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Investigation of usability and measurement accuracy of 3D body scanning mobile applications

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ABSTRACT

In this research project an independent case study on the new contactless 3D body measuring native mobile applications has been carried out. The presented approach allows combination of three different measurement methods: the manual body measuring with the help of traditional instruments, 3D full body scanning technology, and the contactless body measuring via smartphone applications. This paper discusses results of the investigation of usability of the measurement process via 3D body scanning apps on the Gage R&R methodology and the examination of their measuring accuracy. The current research provides analysis of body data obtained by the mobile scanning apps with the help of various methods.

Keywords
3D body scanning technology,
body measuring mobile applications,
body scanning position,
body shape,
body posture,
body measurements,
3D avatar

1 Introduction

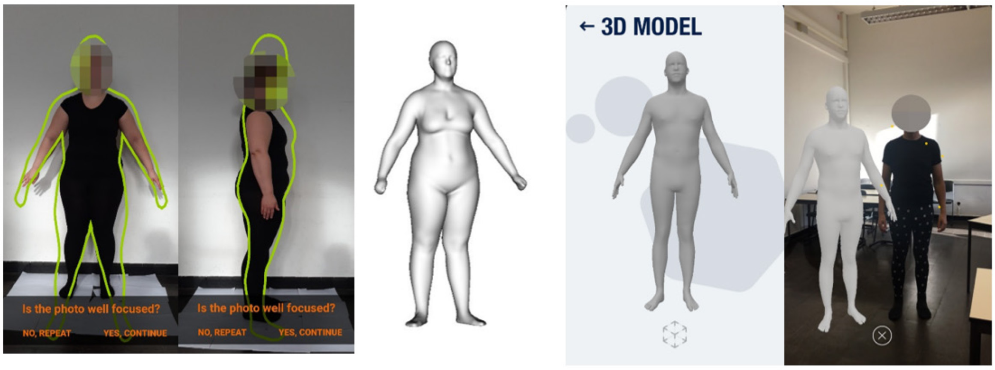
Several years ago, an era of new-app & smartphone commerce [1] has begun. The "explosion" of apparel e-commerce has led to overwhelming number of online returns, which exacerbate the problem of sustainability in the fashion industry. 3D body scanning mobile applications based on 3D body data acquisition and its reconstruction are intended to solve the sizing problem during online shopping. And, particularly, at the current "turbulent" time caused by COVID-19, the contactless mobile body measurement technologies, which can greatly facilitate the consumers' online fashion experience in the quarantine isolation, acquires a new urgency and importance. Nowadays, the investigations on comparing the anthropometric data on living humans using different body measuring methods including smartphone apps are carried out, the results will be released in 2020 [2].

From a scientific perspective, the main challenge is to study the usability, the body measuring accuracy of these new native mobile applications, especially on persons in the group of large sizes, to analyze the quality of body shape recognition, and above all, on figures having nonstandard asymmetrical body posture.
This research consists of two phases based on the systematic analysis. In the 1st phase, the analysis of more than 25 existing 3D body scanning mobile applications was performed and a comprehensive classification of the apps was worked out [3]. The systematic analysis allowed identifying the most important criteria for categorization of the body measuring apps. Table 1 demonstrates the short extracts of the developed classification criteria.

Table 1. Criteria for categorization of the body measuring apps (extracts).

