3D Digital Anthropometry Using the BodySCAN

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Abstract

Over the last several years a number of three-dimensional (3D) anthropometric studies have been performed using fast and contact free measurements by using 3D whole-body scanners. Several 3D scanners are available on the market with a potential for anthropometry; these devices are usually developed using laser or Moiré-fringing-based technologies. In the former a laser stripe is projected onto the body surface and images acquired by several cameras: in this way 3D points representing the body shape can be recovered by triangulation. Examples of this kind are the scanners developed by Cyberware, Hamamatsu, Vitronic or Human Solutions.

In this work we evaluated a new 3D whole-body scanner using structured white light- the Breuckmann BodySCAN - for performance in anthropometric measurement. Twelve young adults (6 men and 6 women; age, 22,7±2,16 yrs; height, 168,2±7,38 cm; body mass 61,5±6,16 kg) underwent both manual and 3D anthropometry (25 measurements) wearing close-fitting underwear.

Duplicate manual measurements taken by one experienced anthropometrist showed correlation coefficients r ranging 0.975-0.999; their means were significantly different in four out of 25 measurements by Student's t test. Duplicate digital measurements taken by one experienced anthropometrist and two naïve anthropometrists showed individual correlation coefficients r ranging 0.975-0.999 and means were significantly different in one out of 25 measurements. Most measurements taken by the experienced anthropometrist in the manual and digital mode showed significant correlation (intraclass correlation coefficient ranging 0.855-0.995, $p<0.0001$).

It is concluded that the Breuckmann BodyScan is a reliable and effective tool for digital anthropometry.

Keywords: 3d body scanning, anthropometry, correlation, reliability.

1. Introduction

Anthropometry has been used for decades in physical anthropology to measure individual human beings in order to quantify human physical variation; moreover, it is currently utilized in several biological and medical settings in order to obtain population reference data, carry out health surveys, perform nutritional assessment and so on. Further, anthropometry is of use in forensic medicine to identify individuals, ergonomics to produce best-fitting objects and tools as well as the clothing industry to realize optimized garment.

Along the last 150 years, anthropometry has been manually performed by trained personnel using dedicated instruments such as tapes, calipers of different size and shape, stadiometers etc [1]; an advantage of manual anthropometry is that it is relatively cheap and can be performed in- and outdoors with minimal effort; drawbacks are, among others, that inter- and intraobserver variability in measurement may be fairly large (hence the need for trained personnel) [2,3] and the information obtained is limited to actual measurements, because the subject must be physically present to allow any measurement.

More recently, 3D scanning technology has come of age to enable anthropometry in an entirely new way [4](see e.g., Robinette and Daanen, 2006). Nowadays, a number of 3D scanners are available on the market, which can be adapted to anthropometric measurements; these devices are usually developed using laser or Moiré-fringing-based technologies. In the former a laser stripe is projected onto the body surface and several cameras acquire images: in this way 3D points representing the body shape can be recovered by triangulation. Examples of this kind are the scanners developed by Cyberware [5], Hamamatsu [6], Vitronic [7] or Human Solutions [8]. In the latter, one or more projectors create light patterns on the body surface and 3D points are estimated by observing the pattern deformations on the body surface with a set of cameras. Examples of this kind are the scanners developed by Textile and Clothing Technology Corporation [9], Telmat [10] inSpeck [11], and the product used for our experiments, i.e. the bodySCAN developed by Breuckmann GmbH [12].

In this paper some preliminary data on the performance of Breuckmann bodySCAN in anthropometry are presented.

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2. Method

2.1 Subjects

Six men and six women, students at the University of Verona, were enrolled in this study after informed consent; the study protocol was in accordance to the Helsinki declaration. The main physical characteristics of the study group were as follows: mean age 22,7±2,16 years (range: 20-27); mean height 168,2±7,38 cm (range: 159-184); body mass 61,5±6,16 kg (range: 53-70). Body mass was assessed to the nearest 0.1 kg using a certified electronic scale (Tanita electronic scale BWB-800 MA (Wunder SA.BI. Srl)). Height to the nearest 0.01 m was measured using a Harpenden portable stadiometer (Holtain Ltd., Crymych, Pembs. UK). During scanning and anthropometry, subjects wore close-fitting underwear.

2.2 Manual anthropometry

A set of 28 anthropometric parameters was chosen to include most of the current circumferences, lengths, and widths taken in anthropometric surveys (Table 1). Measurements were performed on two different occasions by one experienced anthropometrist (CM) according to standard procedures [13]. The body sites were marked prior to measurement using a dermographic pen; such landmarks were found to be easily visible in 3D scanning images in preliminary experiments.

Table 1. The set of anthropometric parameters measured in this study.

Type of measurement	Body site
Circumferences	Head Neck Arm (relaxed) Forearm Wrist Chest Waist Gluteal (hip) Mid-thigh Calf Ankle
Lengths	Shoulder-elbow Radiale-stylion Midstylion-dactylion Iliospinale to floor Trochanterion Trochanterion-tibiale laterale Tibiale lat Tibiale-sfirion tibiale Foot
Widths	Bi-acromial Bi-iliocrestal Chest (transverse) Chest (A-P) Bi-epicondilar (humerus) Wrist Knee Bi-malleolar

2.3 3D scanning

The Breuckmann BodySCAN uses high-speed cameras and a proprietary algorithm to detect the actual position of visible light points projected onto the surface of the body through diffraction fringes and reflected to the cameras. Breuckmann bodySCAN typical acquisition consists of about 400.000 points with a precision from 0.2 mm to 1.4 mm, with a time acquisition of 2.5 or 5.5 seconds, depending on the acquisition mode. In our experiments we found that this acquisition time is enough to obtain sufficient quality for the subsequent processing.
The scanner output consists of a triangular mesh obtained by the registration and merging of the points acquired by the different cameras. Meshes are, however, not very clean, presenting various types of defects like holes, non-manifold edges, bad shaped triangles and outliers, so a pre-processing step is mandatory.
Meshes nodes include also grayscale information. This is extremely important in order, for example, to acquire landmarks position useful for automatic or computer assisted measurements by exploiting natural or added texture (i.e. skin markers).
Figure 1 shows the acquisition setup and an example of textured mesh. It is possible to see holes and inaccuracies caused by occlusions and reflective materials (i.e. hair).
Subjects were scanned standing in the anatomical position.

