Data Compatibility Analysis of 3D Body Scanning

Arzu VURUSKAN*[a,b], Bettina SEIDER[c], Ute DETERING-KOLL[a]

[a] Department of Textile and Clothing Technology, Niederrhein University of Applied Sciences, Mönchengladbach, Germany.
[b] Department of Fashion Design, Faculty of Fine Arts and Design, Izmir University of Economics, Izmir, Turkey.
[c] Adidas Innovation Team, Herzogenaurach, Germany.

Abstract

Precision in measurements for the human body has always been an important issue for clothing industry. The success of a good fit both for ready-to-wear and customized clothing is dependent on the availability of accurate body measurements, a good sizing system and understanding of anthropometrics. There are various body measurement-taking tools that use a variety of techniques. 3D body scanning is the most recent method, which uses a rapid, standardized measuring process to provide body measurements. The purpose of this research was to evaluate the usability of 3D body scan data for apparel product development stages, focusing on accuracy and reliability. The study was designed to reveal the data compatibility of the methods and to investigate the causes of any deviations. A sample group of students were recruited for the trials and data collection. Within the mentioned framework of this research, even if having some limitations, it was shown that body scanning technology can obtain many body dimensions with reliability. If the options are well coordinated and the requirements are well defined, 3D body scanning utility has the potential to provide advantages by adapting new technologies to the demands of specific apparel groups and processes.

Keywords: 3D body scanning, human body measurements, accuracy, anthropometrics, apparel product development

1. Introduction

For more than three decades there have been significant advances in production systems and manufacturing technologies using computer integrated processes. Sizing and body measuring issues for apparel product development have also shown progress by exploiting developments in technology.

Obtaining the most accurate set of body measurements has always been a challenge for the clothing industry. The success of a good fit both for ready-to-wear and customized clothing is important in the apparel industry, and this depends on the availability of an accurate set of body measurements, a good sizing system and understanding of anthropometrics. Peasant (1996) defined anthropometry as the branch of human sciences that deals with body measurements, particularly with measurements of body size, shape, strength and working capacity [1]. The methods and tools of anthropometry have been developed to make valid and reliable body measurements for the design of clothing. Anthropometry has also been used for national size surveys for sizing standardization or for medical purposes as an indicator of the health status. Some other related fields with anthropometry include automobile design, work site ergonomics, equipment design and airplane cockpit design [2].

There are various body measurement taking tools, which use a variety of techniques. The most recent method, 3D body scanning, uses a convenient standard measuring process for body measurement. In addition to the linear measurements, body shapes, angles and relational data points can be obtained with 3D-scanning technologies [3]. 3D body scanners are useful tools in implementing mass customization and automated custom clothing, and have recently become regarded as a method of improving fit and customer satisfaction in the apparel industry [4]. Several large-scale anthropometric surveys have also been conducted exploiting 3D scanners.

* arzu.vuruskan@ieu.edu.tr

3D scanning technology provides a quick and efficient way of measurement extraction. However, the reliability of the measurements has been in question. Research on applications of body scanning, which has received interest since 1980s, has progressed in different directions. One of these is related to investigating the differences between scan-derived measurements and those derived from the traditional methods, and the relative accuracy of the results of the different methods. Posture is an important parameter affecting the accuracy of the measurement results. Current 3D scanners can provide measurements only with a standard static posture. Considering that inconsistent arm postures during scanning may lead to incompatible measurements, Lu, Wang and Mollard (2010) aimed to investigate the effect of arm posture on the scan-derived measurements. Two different arm postures were considered related to the position of the palm, which either faces inwards or backwards. As a result of their research, the arm posture with palms facing backward has been considered as the preferred posture for 3D body scanning. Furthermore, it was pointed out that the scan-derived measurements using either posture can be more precise than manual measurements [5]. Respiration during scanning is another obvious factor that can influence the accuracy of measurements, especially chest related measurements. Similarly, foot placement can influence the lower body measurements significantly. McKinnon and Istook (2002) investigated the effects of variability in subject positioning and respiration on the accuracy of body scan data and found that respiration and foot span have a significant impact on scanned data [6]. According to Feathers, Paquet and Drury (2004), systematic differences can exist between conventional and three-dimensional anthropometric data. These researchers claimed that the reliability of the electromechanical methods was comparable to, but not better than, the conventional methods. They claimed that novice users of the instrumentation can learn to collect measurements with approximately equal consistency compared to those made with conventional methods, but in a much shorter time period [7].