	Criteria name	**Criteria value**	**Comment**
1	Focus of the application regarding to the measuring part of the human body	Body measuring/ foot measuring	This research exclusively concerns the native mobile applications for contactless body measuring.
2	Set of body measurements, measurement up to existing ISO standard	From minimum 8 body control dimensions in the app to maximum 128 in the web application programming interface (Web API)	Most of the investigated apps offer different sets of body control dimensions, which are named and measured with very different methods and under different requirements regarding body position of the measured subject.
3	Measuring mode	Snapshot mode / selfie mode / both	The app can be used alone or/and with the help of another person.
4	Clarity of the body measuring process	Voiceover, animated and/or video user instructions	Simplicity and visibility of the app usage should be provided.
5	Need for subsequent manual calibration for recognition of contours of a human figure	Yes/ No	The additional manual adjusting for more accurate recognition of body contour slows down the process of work with the app.
6	Technical requirements to the mobile device	Smartphone operating system: iOS from the version 7.0 or Android from the version 5.0	Some applications have additional technical requirements, e.g. special depth sensor or 3D-scanner.
7	Default input information		
7.1	Initial anthropometrical information	Gender: female or male, body length, body mass	The initial anthropometrical information is required at the beginning of the app processing. Correctness of default anthropometrical information has large impact on the measuring results.
7.2	Graphical information	Pictures of the measured person or short video of a person moving around	
7.3	Necessary number of pictures of the measured person	One / two	One picture (one front photo of a person and one photo of a background) or two pictures (the front and side photos of a person).
8	Position of the measured person	Five different body positions according to the requirements of the investigated 3D body scanning mobile apps	The analysis revealed that the apps require special body positions which differ from the standard anthropometric position. The body positions were fixed and coded for developing the anthropometric measuring program.
9	Requirements to the clothing and background	Skin-tight clothing, clean and contrast background / scan suit / special measuring kit	Almost all the investigated 3D body measuring apps need skin-tight clothing and clean background in contrast to the color of the clothing.
10	Position of smartphone in the process of graphical data capturing	Fixed on the support surface / in the hand of the operator, approx. on the hip level of the	

		measured figure / on the floor	
11	Place of business or location of the developer	Europe, Asia, North America	Countries: Austria, China, Denmark, Finland, Germany, India, Israel, Japan, Spain, Sweden, Switzerland, Ukraine, USA
12	3D-avatar of the measured figure	Yes / no	Generating of 3D-avatar in one of accepted file formats (e.g. *.obj) via Web API allows to download and analyze it with 3D CAD software.
13	Additional functions	Size recommendation/ Body tracking/ Elements of augmented reality/ Implementation of a virtual dressing room via Web API	Various additional functions depend on the target market: online commerce, final consumer, industry or research purposes [4]. Visualization of the generated 3D avatar in the app allows entertaining the user with the elements of augmented reality (Fig. 1).



a b

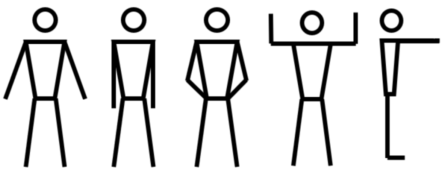
Fig. 1 (a) Visualization of the generated 3D avatar in the mobile app interface; (b) Entertainment of the user with the elements of augmented reality

2 Research methodology

Considering the classification criteria, a set of body control dimensions and the requirements to the position of the measured subject the anthropometric measuring program was developed. This program contains totally 25 body control dimensions which represent 4 following groups:

- girths (U)
- breadths to be measured across the body surface (B)
- vertical and horizontal lengths (L)
- width dimensions / body projections (P).

The program provides descriptions on the measurement method for every control dimension and the information about the necessary body position (Fig. 2).



1 2 3 4 5

Fig. 2 Five default body positions according to the requirements of the investigated 3D body scanning mobile apps

In the first phase a preliminary measuring study on 10 female and male participants of different body sizes and figure types has been carried out. The analysis of usability of 3D scanning apps in a combination with their measurement results allowed choosing only 5 reliable apps for the next phase of the research project. The apps were selected considering the following main criteria:

- Duration of the measuring and calculation procedure should trend to minimum.
- The reliability of the app: only fault-free operation was acceptable.
- Measuring operation on plus size figures must be provided.
- Measuring accuracy of the app: the standard deviation of the measuring results and the relative error (RE, %) in comparison with the traditional manual measuring method should trend to minimum.

In the second phase the investigations have been performed on 20 female and male subjects covering the age range from 18 to 55 years old. The measuring figures belong to different groups of sizes: small, medium/normal and large, and to different groups of body lengths: small, normal and long. There were also participants having individual asymmetric body postures.

The main research challenge was to estimate the measuring process and results on plus size figures and also on figures with nonstandard body posture.

2.1 Measurement technologies

The body measuring was realized with the help of three various technologies:

- 3D full body scanning laser technology: Anthroposcan, Human Solutions GmbH, Virtual Lab at Niederrhein University of Applied Sciences
- Contactless body measuring using one specific selected smartphone and 5 chosen native mobile applications installed. For the process of body measurement via apps the special guidelines on the Gage Repeatability and Reproducibility methodology were developed (see Chapter 2.2 below).
- Manually measuring with the help of traditional technique and instruments according to the previously developed anthropometric measurement program. Herewith, the standard measuring instruments were implemented: tape measure, girths measuring tape with an adjustable fastening and a spreading caliper for measuring width dimensions/ body projections. Every measurement was taken manually and fixed 3 times by the same examiner. The calculated average value was considered as a real value.

