function, joining points, identifying unwanted areas, and deleting them. Confirm deletion by pressing Ctrl and Delete. The 3D model is cleaned and refined using polygonisation and recalculation functions, ensuring accuracy and suitability for analysis. Gaps or holes are automatically closed using the Close Hole tool, preparing it for SOLIDWORKS dimensioning and repeated this procedure for scanning other again.

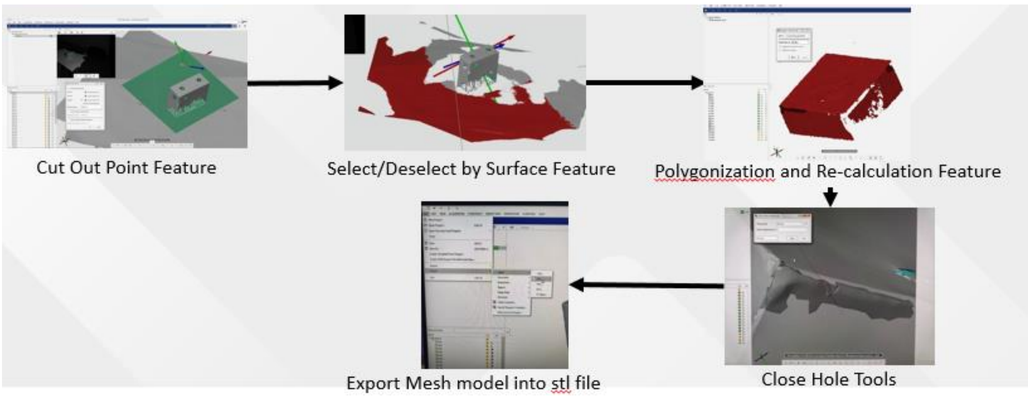


Fig. 5: Data Processing Steps to get clean 3d model

The 3D scanned metal blocks were measured using STL files from ATOS Professional V8 and SOLIDWORKS' "measure" tool. The orientation of the model was crucial for accurate measurement, especially for small and medium blocks. The software calculated the distance between edges, providing digital measurements that could be compared to physical measurements using the Vernier calliper. The Vernier calliper was used to measure the 12 edges of each metal block, taking five readings for each edge to minimize error and ensure reliability. This data was then repeated five times, comparing it with 3D scan measurements.

3.3 Error Analysis Calculation.

To assess the accuracy of the 3D scanning process, an error analysis was conducted. The mean measurement for each edge of three metal blocks was calculated using 15 digital scans and 5 manual measurements. The absolute error for each edge was determined by calculating the difference between the 3D scan and manual measurements. The percentage error for each edge was calculated by dividing the absolute error by the manual measurement.

$$\text{Mean } (\mu) = \frac{\sum_1^n x_i}{n} \quad (1)$$

$$\text{Percentage Error} = \frac{|x_1 - x_2|}{x_2} \text{ x } 100\% \quad (2)$$

Standard deviation is a statistical measure of variability in a data set, crucial for assessing accuracy in engineering applications. It indicates the precision of a measurement and is used to compare 3D scanning measurements with reference tools. Root Mean Square Error (RMSE) is a widely used metric to assess measurement accuracy, ensuring reliable 3D scanned metal block measurements compared to traditional Vernier calliper readings.

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{\Sigma(x_i-\mu)^2}{n}} \quad (3)$$

$$\text{RMSE} = \sqrt{\frac{\Sigma(x_i-y_i)^2}{n}} \quad (4)$$

4. Results and Discussion

4.1 Labelling Edges of Metal Block

The metal block consists of six faces and twelve edges. In order to obtain accurate measurements of the entire metal block, it is necessary to measure all edges individually. To avoid confusion during measurement, edges should be categorised according to their orientation. As a rule, edges can be classified into two categories according to their arrangement horizontal and vertical and depth illustrate in Figure 6.