Brandtmiller and Gross (1999) set out to identify the differences between the traditional anthropometric measurements and scanner extracted measurements and found that the extracted measurements were generally acceptable using the garment standards for comparison [8]. Similar studies were conducted with various scanners. McKinnon and Istook (2001) evaluated the body scan data rendered by two TC^2 scanners, the Image Twin (2T4) and the 3T6 in physical measurements [9]. Brooke-Wavell, Jones and West (1994) compared the The Loughborough Anthropometric Shadow Scanner (LASS) measurements with anthropometric measurements, finding that LASS and anthropometric measurements were generally similar. They claimed that the repeatability of 3-D measurements taken from computerized whole-body scans was no better than that from traditional anthropometric measurements. They pointed out, however, that the scan data have a far greater utilization, providing information on body shapes, segmental volumes and surface areas as well as size [10]. Bougourd, Dekker, Ross and Ward (2000) compared the measurements obtained from Hamamatsu Photonics 3D Body Line Scanner with the measurements obtained by traditional hand methods. Values for the electronic and manual measurements showed good correspondence on many key measurements [11]. Kouchi and Machimaru (2011) obtained quantitative data on the intra- and inter-observer landmarking errors in their study as a reference in the evaluation of software for calculating landmark locations for 3D anthropometry [12].

Robinette and Daanen (2006) investigated the precision of the scanner-derived 1D dimensions from the CAESAR survey, a multinational anthropometric survey. It was concluded that the type of scan-extracted measures used in CAESAR are as good as or better than comparable manual measurements, but only in regard to the point-to-point measurements [13]. Lu and Wang (2008) looked for an automated anthropometric data collection system by using 3D body scanner, aiming to eliminate manual intervention. The validity and reliability of the developed system was accordingly tested and the evaluations of results suggested that the system was effective [14].

Other than clothing, body scan technology can also be applied in various fields and many future applications are yet to be discovered. Since body scanning have many applications in various industries (medical, apparel, military, etc.), accuracy and precision are of the highest importance [6]. Even though many studies have investigated the accuracy of scan-derived measurements, quality parameters are not consistent among these studies since there is no widely accepted quality evaluation criterion, and therefore, the level of accuracy is evaluated and accepted depending on the purpose of measurement [12].

Finding ways of obtaining the most accurate body measurements has always been an important research area. Therefore, exploiting the advances of body scanning for various adaptations is currently an important research topic. The main aim of this study was to create an awareness of the further possibilities of body scanning techniques, especially in the apparel industry, by considering the anthropometric accuracy and reliability of body measuring methods. The study was designed to compare the data collected manually with the scan-derived measurements and to understand the causes of variation between these. In addition, a further goal of the research was to test the repeatability of the body scanning method with repeated scans.

Taking into account these objectives, the research was designed to explore issues in body measurements through measuring groups of subjects.

2. Methods

A sample group of 30 subjects was utilized to examine the body measuring methods. The procedures for the measuring trials included following steps:

- Scanning the subjects with the standard scanning posture
- Taking the body measurements of the subjects manually using a tape measure
- Comparing the results of manually and scan extracted measurements
- Analysis of the repeatability of body scan extracted measurements with repeated scans

2.1. Data collection

2.1.1. Selection of subjects

For the mentioned process, a sample group of students were recruited through announcements, posters and social networks. The sample group consisted of 30 male students. Participants were contacted to arrange an appointment for measurement in the body scanner room at the university. For this study, participants were required to be between the ages of 20-35. No additional limits were placed on participation. Participants were instructed about the procedures and signed a protocol informing that the received data would be kept secure and would only be used for research purposes. One important attribute of the sample group was that all participants were willing to be scanned for research purposes.