2.2 Gage Repeatability and Reproducibility

In the second phase, the usability and the reliability of the measuring process via 3D body scanning apps were investigated. The feasibility of every app was examined with the help of the Gage Repeatability and Reproducibility methodology (Gage R&R or GRR). The GRR methodology requires using of the same measuring system (the same smartphone and the same app), two independent examiners measuring at least twice in random order the same study participants. These requirements were strictly fulfilled.

The practical measuring tests on the GRR methodology have been planned and carried out under the general guidelines:

- Two different examiners/ operators use the same mobile device and measure with the same apps.
- Under gage the measuring system is taken: mobile device with all 5 apps installed.
- The measurement procedure with every app is to be performed twice by operator.
- The operator cannot see the measuring results of the other operator.
- Regular rotation of the operation order, so that the examiners cannot remember the results of the previous measurement procedure.

- The operators 1 and 2 should be always the same by measuring every study participant.

3 Results and discussion

The following chapter presents only a short extract from the results of the independent study. The results can be divided up into three groups:

- Usability of the apps on the methodology GRR
- Measuring accuracy of the apps based on mathematical analysis
- Quality estimation of body posture and shape of the avatars.

3.1 Usability of the apps on the methodology GRR

GRR considers an evaluation of the combined variation of repeatability and reproducibility, see Equation (1). In other words, GRR is the variance equal to the sum of within-system and between-system variances [5].

$$\sigma_{GRR}^2 = \sigma_{reproducibility}^2 + \sigma_{repeatability}^2 \qquad (1)$$

Gage Repeatability and Reproducibility data were collected and evaluated. GRR data results show no obvious problems with the tested measurement systems. The difference between repeatability (Equipment Variation) and reproducibility (Appraiser Variation) is considered to be significant. It was found that the Appraiser Variation can be equated to 0 in most cases (Equation (2)). This allows drawing the conclusion that the influence of the examiner is small enough by measuring via mobile apps.

$$GRR = \sqrt{EV^2 + AV^2},\ AV = 0 \qquad (2)$$

Total GRR percentage was calculated for every control measure by capturing female and male figures using every app separately. This approach enabled evaluating the measurement systems independently and regardless of a set of body measures taken.

Figure 3 shows percentages of body measures obtained by every app with the corresponding acceptance ranges in three colors: green – acceptable, yellow – may be acceptable, and red – unacceptable.

