Influence of Scan Strategies on the Accuracy of 3-Dimensional Optical Scanner for Face Scanning

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Abstract

Accurate digitization is the key to successful treatment in digital dentistry. The impact of scan strategies on the accuracy for face scanning remains unclear at this point in time.

Thus, this in-vitro study was conducted to digitally assess the trueness and precision of face scanning by comparing five different-purposed scan strategies using a specific device.

Twenty-five scanned data were obtained from different scan strategies (Scan technique X, Y, Z, Fixed X, and Fixed Y). A percent difference between the control group and index group was compared by using one-way ANOVA.

Scan technique X showed less deviation among others with statistical significance. Thus, scan technique X may be recommended as a technique of choice for face scanning.

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Introduction

Dentistry has changed the way of assessing and treatment planning for patients since the advent of 3-dimensional (3D) technology. 3D technology in dentistry is a feasible method in various types of use, such as 3D facial analysis, face driven restoration and restorative dentistry. In the digital dentistry work for 3D scanners, they are an essential step that generates the model of an object. These devices make it possible to collect data on the shape and sometimes depending on the 3D scanner, the appearance/surface detail or colors may also be more accurately collected.

3D scanners can be based on different technology, each with their own benefits and limitations. There are two main techniques used for 3D scanners: contact and non-contact. Contact scanner use probes against the surface to generate 3D object. While non-contact scanners projected light rays or use ambient light. Non-contact techniques can be further divided into two main categories: active and passive. Laser scanners and structured light scanners fall under the passive group. Laser scanners are based on triangulation to accurately capture a 3D shape from millions of points. More precisely, they work by projecting a laser point or line onto an object and then capture its reflection with sensors or a camera. Since the sensors are located at a known distance from the laser's source, accurate point measurements can be made by calculating the reflection angle of the laser light. With the known distance of the scanner from the object, the scanning hardware can map the surface of the object onto a point cloud[1]. A structured light scanning system projects different light patterns, or structures, and captures the light as it falls onto the scene. It then uses the information about how the patterns appear after being distorted by the scene to eventually capture the 3D geometry. The potential speed of data acquisition, the non-contact nature, the availability of necessary hardware, and the high precision of measurement are what make them highly adaptable into industries such as medicine, dentistry, biology, manufacturing, security, communications, remote environment reconstruction, and consumer electronics[2].

The reconstruction of a 3D object typically requires a two-stage real-time computation as shown in Figure 1, (1) computing phase in real time and (2) computing 3D point clouds,

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respectively[3]. Investigation in the engineering field reported that scanning direction/strategies/sequence (horizontal axis and vertical axis) affected the 3D point cloud computation[4]. Consequently, the scanning strategy affected the scanning accuracy.

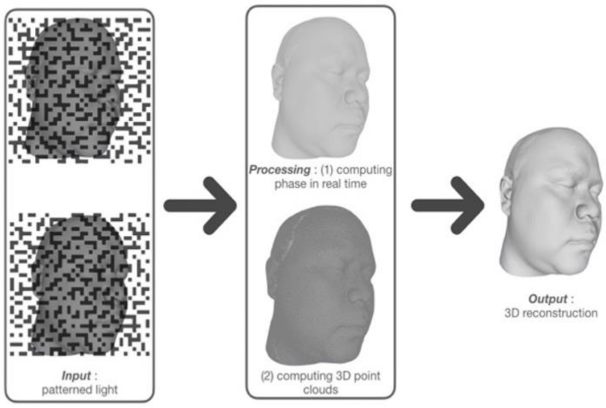

Figure 1. The reconstruction of 3D objects.

For intra-oral scanners, many studies have shown that the scanning strategies affected the accuracy. Mennito et al.[5] reported that scanning strategies affected the accuracy of the sextant scanning impression for both trueness and precision. Müller et al.[6] reported that their scanning strategies affected the scanning accuracy of the full arch scanning. This result is supported by the recent studies by Passos et al.[7], Latham et al.[8], and Diker et al.[9]. Regarding extra-oral scanners, there have been few literature reviews that exist showing whether scanning strategies influence the accuracy of face scanning.

When it comes to facial reconstruction in dentistry, the accuracy of the scanned data is the most important data of 3D workflow. The 'accuracy' is the combination of trueness and precision[10]. The trueness is the capacity of the scanner to produce 3D constructions as close to its true dimension as possible. Precision is the capacity of the scanner to produce a 3D construction within the acquired parameters by repeated scanning under the same conditions.

