Comparative Assessment of Validation and Reliability of Sizestream 3D Scanner for Human Body Measurement Using Two Different Approaches

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https://doi.org/10.15221/22.52

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, including the INDIAsize (the National Sizing Survey of India) being carried out by the National Institute of Fashion Technology, INDIA. The 3D scan results are compared to the manual measurements to establish the accuracy of the scanner. This research paper describes two novel and alternative approaches (based on 1. Bias-shift, and 2. Regression modeling) to check the reliability and validity of the measures derived from 3D Body Scanner in comparison to measures provided by the manual measures. A comparison of both the approaches has also been discussed in this research paper.

The 3-D 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 as confirmed by the high values of Intra-class correlation coefficients (ICC) conducted to check for the consistency and repeatability between different scan measurements. However, 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, two different approaches were applied to establish scanning accuracy and comparative analysis of results has been carried out.

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 (2005) and ISO 8559 (1989). Based on the comparative analysis, the paper also suggest recommended approach to achieve the desired accuracy by overcoming the systematic error in scanner measurement for all the anthropometric dimensions. This may help in making the data acceptable for use for any further analysis.

Keywords: Body dimensions, 3D Scanning, Reliability, Validity, Intra-class correlation (ICC), Bias-shift, Regression Modeling.

1. Introduction

Anthropometric dimensions are essential for any scientific product design, and it works as the foundation knowledge in the ergonomic user-centred 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 [1]. 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

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National Sizing Survey of India (INDIAsize) 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. This paper discusses the two different methods i.e. 1. applying a correction factor (Bias-shift) and, 2. regression modeling to confirm the validity and reliability of Sizestream 3D body scanners. 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.

2. 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 [2].

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 [3]. The ISO 20685:2015 provides guidelines about the evaluation protocol of surface shape and repeatability of relative landmark positions [4]. Tiwari and Anand (2021) conducted the validation and reliability of 3D body scanning systems using a correction factor termed Bias-shift [1]. It was observed that though the approach is scientific and established it has challenges. Some of them are that different correction factors have to be applied for different dimensions and when evaluated against ISO standards, they may result in inconsistent output i.e. someone's measurements may pass and some of the measurements may fail with the latter happening when the errors are not systematic.

3. Methodology

3.1. 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 centimetres and least count 1.0 mm). The girth-related measurements (horizontal dimensions) were taken using a certified flexible non-stretchable steel tape (Length 200 centimetres 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.

3.2. 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).

3.3. Data Analysis

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 [3].

Step 3. Determining the Standard Deviation (SD) of the difference between scanner measurements and manual measurements [5].

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 [6].

Error limits were calculated using the mean of the differences (between scanner measurement and manual measurement) for all the subjects and reported with its associated standard deviation, sample size and 95 % confidence Interval.

$$95\%\ Standard\ Error = 1.96 * Std.\ Deviation\ of\ difference / SQRT(N)$$

$$Upper\ Limit = Mean\ difference\ (+)\ 95\%\ Standard\ Error$$

$$Lower\ Limit = Mean\ difference\ (\text{-})\ 95\%\ Standard\ Error$$

Step 5. Checking the mean differences using the test methods given in Clause 5 of ISO 20685:2005 [4, 7].

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 [1, 8]. 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. The results of the data analysis conducted in step 5 showed that the error of scanner extracted measurements were observed beyond the prescribed acceptable limits of ISO 20685:2005 and ISO 8559:1989. Intra-class correlation coefficients (ICC) was conducted to check for the consistency and repeatability between different scan measurements and it represented the variance attributable to error [9, 10].

Step 7. The Intra-class correlation coefficients (ICC) applied in the step 5 confirmed a high level of consistency and repeatability of the scanners. A correction factor in the form of bias-shift was incorporated to the scanner extracted measurements.

Step 8. Comparing the mean differences between scanner extracted measurements with bias-shift and the manual measurements using the test methods given in Clause 5 of ISO 20685:2005.

Step 9. 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.

Step 10. Creating the normality plot for the residuals and homoscedasticity (homogeneity of variances) was checked while applying regression to adjust scanned measurements.

Step 11. 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 12. Comparing the mean differences between Regressed scanner measurements the manual measurements using the test methods given in Clause 5 of ISO 20685:2005.

Step 13. 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 14. 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.