2.1.2. 3D body scanning

In this study, explorations with 3D body scanning were conducted by using Human Solutions Vitus Smart XXL 3D body scanner. ScanWorX software was used for 3D visualization and the automatic extraction of body measurements. With this software, scanned images can be used to acquire approximately 150 individual measurements that are automatically captured. The interactive tools allow the gathering of additional measurements, depending upon requirements.

All participants were first scanned in the standard posture in their underwear, without shoes, glasses or jewellery. This posture was a necessity to capture as complete a body scan as possible for the extraction of apparel related measurements. All participants were positioned in the scanning booth in the standard posture, with feet apart and arms held at their sides but away from the body, which is the current measuring posture in ScanWorX for clothing-relevant body measurements. It is used for circumferences and the corresponding width and depth measurements[1.]

Suitable clothing is important in order not to falsify the body lines and to reflect the laser light for a complete scan. A relaxed posture is of crucial importance for ascertaining realistic body measurements. Unnatural body repositions, such as stretching the body, erecting the spinal column (back, chest, and neck), tensing the belly or lifting the shoulders should be avoided[2]. Since these facts were prerequisites of the system to obtain the measurements precisely, these directions were considered during the process. The measurements were automatically extracted by the software. No additional intervention was executed. The measurement lists were saved in an MS Office Excel sheet and the priority measurements were chosen from the complete list.

[1,2] ScanWorX, Scan Wizard directions

2.1.3. Measurement taking by traditional anthropometry

Of the total 150 measurements obtained from the scanner, 29 considered as being of key interest from the clothing-technology viewpoint were selected for measurement by hand. Measurement taking was realized according to the procedures described in the international standard ISO 8559 (1989). Landmarks were defined (usually by locating the bones beneath the skin by hand) and were used to identify the measurements. Measurements were taken in a pre-specified sequence and were recorded on pre-designed form.

Having completed the measurement taking process for both methods, participants viewed their body scan image on the computer monitor with different postures, in different side views and in rotating positions. Participants were also given the opportunity to access their measurements and their body scan images by email.

2.1.4. Repeated measurements

Some further research was carried out to define the accuracy and repeatability of scanning. Six of the subjects were chosen to represent different size groups, and each was scanned five times consecutively in order to compare the consistency of scanning over a number of separate scans.

2.2. Data analysis

To investigate the differences between the manual anthropometry and the scanner-derived results, a total of 24 measurements were prioritized and a total of 18 participants were chosen. Measurement differences were evaluated and quantified by subtracting the manual from the scan-derived measurements.

Based on the sample sets, another statistic was chosen to report the variation in measurements, the “Mean Absolute Differences” (MAD), which was also used for various similar comparisons [2,8,9,11,12]. Absolute values are used because the use of directional values could have a misleading effect and lead to false conclusions. With the MAD values, the distances for differences are considered. MAD values were collected with the following formula:

MAD = $\frac{1}{n}\sum_{i=1}^{n}|(si - mi)|$, where s=scan measurement, m=manual measurement

For further analysis, to examine the absolute agreement between the scan and manual measurement pairs, intraclass correlation coefficient (ICC) analysis was realized.

Finally, for the 5 times repeated scans, 28 measurements were processed for the comparison. The differences between the repeated measurements were examined with absolute agreement in intraclass correlation analysis.

3. Results

3.1. Comparison of scan-derived and manually extracted measurements

The first comparison of the two methods was chosen as to subtract the values obtained by one method from the values obtained by the other. If two results were equivalent, subtracted values would be zero. The differences between the body scan and manual measurements were calculated individually for each sample set. By subtracting the manual from the scanner-derived measurements, some negative value results were obtained. This distinction enabled the categorization of the measurements; the scanner results are recorded as being greater or less than the manual measurements. To investigate whether scanner-derived measurements or manually extracted measurements recorded greater values for each of the 24 measurements, the number of greater results among 18 subjects were quantified as listed in Table 1. As another statistic, MAD values were calculated by taking the absolute value of each of the individual differences, and then the mean, minimum and maximum values were checked (shown in Table 1).

The 24 prioritized measurements for evaluation were grouped in three clusters, as circumference measurements, height-related measurements and distance-related measurements.