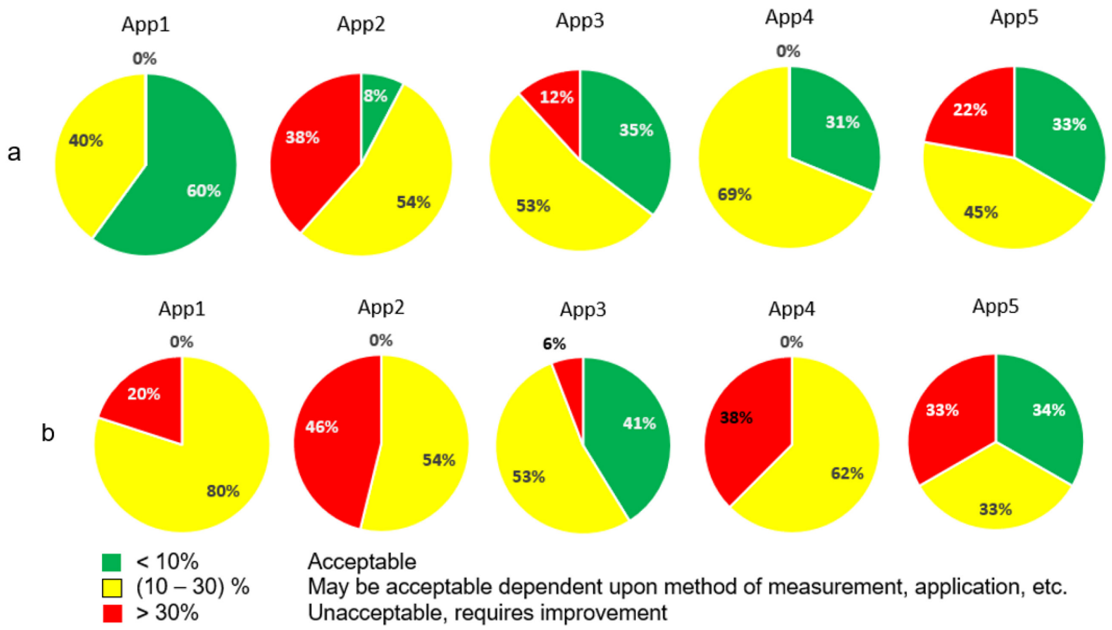


Fig. 3 Total GRR percentage for 5 investigated apps by measuring (a) female, (b) male figures

Total GRR percentage allows concluding that the investigated applications can be generally considered as the acceptable measurement systems (Equation (3)):

$$GRR < 10\% \text{ or } GRR \in (10;30)\% \quad (3)$$

3.2 Measuring accuracy of the apps based on mathematical analysis

The accuracy of body measuring process via 3D body scanning apps was examined by means of the relative error (RE, %) in comparison with the traditional manual measuring method, see Equation (4).

$$RE,\% = \frac{x - x_{real}}{x_{real}} \times 100 \quad (4)$$

x – average of the body measure gained using every app twice by 2 operators

x_{real} – average of the body measure obtained 3 times by the same examiner manually

The following function (Equation (5)) was calculated and the graph curves are discussed by the method of mathematical analysis.

$$RE,\% = f(x), \quad (5)$$

where x takes the values of bust girth (g Bu), waist girth (g Wa) and hip/posterior girth (g Po) in cm.

The research results show that RE-distribution of g Bu of women in the medium group of sizes is almost symmetrical with respect to the x-axis and does not exceed ± 5%. RE,% increases maximum to 8% in the group of small sizes. Furthermore, the RE-distribution of g Bu of women in the group of large sizes trends to the area of negative values, see Fig. 4 and Table 2.

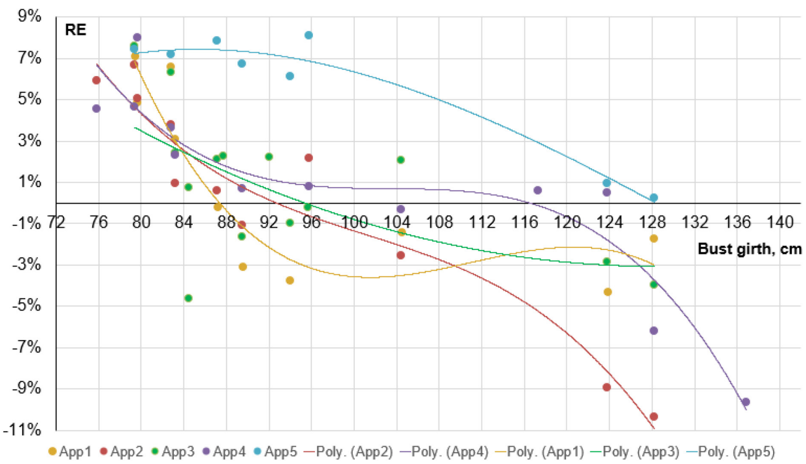


Fig. 4 RE-distribution of g Bu of female figures measured using 5 chosen apps

Table 2. Overview of RE,% in various groups of sizes (g Bu), female.

	Domain of function g Bu (cm)	**RE (%)**
Group of small sizes	$g\,Bu \ll 84$	$RE \in [4;8]\%$
Group of medium sizes	$84 < g\,Bu \ll 96$	$RE \in [-5;3]\%$
	$g\,Bu = 104$	$RE \in [-3;3]\%$
Group of large sizes	$116 < g\,Bu < 136$	$RE \in [-11;1]\%$

Figures 5-6 and Tables 3-4 provide results of mathematical analysis of RE,% for g Wa and g Po of various female figures measured with the help of 5 chosen apps.

