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Investigation into the suitability of kinect sensor for automated body measurement

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ABSTRACT

Due to the low cost and wide availability of the Kinect sensor, researchers and experts in the field of anthropometry, sizing and clothing fiting are leveraging on its inbuilt 3D camera to develop systems for automated body measurement. This study focuses on the evaluation of the Microsoft Kinect (V1) sensor to determine its suitability for automated body measurement. The study was conducted by data collection of various body dimensions of test subjects using a measuring tape as a reference. Furthermore, a statistical approach known as the measurement system analysis was used to investigate the sensor's capability to produce accurate, reliable and consistent body measurements. The results obtained indicates that there exists very little variation when the measurement is repeated. Also, the instrument is relatively stable, with minimal bias which can be corrected by calibration. The outcome of the study proves the effectiveness of the Microsoft Kinect sensor as a means of conducting body measurement.

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1. INTRODUCTION

In modern times, there has been an increase in the demand for customized clothing designs rather than standard-issue designs with generalized sizing [1]. Taking appropriate body measurements is the first step to producing customized garments [2]. This involves the measurement of certain parameters of a human body, such as height, waist, and arm length. It has several applications in a wide range of fields, including medicine, forensics, ergonomics, industrial design and architecture, and most notably, the textile and fashion industry, especially for producing customized garments [3]-[5].

Traditionally, measurement was done with specialized tools such as bicondylar calipers, anthropometers, and stadiometers. Afterwards, measuring tapes were introduced after the emergence of these specialized tools as they were bulky and difficult to use [6]. In recent times, current research efforts have been geared towards technological advancements to improve the process of human body measurement. The technology generally allows measurements with minimal human interaction and produces a three-dimensional (3D) image [7], [8]. 3D image capturing is fast and accurate; therefore, it can measure large numbers of people over time and eliminates the possibility of human error as it requires minimum human interaction for operation [9]. However, the biggest challenge with 3D body scanning is that they are very costly. 3D body scanners may cost from $1000 to as much as $250 000, making them not as readily available as they should be and sometimes it is challenging to manage and operate [10]. However, the Microsoft Kinect sensor, originally created for controlling games on Xbox 360 console, is now gaining popularity in the area of body measurement [11], [12]. Because it is relatively cheap and easy to use, when compared to other automated body measurement devices.

Several interesting studies have been conducted on the use of the Kinect sensor to capture human body measurement. Adikari *et al*. [13] developed a non-contact human body parameter measurement system based on Kinect Sensor (V2). This was aimed at creating a virtual dressing room (VDR) using collected data. A Kinect-based anthropometric measurement application was used to create an anthropometric database for the measurement of latin-american people in [14]. Huang *et al.* [7] used the Microsoft Kinect (V2) to estimate selected human body dimensions. The measurements were repeated under varying light conditions and surrounding elements with a group of six people. The experiments were repeated for the Kinect V1 (Kinect 360) and the Kinect V2 to compare the results.

An automated anthropometric phenotyping with a novel Kinect-based three-dimensional imaging method was developed in [15]. Robinson and Parkinson [16] used Microsoft Kinect for the anthropometric estimation based on skeletal tracking. Four Kinect sensors were set up to conduct body measurements of 17 students according to CAESAR standard. Seo *et al.* [17] carried out an investigation into the possibility of automatically measuring waist circumference based on SVM regression using a Kinect sensor. Bragança *et al.* [18] conducted a validity study by comparing the Traditional approach with a 3D measuring system based on four Kinect sensors to conduct circular body measurements. A low-cost 3D scanning system based on four depth cameras capable of scanning body segments and calculating girth measurements was implemented in [19]. The previous studies have established various techniques and methods in achieving automated body measurements using the Kinect sensor. It has also been discovered from the reviews and surveys carried out that intensive measurement system analysis (MSA) study has never been conducted on the device to ascertain its strength and weakness. It is generally known that no measurement system is perfect [20]. Measuring equipments are prone to errors due to faults and imperfections with hardware, software implementation, and robustness problems associated with the ambient condition. Because of this, it is imperative to conduct a measurement system analysis to appraise its quality under a range of conditions in which the process operates [21]. Hence this study focuses on investigating the measuring capability of the the Kinect sensor, using the simplest method; Skeletal-based tracking as a case study. This is with a view of ascertaining its suitability to adequately carry out body measurement.

