Make It Easy: Reliability of Automatic Measurement for 3D Hand Scanning

Md Arif-Ul-Anwar BHUYAN* and Linsey GRIFFIN
University of Minnesota, St Paul MN, USA.

https://doi.org/10.15221/20.38

Abstract

The purpose of this research was to test the accuracy of automatic measurement systems on 3D hand scans compared to conventional digital measurements. 15 participants' right hand was 3D scanned with Artec Leo scanner, analyzed, and compared for seven measurements (five linear and two surface measures) in Anthroscan measurement software by Human Solutions. Means and standard deviations for each measurement were analyzed between conventional and automatic measurement conditions. Paired t-tests were used to understand significance between the two types of measurements. There was virtually zero difference for all the linear length measurements such as thumb breadth, hand breadth, hand length, wrist-index finger length, and palm breadth. However, a significant difference was found between conventional and automatic surface circumference measurements. Both hand and wrist circumference measurements showed nearly 4% difference between conventional and automatic conditions.

Keywords: 3D body scanning, automatic measurement, hand scans

1. Introduction

Using 3D technology to scan hands is a relatively new tool that can improve the design and development of gloves and tools design [1]. However, challenges exist with adopting 3D technology because hands can be difficult to scan and time-consuming to measure and analyze. There is a need to develop and test automated measurement systems to expand the functionality and acceptance of 3D hand data for the industry. The purpose of this research was to test the accuracy of automatic measurement systems on 3D hand scans compared to conventional manual digital measurements.

1.1. Background

Hand anthropometry data is integrated into many large scale anthropometric studies such as ANSUR, however most hand measurements contained within these datasets are 1-D (linear) and the datasets contain very few measurements overall [1], [2]. The lack of hand measurements and measurement types limits the ability to conduct research on hand size and understand the hand in relation to products such as gloves and tools [3]. 3D hand data offers researchers and designers the opportunity to build body/product knowledge and the 3D data itself is reusable.

In the past, 3D measurements are done using a large number of points from the body surface which can provide more accurate data compared to traditional anthropometry, which is limited to 1-D or 2-D analysis [2]. 3-D technology also offers faster data retrieval and the opportunity of reviewing data for reliability [4].

Automatic measurement extraction is commonly used on full 3D bodies to improve fast retrieval of data, and reliability of automatic measurement data is improved through landmark detection and segmentation. [5]. Due to variability of equipment such as the 3D scanner, operator, and methodology, it is crucial to ensure dimensions that are automatically extracted are consistent with manual conventional measurement [6]. Researchers have evaluated the reliability of automatic measurement extraction techniques for full 3D body scans, however, automatic measurement extraction for 3D hand scans has not been tested or evaluated. [7].

2. Methods

2.1. Instruments

Hands were scanned using the Artec Leo scanner with a support apparatus to stabilize the hand during the scanning process. The Artec Leo is a handheld industrial-grade light-based 3D scanner with an ability to scan 22 frames per second and on-board processing. Anthroscan 2018(version 3.6.1) by Human Solutions GmbH was used for digital landmark placement and extracting the dimension.

*bhuya007@umn.edu; +1-612-840-9266; https://dha.design.umn.edu/research/Human_Dimensioning_Lab.html

Programs for automatic measurements were developed in Visual Studio (Microsoft) using VB script, and the measurements were captured in Anthroscan. Both digital and automatic measurement systems used defined landmarks on each hand as a basis for each measurement.

2.2. Landmark Definition

Prior to scanning, the hand of the participants was landmarked with a washable marker. The landmarking technique was adapted from Griffin et al. (2019) [8]. Figure 1 depicts the visual representation of the landmarks that was placed on the participants' hands and table 1 lists the landmarks and landmark definitions.