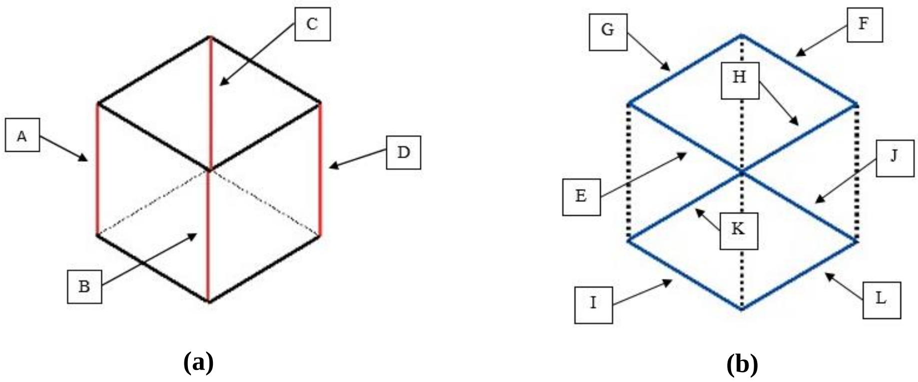


Fig. 6: Labelling Metal Block Edges (a) Vertical (b) Horizontal

4.2 Comparison of Measurements

This section presents the raw measurements of all block sizes captured by the 3D scanner in Table 4 below. Showing the consistency and accuracy of the multiple scanning process and traditional direct contact measurement.

Table 4: Raw measurement of all block sizes with different measurement methods

Block Sizes	Edge	3D Scanning Measurement (mm)					Vernier caliper Measurement (mm)				
		1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Small	A	50.56	50.16	50.11	50.02	50.01	51.20	51.24	51.30	51.26	51.24
Small	B	50.34	50.37	50.45	50.32	50.16	51.28	51.18	51.20	51.18	51.20
Small	C	50.83	50.32	50.58	50.45	50.09	51.30	51.22	51.26	51.28	51.24
Small	D	50.28	50.26	50.50	50.27	50.08	51.20	51.28	51.26	51.18	51.20
Small	E	50.38	50.19	50.25	50.01	50.20	51.22	51.22	51.18	51.16	51.26
Small	F	50.61	49.91	50.09	50.40	50.26	51.22	51.24	51.28	51.22	51.28
Small	G	15.21	14.56	14.24	14.49	14.07	15.10	15.04	15.02	15.08	15.02
Small	H	15.65	14.73	14.61	14.37	14.33	15.00	15.02	15.08	15.10	15.04
Small	I	50.62	50.43	50.33	50.53	50.66	51.26	51.28	51.26	51.26	51.24
Small	J	50.62	50.36	50.88	50.53	50.54	51.28	51.22	51.22	51.28	51.24
Small	K	15.11	14.89	14.87	14.57	14.65	15.10	15.00	15.02	15.10	15.06
Small	L	15.14	14.95	14.72	14.94	14.89	15.04	15.06	15.06	15.08	15.04
Medium	A	49.78	49.92	49.67	50.11	49.86	51.12	51.18	51.22	51.16	51.16
Medium	B	50.33	49.66	49.97	49.52	50.10	51.12	51.14	51.14	51.10	51.16
Medium	C	49.86	49.79	49.72	49.54	49.65	51.16	51.02	51.00	51.02	51.06