2. METHOD

This section discusses the experimental procedure for setting up the implemented measurement system. It also gave an insight into the method employed in measuring subjects. Furthermore, metrics used to carry out the measurement system analysis of the sensor were presented.

2.1. Experimental procedure

Figure 1 shows the setup of the measuring instrument. The Microsoft Kinect sensor version 1 with a resolution of 640×480 pixels, which captures at the rate of 30 fps, was employed to acquire the human body image to be measured. It was connected to a computer system that runs on a Windows 10 Professional operating system with Intel Core i3-2348M (2.3 GHz), 64-bit processor, and random-access memory (RAM) of 4 gigabits. The Kinect sensor was interfaced with the PC by installing Kinect driver v1.8, Microsoft .NET Framework 4.0, Microsoft DirectX 9, Windows runtime, and SDK v1.8. The computer system handles the image processing and extraction of the data point, which is displayed via the graphic user interface. After the system was set up, the Kinect sensor was mounted on a tripod stand at the height of 30 inches and a distance of 120 inches from the subject for full-body capture as shown in Figure 2.

2.2. Body measurement based on skeletal tracking

The extraction of data points was achieved through skeletal tracking to locate users' joints and track their movements in real-time. The Kinect V1 has the capacity of tracking 20 joints of 2 users simultaneously. The system extracts X, Y, and Z coordinate for every detected joint. The dimension of each part is computed with the Pythagoras theorem in 3D space, using (1).

$$\text{Distance (d)} = \sqrt{(X1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2} \tag{1}$$

Assuming that P1 and P2 denote the distance between two points on the target's body, point $P_1=(X_1, Y_1, Z_1)$ and point $P_2=(X_2, Y_2, Z_2)$. The computed body parts of the target's body considered in this study, as shown in Figure 3, are height, shoulder width, arm length, upper arm length, hip to leg length, and upper leg length.

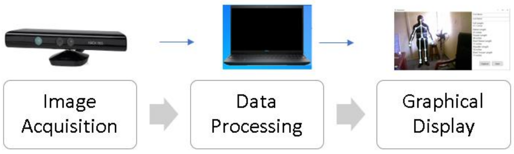


Figure 1. Experimental setup of the system

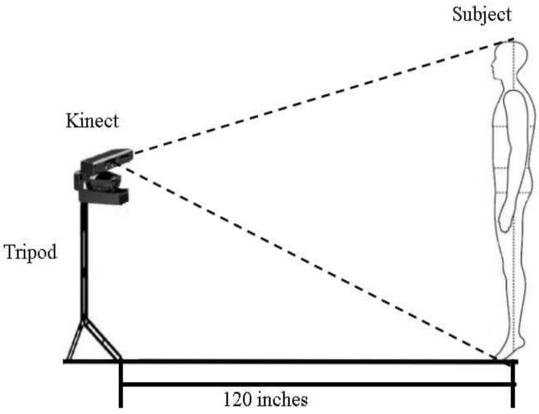


Figure 2. Diagrammatic illustration of the measurement setup

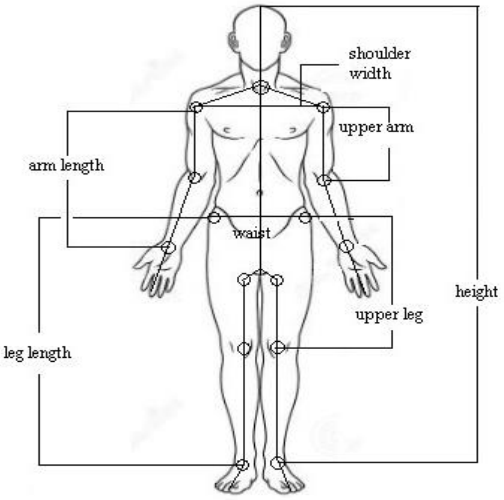


Figure 3. Diagrammatic emphasis on the considered body dimension

2.3. Evaluation based on measurement system analysis (MSA)

MSA uses a mathematical and statistical approach to determine the amount of variation that exists in a measurement process. This will help to ascertain the strength of the equipment and identify possible areas of improvement of the system [22], [23]. Therefore, MSA is based on five metrics, which are highlighted with explanations in the following sub-sections.