Fig. 1. The Breuckmann BodySCAN during acquisition

2.4 Digital anthropometry

The experienced anthropometrist was instructed to perform digital anthropometry on 3D images of the twelve subjects using the same landmarks as for manual anthropometry. Manual measurement procedures have been simulated through the development of a user friendly measurement interface that enables the operator to easily place landmarks on the virtual body surface and automatically obtain the related set of measurements. Our dedicated software tool has been realized using the based on the VTK library[14] and exploits for the measurement procedures an automatic mesh processing that pre-computes body posture and limb directions and recognize the main body parts [15].

All measurements were obtained in duplicate. Two naïve anthropometrists carried out the same procedure independently from each other.

2.5 Statistical analysis

Descriptive statistics were calculated for all variables (measurements) by each method (manual/digital). Normality of data was assessed with the Kolmogorov-Smirnov test. Reliability of measurement was assessed by calculating the product-moment Pearson's correlation coefficient, the Student's t test (two-tailed), and the intraclass correlation coefficient (ICC; Crombach's alpha using a mixed model [type: consistency]). All statistical analyses were performed with the SPSS package (v. 15). The level of significance for all statistical tests was set at P=0.05.

3. Results

3.1 Manual Anthropometry

Manual anthropometry showed intraobserver correlation coefficients r for duplicate measurements in the range 0.975-0.999 (P<0.0001 for all) but for mydstilion-dactylion (r=0.781, P=0.003); the Student's t test (two-tailed) showed that mean values of duplicate measurements for individual anthropometric variables were not significantly different by two-tailed t test with the exception of mydstilion-dactylion (188.08± vs. 186.17± mm; t=8.815, P<0.001) and tibiale laterale to floor (453.17± vs. 451.83± ; t=2.402, P=0.035) as well as, at the limit of significance, bi-iliocrestal (284.58± vs. 283.25± ; t=2.111, P=0.058); and wrist width (54.50± vs. 55.17± ; t=2.152 P=0.054). The ICC was in the range 0.955-0.998 (P<0.0001) with Cronbach's alpha ranging 0.977-0.999.

3.2 Digital anthropometry

Duplicate measurements taken digitally by one experienced anthropometrist and two naïve anthropometrists showed intraobserver correlation coefficients r in the range 0.975-0.999 (P<0.0001 for all). Mean values of duplicate measurements for individual anthropometric variables were generally not significantly different intraobserver by two-tailed t test. The ICC was in the range 0.759-0.999 (P<0.001-P<0.0001) with Cronbach's alpha ranging 0.863-0.999.

Most measures taken by the experienced anthropometrist in the manual and digital mode showed ICC ranging 0.855-0.995 (Krombach's alpha 0.959-0.999), p<0.0001 for all; lower, albeit significant, ICC values were found for head circumference (0.446; alpha 0.763 P<0.001), wrist circumference and breadth (0.678 and 0.654, respectively), bi-epicondilar humerus (0.695; alpha 0.901).

4. Discussion

Body scanners are increasingly used in health assessment and physical anthropology [14-17] and it is probable that they will represent the standard anthropometric tool in the future. In this work we evaluated the ability of a 3D scanner, the Breuckmann BodySCAN, to allow reliable anthropometric measurements.

Results show that when duplicate measurements are performed of standard anthropometric parameters by and experienced anthropometrist, excellent correlation coefficient r is found in either the manual or digital mode; this suggests that digital measurement of anthropometric parameters is at least as reliable as manual. In order to check for possible systematic error in measurement the t test was also performed, showing significant/borderline difference of the duplicate means in four and none anthropometric parameters with the manual and digital mode, respectively. This suggests that digital measurements are less prone to systematic measurement error. The ICC, an alternative test of reliability using the F test from repeated measures analysis of variance, was high (>0.9) for all measurements in the manual mode; in the digital mode, the ICC was somewhat lower for some anthropometric parameters, still showing high P values. This indicates that digital measurement is at least comparable to manual in terms of reproducibility.

When the agreement of manual and digital measurements taken by the experienced anthropometrist was tested, the ICC resulted good (>0.8-<0.9) to high (>0.9) in the majority of anthropometric parameters. As expected, less than satisfactory agreement was found for head circumference due to the better performance of manual measurement in minimizing hair bias; further investigation is needed to clarify the reason for the relative disagreement in wrist and bi-epicondilar measurements.

Interestingly, when naïve anthropometrists took measurements in the digital mode the correlation coefficient r and the ICC for duplicate measurements were mostly high (>0.9) with no systematic error (as assessed by t test); this clearly show that digital anthropometry, which is independent of subject's movement/sway as well as most ambient detrimental factors eg., noise, temperature or observer-subject interaction allows for good to excellent measurement performance of observers in the absence of specific time-consuming training.

In conclusion, the Breuckmann BodySCAN revealed a reliable and effective tool for digital anthropometry comparing well with traditional manual procedures as well as allowing for reproducible measurements in the absence of specific anthropometric training.

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