Medium	D	50.17	50.31	50.11	49.47	50.08	51.02	51.06	51.08	51.10	51.10
Medium	E	50.01	50.20	50.43	49.97	50.12	51.04	51.04	51.00	51.02	51.00
Medium	F	50.11	49.90	50.47	50.31	50.05	50.88	51.00	50.90	50.92	50.96
Medium	G	21.66	21.08	21.37	21.61	21.44	21.74	22.04	22.04	22.00	22.08
Medium	H	21.30	21.49	21.48	21.67	21.56	21.80	22.02	22.00	22.06	21.84
Medium	I	50.00	50.25	50.10	50.08	50.15	50.82	51.02	50.80	50.96	50.84
Medium	J	50.46	50.39	50.33	50.32	50.42	50.84	50.84	50.88	50.88	50.88
Medium	K	21.47	21.16	21.87	21.35	21.59	21.94	21.96	21.94	21.96	21.96
Medium	L	21.62	21.34	21.15	21.47	21.58	21.90	21.88	21.84	21.86	21.86
Big	A	74.20	73.96	73.83	73.98	74.15	74.90	74.98	74.90	75.00	74.92
Big	B	73.65	73.79	73.90	74.29	74.95	75.02	75.02	75.04	75.02	75.02
Big	C	73.93	74.02	73.97	73.53	73.86	75.00	74.96	75.02	74.94	74.96
Big	D	73.27	73.72	73.50	73.60	73.91	74.96	74.94	74.90	74.98	74.94
Big	E	74.27	73.85	73.87	74.37	73.96	74.84	74.92	74.94	74.96	74.94
Big	F	74.21	73.31	73.78	74.46	74.59	74.94	75.00	74.98	75.02	74.94
Big	G	24.21	24.94	24.52	24.40	24.78	25.04	25.02	25.06	25.00	25.04
Big	H	24.52	24.65	24.29	24.33	24.83	25.00	24.92	24.94	25.14	24.98
Big	I	74.35	74.50	73.59	74.24	74.12	74.82	74.92	74.88	74.90	74.94
Big	J	74.05	73.93	74.39	74.18	73.98	74.90	74.90	74.86	74.88	74.84
Big	K	24.70	24.68	24.24	24.46	24.93	25.00	25.02	25.04	24.98	24.98
Big	L	24.02	24.46	24.90	24.91	24.75	24.96	24.98	24.98	24.92	24.94

4.3 Error Analysis

This section discuss about result of calculation for error analysis and statistical analysis obtained across different metal block sizes using 3D Scanner and a Vernier calliper measurement.

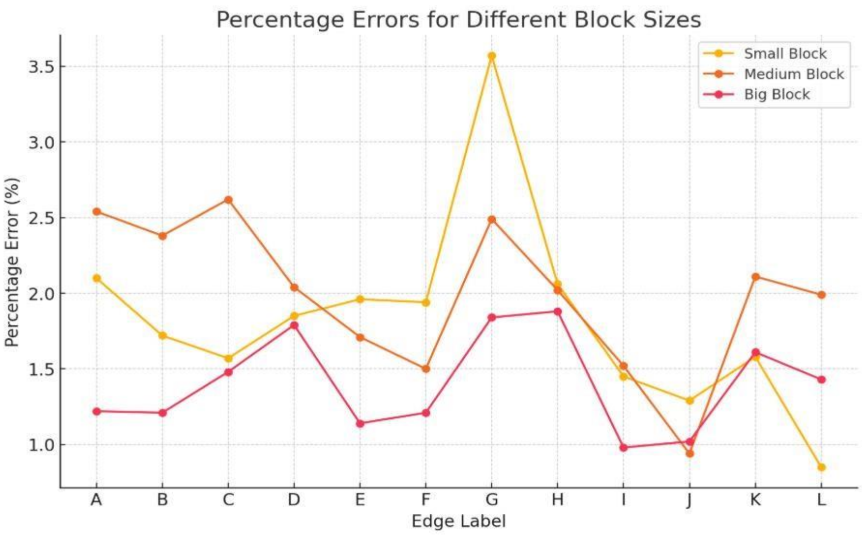


***Fig. 7*:** Percentage Errors for Different Block Sizes

Based on Figure 7 The study assessed the accuracy of the 3D scanner by comparing its measurements with those made using vernier calipers on small, medium and large metal blocks. For the small metal blocks, the percentage error of the vertical edge ranged from 1.572% to 2.100% and the absolute error ranged from 0.806 mm to 1.076 mm. For smaller metal blocks, the scanner showed consistent accuracy; however, there was a slight increase in the vertical edge error. Horizontal edge measurements were more variable, with percentage errors of 3.574% for edge G and 2.060% for edge H. The horizontal edge measurements were more variable, with percentage errors of 3.574 per cent for edge G and 2.060 per cent for edge H.

The medium-sized metal blocks performed the worst of the three sizes, with a slight increase in percentage error for vertical edges compared to the small-sized blocks. Horizontal edge errors ranged from 0.944% to 2.493%. This size category produced the highest overall percentage error, indicating a decrease in scanner accuracy for the medium-sized metal block.

For the large metal block, the scanner had the smallest percentage error of all sizes and the horizontal edge error was consistently below 2%. The percentage errors for horizontal edges were 1.143% and 1.434%, respectively, indicating an improvement in accuracy. Absolute errors were also lower for larger blocks. Repeated trials confirmed that the scanner performed well when scanning larger plots, highlighting its effectiveness when scanning larger and longer surfaces.