2.3.1. Bias and stability

This is the difference between the average of measured values and the actual value of a part. In an ideal (perfect) system, bias should be zero. It is often caused by the aging of equipment and improper calibration. As systems are often not ideal (and no system in reality is), we expect some form of bias. Given in (2).

$$\text{Bais} = \text{average of measured values of a part} - \text{ the actual value of a part} \qquad (2)$$

Stability is used to determine the degree of variation in the measurement system over time with the same sample. In other words, it reflects the variation in bias over time; such drift can be attributed to machinery warm-up effects, a shift in environment, or a change in operating procedures [24].

2.3.2. Linearity

This may be described as the change in bias value within the range of normal process operation. It may also be described as the measure of the consistency of measurements over the entire range of measurements. A perfectly linear measurement is one in which the plot of the readings on a graph has a slope of zero. Linearity can be determined using the equation of a line presented in (5)-(7).

$$y = ax + b \qquad (5)$$

$$a = \frac{\sum xy - \frac{(\sum x)(\sum y)}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}},\ b = \bar{y} - ax\bar{x},\ R^2 = \frac{\left[\sum xy - \sum x\left(\frac{\sum y}{n}\right)\right]^2}{\left[\sum x^2 - \frac{(\sum x)^2}{n}\right] \times \left[\sum y^2 - \frac{(\sum y)^2}{n}\right]} \qquad (6)$$

$$s = \sqrt{\frac{\sum y^2 - b\sum y - a\sum xy}{n-2}} \quad |t_{lin}| = \frac{|a|}{\left[\frac{s}{\sqrt{\sum(x-\bar{x})^2}}\right]} \tag{7}$$

Where: $|t_{lin}|$=linearity, a=slope, x=reference value, y=bias, b=y-intercept, n=total number of measurements made, R^2=coefficient of determination.

2.3.3. Gauge repeatability and reproducibility

Repeatability is often carried out to check if the same appraiser can measure the same part multiple times with the same measurement device and get the same measured value. It may also be called precision or equipment variation (EV). Also, reproducibility is used to check if different appraisers can measure the same part multiple times with the same measurement device and get the same measured value. It is also known as appraiser variation (AV). The primary purpose of conducting a gage R & R study is to ascertain the cause of variation in a measuring system or device. The Automotive Industries Action Group [25] postulated that reproducibility can only be valid when the measurement is performed manually; therefore, appraiser is not a significant source of variation in autonomous systems. However, the gage reading in this study is in digital form, and the measurement is automated, resulting in zero influence from an appraiser, so reproducibility will not be considered. There are several methods of conducting this study, but the analysis of variance (ANOVA) method is preferable because it is more adaptable to solving complex problems [26]. The Analysis of variance (ANOVA) method is computed using (8)-(13).

$$MS = \frac{1}{n-1} \times \sum(x_i - \bar{x})^2 \tag{8}$$

$$\text{Repeatabity } (\sigma_{repeat}) = \sqrt{MS_{residuals}} \tag{9}$$

$$\text{Interaction } (\sigma_{interactions}) = \sqrt{\frac{(MS_{operators} - MS_{parts})}{r}} \tag{10}$$

$$\text{combined variability } (\sigma_{R\&R}) = \sqrt{\sigma^2_{repeat} + \sigma^2_{repro} + \sigma^2_{interactions}} \tag{11}$$

$$\text{Variability due to parts } (\sigma_{parts}) = \sqrt{\frac{(MS_{parts} - MS_{residuals})}{r}} \tag{12}$$

$$\text{Total variabity } (\sigma_{Total}) = \sqrt{\sigma^2_{repeat} + \sigma^2_{repro} + \sigma^2_{interactions} + \sigma_{parts}} \tag{13}$$

Where: n=number of parts, m=number of operators, r=number of trails, $\bar{x}$=measured reading, x_i=reference value, μ=mean of measured values.