Table 1. Results of comparisons

	Frequency of differences (manual and scan-derived)				**MAD (cm)**		
	n	m>s	s>m	s=m	mean	max.	min.
Circumference measurement							
Chest circumference	18	4	13	1	2,15	4,4	0
Waist circumference	18	6	11	1	1,38	4,3	0
Hip circumference	18	4	14	0	1,86	4,5	0
Neck base circumference	18	10	8	0	0,64	2,4	0,1
Elbow circumference	18	9	9	0	0,58	1,6	0,05
Upper arm circumference	18	14	4	0	0,99	2,6	0,05
Forearm circumference	18	11	7	0	0,54	1,4	0,1
Wrist circumference	18	13	4	1	0,44	1,1	0
Thigh circumference	17	10	7	0	0,94	3,15	0,15
Circumference over knee	18	14	4	0	1,29	2,95	0,15
Calf circumference	18	14	4	0	0,49	1,2	0,1
Min. leg circumference	17	17	0	0	0,46	1,1	0,15
Ankle circumference	18	9	9	0	1,37	3,05	0,3
Height related measurements							
Back length till waist	18	8	8	2	1,34	2,7	0
Side length from waist till ground	18	6	11	1	1,50	4,55	0
Side length from waist till mid over leg	18	11	7	0	3,63	10,7	0,25
Step length	8	4	4	0	0,91	2,2	0,25
Distance measurements							
Backbreadth from armhole till armhole	18	5	13	0	1,96	7,9	0,4
Cross front	18	3	15	0	3,81	8,1	0,4
Shoulder breadth	18	6	12	0	1,05	2,55	0,1
Shoulder breadth complete	18	6	12	0	2,71	7,6	0,1
Shoulder with sleeve length	18	14	4	0	2,42	5,2	0,15
Sleeve length long	18	16	2	0	2,81	5,35	0,8
Sleeve length till elbow	18	14	4	0	1,79	4,65	0,05

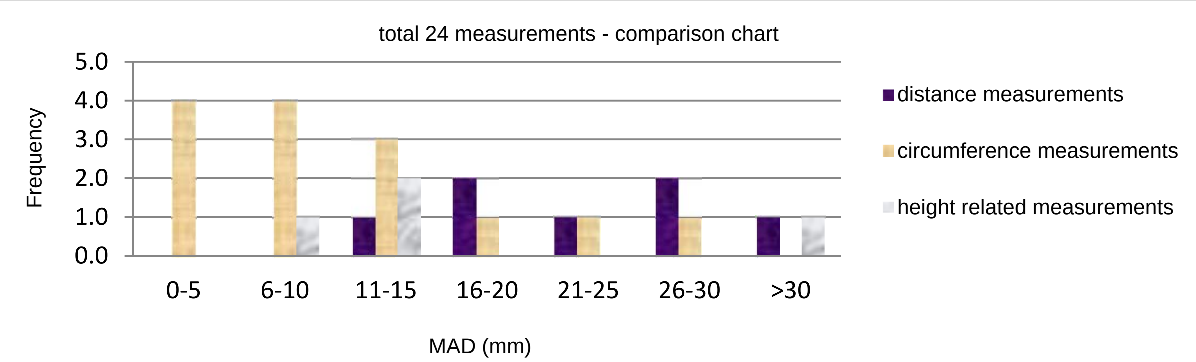

Fig.1. Frequency of MAD values for all groups of measurements

Figure 1 shows the histograms indicating that most measurements have a MAD value of 6-10 (circumference and height-related measurements) and 11-15 (all three groups).

Absolute agreement between the manual measurements and the scan-derived measurements was checked by intraclass correlation analysis. Table 2 shows the results where most of the comparisons were found to be reliable.

