Computer Vision System for Human Anthropometric Parameters Estimation

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Abstract: -In this paper we have proposed and evaluated a new method for human anthropometric parameters estimation. Method is planed to be simple and fast, thus suited for examiners with no experience in the anthropometric measurements. An anthropometric data obtained by this method, segments masses and lengths, are primarily used for biomechanics applications, but could be adapted to other fields, as well. Estimates of segment inertial properties are frequently based on data and procedures developed for human cadavers in whom inertial properties have been measured directly, using complicated and time consuming procedures. For that reason, we have designed a measurement system that consists of singe digital camera, PC and requires simple experimental set–up with a few considerations. Proposed method comes with some disadvantages, due to which it could be rather used as an estimation tool than as a highly-precise measurement procedure of anthropometric parameters. Measurement using proposed method is completely contactless with the subject, which result in minimizing examiners physical intervention and considerable reduction of time required for measurements. Therefore, measurement procedure is adopted to be executed on a large number of subjects in short time. An algorithm was developed that creates 3D model of the human body using only data obtained from 2D subject's image, and ellipses as basic building objects. Finally, results of anthropometric body parameters obtained for three subjects were compared with referent anthropometric data and manual measurement.

Key-Words: - biomechanics, human anthropometry, computer vision, image processing

1 Introduction

Measurements of a human anthropometry by traditional methods are complicated and time consuming procedures, while modern measurement requires use of expensive medical equipment. When traditional measurements methods are used, in order to obtain precise results, measurements are executed by well experienced examiner using various techniques and methods for each parameter [1]. First detailed anthropometric measurements were preformed on human cadavers [1,2]. Because of lack of modern body scanning technologies and precise electronic measurement devices, direct measurement on a segments removed from the body was the only option. W. Dempster at the University of Michigan made a very thorough study of human body segment measurements [2]. His investigations were based on values obtained on eight white male cadavers. Besides volumes, he obtained values of mass, density, location of mass center, and mass moments of inertia. Results acquired using measurements executed on cadavers are questionable, due to different physical characteristics of living and deceased human body, loss of body liquids and body stiffens. The immersion method was introduced to determine subject's segments volume. However, these data have limited application since all of Dempster's subjects were over 50 years of age and underweight. Several efforts are made to replace immersion method with another body volume measurement method. Computational methods is introduced as alternative to the immersion method for determining body volume and mass; modification of that method is used in our work to calculate body volume and mass from 3D model. Reaction board was introduced by Drillis of New York University to measure segments mass without having to separate human body in to segments [1]. Reaction board method uses balance to measure reaction forces of a board while the subject is lying at rest on it. By manipulating position of body segments, change in reaction force is measured and body segment mass calculated. Technique for the determination of segment moments of inertia, based on Newton's Law for rotation also known as Quick release method was also introduced by Drills [1]. Zatsiorsky obtained, by means of a gamma-ray scanning technique, relative body segment masses, center of mass (CM) positions, and radii of gyration for samples of college-aged Caucasian males and females [3]. Although these data are the only available and comprehensive set of inertial parameters regarding young adult Caucasians, data have been rarely utilized for biomechanical analyses. The main reason is that Zatsiorsky used bony landmarks as reference points for locating segment's CM and defining segment lengths. In work [4] de Leva adjusted the mean relative CM positions and radii of gyration reported by Zatsiorsky, in order to reference them to the joint centers or other commonly used landmarks, rather than the original landmarks. The adjustments were based on a number of carefully selected sources of anthropometric data, and are today most representative set of anthropometric data used for biomechanical applications. Magnetic resonance imaging was used as a means of estimating inertial property of a body segments, authors reported that using MRI, results obtained were matching referent data [5]. Dual energy X-ray absorptiometry (DXA) was used in work of Jennifer Durkin [6] to accurately measure the BSP (Body Segment Parameters) of scanned human subjects. Described methods are individualized and precise measurements; their limitation is expensive equipment involved in process and long measurement and processing time. In order to speed up estimation of BSP, generalized anthropometry tables were built based on these measurements [1,7]. By using anthropometry tables and with knowledge of basic information of subject's body (weight and height) anthropometry parameters for each person are calculated. Results are instantly obtained, but are unsatisfactory for biomechanics applications, due to tables that are in generalized form and not prepared for each individual subject. Today's approach to individualized precise garment manufacturing requires correct anthropometry data of every individual, measurement are usually done using highly sophisticated body scanners [8,9,10,11,12,13]. Unfortunately, body scanners are today too expensive for most of biomechanics laboratories, and are only available to the large companies and organizations. Thus, development of system that could estimate anthropometry parameters for each individual, with its complexity and cost placed between generalized anthropometry tables and full body scanners makes sense. Such system is proposed and evaluated in this paper.

