ORIGINAL ARTICLE

3D Scanner's Accuracy In Different Races Of Head And Face Measurement For Ergonomic Design

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ABSTRACT

Introduction: 3D scanning of the head and face has been growing to a vital technique in the field of anthropometrics such as the creation of a sizing chart for medical wearables and motorcycle helmet. This research project targets to identify the optimize setting so that we can obtain better accuracy of head and face scanning for various races. **Methods:** The review process involved few factors such as brightness, skin colour, glossiness, scanning angle, head and face shape and scanning duration. From the 3 chosen factors, scanner brightness, skin colour, and process layout, we have conducted DOE experiment to identify the significant factors affecting the 3D scanner accuracy. **Results:** The ANOVA result of experiment imply that Factor A-Scanner Brightness is the most significant factor ($p<0.0001$) in affecting the 3D scanning result of head circumference and face width. Factor B-Skin Colour is only significant factor affecting face width dimension. Factor C-Process Layout is not significant. Increasing the scanner brightness will further worsen the accuracy of 3D scanner due to increased light exposure to 3D scanner camera. Factor B-Skin Colour only appears to be significant on the face width dimension because some of the landmark stickers are pasted on the grey wig cap. **Conclusion:** In coherent with the objective discussed, the study of significant factors from scanner brightness to the skin colour has been identified for the 3D scanner accuracy which creates a milestone to contribute to the diagnostic of skin cancer, forensic studies and medical wearable product design.

Keywords: Ergonomics, Handheld 3D scanning, 3D point cloud, Anthropometry

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INTRODUCTION

From the history of 3D scanning technology, a need of reverse engineering of free form object have led to the invention of 3D scanning technology since the 1960s. However, current modern 3D scanner accuracy still depends on environmental factors other than the scanning technology itself. For example, subject colour. Light grey colour card is the least sensitive to ambient light in lowering the accuracy of a 3D scanner (1).

Also, Malaysia is a multiracial country. Since 3D scanning of the head and face need to be done for each citizen for product design, medical, and anthropometric data, it is very important to adjust the correct brightness of the 3D scanner projected light. Extremely bright or over dark during 3D scanning will cause the undesirable result to the 3D point cloud. Thus, it is very important to adjust the correct brightness of the 3D scanner projected light for each race.

Besides that, there are reported problems of 3D scanning like miss-scan areas, especially near small radius of curvature. In addition, the face structure which has a large depth also cause the miss-scan area. For example, nose hole and ear hole.

With the emerging post-processing software such as filtering, meshing and alignment, we might overlook the physical environmental factor which might affect the quality of the 3D point cloud. Even handheld 3D scanners introduced in recent years can improve the portability of 3D scanning; however improper techniques will lower down the quality of 3D point clouds such as miss-scan areas and noisy point clouds.

Therefore, this review targets the previous study of several identified environmental and physical factors which might affect the result of 3D scanning to be studied. Lastly, the research gap was summarized to discuss the connectivity of the result in the existing study and research objective.

MATERIALS AND METHODS

Types of 3D Scanner

There are three main types of 3D scanner existing in the market, namely triangulation type, time-of-flight type and structured light type 3D scanner. Triangulation type 3D scanner collects the data by using its' laser launcher and CCD camera. The laser dot projected by its' laser launcher form a triangle. The known distance from the CCD camera to the laser launcher, the known angle between incident ray path and reflection ray path, the distance of each point coordinate on the subject surface can be calculated by using the theory of trigonometry (2). On the other hand, the time-of-flight system 3D scanner deduce the coordinate of a point on the subject surface by recording the travel time of the laser beam from itself to the subject surface. For structured light 3D scanner, such as EinScan Pro+ handheld 3D scanner which we will be used in our research, it project a patterned light called "structured light". This mechanism enables the structured light 3D scanner to scan multiple points at a time. Therefore, it is able to prevent the motion distortion of the subject.