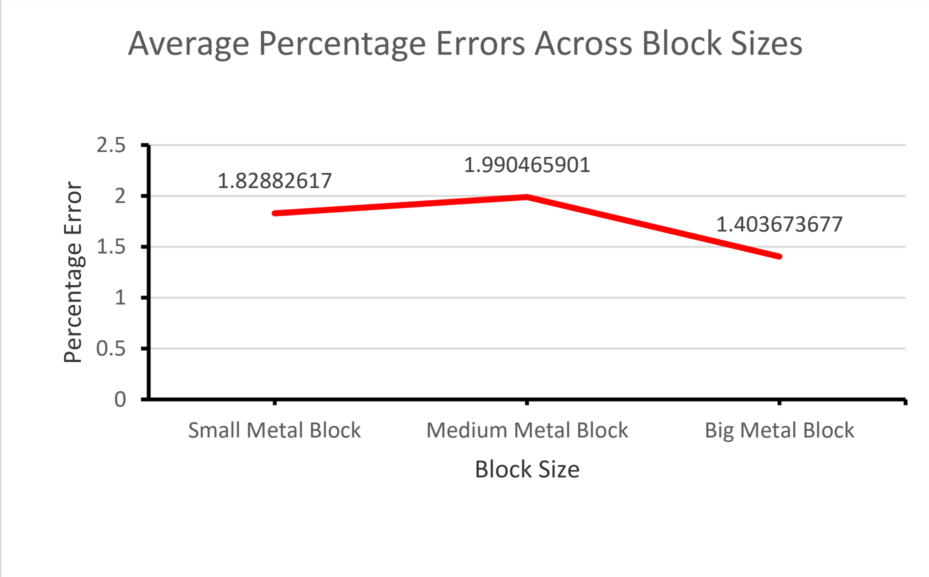


Fig. 8: Average Percentage Errors Across Block Sizes

Overall, the results show that medium blocks have the highest average percentage error (±1.990%), followed by small blocks (±1.828%), while large blocks have the lowest error (±1.404%). Medium have highest because have extra cause inaccuracy compare to other sizes is persistent surface imperfections of developer spray despite several attempt to repaint black area. This trend indicates that measurement accuracy decreases with decreasing block size. Further analyses are needed to determine the root cause of this trend and to improve the measurement accuracy of smaller blocks.

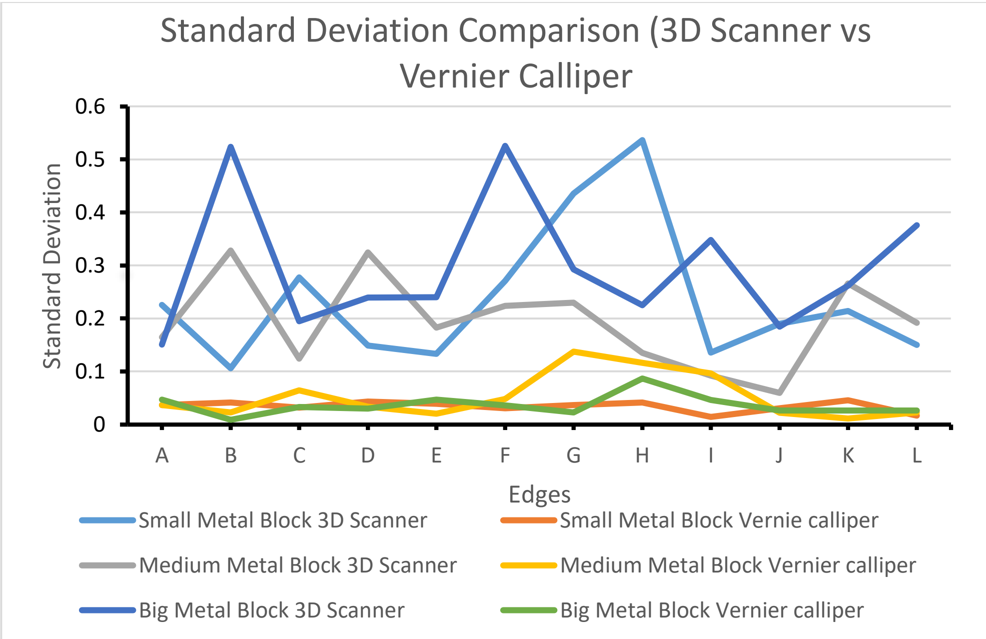


Fig. 9: Comparison Standard Deviation between 3D Scanner and Vernier Calliper Measurement