Table 2. Results of ICC analysis

	Intraclass correlation coefficient (ICC)	95% confidence interval		*p*
		Lower Bound	Upper Bound	
Circumference measurements				
Chest circumference	0,964	0,782	0,989	p<0,001
Waist circumference	0,990	0,971	0,996	p<0,001
Hip circumference	0,910	0,618	0,971	p<0,001
Neck base circumference	0,969	0,916	0,988	p<0,001
Upper arm circumference	0,955	0,792	0,986	p<0,001
Elbow width	0,951	0,872	0,982	p<0,001
Forearm circumference	0,972	0,923	0,989	p<0,001
Wrist circumference	0,897	0,704	0,962	p<0,001
Thigh circumference	0,983	0,953	0,994	p<0,001
Circumference over knee	0,898	0,579	0,967	p<0,001
Calf circumference	0,991	0,923	0,998	p<0,001
Min. leg circumference	0,962	0,201	0,992	p<0,001
Ankle circumference	0,449	-0,521	0,796	p=0,122
Height related measurements				
Back length till waist	0,764	0,356	0,912	p=0,003
Side length from waist till ground	0,967	0,902	0,988	p<0,001
Side length from waist till mid over leg	0,422	-0,452	0,778	p=0,126
Step length	0,982	0,917	0,996	p<0,001
Distance measurements				
Backbreadth from armhole till armhole	0,843	0,59	0,941	p<0,001
Cross front	0,356	0,402	0,739	p=0,091
Shoulder breadth	0,102	-1,478	0,668	p=0,415
Shoulder breadth complete	0,752	0,234	0,912	p=0,001
Shoulder with sleeve length	0,835	0,16	0,951	p<0,001
Sleeve length long	0,747	-0,066	0,922	p<0,001
Sleeve length till elbow	0,564	-0,127	0,835	p=0,022

3.2. Evaluations of comparison results

Results summarized with Table 1 and Table 2 showed good correspondence on some measurements and errors with others, especially for those sensitive to posture, or features normally hidden by body tissue. The evaluation aimed to investigate the causes of the tendencies shown in the variances discovered.

- **Chest-waist-hip circumference measurements**

For the main three circumferences, chest, waist and hip, body scan measurements mostly obtained higher values (Table 1). This is mainly because of the measurement technique of body scanning, where the outermost data points are used to create the circumference measurement, as seen in the cross section in Figure 2. The data points do not form exact lines; some of the points remain inside and some of the points remain outside of the determined circle. Furthermore, a very low pressure is unavoidable with the manual measurement taking method.

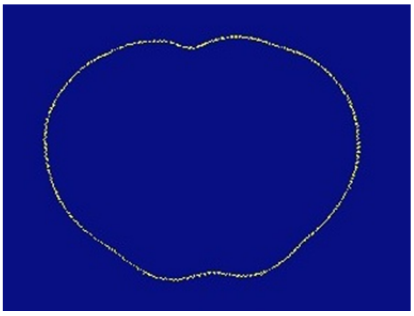

Fig.2. Cross section of the waist

Chest circumference is closely related with breathing, and this can cause small deviations for both measuring methods (MAD chest=2, 15 cm.).

For the standard posture, the person should stand with legs apart, which causes an increase in the value of the hip circumference (MAD hip=1, 86 cm.).

The identification of the exact height of the waist has always been a problematic issue for both manual measurement taking and body scan technology. Therefore, a high MAD value was an expected result (MAD waist=1, 38 cm.). However, since the circumference is smaller than the hip and chest circumferences and the affecting factors are less, the MAD value was found to be less than both of these measurements.

- **Other circumferences**

No significant deviations were observed for circumference measurements of legs and arms, because the locations of these were easy to determine in relation to height. Manual measurements were noted as being greater than or equal to the scan measurements but with very small deviations, as seen with MAD values. This is because automated software can easily carry out landmarking by building up proportions between the length measurements of the body.

- **Height related measurements**

The most problematic case among this group of measurements was the side length from waist to mid over leg. MAD for this measurement was found to be the second highest (MAD=3, 63 cm) showing that there is a significant deviation between the methods. Reliability check for this measurement was also low (ICC=0,422). This is mainly caused by the difficulty of finding the midpoint of the over leg by manual measurement method. The body scan software gives a more accurate result by proportioning the leg length measurements.

The differences for other height-related measurements showed lower differences and more reliability.