However, little information existed in the literature review undertaken in this research, on the impact of different scan strategies on the accuracy for face scanning. Thus, the aim of this in-vitro study was to digitally assess trueness and precision of face scanning by comparing five different-purposed scan strategies using a specific device.

Materials and methods

The overview of this study is shown in Figure 2. The study was divided into 3 parts: scanning, measurement, and comparison.

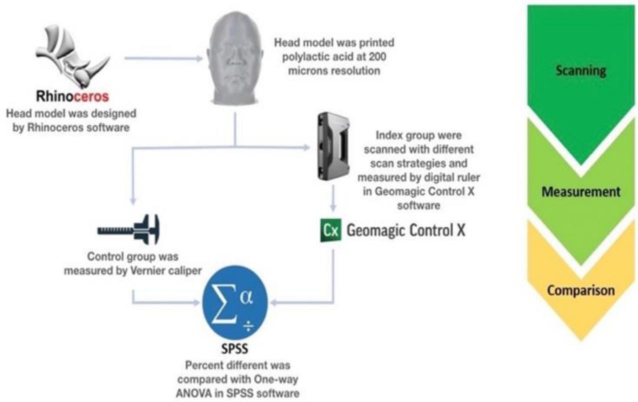

Figure 2. Study overview.

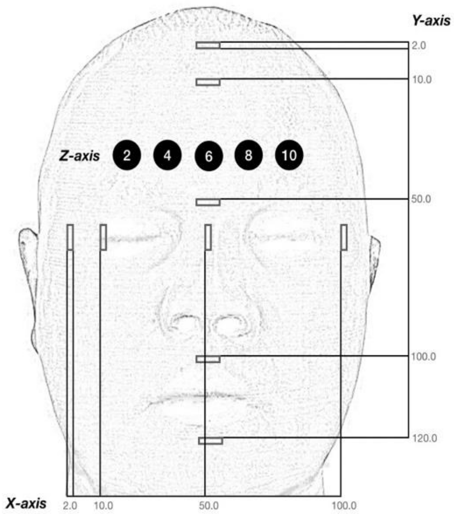

Figure 3. Head model: Rectangle parts and hole parts on X, Y, and Z axis are marker for measurement. Rectangle parts on X and Y are gradually widened from 2.0 to 120.0 mm. Hole parts on Z axis are gradually deepened from 2.0 to 10.0 mm.

Head model acquisition

A human head model was designed as close as possible to human size as shown in Figure 3. The face model was printed with polylactic acid with 200 microns resolution. The reference values were obtained from Vernier caliper by intra-calibration and inter-calibration.

Scanning

The head model was set as a center of rotation. The scanner was moved around at a 60 cm radius. Index groups were divided into 5 groups as shown in Figure 4. Group 1 (X): scanner was moving around face model on horizontal axis. Group 2 (Y): scanner was moving around face model on vertical axis. Group 3 (Z): scanner was moving around face model diagonally. Group 4 (FX): face model was stood on turntable, and the scanner was attached to a customized grip and tripod in a horizontal axis. Group 5 (FY): face model was stood on turntable, and the scanner was attached to a customized grip and tripod in a vertical axis. The total sample size that was required for this study was 25, with 5 per group.

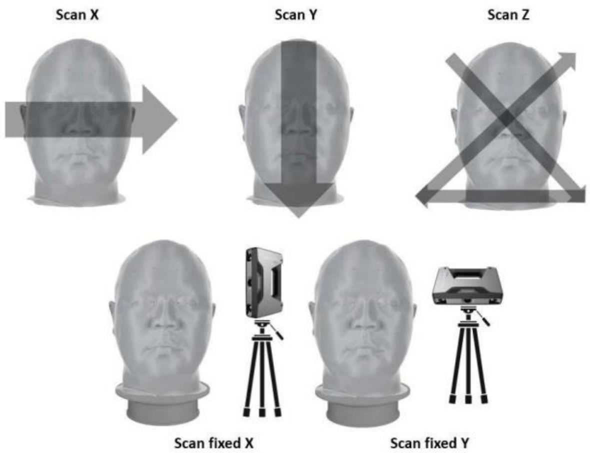

Figure 4. Five purposed-different scan strategies.

Measurement and data analysis

All scanned data were imported to MeshLab software to trim out and define definite borders using the same boundary cutting planes. The results of all measurements were described in terms of trueness and precision. The distance between markers in index group by using a software ruler was compared with the control group by using a Vernier caliper. The percent difference of deviation value will perform a statistic analysis in SPSS. Prior to analysis, the Shapiro-Wilk test was performed to normally distribute measurement and the test of homogeneity of variances was performed using the Levene test. Then, followed by the one-way analysis of variance (ANOVA) test and multiple comparisons with the Tukey method. The significance level was defined as $p < 0.05$.