4. Results and Discussion

4.1. Comparing the mean difference of scanner measurement to the manual measurements

As indicated in the step 1 to step 5 in the data analysis, the mean difference of scanner measurement to the manual measurements were compared as per the Clause 5 of ISO 20685:2005 [4, 7].

Please refer table 1 for the scanner validation analysis on the actual extracted measurements from the scanner. Table 1 illustrates the summary statistics for scan measurements-manual measurements for different body dimensions measured during the scanner validation exercise. The upper limit and lower limits of the differences as derived by following the process mentioned in step 4 were compared to the ISO 20685:2005 standard values for the permissible error. The result of the comparison of error values obtained from scanner measurements to the ISO 20685:2005 permissible error is shown as "Outcome" with P for Pass or F for Fail. It can be observed that the upper and lower limit of all the differences were observed beyond the permissible limit except WBL (Waist back length) and WH (Waist height), where the lower limit and the upper limit was observed within permissible range for WBL (Waist back length) and WH (Waist height) respectively.

To accept the scanner extracted measurements, both the upper value and lower value should be within the ISO 20685:2005 prescribed limit. For example, for Stature the upper limit and lower limit are 1.42 cm and 1.17 cm respectively, while the ISO 20685:2005 permissible error value is +/- 0.4 cm. Here both the values of upper limit and lower limit are beyond the ISO 20685:2005 permissible error value, hence all the scanner extracted measurements were considered as "FAIL".

Further, the same procedure was followed while checking the accuracy as per ISO 8559:1989 standard by comparing the difference between scanner measurements and manual measurement to the ISO 8559:1989 values is the smaller) [11]. As indicated in table 1, While comparing the mean difference of scanner measurement – manual measurements to the ISO 8559:1989 prescribed error limits, it was observed that that all the differences were observed beyond the permissible limit. However for the WH (Waist height), upper limit was observed in the ISO Range (Error of -0.43 against standard acceptable error value of -0.497) and lower limit was observed out of the ISO Range (Error of -1.02 against standard acceptable error value of -0.497), hence all the scanner extracted measurements were considered as "FAIL".

Table 1. Scanner Validation (Actual Scanner Extracted Measurements).

Measurement	Stature	Waist Back Length	Shoulder Height	Inside Leg-length	Waist Height	Across Shoulder	Chest Girth	Waist Girth	Hip Girth	Neck Girth	Thigh Girth	Chest Depth
Mean Diff (SCAM-MAM) (cm)	1.294	0.812	-1.382	-2.088	-0.723	3.947	1.927	3.292	2.017	2.648	1.564	0.999
SD. Of Diff (cm)	1.518	3.914	1.889	1.541	.6293	3.256	2.024	5.369	2.085	3.978	2.373	1.386
Error @95% (+/-)	0.123	0.316	0.153	0.125	0.293	0.263	0.164	0.434	0.169	0.322	0.192	0.112
Upper Limit	1.42	1.13	-1.23	-1.96	-0.43	4.21	2.09	3.73	2.19	2.97	1.76	1.11
Lower Limit	1.17	0.50	-1.53	-2.21	-1.02	3.68	1.76	2.86	1.85	2.33	1.37	0.89
ISO 20685:2005 Accept. Limit (cm)	0.4	0.5	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.4	0.4	0.5
Outcome*	F	F	F	F	F	F	F	F	F	F	F	F
Accept. Error Based on ISO 8559:1989, % values (cm)	0.500	0.371	0.500	0.500	0.500	0.314	0.500	0.500	0.500	0.367	0.500	0.238
Outcome	F	F	F	F	F	F	F	F	F	F	F	F

* P: Pass, F: Fail

4.2. Checking for the Scanner consistency

ICC reflects both degree of correlation and 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 [5]. The ICC between the different scan measurements (for a given dimension) were calculated using IBM SPSS Statistics 23.0. Please refer table 2 for ICC values of scanner measurements between one to other.

Table 2. Intra-class Correlation (ICC)- Scanner Measurements.