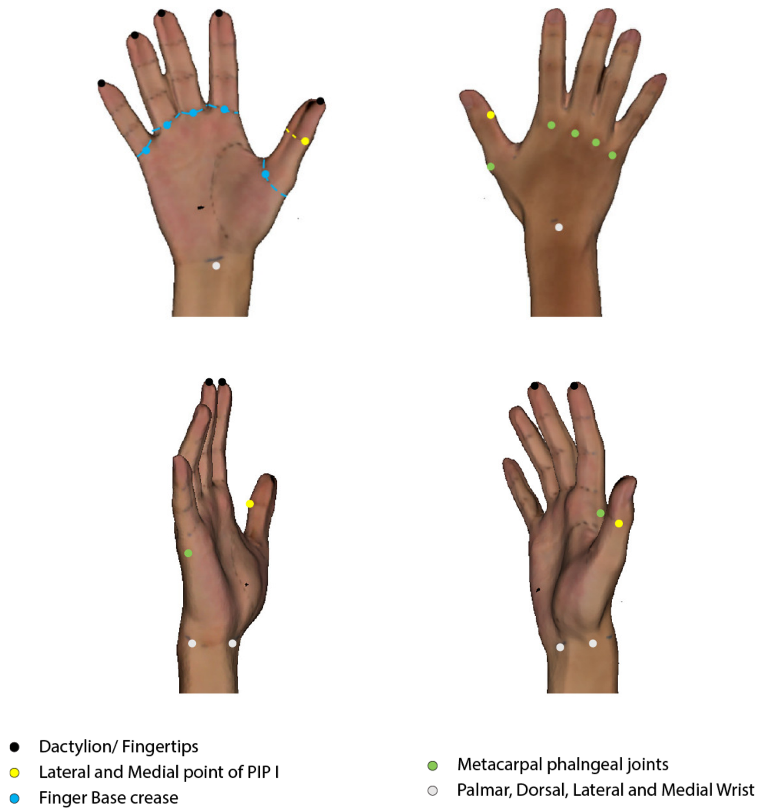


Fig. 1: Pictorial representation of the landmark placement

2.3. Measurements

Seven measurements (Table 2) were compared based on common anthropometric hand measurements used in previous studies (see e.g. Gordon et al.,1989, 2014; Greiner, 1991; Robinette et al.,2002). Manual and automatic measurements were taken in Anthroscan using the same digital landmarks. For manual measurements, each measurement was taken 3 times in Anthroscan and recorded.

2.4. Sample Size

Participants were selected from a database of 800 3D hand scans that was collected during 2019 Minnesota State Fair. During the scanning, a small demographic survey, manual hand breadth, height, and weight was recorded from each participant. To accommodate a population representing sample of hand sizes and shapes, manual hand breadths were analyzed, and fifteen 3D, full-color right- handed were selected based on percentiles (min/5%/25%/50%/75%/95%/max) breadths for men and women from Gordon, et al (2012) [10].

2.5. Measurement Procedure

The models were scanned and cleaned using the Artec Leo scanner and software. Once cleaned, the scans were brought into Anthroscan 2018(version 3.6.1) by Human Solutions GmbH. The scans are rotated and scaled to the ratio for exact measurement.

Table 1: Landmark Definition

Landmark Required	Code	Reference	Landmark Definition
Lateral Side PIP I	PIP_L_D1		Lateral side center of 1st digit's interphalangeal joint.
Medial Side of PIP I	PIP_M_D1		Medial side center of 1st digit's interphalangeal joint.
Lateral side of metacarpal 2	MCP_L_D2	[9]–[12]	The lateral side of the metacarpophalangeal joint at the base of the 2nd digit.
Medial side landmark of metacarpal 5	MCP_M_D5	[9]–[12]	The medial side of the metacarpophalangeal joint at the base of the 5th digit.
Dactylion III	FT_D3	[9]–[12]	The most distal point or fingertip of the 3rd digit.
Dactylion II	FT_D2	[9], [11]	The most distal point or fingertip of the 2nd digit.
Metacarpal III-Dorsal	MCP_D3		The center of the metacarpophalangeal joint at the base of 3rd digit on the dorsal side of hand.
Metacarpal III-palmar	MCP_P_D3		The center of the metacarpophalangeal joint at the base of 3rd digit on the palmar side of hand.
Finger Base of Digit III	FB_D3	[9], [11]	The center at the base crease of 3rd digit following its axis.
Wrist Styloid Dorsal	W_D	[9]–[11]	The center at the wrist crease on the dorsal side of the hand.
Wrist Styloid Palmar	W_P	[9]–[11]	The center at the wrist crease on the palmar or ventral side of the hand.
Wrist Styloid Lateral	W_L	[11], [12]	The landmark at the lateral or radial side of the hand that projects horizontally to the surface at the wrist base line perpendicular to the forearm axis.
Wrist Styloid Medial	W_M	[11]–[13]	The landmark at the medial or ulnar side of the hand that projects horizontally to the surface at the wrist base line perpendicular to the forearm axis.