Results

Distance	Groups	Mean ± SD	Comparison from reference using ANOVA				
			X	Y	Z	FX	FY
X2	Ref.	2.10 ± 0.023					
	X	2.038 ± 0.38					
	Y	1.81 ± 0.31					
	Z	1.48 ± 0.16					
	FX	2.13 ± 0.40					
	FY	1.71 ± 0.24					
X10	Ref.	10.18 ± 0.31					
	X	9.74 ± 0.22					
	Y	9.66 ± 0.26					
	Z	10.16 ± 1.18					
	FX	10.72 ± 1.04					
	FY	11.15 ± 0.25					
X50	Ref.	49.78 ± 0.19					
	X	49.33 ± 0.24					
	Y	49.65 ± 0.30					
	Z	49.54 ± 0.15					
	FX	49.42 ± 0.14					
	FY	49.56 ± 0.27					
X100	Ref.	99.27 ± 0.04	.989	.987	.999	.878	.778
	X	99.35 ± 0.62	-	.851	.543	.999	.000***
	Y	99.63 ± 0.17	.851	-	.981	.707	.000***
	Z	99.42 ± 0.24	.543	.981	-	.387	.000***
	FX	99.83 ± 0.34	.999	.707	.387	-	.000***
	FY	101.11 ± 0.32	.000***	.000***	.000***	.000***	-

Table 1. Comparison of One-way ANOVA in X-axis.
The grey cells are not statistically difference. ***p-value<.000

Distance	Groups	Mean ± SD	Comparison from reference using ANOVA				
			X	Y	Z	FX	FZ
Y2	Ref.	1.85 ± 0.01					
	X	2.02 ± 0.43					
	Y	1.83 ± 0.24					
	Z	2.00 ± 0.69					
	FX	2.14 ± 0.37					
	FY	2.39 ± 0.58					
Y10	Ref.	9.95 ± 0.06					
	X	11.19 ± 2.09					
	Y	11.55 ± 0.61					
	Z	13.68 ± 1.11					
	FX	12.96 ± 1.14					
	FY	15.10 ± 4.73					
Y50	Ref.	50.20 ± 0.33	.998	.999	.847	.879	.878
	X	50.38 ± 0.24	-	.371	.268	.000***	.023*
	Y	51.53 ± 0.82	.371	-	.999	.019**	.574
	Z	51.61 ± 0.45	.268	.999	-	.031*	.706
	FX	52.85 ± 0.56	.000***	.019**	.031*	-	.327
	FY	52.10 ± 0.79	.023*	.574	.706	.327	-
Y100	Ref.	100.51 ± 0.21	.887	.998	.987	.897	.788
	X	100.48 ± 0.49	-	.997	.010**	.053	.682
	Y	101.29 ± 0.21	.997	-	.021*	.100	.853
	Z	103.93 ± 2.02	.010**	.021*	-	.940	.156
	FX	103.35 ± 1.62	.053	.100	.940	-	.489
	FY	102.07 ± 0.88	.682	.853	.156	.489	-
Y150	Ref.	151.35 ± 0.54					
	X	150.43 ± 0.88					
	Y	151.10 ± 0.95					
	Z	151.72 ± 1.10					
	FX	127.90 ± 57.77					
	FY	151.60 ± 0.54					

Table 2. Comparison of One-way ANOVA in Y-axis. The grey cells are not statistically difference.
***p-value<.000, ** p-value<.01, * p-value<.05

For trueness in X-axis (Table 1), every scanning technique performed well in measurement of X2-X50 with no statistically difference. When it came to a measurement of X100, technique FY performed the worst for accuracy (1.81 ± 0.33) with statistically difference (p-value < .000). Technique Z, Y, X, and FX still performed well at this measurement, respectively (0.23 ± 0.11, 0.32 ± 0.17, 0.49 ± 0.41, 0.53 ± 0.33).

In Y-axis (Table 2), scanning technique performed well in every measurement except the measurement of Y50 and Y100. At Y50, technique X performed the best accuracy (0.46 ± 0.41) with statistically difference. Technique Y, Z, and FY came in second (1.87 ± 1.62, 2.04 ± 0.89, 3.01 ± 1.55). While, technique FX performed with the worst accuracy (4.49 ± 1.10).