3. RESULTS AND DISCUSSION

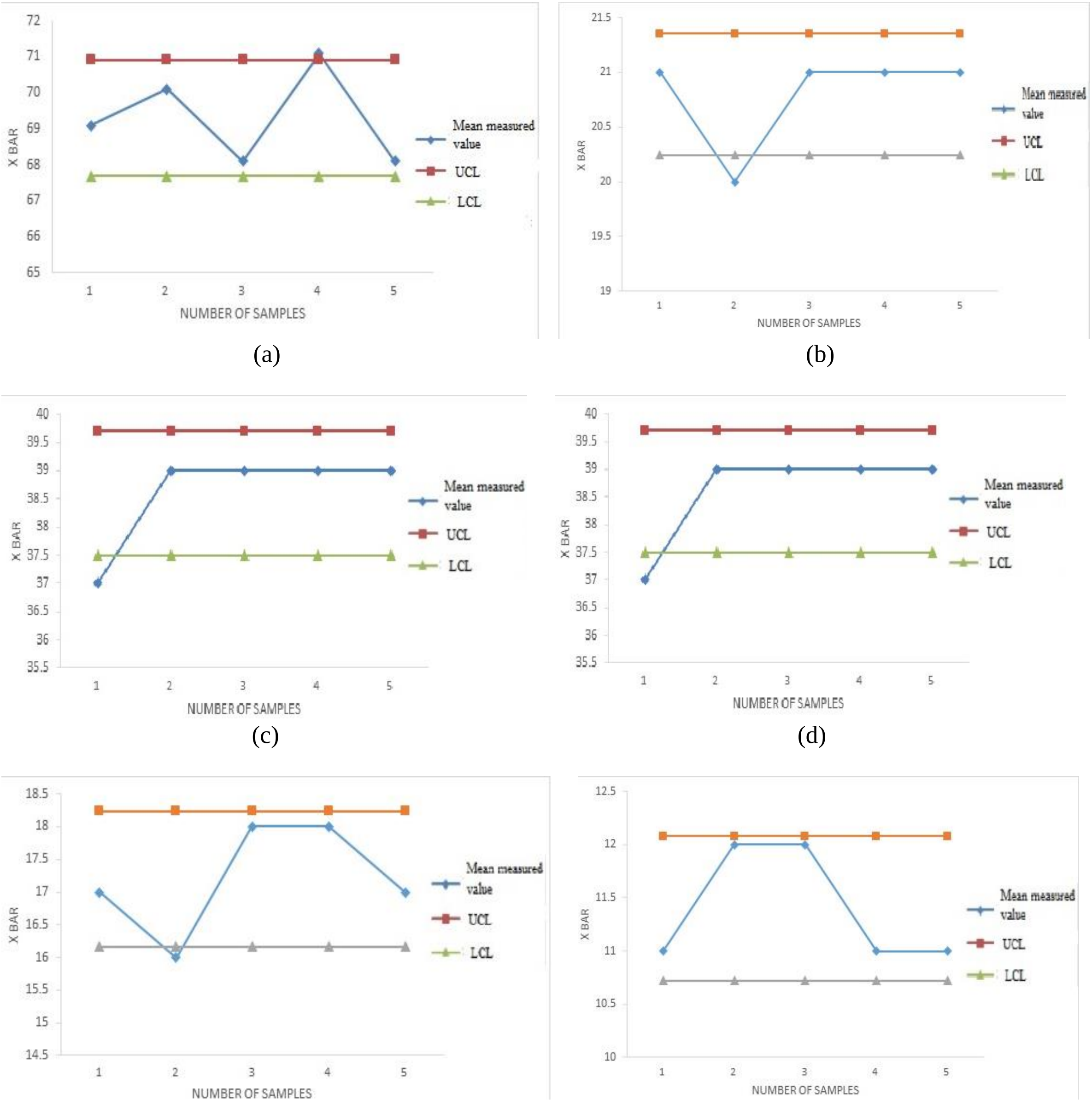
3.1. Bias

Table 1 shows the computed bias of the six major body dimensions. It was observed that the bias for some of the body dimensions produces negative while others produce positive values that are relatively low. It is an indication that the sensor has a higher tendency to produce results that are less than the actual value. In contrast, the others produce a result that is higher than actual. However, the data display is digital, and the measurement is automated; therefore, there is no human influence, thereby eliminating the probability of bias resulting from appraiser/technique.

Consequently, this slight error can still be corrected by recalibration. Further analysis was conducted by trying to ascertain the status of the measured values within the upper and lower clearance limit, as shown with the graphical plot in Figure 4. Figure 4(a) present the X bar chart for the height; Figure 4(b) shows the X bar chart for full arm length. Figure 4(c) shows the X bar chart for the leg length, Figure 4(d) present the X bar chart for the upper arm length. Figure 4(e) present the X bar chart for the shoulder lenghtb; Figure 4(f) present the X bar chart for the upper leg lenght It reveals that most of the measured values fall within the upper and lower clearance limits.