The digital landmarks were selected manually based on the original in both conventional and automatic measurement processes, but they have used the same set of landmarks that were saved for each participant scans. All measurements were done with the same measurer in the same setting to avoid any fluctuation of the variables that can affect the measurement.

2.5.1. Automatic Measurement (A)

For automatic measurements, a program was written using Microsoft Visual Studio to align with requirements from the Anthroscan software. The initial automatic measurement codes were piloted on a scanned model and corrections were made to ensure each measurement followed the intended pathway based on the digital landmarks. Once the automatic measurement program was refined and tested; data was collected for each participant. Every measurement was collected three times to ensure reliability. Measurements were recorded.

2.5.2. Conventional Measurement (C)

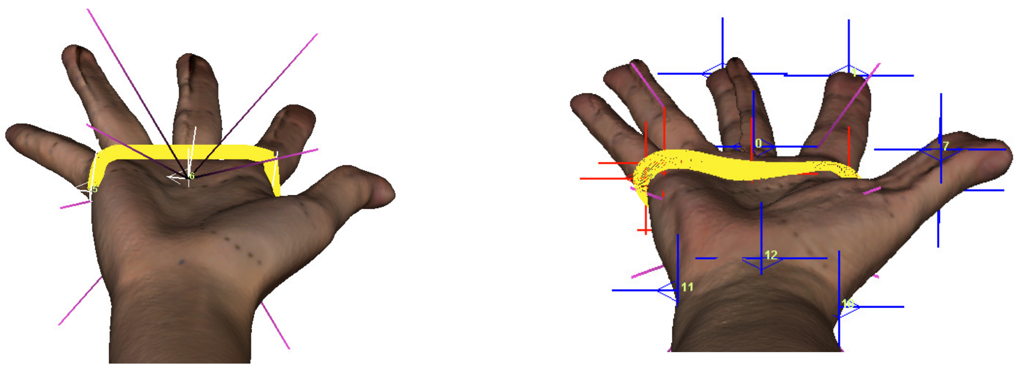
For conventional measurements (C), saved landmarks were reloaded to control variability. Then a skilled measurer manually measured the model, connecting the landmarks in the intended measurement path. Each measurement was measured three times to ensure reliability. The data was recorded for each dimension.

2.5.3. Semi-Automatic Measurements (Sa)

Semi-Automatic measurements were applied when the automatic measurement was not following the intended path. In this measuring system the automatic measurements are applied first and if there was significant aberration from expected course of measurement then, it was adjusted by an operator to follow the marked landmarks and intended path as much possible. Figure 4 shows the original automatic measurement (2a) compared to the semi-automatic corrected measurement (2b).

Table 2. Hand Measurements and Definitions

Measurement Name	Measure Type	Measurement Definition	Reference
Thumb Breadth	Linear	The widest part of 1st digit from lateral PIP I landmark to the medial PIP I landmark.	[9]–[11], [14]
Hand Breadth	Linear	Distance between the lateral side of metacarpal 2 to the medial side of metacarpal 5.	[9]–[11], [14]
Hand Length	Linear	Measured from the palmar center of the wrist baseline to the third digit's fingertip.	[9]–[12], [14]
Wrist-index finger length	Linear	Measured from the palmar center of the wrist baseline to the 2^{nd} digit's fingertip.	[9], [11]
Palm Length	Linear	Distance between the center of the base of digit 3 to the palmar center of the wrist baseline.	[10], [11], [14]
Hand Circumference	Surface	Measured around the landmarks at lateral side of metacarpal 2 and medial side of metacarpal 5.	[9]–[12]
Wrist Circumference	Surface	This circumference around the landmarks at wrist at styloid landmarks.	[9]–[11]



a b

Fig. 2: a) Bridge in automatic measuring; b) Correction in semi-automatic measuring

2.6. Data Analysis

Basic statistics for Conventional (C), Automatic (A), and Semi-Automatic (SA) measurements were calculated. To understand if there were any statistically significant differences between measurement methods, the mean measurement difference was calculated to compare conventional measures to automatic and semi-automatic measurements and paired t-tests were performed. The type-I error rate was assumed to be α= 0.05.