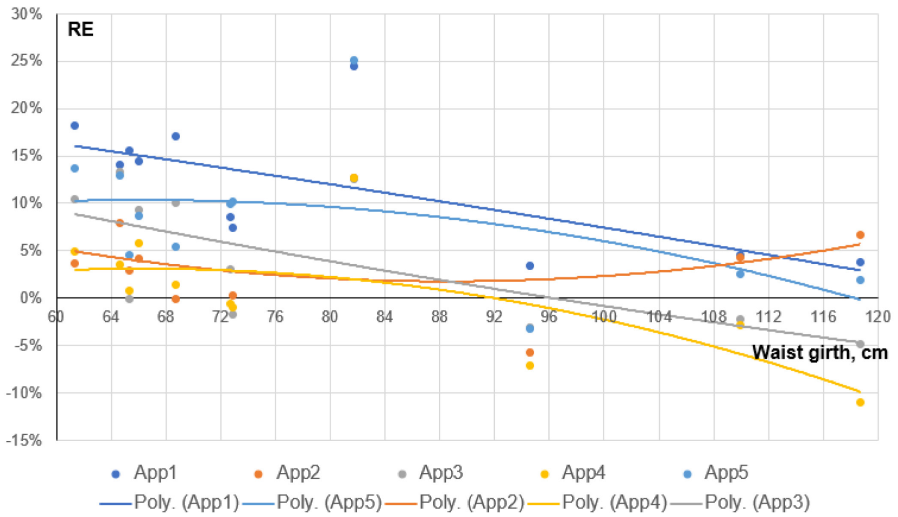


Fig. 5 RE-distribution of g Wa of female figures measured using 5 chosen apps

Table 3. Overview of RE,% for various g Wa, female.

	Domain of function g Wa [cm]	**RE [%]**
Small values g Wa	$60 < \mathrm{g\,Wa} \ll 73$	$\mathrm{RE} \in [0; 15]\%$
	$\mathrm{g\,Wa} = 94$	$\mathrm{RE} \in [-7; 4]\%$
Large values g Wa	$110 < \mathrm{g\,Wa} < 120$	$\mathrm{RE} \in [-11; 6]\%$

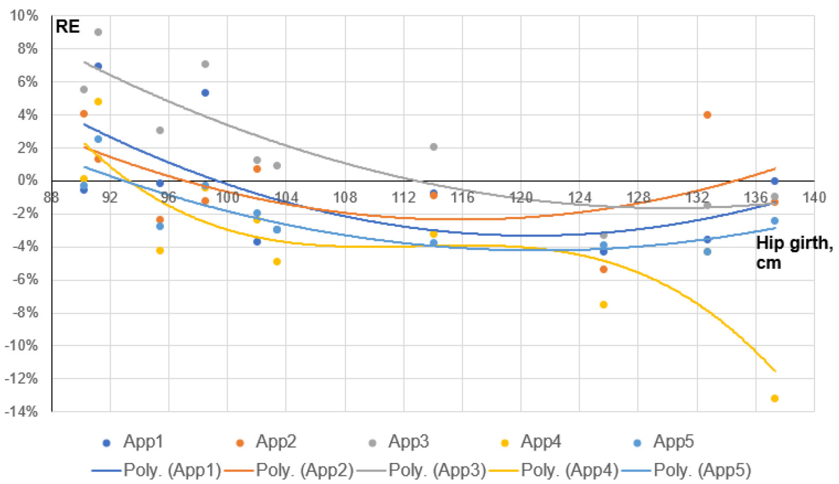


Fig. 6 RE-distribution of g Po of female figures measured using 5 chosen apps

Table 4. Overview of RE, % for various g Po, female.

	Domain of function g Po [cm]	**RE [%]**
Small and medium values g Po	$90 < \mathrm{g\,Po} \ll 104$	$\mathrm{RE} \in [-5; 8]\%$
	$\mathrm{g\,Po} = 114$	$\mathrm{RE} \in [-4; 2]\%$
Large values g Po	$126 < \mathrm{g\,Po} < 138$	$\mathrm{RE} \in [-12; 4]\%$

The study suggests that the measuring accuracy in the group of medium/normal sizes can be generally considered as acceptable. The relative error trends to negative values to -12% by measuring primary girths in the group of large sizes. These results were confirmed by comparison of body measurements using different measuring systems including 3D body scanning technology, see an extract in Table 5 for one female figure, plus size.

Table 5. Comparison of body measurements from different measuring systems, female plus size.