Table 1. Index test subject bias for Kinect sensor

Value	Height	Full arm	Full leg	Upper arm	Shoulder	Upper leg
X bar	69.3	20.8	38.6	11.4	17.2	19
bias	0	-2.7	2.1	-1.1	0.2	-0.6
Reference value	69.3	23.5	36.5	12.5	17	19.6



(a) (b)

(c) (d)

(e) (f)

Figure 4. X-bar chart showing stability of the bais for (a) height, (b) full arm length, (c) leg, (d) upper arm length, (e) shoulder length, and (f) bais for upper arm length

3.2. Linearity

Figure 5 shows a fitted regression line used to access the linearity of the measurement system, to see how the bias values vary for each part. The blue dots represent the bias values for each reference value. The red square represents the average bias value for each reference value. A gage linearity of 2.4%, indicates the overall process variation. Also, the p-value for the slope is 0.127 (which is greater than α=0.05), which suggests that changes in the measured value are not affected by changes in the actual value. A very low R-sq value of 8.10% shows that the model does not fit the data, as shown in Figure 5. Also, the standard deviation of 1.6 indicates less variability in the bias estimate.

3.3. Repeatability

Using the ANOVA procedure, the % variation of the components was computed to ascertain the degree of repeatability of the system. The result indicates that the high % Contribution obtained from part-to-part variation proves that the measurement system can reliably distinguish between parts. The total Gage R represents only 4.02% of the total variation, compared to 99.802% of part variation affecting total variation, indicating that most of the variation is as a result of the difference between parts, rather than the repetition of the measurement process, shown in Figure 6. The % study variation at 4.45 indicates that there exists very little variation when the measurement is repeated, according to [25].

3.4. Stability

This test was conducted to ascertain how the accuracy and precision of individual parts perform over time, using the individuals-moving range (I-MR) chart as shown in Figure 7. Figure 7(a) shows the I-MR chart for height, Figure 7(b) shows the I-MR chart for full arm lenght, Figure 7(c) shows the I-MR chart for leg, Figure 7(d) shows the I-MR chart for the upper arm lenght, Figure 7(e) shows the I-MR chart for the shoulder length, Figure 7(f) shows the I-MR chart for the upper leg length. The I chart displays the individual data points and monitors mean shifts when data points are collected at regular intervals of time. The MR chart monitors process variation when the data points are collected at regular intervals of time. In Figure 7(c)-(f), it was observed that they fall within the UCL and LCL. While the Leg and Shoulder measurements in Figures 7(e) and (f), show outlying values for the moving range chart. Since the MR chart is not in control, then the control limits on the I chart are not accurate.