- **Distance measurements**

  Cross front and back breadth from armhole to armhole are the two main chest related measurements, and thus indicate a strong sensitivity to posture of the body and the arms. The great difference, especially for cross front measurement, can be explained by the scanning posture, where the arms are held away the body. In contrast, manual measurements are taken with the arms relaxed at the sides. This is also the reason that the scanner-derived measurements obtained greater values for most of the subjects.

  Shoulder and arm related measurements show a variation which can be explained by the position of the arms and difficulty in locating landmarks at the shoulder points. The ICC with the shoulder breadth was therefore rather low.

  Measurements of sleeve length mostly obtained greater values for manual measurement since these measurements are extracted by bending the arms 90 degrees, whereas with the scanner posture, arms are only slightly bent away from the body. This was also the reason for high MAD values.

Apart from individual measurement related remarks given above, some general points for the comparison of two measurement-taking methods have been determined as follows:

- Scanning postures are determined to capture the best scan data and the maximum number of data points with the current technology, however, not all the measurements taken by traditional means use this standard scan posture. The posture required for manual measurement-taking is different for some measurements. This causes measurement variance between methods.

- The identification of the measurements with the scanner software is based on the cloud of points obtained by approximating for the outermost data points and defining the curve according to this approximation.

- The manual measurement method entails unavoidable low pressure.

- For both methods locating landmarks hidden underneath the body tissue can be difficult.

- The international standard ISO 8559 covers the body dimensions for garment construction and anthropometric surveys. The method specified in the procedure of the body-measuring method is the use of a tape measure. However, other methods of measuring the body may also be used, provided that they are at least as accurate as the method specified in this standard. An accuracy of +/- 1% or +/- 5 mm., whichever is the smaller, should be adequate for most measurements. Not all the results obtained in this study are within the acceptable accuracy limits of this standard. However, understanding the reasons for such variances will help to evaluate these data and enable them to be used for further development.

3.3. Testing the repeatability of body scan measurements

Comparing to manual measuring, the body scanning process was efficient, quick and provided a greater amount of information regarding the body of the subject. Furthermore, errors in the scan measurements were easier to spot and review. Automated generation of body scan-extracted measurements was fast and the method was practical to apply. However, repeatability of the scan measurements was noted as being an area for further research. To determine the level of accuracy of the scanner used in this research, evaluations were performed on five repeated scans from each of six participants. Differences between the maximum and minimum values for the repeated scans for each subject were given in Table 3. No standardization procedure was available to determine acceptable margins. However, significant deviations were not noticed and therefore, based on the ICC analysis, the repeatability of the measurements within these circumstances was accepted.