Measurement	**Measuring Technology**						
	Anthroposcan	Manually	App1	App2	App3	App4	App5
Bust girth	141.7	141	138	124	118	128	133
Waist girth	135.0	134	131	113	118	119	119
Hip girth	143.2	144,5	141	134	127	136	136

3.3 Quality estimation of body posture and shape of the avatars

The surface of a human body can be characterized as an object having a sophisticated 3D shape. The fundamental anthropometrical information about the human figure can be obtained from various informational sources:

- Set of primary body control measures: the body length and the main girths: g Bu, g Wa, g Po.
- Body back posture in side view which is determined by side spinal contour. The spinal contour outlines are characterized by cervical and lumbar lordoses and thoracic kyphosis. It is well known that the individual figures are often asymmetric. Figure 7 shows a scanned individual body with a sideways curvature of the spine. Photogrammetry and 3D body scanning technology capture the individual body posture sufficiently, so that the corresponding posture parameters can be investigated with the help of graphics software.

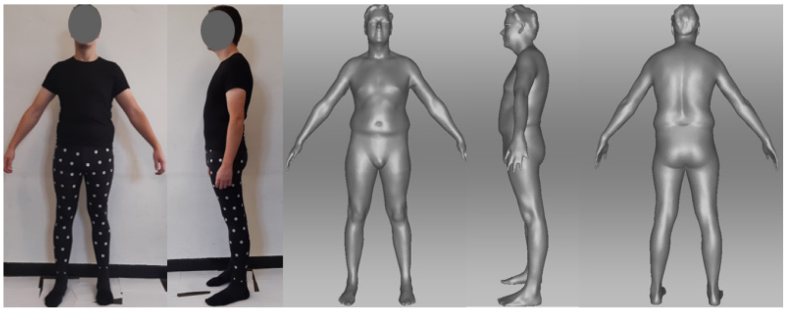


Fig. 7 Scanned individual figure with a sideways curvature of the spine

The front median contour in the side view determines the shape of the bust and trunk areas and delivers balance characteristics and parameters of 3D forming elements (e.g. length and breadth of darts) into garment construction [6].

The individual body shape can be validated with the help of horizontal sections of the scan on the horizontal control planes, e.g. bust plane, waist plane and hip plane.

In this research the detailed graphical analysis of body shapes of scanatars obtained from 3D full body scanner and of simplified 3D avatars generated via Web API was carried out.

Figure 8 shows the substantial differences of body shape of the 3D scan (a) and the 3D avatars (b, c) generated via Web API for one female figure in the group of medium/ normal sizes. The corresponding bust, waist and hip horizontal sections indicate apparent differences of the outlines and the circumference values. For the large group of sizes, these differences become much more significant, see Fig. 9.

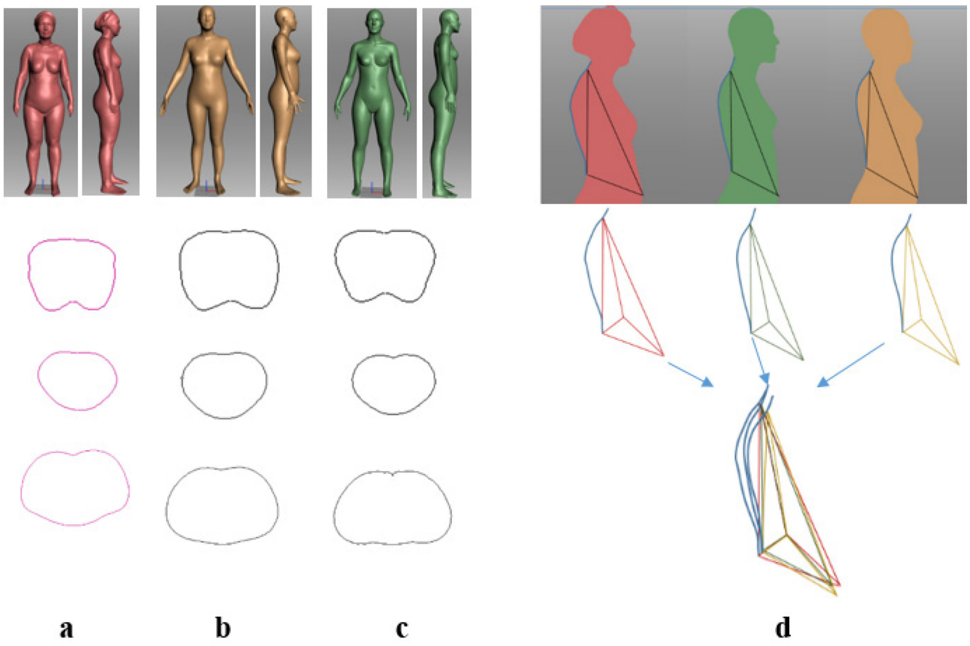


Fig. 8 Comparative graphical analysis of scanatar (a) and two different 3D avatars (b, c), female figure in the group of medium sizes