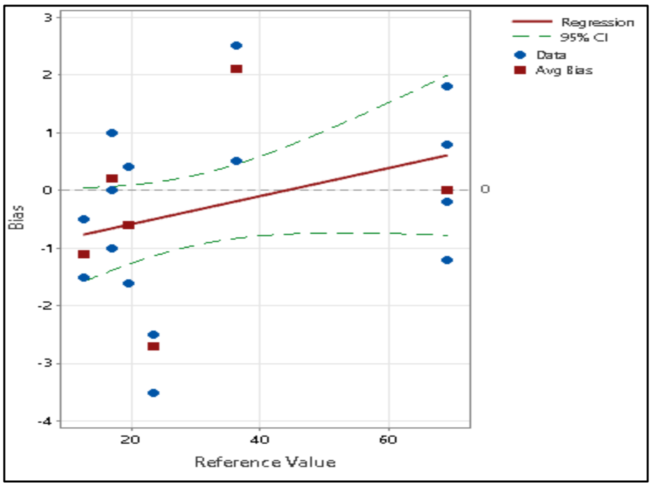


Figure 5. Gage linearity and bias for reading

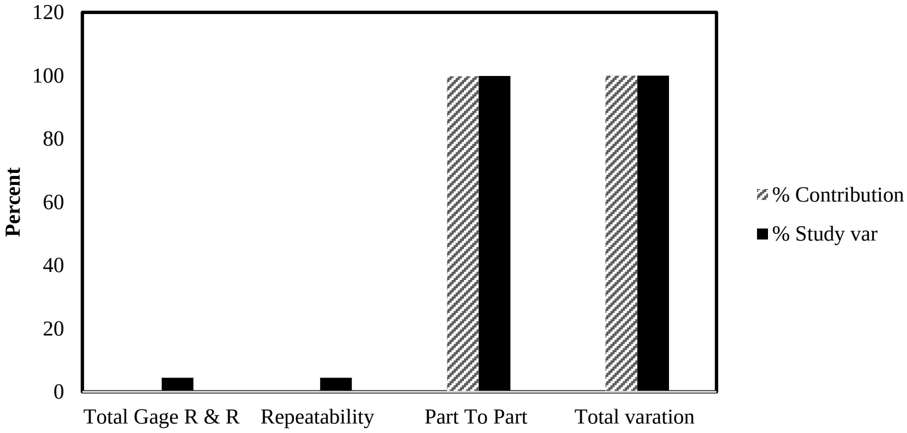
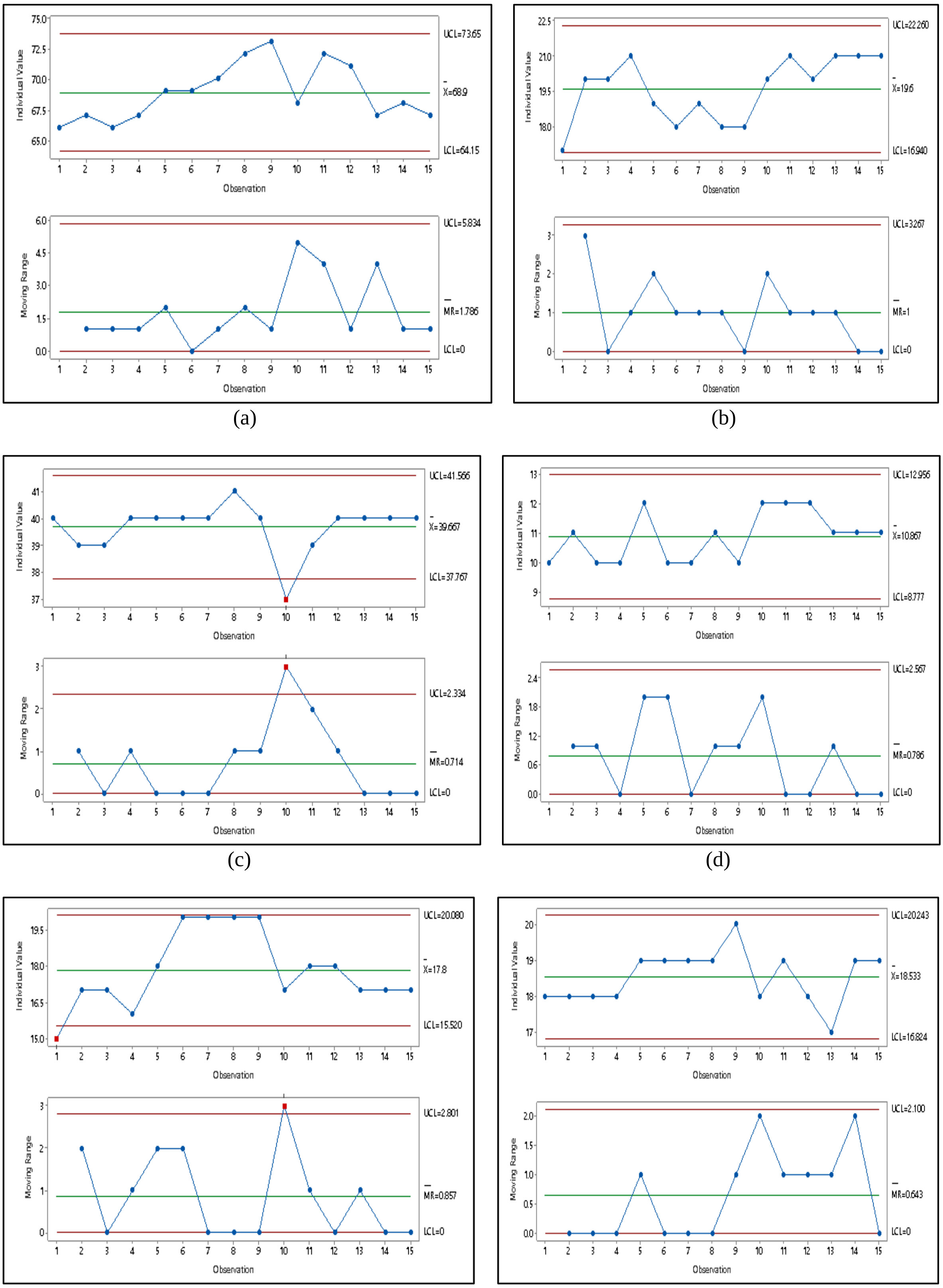