Based on Figure 9, The 3D scanner and Vernier calipers showed different measurement accuracies for the front vertical edges (A and B), with large standard deviations for most metal block dimensions. This indicates poor consistency of measurements, especially in the larger blocks where edge B has more variation. The scanner also showed greater variability in the rear vertical edge, which could be due to scanner capability detect reference point on target surface. The standard deviation of the top horizontal edges is larger, especially edges G and H, which may be more sensitive to surface irregularities or scanning angles. Vernier calipers show low variability, indicating their reliability. The standard deviation of the bottom horizontal edge is lower, but the deviation of the 3D scanner is still higher, which may be due to scanning difficulties (detect reference point and software use best-fit approach) and Vernier caliper have direct contact with test subject to measure dimension . Overall, the Vernier calipers provided more consistent results, but the performance of the 3D scanners varied, with larger deviations at the front and top edges.

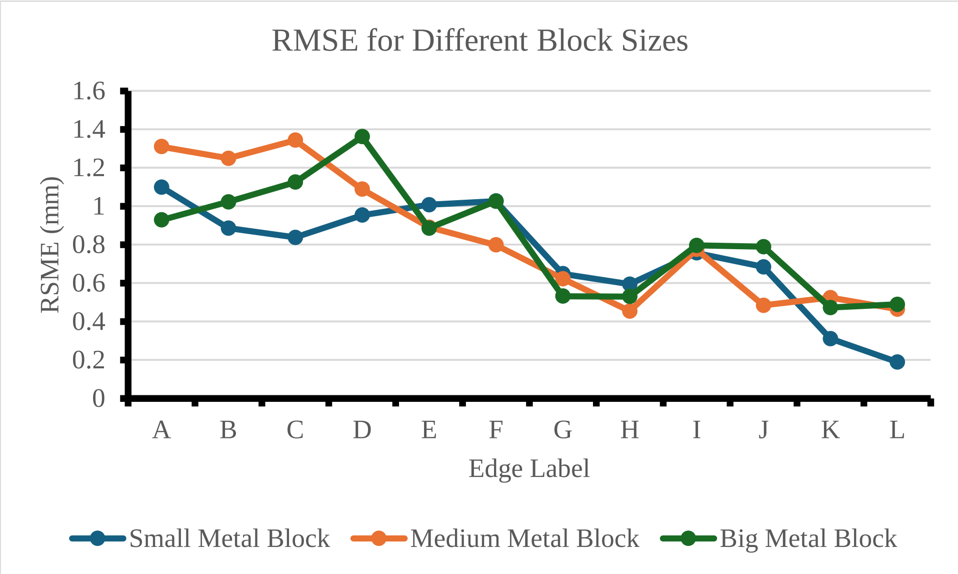


Fig. 10: Root Mean Square Error (RMSE) for Different Block Sizes

Based on the Figure 10 show Root Mean Square Error (RMSE) plots and tables, the analyses show significant trends in the edges of the different blocks. Edges A and B, which represent the front vertical edge, show relatively high RMSE values in small and medium-sized blocks, indicating a large deviation in measurement accuracy. In contrast, large blocks show moderate RMSE values, indicating better agreement with larger block sizes. Edges C and D, corresponding to the back vertical edges, show a similar trend, with moderately high RMSE values for small and medium-sized blocks, and increased bias for large blocks, especially for edge D. The RMSE values for the top horizontal edges (E, F, and D) are moderately high, suggesting a higher bias in measurement accuracy than the top horizontal edges.