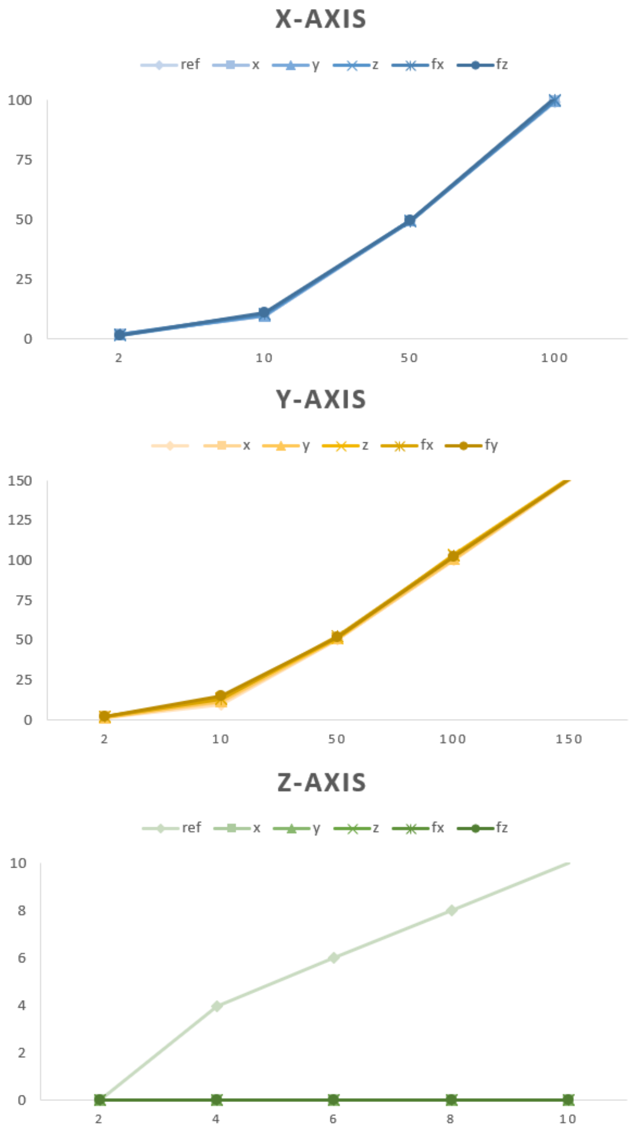

Figure 5. Mean measurement from caliper in X, Y, and Z-axis.

Figure 5 a,b,c shows the mean measurement of X-axis, Y-axis, and Z-axis of reference and scanning techniques. The purposed techniques had the ability to measure in X and Y axis, but none of the purposed techniques could capture the Z-axis or depth (lines are not along with reference line).

For precision in X-axis, technique FY performed the lowest SD (199.2), while technique Y performed the highest SD (255.9). In Y-axis, technique Z performed the lowest SD (280.5) and technique X performed the highest SD (439.3) as shown in Figure 6.