Figure 6. Components of variation-Gage R&R (ANOVA) for value



(a) (b)

(c) (d)

(e) (f)

Figure 7. I-MR chart for (a) height, (b) full arm length, (c) leg, (d) upper arm length, (e) shoulder length, and (f) upper leg

4. CONCLUSION

An investigative study on Kinect sensors-based skeletal tracking has been conducted using an experimental and mathematical approach. It was used to determine its appropriateness in taking automated body measurements based on accuracy and precision. The study's outcome indicates that slight bias and linearity problems were encountered, which can easily be corrected by proper calibration of the instrument. Also, the measuring instrument is relatively stable and accurate in taking repeated measurements over a long period. Finally, the study has affirmed that the instrument is fit and suitable for its intended purpose, which can also serve as a good cost-effective alternative with little or no trade-off.

REFERENCES

[1] J. Geršak, *Design of clothing manufacturing processes*, 1st ed. Cambridge, UK: Woodhead Publishing Limited, 2013,doi: 10.1533/9780857097835.

[2] A. Certain and W. Stuetzle, "Automatic body measurement for mass customization of garments," in *Proceedings - 2nd International Conference on 3-D Digital Imaging and Modeling, 3DIM 1999*, 1999, pp. 405–412, doi: 10.1109/IM.1999.805371.

[3] N. D'Apuzzo, "Recent advances in 3D full body scanning with applications to fashion and apparel," *Optical 3-D Measurement Techniques IX, Vienna, Austria*, vol. 2, 2009.

[4] S. Yan, J. Wirta, and J. K. Kämäräinen, "Anthropometric clothing measurements from 3D body scans," *Machine Vision and Applications*, vol. 31, no. 1, p. 7, Feb. 2020, doi: 10.1007/s00138-019-01054-4.

[5] I. Dianat, J. Molenbroek, and H. I. Castellucci, "A review of the methodology and applications of anthropometry in ergonomics and product design," *Ergonomics*, vol. 61, no. 12, pp. 1696–1720, Dec. 2018, doi: 10.1080/00140139.2018.1502817.

[6] M. J. J. Wang, W. Y. Wu, K. C. Lin, S. N. Yang, and J. M. Lu, "Automated anthropometric data collection from three-dimensional digital human models," *International Journal of Advanced Manufacturing Technology*, vol. 32, no. 1–2, pp. 109–115, Feb. 2007, doi: 10.1007/s00170-005-0307-3.

[7] B. Xu, Y. Huang, W. Yu, and T. Chen, "Body scanning and modeling for custom fit garments," *Journal of Textile and Apparel, Technology and Management*, vol. 2, no. 2, 2002.

[8] O. Kainz, F. Jakab, M. Michalko, R. Vapenik, and D. Cymbalak, "Kinect as a tool in estimation of selected human body dimensions," in *2016 International Conference on Emerging eLearning Technologies and Applications (ICETA)*, Nov. 2016, pp. 157–163, doi: 10.1109/ICETA.2016.7802050.

[9] L. R.-Rodríguez, M. S.-Sansegundo, R. F.-Cascales, N. G.-D'urso, J. A. H.-Sánchez, and A. Z.-Martí, "Comparison of body scanner and manual anthropometric measurements of body shape: A systematic review," *International Journal of Environmental Research and Public Health*, vol. 18, no. 12, p. 6213, Jun. 2021, doi: 10.3390/ijerph18126213.

[10] Z. Zhang, "Microsoft kinect sensor and its effect," *IEEE Multimedia*, vol. 19, no. 2, pp. 4–10, Feb. 2012, doi: 10.1109/MMUL.2012.24.

