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Validation and Reliability of Sizestream 3D Scanner Using Regression Modeling

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ABSTRACT

3D scanning has evolved as one of the most advanced and accurate technology to measure humans and products. Quick and reliable results achieved by 3D scanning over manual measurements, make it the most preferred tool for measurement. 3D scanning has been extensively used in various national sizing surveys worldwide. The 3D scan results are compared to the manual measurements to establish the accuracy of the scanner. This research paper describes a novel and alternative approach to check the reliability and validity of the measures derived from 3D Body Scanner in comparison to measures provided by the manual measures. The 3D Body scanning was done by Sizestream 3D Body Scanner - SS14. The manual body measurements were taken by experienced experts using an anthropometer, stadiometer, and certified flexible non-stretchable steel tape. In total 133 subjects (68 male and 65 female subjects) covering 102 body dimensions were taken manually and were used while comparing 3D scan measurements to establish the validity and reliability of the scanner. The procedure adopted for validation and reliability check for the 3D scanner was as prescribed in the ISO 20685:2005 and ISO 20685:2018. It was observed that the Sizestream - SS14 scanners used were highly consistent in measuring the subjects, though a systematic error was reported in the process failing some of the measurements in terms of accuracy levels (as per ISO 8559:1989 and ISO 20685:2005) achieved against manual measurements used as the gold standards. Subsequently, a novel approach based on regression modeling was applied to establish scanning accuracy. This research paper describes the validation and reliability procedure as per ISO protocols. It also discusses the regression-based statistical procedure adopted to confirm the desired measurement accuracy of the scanners within the permissible error limits of ISO 20685:2018 and ISO 8559:1989.

Keywords: 3D body scanning, Validation and reliability, Scanner consistency, Intra-class correlation (ICC), Regression modeling

INTRODUCTION

Anthropometric dimensions are essential for any scientific product design, and it works as the foundation knowledge in the ergonomic user-centered design. Anthropometric measurements are widely used in several areas automobiles, medical sciences, aviation, architecture, and of course apparel where it is extensively used for mass customization for an improved fit (Tiwari &

Anand, 2021). The traditional approaches of anthropometry are primarily contact-based methods that consume more time, effort as well as money. In the past few years, 3D body scanning technology has emerged as a key medium for human body measurements. It is a noncontact method that provides faster and more accurate results. In the last 50 years, there have been several countries (including the USA, the UK, Germany, France, Japan, Korea, China, etc.) have undertaken their national sizing surveys using 3D body scanning. Currently, the INDIAsize (National Sizing Survey of India) is going on using 3D body scanning. This research paper discusses the procedure for validation and reliability of the 3D body scanners being used in the INDIAsize survey. The background section provides necessary justification about the need for validation and reliability of the 3D body scanners. The methodology section discusses the subject details, manual and 3D scanning procedures adopted, data preparation, and data analysis. The methods of applying a correction factor (Bias-shift) and regression modeling and checking the results with ISO 8559:1989 and ISO 20685:2005 have also been discussed in this section. The key findings have been discussed in the results and discussion section while the last section provides the conclusion of the research and future directions.

BACKGROUND

In recent years, anthropometric data collection using 3D body scanning has gained popularity and it is preferred over manual measurement techniques. Still, the manual measurement techniques have maintained their importance as these are considered gold standards while establishing the accuracy of the body measurements obtained using 3D body scanning. It becomes vital to establish the validity and reliability of the 3D body scanning systems to ensure that the output measurements are trusted and applied for further use. It is important to understand how the scanner extracted measurements are concurring with the measurements taken manually for the same dimensions (Mckinnon & Istook, 2001). There are several research works have been conducted to establish the validation and reliability of 3D body scanning systems. Also, there are some ISO standard procedures available to establish 3D scanners' reliability and accuracy. ISO 20685:2005 provides 3D scanning methodologies for internationally compatible anthropometric databases (ISO 20685, 2005). The ISO 20685:2015 provides guidelines about the evaluation protocol of surface shape and repeatability of relative landmark positions (ISO 20685, 2015). Tiwari and Anand (2021) conducted the validation and reliability of 3D body scanning systems using a correction factor termed as Bais-shift (Tiwari & Anand, 2021). It was observed that the approach of applying Bais-shift was scientific and established, it has some challenges involved. There are different correction factors to be applied for different dimensions. The corrected values (after application of the Bais-shift) when evaluated against ISO standards, it may result in inconsistent output i.e. some of the measurements may pass and some of the measurement may fail with the latter happening when the errors are not systematic.