3. Results and Discussions

A summary of the mean for each dimension and measurement method, t-test value, standard deviation, and percent difference is presented in table 3. Results show that there was no statistical difference between conventional (C) and Automatic (A) linear measurements: hand breadth, hand length, palm length, thumb breadth, and wrist-index finder length. In fact, the linear measurements (length and breadth) were identical for both conventional and automatic measurements. As a result, MAD and MD resulted in 0 (zero) for all linear dimensions of automatic and conventional measurements. For circumference measurements, surface measures, there was a statistical difference between conventional and automatic methods.

Table 3. Statistical findings between Conventional and Automatic Measure

Dimensions	Mean Conventional Measure MCM	Mean Automatic Measure MAM	Mean absolute difference MAD(A)	MD (A)=(MCM-MAM) t-test	SD of MAD(A)	SD of MD(A)	CV of MD(A)	Percent difference (MCM-MAM)
Hand Breadth	8.59	8.59	0.00	0.00	0.00	0.00	NaN	0.00%
Hand Circum.	20.38	21.20	0.82	-0.82***	0.48	0.48	-0.59	-4.02%
Hand Length	10.67	10.67	0.00	0.00	0.00	0.00	NaN	0.00%
Palm Length	10.67	10.67	0.00	0.00	0.00	0.00	NaN	0.00%
Thumb Breadth	2.21	2.21	0.00	0.00	0.00	0.00	NaN	0.00%
Wrist Circum.	16.80	17.49	0.69	-0.69***	0.37	0.37	-0.54	-4.11%
Wrist-Index Finger Length	17.64	17.64	0.00	0.00	0.00	0.00	NaN	0.00%

*p<0.05, **p<0.01, ***p<0.001

Because of the circumference measurement difference, a semi-automatic measurement process was applied, and the values compared to conventional values for the hand circumference and the wrist circumference. The measurement values were analyzed with descriptive statistics and the summary presented in table 4. The difference percentage between conventional and Semi-automatic technique showed there was still a statistically significantdifference in both measurements, however the technique was an improvement over standard automatic measurement. improved then the difference between conventional and automatic measure. For hand circumference, the difference percentage reduced from 4.02% (MCM-MAM) to 2.21% (MCM-MSaM). For wrist circumference, there was less of a difference between automatic and semi-automatic measurements when compared to conventional measurement techniques and it only changed from 4.11% (MCM-MAM) to -3.93% (MCM-MSaM).

Table 4. Statistical findings between Conventional and Semi-automatic Measure for Circumferences

Dimensions	Mean Conventional Measure MCM	Mean Semi-Automatic Measure MSaM	Mean absolute difference MAD(Sa)	MD(Sa)=(MCM-MSaM) t-test	SD of MAD(Sa)	SD of MD(Sa)	CV of MD(Sa)	Percent difference (MCM-MSaM)
Hand Circum.	20.38	20.83	0.45	-0.45***	0.24	0.24	-0.53	-2.21%
Wrist Circum.	16.80	17.46	0.66	-0.66***	0.40	0.40	-0.61	-3.93%

*p<0.05, **p<0.01, ***p<0.001

4. Conclusion

Overall, using automatic measurement systems to take linear measurements of 3D hand scans are an accurate and reliable method compared to conventional measurements. For circumference measurements and surface measurements, research and development is needed to develop a reliable automatic measurement system. While a semi-automatic measurement method for circumference or surface measurements was an improvement, it is still not as accurate as conventional or manual methods for circumference measurements.

4.1. Future work

For 3D hand scans to be adopted industry wide, standardized tools like automatic measurements need to be developed. The results of this research demonstrate the feasibility of automatic measurements for linear measurements of hands which is time-saving and efficient. Future research is needed to investigate a more accurate approach to automatic circumference measurements of the hand.