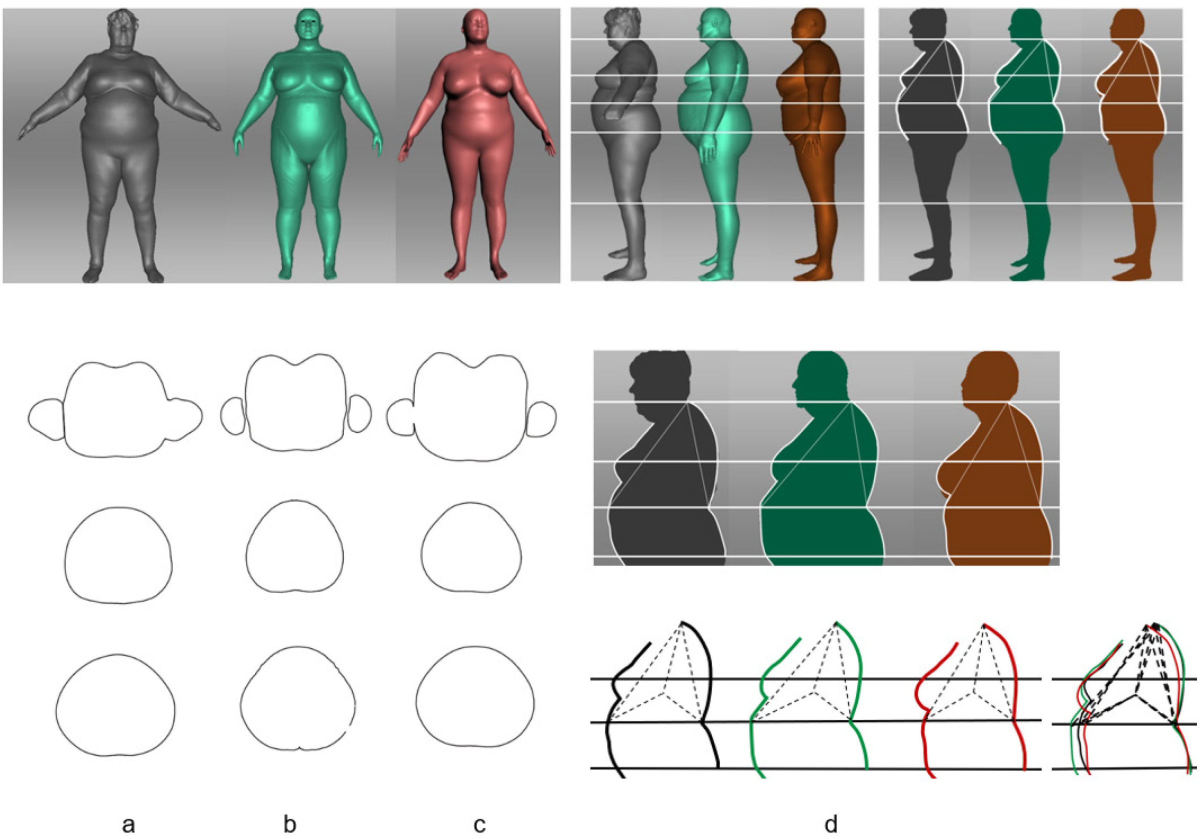


Fig. 9 Comparative graphical analysis of scanatar (a) and 3D avatars (b, c), female figure in the group of large sizes

Comparative graphical analysis of back spine contour based on back posture triangle (Fig. 8 d, Fig. 9 d) and the differences of posture angles characterizing lordosis and kyphosis show, that the 3D avatars do not repeat properly the back posture of the sufficiently precise individual 3D scanatars.

The individual figures with nonstandard configuration of back spine contour were repeatedly scanned with the help of different apps. Figure 10 shows the result of graphical analysis of the generated 3D avatars in comparison with the individual scanatars.