Head and Face Scanning

Previously, the head and face dimension of human being was measured by using mechanical instruments. Nonetheless, it suffered from accuracy issue due to the possibility of skin being compressed during measurement (3). However, with the emerging 3D scanning technologies, these technologies have been applied in head and face anthropometric due to their better accuracy, particularly by avoiding the possibility to compress the skin.

Human head and face shape exhibit the nature of free form head and face geometry consist of many small radii of curvature. Just by mechanical instrument alone is insufficient to capture all its shape information. In addition, parallel with the emerging CAD technologies, design engineers need a 3D scanner to generate a 3D CAD model of head and face from a 3D point cloud to design head gear equipment to better fit human head and face. This industrial trend has created a need in the research of head and face scanning accuracy.

Literature Review

For this section, we have conducted several literature studies particularly on the following six factors discussed.

The first factor of study is brightness. Since the year 2010, it has been mentioned that sunlight can affect the performance of the 3D scanner (4). Consecutively, Leme et al. study on the number of cloud point after trimmed in OBJ data formats collected (1). They found that ambient light is a source of error, especially for the structured light 3D scanner. The object however, can be scanned as long as the ambient light is not shining until it causes an apparent interference to the 3D scanner projected light (5). In currently emerging handheld 3D scanner, we just need to adjust the 3D scanning brightness setting by looking at the preview of the 3D point cloud collected.

For the second factor, skin colour. Our country, Malaysia is a unique country with different races living harmonically and rich with various cultures and festivals. According to Knaggs, the skin of Malay generally have Skin Type 5, Dark Brown; Chinese, Type 4, Medium Brown and Indian, Type 6-Black (6). Therefore, skin colour is a vital factor in this head and face 3D scanning project.

3D scanning brightness is the main setting to be determined according to the colour of the subject. For example, the black strips of the shoes. There is a preview resulting from the 3D scanning brightness setting of the EinScan-SE 3D Scanner. An optimum setting is found when the area of overexposure highlighted in red is minimized.

Third factor of study discussed in this paragraph is glossiness. High glossiness colour object such as gold has been proven to cause issues to the result (4). For instance, as advised by EinScan user guideline, high glossiness subject is considered as the difficult-to-scan subject. In this case, spraying white powder or bright colour paint is suggested. In our case, we might have a possibility where the subject has a glossy face due to an oily face after work. Therefore, it is advised to remove the oily face by washing face or put powder before scanning.

Fourth factor, scanning angle factor has been studied by Kovacs et al. in affecting the 3D scanning result of Minolta Vivid 910 which is not so portable (7) . With handheld 3D scanner such as EinScan Pro+, scanning angle has been very flexible by adjusting the 3D scanner so that it is parallel to the subject to function properly. Though, to ensure smooth scanning motion while looking at the preview screen, 3D scanning training is vital to reduce any possible noise to the point cloud.

From the existing literature review, fifth factor, head and face shape do not found to greatly affect the result of 3D scanning. To illustrate, 3D scanning result from children up to old man which has different shape and size does give the promising result of the point cloud as shown in following Fig. 1.

During 3D Scanning, the participants have to maintain in static position for scanning accuracy (11). However, sustaining static posture in long scanning duration, human tend to relax and jiggle in nature rather in static position. No doubt, Yu has mentioned that image distortion happened to the structured light 3D scanner due to postural changes of an involved participant (12).

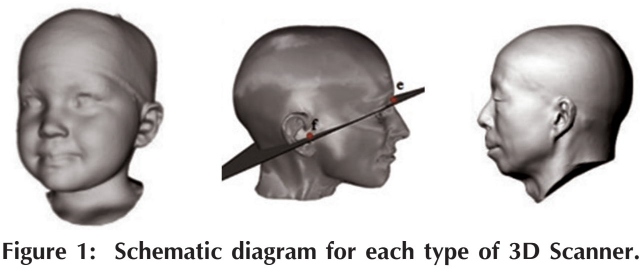

Figure 1: Schematic diagram for each type of 3D Scanner. (2,4)

Moreover, Zeraatkar and Khalili have even proposed to minimize the scanning time to avoid the error from the participant possibility of movement (13). Therefore, sixth factor, scanning duration is significant in influencing the 3D scanning accuracy.