METHODOLOGY

Procedure and Equipment

In total 379 subjects (207 Males and 172 Females) with varied ages, shapes and sizes were measured using 3D body scanning. Out of these 379 subjects, 133 subjects (68 males and 65 females) were measured manually using the traditional approach. The manual anthropometric measurements were taken by the experienced anthropologists using certified tools such as a stadiometer, anthropometer, and steel tapes.

In total 102 body dimensions were measured using 3D scanning and manual body measurements. These 102 body dimensions included the dimension categories as prescribed in the ISO 20685:2005.

The manual body measurements were taken by two (02) experienced anthropologists. Every subject was measured twice independently by the measurers in adherence to the prescribed protocol of ISO 8559:1989. The lengthwise body measurements (vertical dimensions) were taken using a certified anthropometer and the sliding stadiometer (Length of 210 centimeters and least count 1.0 mm). The girth-related measurements (horizontal dimensions) were taken using a certified flexible non-stretchable steel tape (Length 200 centimeters and least count 1.0 mm). A mirror was fitted on the wall (behind the subject) to ensure the correct landmark positioning and placement of measuring tape. This entire exercise manual body measurement was conducted under the supervision of a senior anthropologist having more than 20 years of field experience.

The 3D whole-body scanning of the subjects was conducted using the SS14 3D Body scanning system of Sizestream. SS14 scanners capture body measurements using infrared technology. ISO 20685:2005 protocol was followed while 3D scanning of the subjects. As per the standard practice, the scanners were duly calibrated at the start of the exercise on each. Each of the subjects was measured once using 3D Scanning and the scanning setting was kept at 3 bursts per scan. The final dimension for a given measurement was taken from the median value of the dimensions out of these three bursts. Each of the subjects was provided specially designed scan suits made of material with sufficient stretch to avoid body compression as well as any kind of slackness or looseness from the body. While 3D body scanning, the subjects were asked to maintain the posture as prescribed in the ISO 20685:2010-11.

Data Preparation

Data preparation was done in the five steps as, 1. 3D body scan of the subjects and getting the composite file indicating median values of the measurements, 2. Manual body measurements (Each of the subjects was measured once by each of the two measures) and recording the measurement values in MS Excel file for every subject, 3. Preparing a combined data file with both the manual measurements values (named as M1 and M2) and 3D scan median values (names as S) for the selected 133 subjects, 4. Exporting the data file in SPSS V. 23 for further statistical analysis, 5. Data cleaning by identifying and removing the extreme values and outliers (the values beyond +/-3 Standard Deviation were discarded)

Data Analysis

Statistical data analysis was undertaken with these steps,

- **Step 1.** Calculating the mean value (termed as M) of the manual measurements as M1 and M2 for each of the subjects for every dimension.
- **Step 2.** Calculated the mean difference by averaging all the differences between the scanner measurements and the average measurements taken manually (ISO 20685, 2005).
- **Step 3.** Determining the Standard Deviation (SD) of the difference between scanner measurements and manual measurements (Kouchi & Mochimaru, 2011).
- **Step 4.** Determining the error limits@95%confidence level using the mean of the differences (between scanner measurement and manual measurement) for each of the subjects and all the dimensions (Kouchi, 2014).
- **Step 5.** Checking the mean differences using the test methods given in Clause 5 of ISO 20685:2005 (ISO 20685, 2015), (Han et al., 2010).
- According to ISO 20685:2005, if the 95% confidence interval for the mean of regressed scan-minus-manual measure differences is within the plus or minus interval values (please refer to table 1), then the 3D scanning system can be considered acceptable (Tiwari & Anand, 2021), (ISO 8559, 1989). To accept the regressed scanner extracted measurements, both the upper value and lower value should be within the ISO 20685:2005 prescribed limit.
- **Step 6.** Determining the regression equation between mean manual measurement value (M) and scanner measurement value (S). Here S was taken as an independent variable. Further, the scanner measurement value was regressed (termed as SR) for each of the dimensions. Scatter plots for some of the dimensions with regression equation and respective R^2 values are illustrated in figure 1.
- **Step 7.** Creating the normality plot for the residuals and homoscedasticity (homogeneity of variances) was checked while applying regression to adjust scanned measurements.
- **Step 8.** Checking the R^2 values of the regression equations for each of the dimensions to confirm the robustness of the regression model, and predict the regressed scanner value (SR) as an outcome.
- **Step 9.** Perform steps 2 to step 5 to check the mean differences using the test methods given in Clause 5 of ISO 20685:2005.
- **Step 10.** Conducting performance test-retest procedure using 80% values to predict 20% of the values, and testing it against as per the ISO 20685:2005 protocol as well as per ISO 8559:1989 limits based on % error.
- **Step 11.** Conducting paired comparison t-test between the regressed scanner measurement values and manual measurement values to identify and re-confirm (addition to the checking of error limits as mentioned in step 8 above) whether there is any significant difference between regressed scanner measurements (SR) and the average of the manual measurements (M). Regressed scanner values (SR) to be accepted if there is no significant difference between SR and M.