The top horizontal edges (E, F, G, and H) show differences in RMSE across block sizes. However, the RMSE values for edges G and H increased as the block size increased, suggesting that maintaining measurement accuracy for these edges in larger blocks may be challenging. In contrast, the RMSE values for the bottom horizontal edges (I, J, K, and L) were generally lower, especially in small plots, with edge L showing the least deviation. However, for medium and large blocks, the RMSE values for these edges increase, with greater deviations for edges I and J. The RMSE values for the bottom horizontal edges (I, J, K, and L) are generally lower, especially in small blocks.

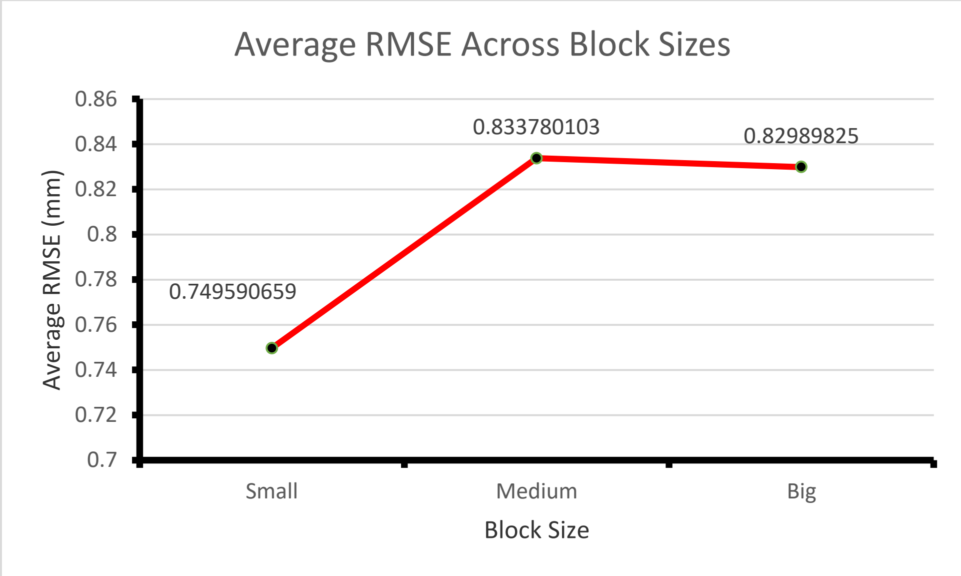


Fig. 11: Average Root Mean Square Across Error Across Block Sizes

In summary from Figure 11, the RMSEs for horizontal edges (both top and bottom) tend to show greater consistency for smaller blocks, but their accuracy is challenged as the block size increases. Vertical edges, particularly the front edges (A and B), have higher RMSE values in smaller blocks, reflecting the potential sensitivity of these locations to the measurement method or geometry. This trend emphasises the impact of edge orientation and block size on measurement accuracy.

4.4 Cause affect 3D Scanning Accuracy.

There are many reasons for inaccurate 3D scanner measurements, including surface preparation, operator handling, environmental conditions, and software limitations. Surface preparation problems can occur if the developer is not sprayed or removed properly, resulting in surface reflections that distort scanner readings. Operator skills play a critical role, as improper reference point detection can lead to incomplete scans quality. Variations in ambient light, especially natural light, can affect the consistency of the scan, and the substrate proximity effect can lead to data loss or edge distortion when scanning near support surfaces. In addition, digital measurement challenges in software such as SOLIDWORKS make it difficult to accurately select vertices, further reducing accuracy.

5. Conclusion

An analysis of the accuracy of the GOM II ATOS Triple Scan 3D Scanner on small sized metal objects reveals important findings in terms of accuracy, reliability and influencing factors. By comparing 3D scanning measurements with manual Vernier caliper readings, the study found that the scanner produced consistent deviations on all sizes of metal blocks, with the highest percentage of error on medium-sized blocks. The final results showed average percentage errors of 1.828%, 1.990% and 1.404% for small, medium and large blocks respectively, confirming the significant effect of size variation on scanning accuracy. Root Mean Square Error (RMSE) analyses highlighted that inadequate calibration, improper surface preparation and ambient lighting conditions were responsible for measurement variations. Despite these limitations, the scanner proved to be a reliable tool for capturing complex geometries, although improvements in scanning technology and software post-processing are necessary for high-precision applications. This study validates the GOM ATOS triple scanner as an important tool for engineering metrology, while identifying its limitations when scanning small objects..

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