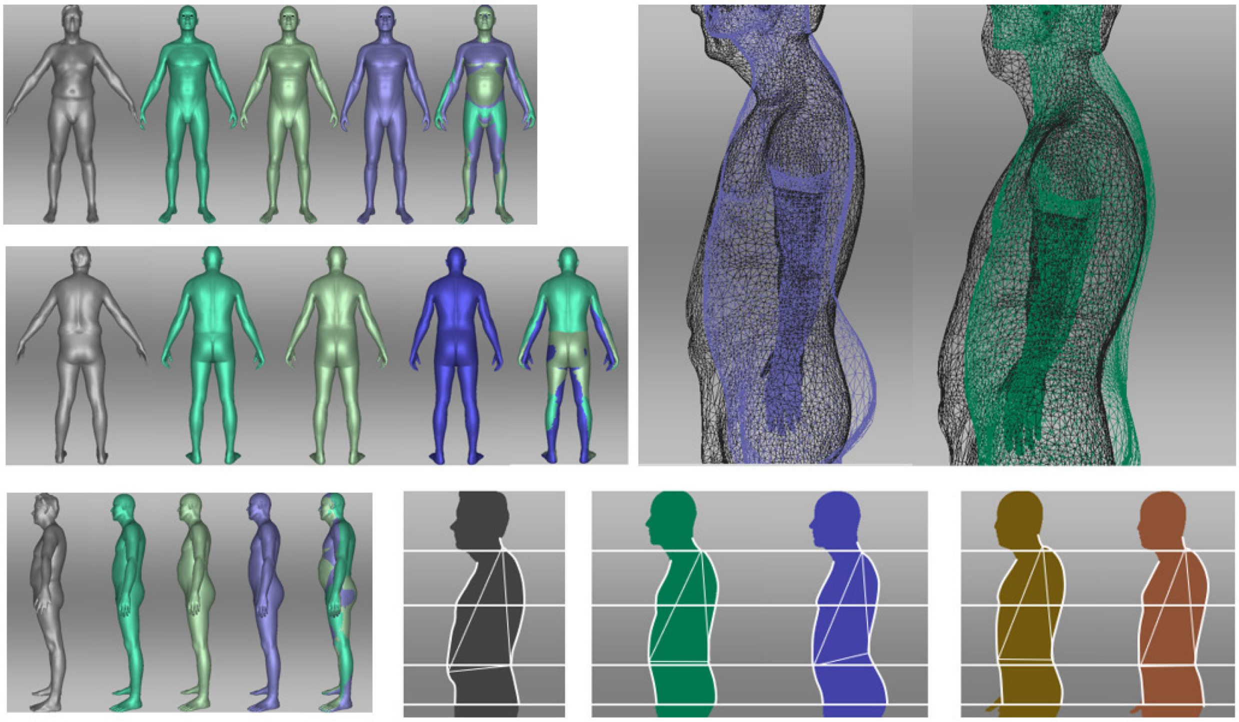


Fig. 10 Comparative graphical analysis of scanatar and repeatedly generated 3D avatars

4 Conclusions

The investigated technology of body measuring and scanning via applications for mobile devices is exclusively useful, relatively fast and easy in usage, and becomes particularly relevant in a wide variety of potential areas, e.g. apparel personalization, made-to-measure, virtual try-on of individualized garments, fitness, medicine, etc.

The examination of usability of the mobile body measuring apps by the methodology GRR showed that the investigated applications can be considered as acceptable measurement systems.

Moreover, the study suggests that the measuring accuracy of body measuring process via 3D body scanning apps in the group of medium/normal sizes can be generally considered as acceptable. The relative error of measuring increases significantly by capturing primary girths of the subjects in the group of large sizes.

The detailed body shape analysis of different 3D avatars generated repeatedly via various Web API shows that they do not correspond sufficiently and do not describe the individual body shape with the required quality. The analyzed 3D avatars differ greatly in the body shape, back posture and front median outline from the sufficiently precise scanatars and accordingly from the real human figures as well. The findings of the research allow highlighting that the algorithm of 3D body data capturing using mobile scanning technology is still not sufficient and there is a demand for great enhancement. Accordingly, from the anthropometrical point of view, there is a need for the continuation the current research in one fundamental study.

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