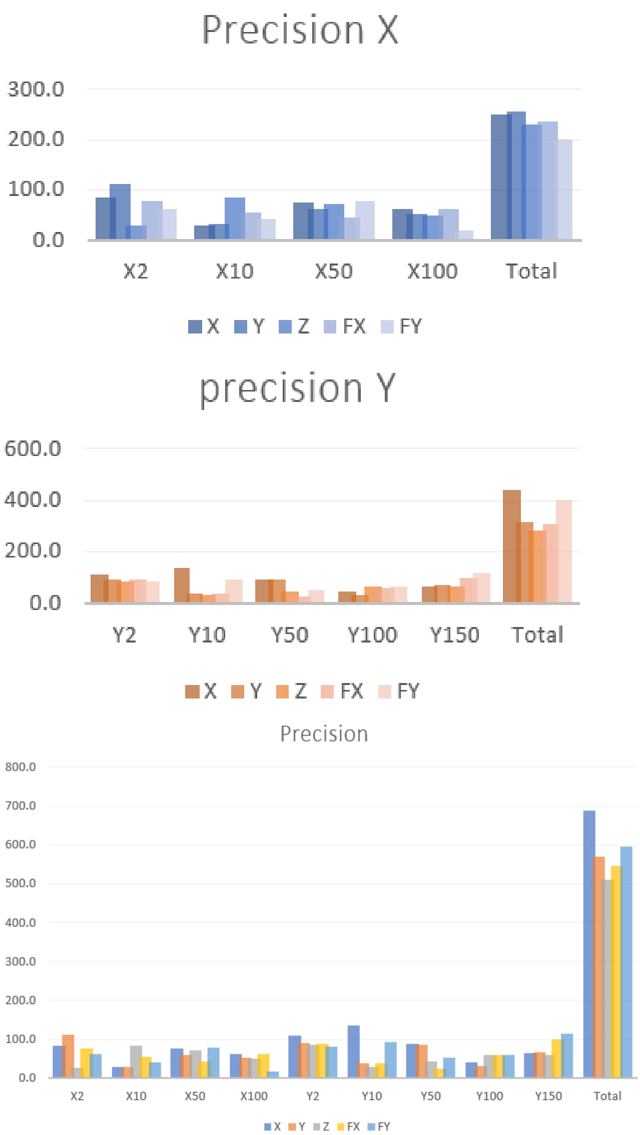

Figure 6. (a, b) SD of precision in individual axis. (c) Sum of SD of precision in all axis and techniques.

Discussion

Accurate digitization is the key for successful treatment in digital dentistry. The aim of this study was to assess trueness and precision of five different-purposed scan strategies. The results of this study have shown that scan strategy affected the accuracy of the scanner for face scanning. This study showed that technique X had the least deviation in most of the measurements, while the others showed more deviations. In other words, technique X is the most accurate scan strategy for face scanning in term of trueness.

From the point of view of precision, the result was excellent for technique FY in X-axis, technique Z is excellent for Y-axis. However, the less that distance was measured, the more deviation had grown. This was not only the precision but also the trueness. A high precision of fit in the computer-aided design/computer-assisted manufacture (CAD/CAM) fabrication is theoretically and practically easier to obtain for short-span FDPs than for long-span reconstructions [6]. Misfit values of less than 100 µm are considered to be clinically acceptable[11]. Similar to what was found in this in vitro study, the precision was high in individual axes, but the results need to be interpreted within the range of clinically acceptable values.

In depth measurement or Z-axis, the scanners showed less accuracy[12]. In agreement to these findings, was that all of the purposed scan strategies cannot capture the depth of the objects due to the inability of light passing through. According to Amornvit et al.[12], the depth areas in facial structure such as nostril and external auditory meatus have convex geometry. Thus, those structures are difficult to scan.

Most accuracy studies always tested their hypothesis by using the Root Mean Square Error (RMSE), which is just the summary of the mismatch area between the scanned data and reference data that has no meaning for clinical applications. In this study, the difference in the measured distance was used instead, which can explain how the scan strategies affected exactly on the accuracy in clinical situations.

Another result from this study that is worthy to discuss is the trend of deviation. Figure 7 has shown percent different of trueness, which shows a trend of deviation. The smaller of the marker sizes, the lower accuracy of the scanner. In the literature, a discrepancy of 2.0 mm is considered to be clinically acceptable[13]. Thus, the scanner and the purposed scan strategies are appropriate to use in tasks that need accuracy of more than 2.0 mm. On the other hand, if the marker size is smaller than 2.0 mm, the result will give more information about the accuracy.

In the future, those devices and techniques will become a routine practice. The scan strategy might be an important step in the continuing of clinical practice. The purposed technique Scan X might be the technique of choice for all structured-light scanners. This technique would be advantageous and beneficial in all clinical aspects using trueness as a primary goal. Subsequently, the errors will be eliminated. Furthermore, any clinical studies ought to be done in every aspect before any clinical implementation.

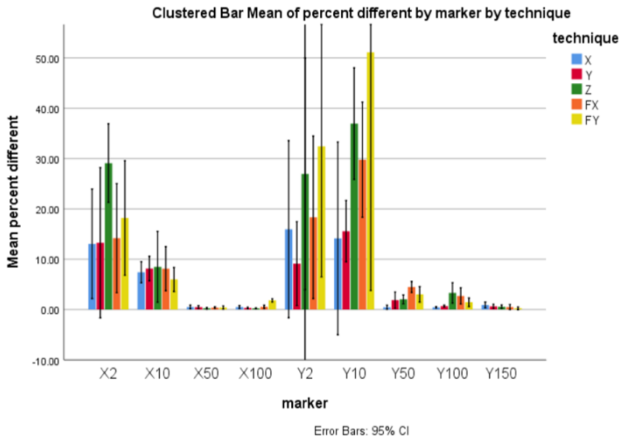

Figure 7. Percent difference by distance and technique.

Conclusions

Scan technique X showed the lowest deviations among others in terms of trueness. While, the precision was highest in Scan technique X and lowest in technique Z. Thus, Scan technique X may be recommended as a technique of choice for using structured-light scanners for face scanning, as it provided the highest trueness.

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Declaration of Interest

The authors declare that there are no conflicts of interest.

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