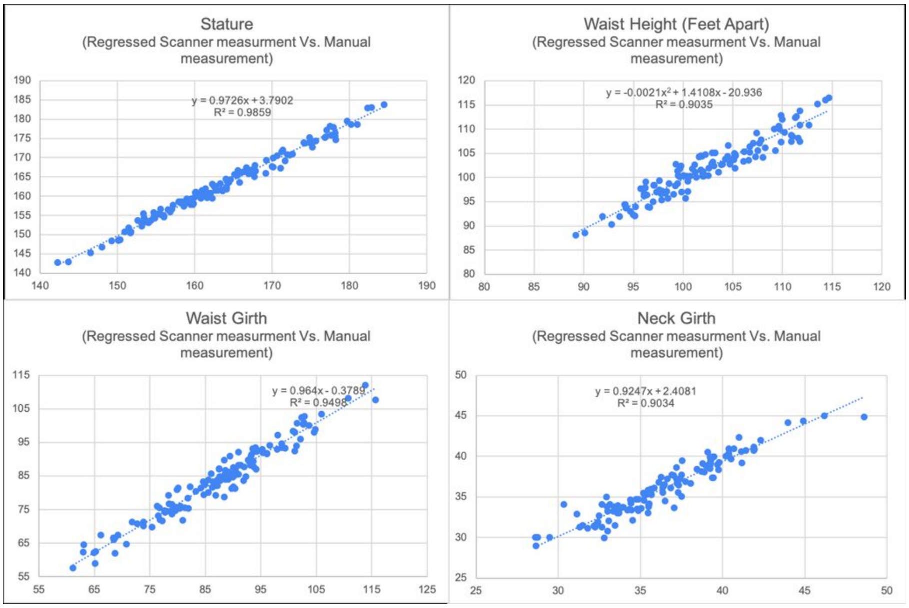

Figure 1: Scatter plots (regressed scanner measurement vs. manual measurement).

While checking the scanner extracted values to the manual measurement values as per ISO 20685:2015 and ISO 8559:1989 standard acceptable error limits, it was observed that the upper and lower limit of all the differences were observed beyond the permissible limit except for a few dimensions as back neck height, shoulder height, upper hip height, calf height, midriff height, back neck point to waist (center back length), upper arm length, elbow girth, and wrist girth. Here it may be noted that the permissible error limits as prescribed in ISO 20685:2015 and ISO 8559:1989 standards are a bit stringent, and that may be the reason that the deviations between scanner extracted values and manual measurement values go beyond the permissible prescribed limits. However, in the context of apparel applications to achieve a good fit we may need to relax such limits in due consultation with the clothing fit experts.

The checking of regressed scanner values against the manual measurement values as per the ISO 20685:2005 and ISO 8559:1989 were done for all the 102 dimensions. Please refer to table 1 for the testing on error limits for some of the dimensions.

From table 1 it can be learned that the regressed measurement values were observed as Pass (P) to most of the dimensions, however, for two of the dimension (1. Inside leg-length, and 2. Across shoulder) the upper limit was marginally out for Inside leg-length for ISO 20685:2015, and Across shoulder for ISO 8559:1989 standard error limits.

The scanners were observed as highly consistent and the same was statistically confirmed by determining the intra-class correlation (ICC) values. ICC is used to check for the consistency and repeatability between different scan measurements and it represented the variance attributable to error (Koepke et al., 2017), (Koo & Li, 2016). ICC reflects both degrees of correlation and

Table 1. Scanner validation (regressed scanner measurement vs. manual measurements).