[11] W. Z. W. Z. Abiddin, R. Jailani, A. R. Omar, and I. M. Yassin, "Development of MATLAB Kinect Skeletal Tracking System (MKSTS) for gait analysis," in *ISCAIE 2016 - 2016 IEEE Symposium on Computer Applications and Industrial Electronics*, May 2016, pp. 216–220, doi: 10.1109/ISCAIE.2016.7575066.

[12] B. Runje, A. Razumić, and A. H. Novak, "Measurement system analysis in production process," in *International Scientific Conference on Industrial Systems*, 2017, pp. 274–277.

[13] A. M. S. B. Adikari, N. G. C. Ganegoda, and W. K. I. L. Wanniarachchi, "Non-contact human body parameter measurement based on kinect sensor," *IOSR Journal of Computer Engineering*, vol. 19, no. 3, pp. 80–85, May 2017, doi: 10.9790/0661-1903028085.

[14] A. Espitia-Contreras, P. Sanchez-Caiman, and A. Uribe-Quevedo, "Development of a Kinect-based anthropometric measurement application," in *2014 IEEE Virtual Reality (VR)*, Mar. 2014, pp. 71–72, doi: 10.1109/VR.2014.6802056.

[15] L. Soileau *et al.*, "Automated anthropometric phenotyping with novel Kinect-based three-dimensional imaging method: Comparison with a reference laser imaging system," *European Journal of Clinical Nutrition*, vol. 70, no. 4, pp. 475–481, Apr. 2016, doi: 10.1038/ejcn.2015.132.

[16] M. Robinson and M. B. Parkinson, "Estimating anthropometry with Microsoft Kinect,"in *Proceedings of the 2nd International Digital Human Modeling Symposium*, 2013.

[17] D. Seo, E. Kang, Y. M. Kim, S. Y. Kim, I. S. Oh, and M. G. Kim, "SVM-based waist circumference estimation using Kinect," *Computer Methods and Programs in Biomedicine*, vol. 191, p. 105418, Jul. 2020, doi: 10.1016/j.cmpb.2020.105418.

[18] S. Braganca, M. Carvalho, B. Xu, P. Arezes, and S. Ashdown, "A validation study of a kinect based body imaging (KBI) device system based on ISO 20685:2010," in *Proceedings of the 5th International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 21-22 October 2014*, Oct. 2014, pp. 372–377, doi: 10.15221/14.372.

[19] S. Clarkson, J. Wheat, B. Heller, and S. Choppin, "Assessment of a Microsoft Kinect-based 3D scanning system for taking body segment girth measurements: a comparison to ISAK and ISO standards," *Journal of Sports Sciences*, vol. 34, no. 11, pp. 1006–1014, Jun. 2016, doi: 10.1080/02640414.2015.1085075.

[20] S. Tavoularis, *Measurement in fluid mechanics*. Cambridge University Press, 2005.

[21] O. M. Arani and N. O. Erdil, "Measurement system analysis in healthcare: Attribute data," in *67th Annual Conference and Expo of the Institute of Industrial Engineers 2017*, 2017, pp. 1109–1114.

[22] M. Abdelgadir, C. Gerling, and J. Dobson, "Variable data measurement systems analysis: Advances in gage bias and linearity referencing and acceptability," *International Journal of Metrology and Quality Engineering*, vol. 11, p. 16, Dec. 2020, doi: 10.1051/ijmqe/2020010.

[23] R. Schmitt and M. Bauza, "Measurement system analysis," in *CIRP Encyclopedia of Production Engineering*, Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 1–7.

[24] D. C. Montgomery and W. H. Woodall, "An overview of six sigma," *International Statistical Review*, vol. 76, no. 3, pp. 329–346, Dec. 2008, doi: 10.1111/j.1751-5823.2008.00061.x.

[25] AIAG, "Measurement systems analysis (MSA)," in *Fourth Edition*, The Automotive Industries Action Group, 2010, p. 241.

[26] R. K. Burdick, C. M. Borror, and D. C. Montgomery, "A review of methods for measurement systems capability analysis," *Journal of Quality Technology*, vol. 35, no. 4, pp. 342–354, Oct. 2003, doi: 10.1080/00224065.2003.11980232.

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