In the study of 3D scanning accuracy evaluation, one of the methods is subjective evaluation of the presence of miss-scan areas or occlusion defect in the 3D point cloud. For instance, there are several past studies using subjective explanation for the presence of miss-scan areas on the 3D scanning result as shown by Fig. 2 (15,16,17).

Besides subjective evaluation, deviation analysis is obtained by calculating the difference of dimension between the 3D CAD Model and 3D scanned point cloud. For instance, Eklund have applied deviation analysis to the mannequin (18) as shown in Fig. 2(b). Furthermore, root means square deviation analysis has been applied by the existing researcher. For example, Knoops et al. collected data have been obtained by using the root mean square error (RMSE) formula as the metrics of evaluation of 3D scanning of the face as shown in Fig. 2(c) (9).

Materials and Methodology of Experiment

In this section, DOE experiment was conducted with the method described as follows. 3 participants, each for each skin colour were scanned using EinScan Pro+ handheld 3D scanner for their head and face with constant room light after wear the grey swimming cap. The reference dimensions of their head circumference and face width were measured using measurement tape and anthropometric calliper on the landmark shown in following Fig. 3(a). The factors of interest to be studied after literature review are Factor A-Scanner Brightness, Factor B-Skin Colour, and Factor C-Process Layout as shown in Fig. 3(b). 2k factorial was applied to analyse the deviation data collected as shown in the results and discussions section. For the factor of process layout, Type 1, Non-Swivel Chair layout is where the participant will be static and the 3D scanner user need to move around the participant to scan his head and face. For Type 2, Swivel Chair layout is where the participant need to sit down and 3D scanner user rotate swivel chair for the 3D scanner user to scan 360 degree of his head and face.

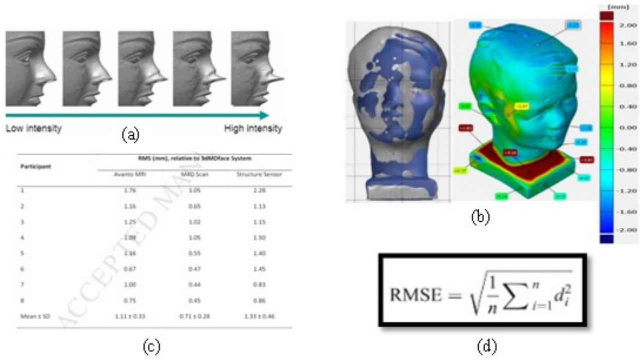

Figure 3: Various evaluation method of the 3D scanning result. (a) Eye observation on nose deformation (15), (b) Deviation analysis (18), (c) RMS method & (d) RMSE formula (17)

Factor A, B and C were evaluated by conducting 2k factorial design experiment. The detail of the experiment result is shown in next section.

RESULTS

The result of deviation for head circumference and face width were obtained by calculating the differences between 3D point cloud dimensions and manual measurement using calliper (for Face Width, FW) and measurement tape (for Head Circumference , HC) as referenced from Table I. Next, we analyse the 2k factorial experiment by using Design Expert software to get the result shown in next Table II.

From Table II, both (HC and FW deviation response) ANOVA results of 2k factorial analysis shows that the Factor A-Scanner Brightness is the most significant factor ($p<0.0001$) in affecting the result of deviation. However, Factor B-Skin Colour is only significant in FW deviation. Factor C-Process Layout does not appear to be significant. However, there is also significant curvature ($p<0.0001$) detected in both of these result.

For the optimized settings, we found that the 3D scanning result is the most accurate in the low level of scanner brightness, level 2 and worsening while increasing the scanner brightness for HC and FW Deviation.

The optimum 3D scanner brightness setting is found from level 2-6 brightness for all skin colours or races.