Dimension	Stature	Waist Back Length	Shoulder Height	Inside Leg Length	Waist Height	Across Shoulder	Chest Girth	Waist Girth	Hip Girth	Neck Girth	Thigh Girth	Chest Depth
ICC (SCAN1-SCAN2)	0.995	0.905	0.997	0.988	0.953	0.989	0.999	0.978	0.998	0.384	0.985	0.998
ICC (SCAN1-SCAN3)	0.993	0.922	0.996	0.976	0.939	0.983	0.998	0.956	0.997	0.419	0.978	0.997
ICC (SCAN2 -SCAN3)	0.999	0.937	0.997	0.989	0.948	0.988	0.998	0.968	0.998	0.865	0.988	0.998

As indicated in table 2, the higher values of ICC (>=0.90) for each of the dimension except for Neck girth. The reason of low ICC values for neck girth may be due to the disturbance in scanning caused by hair specially with female subjects. This might have caused error while scanner identifies landmark to measure the neck girth. The ICC values for male subjects were observed good (0.912, 0.947, and 0.903) and confirmed good level of consistency and reliability.

4.3. Applying correction factor as Bias-shift

The concept of bias-shift is like a tare function where going forward, the average difference between scanner measurement and the manual measurement (as a standard correction value associated with specific body dimension) were adjusted to the scanner extracted measurement. It is suggested that the two measurements would become comparable by reducing the bias (mean) and/or random fluctuation (SD) of errors, however reducing mean error (bias) is more effective than reducing SD to make the two measurements comparable [12]. A bias is a noticeable systematic error in the scanner measurements, which can be used as an offset to correct the scanner measurements in order to achieve improved concordance [13, 14]

Impact of applying bias-shift on the accuracy level achieved against ISO 20685:2005 prescribed error levels was checked by repeating the validation analysis (as explained in the step 2) after applying bias-shift as a correction factor. It was observed that after incorporating the bias-shift, all the differences between the scanner and manual measurements were observed within the ISO 20685:2005 prescribed acceptable limits (refer table 3 for Summary results after incorporating bias-shift), hence the scanner measurements could be considered comparable against the manual measurements, which were used as prescribed gold standards for checking the accuracy. Hence, the scanner extracted measurements were considered as “PASS”.

Following the same procedure, the average difference between scanner measurements and the manual measurements for each of dimension was also compared to the ISO 8559:1989 prescribed limits. As indicated in table 3, it was observed that the error between scanner measurements and the manual measurements for all the dimensions was within the ISO 8559:1989 limits. Hence, the scanner extracted measurements were considered as “PASS”.

Table 3. Scanner Validation (After incorporating Bias-Shift).

Measurement (BIAS-SHIFT) Combined - MALE - FEMALE	Stature	Waist Back Length	Shoulder Height	Inside Leg-length	Waist Height	Across Shoulder	Chest Girth	Waist Girth	Hip Girth	Neck Girth	Thigh Girth	Chest Depth
Bias-Shift Applied (cm)	-1.2935	-0.8123	+1.3821	-2.0881	+0.7228	-3.9474	-1.9270	-3.2917	-2.0171	-2.6476	-1.5642	-0.9987
Mean Diff (SCAM-MAM) (cm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SD. Of Diff (cm)	1.518	3.914	1.889	1.541	3.629	3.256	2.024	5.369	2.085	3.978	2.373	1.386
Error @95% (+/-)	0.123	0.316	0.153	0.125	0.293	0.263	0.164	0.434	0.169	0.322	0.192	0.112
Upper Limit	0.10	0.32	0.15	0.10	0.29	0.26	0.16	0.43	0.17	0.32	0.19	0.11
Lower Limit	-0.10	-0.32	-0.15	-0.10	-0.29	-0.26	-0.16	-0.43	-0.17	-0.32	-0.19	-0.11
ISO 20685:2005 Acceptable Limit (cm)	0.400	0.500	0.400	0.400	0.400	0.400	0.900	0.900	0.900	0.400	0.400	0.500
Outcome*	P	P	P	P	P	P	P	P	P	P	P	P
Acceptable Error Based on ISO 8559:1989, % values (cm)	0.500	0.371	0.500	0.500	0.500	0.314	0.500	0.500	0.500	0.367	0.500	0.238
Outcome	P	P	P	P	P	P	P	P	P	P	P	P

* P: Pass, F: Fail

4.4. Applying Regression modeling

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 4 for the testing on error limits for some of the dimensions.

Table 4. Scanner Validation (Regressed Scanner Measurement Vs. Manual Measurements).