Table 3. Comparisons of repeated scans

	Difference of max. and min. measurements for each subject (cm.)							95% confidence interval		
Body measurements	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	ICC	Lower Bound	Upper Bound	*p*
Body height	1,4	0,8	1,1	1,1	1,1	3,2	0,998	0,995	1,000	p<0.001
Neck width	0,8	0,4	0,7	1,3	1,1	0,8	0,998	0,994	1,000	p<0.001
Total torso circumference	0,5	1,6	1,7	2,5	1,4	1,9	0,999	0,996	1,000	p<0.001
Shoulder breadth complete	0,8	4,3	2,7	1,1	1,4	1,2	0,990	0,967	0,998	p<0.001
Shoulder breadth	0,7	0,9	2,2	1,8	0,5	1	0,960	0,872	0,994	p<0.001
Cross front	3,7	1,6	3,6	6,7	2,2	1,1	0,942	0,817	0,991	p<0.001
Chest lowness fr shoulder till waist	0,1	1,2	0,5	1	1,3	0,3	0,996	0,986	1,000	p<0.001
Chest lowness fr shoulder till bust point	0	0,7	1,3	1,4	1,9	0,7	0,991	0,966	0,999	p<0.001
Chest circumference	8,8	2,4	1,6	1,4	2,6	1,6	0,994	0,980	0,999	p<0.001
Backbreadth fr armhole till armhole	1,6	3,8	3,2	2,6	1,8	1,1	0,981	0,937	0,997	p<0.001
Back length till waist	3,3	1,3	1,2	1,1	0,8	0,4	0,983	0,944	0,997	p<0.001
Waist circumference	2,9	0,6	1,6	1,5	1,8	1,7	0,999	0,998	1,000	p<0.001
Side length fr waist till mid over leg	3,6	1,3	0,5	1,1	0,8	1,5	0,981	0,941	0,997	p<0.001
Hip circumference	1,5	0,7	2,2	1,7	0,9	0,5	0,999	0,997	1,000	p<0.001
Shoulder with sleeve length	1,9	0,6	0,6	1,4	1,2	1,6	0,997	0,991	1,000	p<0.001
Sleeve length long	2,3	0,2	2	2,2	1,4	2,5	0,994	0,982	0,999	p<0.001
Sleeve length till elbow	1,9	1,5	1,4	2,3	0,8	2,7	0,960	0,873	0,994	p<0.001
Upper arm circumference	0,6	0,5	1,5	0,5	1,1	1,4	0,998	0,992	1,000	p<0.001
Elbow width	0,9	0,3	0,8	0,7	0,6	0,1	0,998	0,995	1,000	p<0.001
Forearm circumference	0,3	0,5	0,1	0,7	0,6	0,6	0,999	0,997	1,000	p<0.001
Wrist circumference	0,1	0,3	0,6	0,5	0,2	0,5	0,996	0,988	0,999	p<0.001
Step length	0,7	0,9	0,8	0,9	0,4	1,3	0,999	0,996	1,000	p<0.001
Side length from waist till ground	4,2	0,8	0,6	0,5	0,8	0,7	0,997	0,989	0,999	p<0.001
Thigh circumference	0,6	0,5	0,5	1	1	0,6	1,000	0,999	1,000	p<0.001
Circumference over knee	2,2	0,2	1,5	1,8	0,6	0,4	0,994	0,982	0,999	p<0.001
Calf circumference	0,2	0,2	0,3	0,4	0,1	0,2	1,000	1,000	1,000	p<0.001
Ankle circumference	0,3	0,4	1,1	0,3	0,3	1,8	0,982	0,943	0,997	p<0.001
min. leg circumference	0,2	0,1	0,1	0,2	0,1	0,1	1,000	0,999	1,000	p<0.001

Interpreting the comparison chart, results that are in accordance with previous research findings can be itemized as follows:

- The deviations are mainly due to the difficulties in automatic landmark locating, the posture differences from one scan to another and inadequate posture. The deviations are mostly noticed in the chest and the arm related measurements, resulting from changes caused by breathing at the chest level, and the bending angle of the arm.

- The deviations in the lower body are negligible, showing that the possibility of movement most frequently affects the upper body.

- It is a fact that the human body is not a rigid structure, but a living organism. Even though the scan duration is only approximately 12 seconds, the body shape can change during this time, causing variation from one scan to another.

- When there is a problem with the measurements rather than the scan itself, it is not always necessary to rescan the subject; instead the measurements can be examined and retaken manually from the scan using the software tools (ScanWorX Interactive measurement tools).

- Since the body is covered with tissue, it might be difficult to locate the landmarks automatically. This difficulty depends on the posture of the person, as well as the body form. The difficulty in finding landmarks directly is related to the accuracy of the scanning. For example, if the shoulder point cannot be defined clearly, the software will choose a different point each time, which will cause deviations from one scan to another regarding the shoulder related measurements. This difficulty could be overcome by integrating a user defined measurement-scenario to obtain an accurate result. Although time-consuming, it would result in a better solution for customized approaches, such as in the case of made-to-measure clothes. By taking a statistical approach, the most problematic cases can be defined and subsequently manually adjusted in a systematic base.

4. Discussions and future work

- Results from the study provided an understanding of both body scanning and traditional anthropometry. The acquisition of reliable body measurements is an important issue common to all fit matters. Furthermore, this research can be a foundation for investigating additional opportunities to use the scanner for alternative product groups.

- Based on the results, it was seen that body scanning as a tool to improve the apparel product development steps has limitations as well as the opportunities. However, the results of accuracy trials were found to be encouraging and indicate reliability.

- Respiration, changes in posture, foot placement and such parameters influence the accuracy of measurements, however, by controlling such parameters, 3D scanning can be accepted as a practical tool compared with traditional anthropometric methods, since the accuracy of manual anthropometric methods mainly depends on the level of experience of the measurer, which can be a source of systematic and random error.