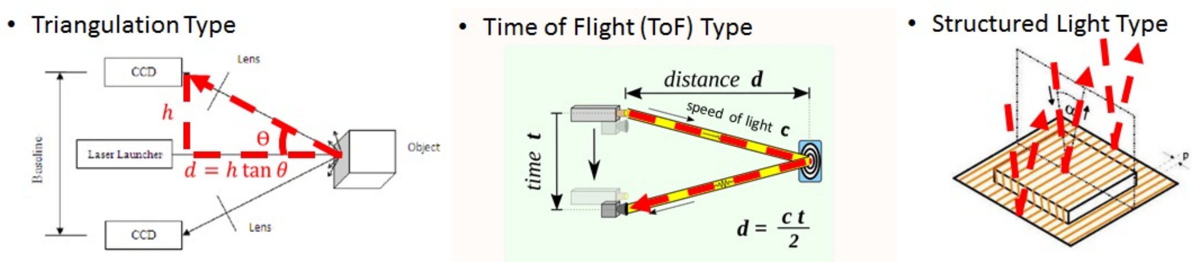

Figure 2: Promising 3D scanning result of various head and face shape. Kid (8); adult ranged 23-27 years' old head scanning (9) and old man (10)-from left to right.

Table I: Head Circumference (HC) and Face Width (FW) Deviation Result from 2k Factorial Experiment

Factor/Deviation			Head Circumference, HC/mm				Face Width, FC/mm			
A	B	C	HC1	HC2	HC3	HCavg	FW1	FW2	FW3	FWavg
-1	-1	-1	7.9	21.99	20.63	16.84	0.47	0.21	0.24	0.31
+1	-1	-1	458.03	400.18	470.43	442.88	44.37	43.63	42.52	43.51
-1	+1	-1	4.43	5.97	3.99	4.80	16.50	15.66	16.30	16.15
+1	+1	-1	516.84	557.52	496.48	523.61	91.81	66.43	91.81	83.35
-1	-1	+1	47.46	6.64	27.42	27.17	0.21	0.04	0.22	0.16
+1	-1	+1	521.27	522.33	544.8	529.47	32.62	46.33	60.83	46.59
-1	+1	+1	2.58	4.92	2.79	3.43	15.60	15.84	16.04	15.83
+1	+1	+1	561.98	535.79	511.25	536.34	77.35	53.17	91.81	74.11
0	0	-1	5.95	105.75	21.75	44.48	0.61	0.31	0.09	0.34
0	0	+1	13.88	34.33	3.77	17.33	0.27	0.16	0.58	0.34

Legends

Level/Factor	A, Scanner Brightness	B, Skin Colour	C, Process Layout
-1	2	Dark (Indian)	Non-Swivel Chair
0	8	Medium (Malay)	-
+1	14	Fair (Chinese)	Swivel Chair

Non-Swivel Chair type process layout is better than Swivel Chair type in terms of better ergonomics to the research participant even though it does not found to be significant. This finding has fulfilled our research objective, which is to identify the optimal setting of 3D scanner for the minimum deviation.

DISCUSSION

From the 3D Surface plot, we found that 3D scanning result is the most accurate in the low level of scanner brightness, level 2 and deteriorating while increasing the scanner brightness. This is because when the scanner brightness is increased, increasing light exposure caused the miss-scan area to increase due to loss tracking by the 3D scanner. Loss tracking happened when the 3D scanner unable to combine the 3D point cloud scanned with previous point cloud. As a result, the miss-scan area caused a large deviation due to the missing point cloud, which cannot be measured.

Factor B-Skin Colour is only significant to FW deviation because some of the landmark stickers for head circumference are pasted on the grey wig cap which is not depend on skin colour.

Factor C-Process Layout is not significant because the scanning process layout of swivel chair layout and non-swivel chair layout have almost the same process time ranging between 1-2 minutes. It is better to choose a Non-Swivel chair process layout since rotating the chair will cause dizziness to the research participant.

The weakness of this experiment is curvature detected in the model is significant. Therefore, the linear model generated is not sufficient to predict the result. So, we suggest to perform face-centred design experiment for future follow-up works in order to generate 2nd order model. The originality or value of this paper is the study of significant factors from scanner brightness to skin colour has been identified for 3D scanner accuracy study. This will create a good milestone for the researcher to improve 3D scanning accuracy and contribute to the accuracy of forensic studies (19) and diagnostic of skin cancer (20) besides leading to improved ergonomics of medical wearable product design.