Measurement	Stature	Shoulder	Inside Leg-	Waist Height	Across	Chest Girth	Waist Girth	Neck Girth	Chest Depth
Mean Diff (SR-M) (cm)	0.001	0.000	0.238	0.076	0.051	0.004	0.004	0.001	0.001
SD. Of Diff (cm)	1.108	1.233	1.749	1.939	2.257	2.757	2.551	1.170	1.416
Error @95% (+/-)	0.135	0.151	0.216	0.244	0.278	0.343	0.317	0.148	0.176
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

From table 4 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 [9, 10]. ICC reflects both degrees of correlation and 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 [5]. 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 [7, 2, 14, 9, 15]. 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 [7]. 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 [14]. Scatter plots for some of the dimensions with regression equation and respective R^2 values are illustrated in figure 1.

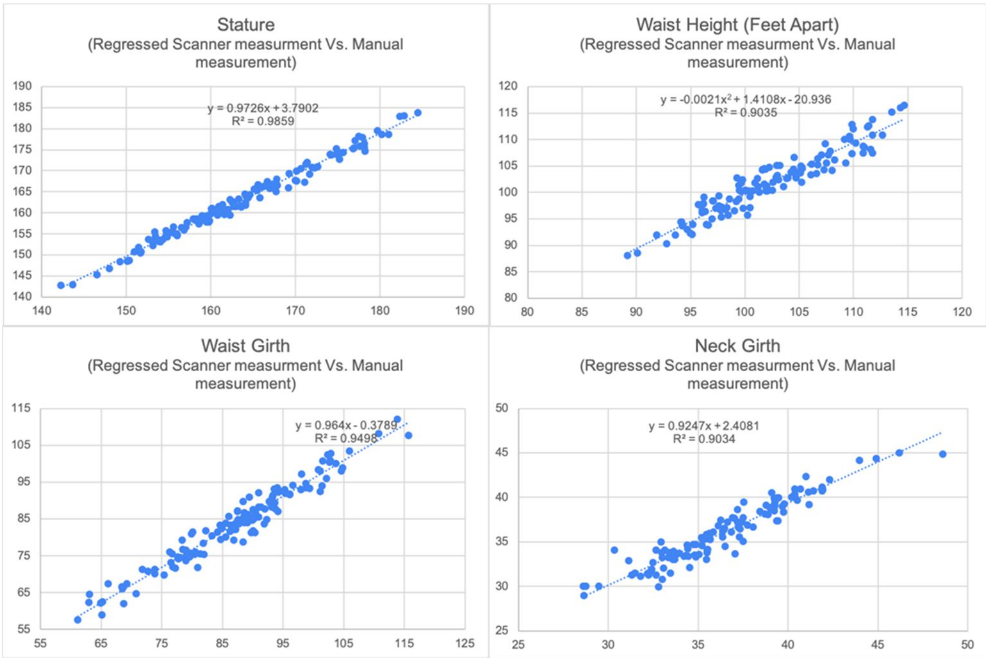

Figure 1. Scatter plots (Regressed Scanner measurement Vs. Manual measurement).

Test-retest performance procedure using 80% values to predict 20% of the values was conducted. The outcome of test-retest perfromance was checked again as per the ISO 20685:2005 protocol as well as per ISO 8559:1989 limits based on % error. All the dimensions confirmed the deviations well within the acceptable limits as prescribed in both the mentioned ISO protocols. Further, the paired comparison t-test between the regressed scanner measurement values and manual measurement values was conducted to identify and re-confirm whether there is any significant difference between regressed scanner measurements (SR) and the average of the manual measurements (M). The results of the paired comparison t-test confirmed that Regressed scanner values (SR) to be accepted as there was no significant difference between SR and M.

5. Conclusion

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). This paper discussed two differen approaches of scanner validation and relaibility check as by applying Bias-shift and by Regression modeling. A correction factor in the form of bias-shift was determined, and same was incorporated to the scanner extracted measurements and scanner measurement accuracy was achieved. 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.

6. Future Scope

This paper discussed a step-by-step methodologies for validation and reliability of the Sizestream 3D body scanners using two different methods. Frequent deviations between the scanner extracted measurement values and manual measurement values were observed, though scanners were witnessed as highly consistent. Correction factor based Bias-shift approach and Regression equation-based approach were applied to estimate the regressed measurement values to all other SS 14 body scanners. The application of both the approaches 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.

Acknowledgements

The authors would like to acknowledge the valuable contributions from Prof. Vandana Narang, Prof. Suhail Anwar, Prof. Monika Gupta, and Prof. S.S. Ray of the National Institute of Fashion Technology, India for their technical inputs to carry out this research. We are also highly thankful to the participants for their volunteer contribution as subjects for 3D scanning in this study.

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