- An automated anthropometric data collection system helps to increase the speed of the process and provides a greater level of detail. Findings of the trials in this research showed that manual intervention might be necessary due to deficiencies in the current body scanning technology. Positioning of landmarks by specialists and checking the accuracy of the landmarks would be a strategy for coping with the errors caused by automatic landmark definition.

- The relatively small size of the sample group in the trials of this study was a limitation for this research. However, results of this analysis give a general indication of the possibilities for data extraction from the body scanner. These findings could be the basis for further research applications, and by increasing the sample size, a possible correlation formula could be generated to account for differences in measurements between two techniques.

- Within the mentioned framework of this research, even with its limitations, it can be seen that the body scanning utility would create advantages for apparel product development stages if the options are well coordinated and the requirements are well defined. The preparations for the implementation of different product groups need to be realized accordingly. Additionally, there are potentially a great many opportunities to integrate scanning technology into the process of development of different product groups, such as the sportswear. Scanning using a range of posture alternatives would be an example for further analysis, as well as product-focused research on body scanning technology. With such options, specific product groups can be provided with and benefit from the advantages of advanced technology.

References

1. Peasant, S. (1996): “Bodyspace: Anthropometry, ergonomics and the design of the work, Second Edition, CRC Press LLC.
2. Simmons, K. and Istook, C.(2003): “Body measurement techniques: Comparing 3D body-scanning and anthropometric methods for apparel applications”, Journal of Fashion Marketing and Management, Vol.7, No.3, pp. 306-332.
3. Fan, J., Yu W. and Hunter, L. (2004): “Clothing appearance and fit: Science and technology”, Woodhead Publishing Limited and CRC press LLC.
4. Song, H.K. and Ashdown, S. (2011): “Categorization of lower body shapes for adult females based on multiple view analysis”, Textile Research Journal, Vol.81, No.9, pp.914-931.
5. Lu,J., Wang, M. and Mollard, R. (2010): “The effect of arm posture on the scan derived measurements”, Applied Ergonomics, Vol.41, No.2, pp.236-241.
6. Mckinnon, L. and Istook, C.L. (2002): “The effect of subject respiration and foot positioning on the data integrity of scanned measurements”, Journal of Fashion Marketing and Management, Vol.6, No.2, pp.103–121.
7. Feathers DJ., Paquet VL. and Drury CG.(2004): “Measurement consistency and three-dimensional electromechanical anthropometry”, International Journal of Industrial Ergonomics, Vol:33, pp. 181–190.
8. Bradtmiller, B. and Gross, M.E., (1999): “3D whole body scans: Measurement extraction software validation”, Proceedings of Digital Human Modeling For Design and Engineering Conference and Exposition, May 1999, Hague,
9. Mckinnon, L. and Istook, C.(2001): “Comparitive analysis of the image twin system and the 3T6 body scanner”, Journal of Textile and Apparel, Technology and Management, Vol.1,No.2.
10. Brooke-Wavell, K., Jones, P.R. and West, G.M.(1994): “Reliability and repeatability of 3-D body scanner (LASS) measurements compared to anthropometry”, Annals of Human Biology, Vol.21, No:6, pp.571-577
11. Bougourd, J.P., Dekker,L., Ross, P.G. and Ward, J.P. (2000): “A comparison of women’s sizing by 3D electronic scanning and traditional anthropometry”. Journal of Textile Institute, Vol:91, Part 2, No.2, pp 163-173.
12. Kouchi, M. and Mochimaru, M. (2011): “Errors in landmarking and the evaluation of the accuracy of traditional and 3D anthropometry”, Applied Ergonomics, Vol.42, No:3, pp. 518-527.
13. Robinette, K. and Daanen, H. (2006): “Precision of the CAESAR scan-extracted measurements”, Applied Ergonomics, Vol.37. No.3. pp. 259-265.
14. Lu, J.M. and Wang, M.J.J.(2008): “Automated anthropometric data collection using 3D whole body scanners”, International Journal: Expert Systems with Applications, Vol.35, No.1-2, pp.407-414.