CONCLUSION

We have study the optimal 3D scanning brightness setting and scanning process layout for 3 main races. From the experiment, Factor A- Scanner Brightness is the significant factor in affecting the accuracy of handheld 3D scanner, EinScan Pro+. Factor B-Skin Colour is only significant for FW deviation. For future, face centered design experiment is needed in generating 2nd order model as linear model generated from 2k factorial experiment is insufficient.

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Table II ANOVA for Mean Head Circumference, HC and Face Width, FW Deviation from 2k Factorial Experiment

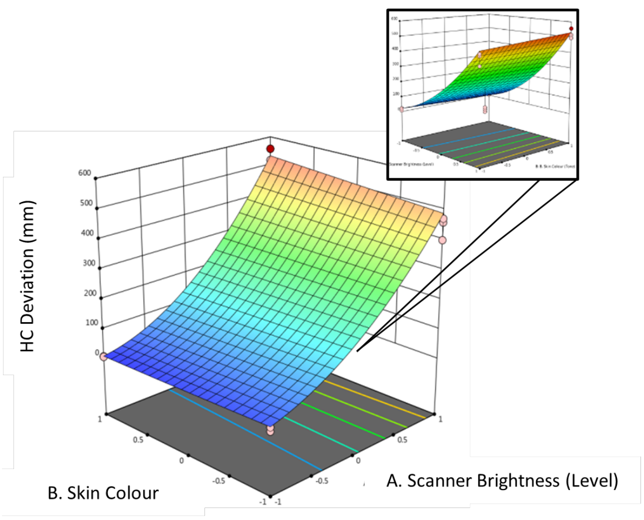
Transform: Square Root

Constant: 1

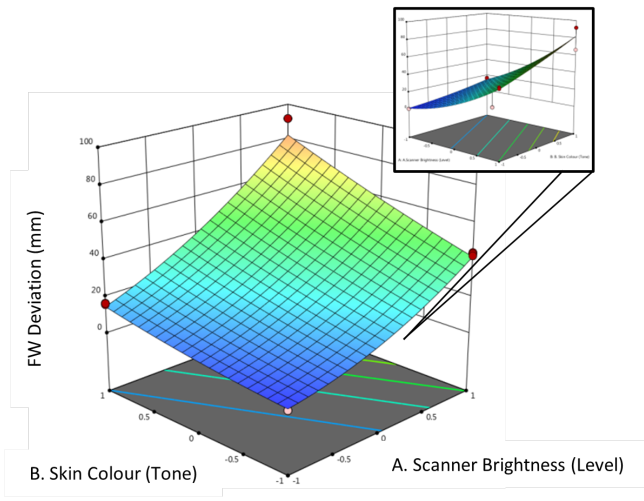
Response 1	**Head Circumference, HC Deviation**					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	2214.29	3	738.1	279.6	< 0.0001	significant
A-A.Scanner Brightness	2194.97	1	2194.97	831.5	< 0.0001	
B-B. Skin Colour	2.7	1	2.7	1.02	0.3218	
AB	16.62	1	16.62	6.3	0.0189	
Curvature	308.96	1	308.96	117	< 0.0001	
Residual	65.99	25	2.64			
Lack of Fit	8.79	5	1.76	0.614	0.6902	not significant
Pure Error	57.21	20	2.86			
Cor Total	2589.24	29				

Response 2	**Face Width, FW Deviation**					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	202.41	2	101.2	333.2	< 0.0001	significant
A-A.Scanner Brightness	162.75	1	162.75	535.8	< 0.0001	
B-B. Skin Colour	39.66	1	39.66	130.6	< 0.0001	
Curvature	79.36	1	79.36	261.3	< 0.0001	
Residual	7.9	26	0.3038			
Lack of Fit	1.68	6	0.2797	0.9	0.5144	not significant
Pure Error	6.22	20	0.311			
Cor Total	289.66	29				

3D Surface



3D Surface



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