References

[1] L. A. Griffin, S. Sokolowski, E. Savvateev, A.-U.-A. Bhuyan, and N. Roese, "Comparison of Glove Specifications, 3D Hand Scans, and Sizing of Sports Gloves for Athletes," in *Proceedings of 3DBODY.TECH 2019 - 10th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland, 22-23 Oct. 2019*, Lugano, Switzerland, Oct. 2019, pp. 109–118, doi: 10.15221/19.109.

[2] C.-C. Chang, Z. Li, X. Cai, and P. Dempsey, "Error control and calibration in three-dimensional anthropometric measurement of the hand by laser scanning with glass support," *Measurement*, vol. 40, no. 1, pp. 21–27, Jan. 2007, doi: 10.1016/j.measurement.2006.05.006.

[3] A. Klepser, M. Babin, C. Loercher, E. Kirchdoerfer, J. Beringer, and A. Schmidt, "3D Hand Measuring with a Mobile Scanning System," in *Proceedings of the 3rd International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 16-17 October 2012*, Lugano, Switzerland, Oct. 2012, pp. 288–294, doi: 10.15221/12.288.

[4] F. Forchino, S. D. Galloway, A. Douglas, A. Hazeldine, C. Brandner, and P. C. Bourdon, "Reliability and Validity of 3D Body Scanning for Anthropometric Profiling: 3572 Board #11 June 4, 8," *Med. Sci. Sports Exerc.*, vol. 48, p. 990, May 2016, doi: 10.1249/01.mss.0000487975.15186.13.

[5] B. R. Lv, S. Q. Sun, R. M. Lv, Z. D. Zhang, and Y. Liu, "Automatic measurement of scanned human body in fixed posture," in *2010 IEEE 11th International Conference on Computer-Aided Industrial Design & Conceptual Design 1*, Yiwu, Nov. 2010, pp. 575–578, doi: 10.1109/CAIDCD.2010.5681284.

[6] Z. Li, C.-C. Chang, P. G. Dempsey, L. Ouyang, and J. Duan, "Validation of a three-dimensional hand scanning and dimension extraction method with dimension data," *Ergonomics*, vol. 51, no. 11, pp. 1672–1692, Nov. 2008, doi: 10.1080/00140130802287280.

[7] P. R. A. -, "Application of 3D body scanning technology to human measurement for clothing Fit," *Int. J. Digit. Content Technol. Its Appl.*, vol. 4, no. 7, pp. 58–68, Oct. 2010, doi: 10.4156/jdcta.vol4.issue7.6.

[8] L. Griffin, S. Sokolowski, H. Lee, E. Seifert, N. Kim, and R. Carufel, "Methods and Tools for 3D Measurement of Hands and Feet," in *Advances in Interdisciplinary Practice in Industrial Design*, vol. 790, W. Chung and C. S. Shin, Eds. Cham: Springer International Publishing, 2019, pp. 49–58.

[9] C. C. Gordon *et al.*, "1988 ANTHROPOMETRIC SURVEY OF U.S. ARMY PERSONNEL: SUMMARY STATISTICS INTERIM REPORT," *Anthropol. Res. Proj. INC YELLOW SPRINGS OH*, vol. Interim report for 1988, 1989.

[10] C. C. Gordon *et al.*, "2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics," *Yellow Springs OH 45387*, vol. II, Dec. 2014.

[11] T. M. Greiner, "Hand Anthropometry of U.S. Army Personnel," p. 428.

[12] K. M. Robinette, S. Blackwell, H. Daanen, M. Boehmer, and S. Fleming, "Civilian american and european surface anthropometry resource (caesar), final report.," *SYTRONICS INC Dayt. OH*, vol. 1, no. Summary, 2002, [Online]. Available: https://apps.dtic.mil/dtic/tr/fulltext/u2/a406704.pdf.

[13] International Organization for Standardization., "ISO 7250-1: 2017 Basic human body measurements for technological design—Part 1: Body measurement definitions and landmarks." 2017.

[14] M. Stirling, "National anthropometry survey of female firefighters.," *Amington UK Chief Assist. Chief Fire Off. Assoc.*, 2002.