Measurement	Stature	Shoulder	Inside Leg-length	Waist Height	Across Shoulder	Chest Girth	Waist Girth	Neck Girth	Chest Depth
Mean Diff (SR-M) (cm)	0.0015	0.0006	0.2381	0.0763	0.0515	0.0042	0.0041	0.0011	0.0011
SD. Of Diff (cm)	1.1082	1.2337	1.7492	1.9392	2.2572	2.7572	2.5511	1.1704	1.416
Error @95% (+/−)	0.135	0.151	0.216	0.2443	0.2787	0.3432	0.3175	0.1487	0.1769
Upper Limit	0.136	0.152	**0.454**	0.321	**0.330**	0.347	0.322	0.150	0.178
Lower Limit	−0.133	−0.151	0.0221	−0.168	−0.227	−0.339	−0.313	−0.148	−0.176
ISO 20685:2005 Acceptable error Limit (cm)	0.400	0.400	0.400	0.400	0.400	0.900	0.900	0.400	0.500
Outcome*	P	P	F#	P	P	P	P	P	P
Acceptable Error Based on ISO 8559:1989, % values (cm)	0.500	0.500	0.500	0.500	0.314	0.500	0.500	0.367	0.238
Outcome	P	P	P	P	F#	P	P	P	P

*P: Pass, F: Fail, F#: Failed at one limit

agreement between measurements. Values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability and values greater than 0.90 indicate excellent reliability (Kouchi & Mochimaru, 2011). While measuring the same subject multiple times in the same scanner the ICC values for all the dimensions were observed excellent ranging between 0.865 and 0.999.

There have been several research works confirming deviations between the scanner extracted measurements and the manual measurements. In most of the researches it is observed that that scanner measurements were generally larger than manual measurements with that the mean differences of circumferences being larger than those of lengths and heights (Han et al., 2010), (Mckinnon & Istook, 2001), (Gordon et al., 2012), (Koepke et al., 2017), (Simenko & Cuk, 2016). As far as the application of regression modeling is concerned, there has been limited research reported in the special context of scanner validation and reliability. Han et al. 2010 conducted a comparative analysis of 3D body scan measurements and manual measurements of south Korean adult females and estimated some of the scanner dimensions (such as chest circumference, under-bust circumference, and arm length) using regression equations. Further, the researchers advocated the use of regression-based estimation equations in compensating for the drawbacks of 3D scanning and aiding in the practical application of scanner measurements (Han et al., 2010). This application of regression equations as applied by Han et al. 2010 in estimating corrected or adjusted scanner measurements has been reported by Gordon et al. 2012 as well (Gordon et al., 2012).

RESULTS AND DISCUSSION

As confirmed by several works done in the area of 3D body scanning, this research also confirmed that the Sizestream SS14 3D body scanners were highly consistent, however, some deviations between scanner measurement to the manual measurements (used as a gold standard to check errors in 3D scanning) were witnessed throughout the process. Such variations failed most of the measurements in terms of accuracy levels (as per ISO 8559:1989 and ISO 20685:2005). In such a situation, the application of regression modeling-based equations to predict the regressed scanner values as adjusted measurement values was observed as more accurate while testing as per ISO 8559:1989 and ISO 20685:2005 standard protocols.

Here it is worth mentioning that for most of the dimensions (while estimating the regressed scanner values) R^2 value was observed as excellent (above 0.9), however for some of the dimensions (such as calf height, neck point to waist-CBL, upper arm length, and lower arm length) R^2 value was observed as poor (below 0.6) and the scatter plot didn't reflect a clear pattern. Despite that such dimensions (indicating poor R^2 value) were observed as Pass as per the acceptable error limits of ISO 8559:1989 and ISO 20685:2005 standard protocols. The researchers believe that this behavior is an area of further investigation.

CONCLUSIONS AND FUTURE SCOPE

This paper discussed a step-by-step regression modeling-based methodology for validation and reliability of the Sizestream 3D body scanners. Frequent deviations between the scanner extracted measurement values and manual measurement values were observed, though scanners were witnessed as highly consistent. A regression equation-based approach was applied to estimate the regressed measurement values to all other SS 14 body scanners. The application of regression modeling (to predict the adjusted scanner values) confirmed the scanner measurements within the permissible error limits of ISO 20685:2005 and ISO 8559:1989. The 3D scanner validation methodology discussed in this paper may be applied successfully in future research related to 3D scanning recommended for conducting sizing surveys.

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