2 Human anthropometric parameters

A wide variety of physical measurements are required to describe characteristic of a human body for the needs of today technological developments and applications, especially man-machine interfaces, workspace and individual garment design [14,15]. Most of these needs are satisfied by the simplest linear and volumetric measurements. However, biomechanics analysis of the human movement requires kinetic measurement as well; knowledge of segments masses, moments of inertia and their positions in human body are mandatory. These measurements are, complicated and require vast knowledge of a human anatomy (joints center of rotation, muscle placements, etc). In biomechanics, human body is described as a body composed of rigid segments connected in the joints. Rigid body is assumed to be object that deformations of shape are consider negligible for the current application and can be ignored [14,15,16]. As mentioned in introduction, by most early researchers physical characteristics of body segments are measured, statistically arranged and filled in special prepared anthropometry tables so can be used for fast BSP estimation over the same population. Number of body segments in available anthropometry tables vary between authors and applications [1,4]. For our work we have created a 3D model of a human body, where body was divided in to the 14 segments, as follows: left and right hand, forearm, upper arm, foot, shank, tight; trunk and head + neck segment, as depicted in Fig. 1.

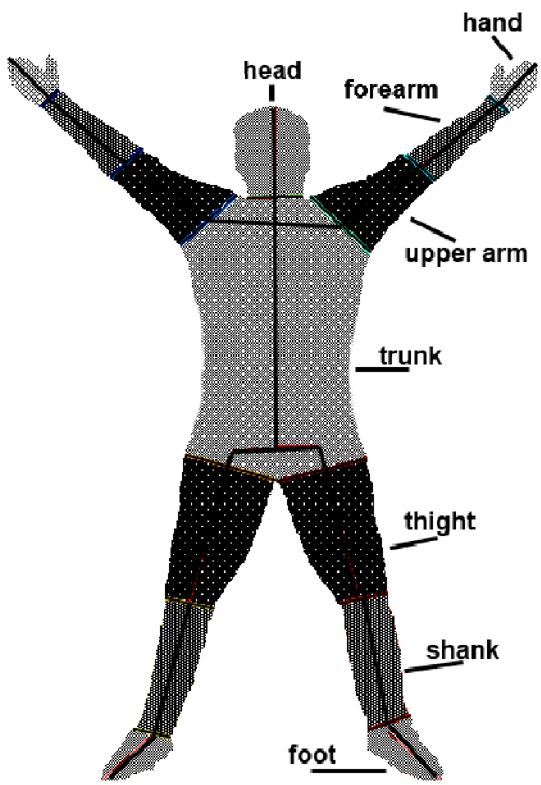


Fig.1, Human body divided into the 14 segments

3 Measurement and methods

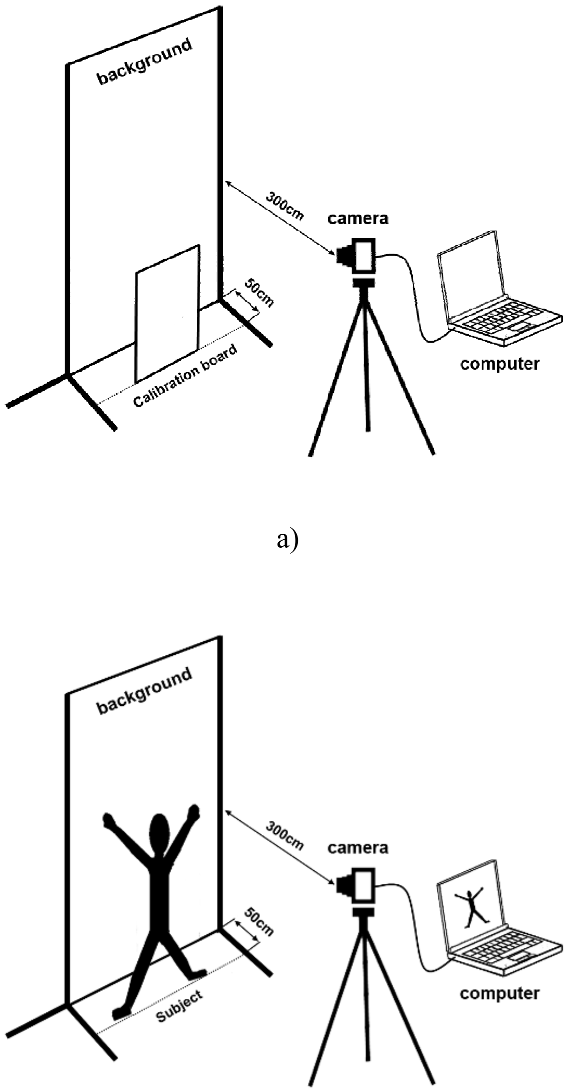
Method of anthropometric measurement proposed in this work is planned to be fast and simple. Simplification of measurement process is made so the examiner with no experience in traditional anthropometric measurements, as mentioned in the introduction, could correctly execute measurements. Results after measurement were individualized and fast-obtained analysis of human body anthropometric values, while still keeping acceptable accuracy. By using digital camera and computer instead of mechanical measuring devices, and computer program that takes care of all calculations and analysis, measurement process is simplified and semi-automated. One of goals of this work was to propose method that requires minimal physical and psychical involvement of the examiner, thus minimizing examiners fatigue that could result in human error. Another benefit of using computer in measurements process is automatic results validation and comparison with their estimated values from model, which is greatly reducing human error and illogical results.

3.1 Measurement equipment

For the measurement process simple setup was required, one small room or area of $10m^2$ is considered as minimum. One vertical surface has to be covered with the uniform color, in order to create background for the Chrome key technique that is in detail explained in section 4.1 [17,18]. To archive uniformly colored background, we used single sheet of a green fabric with dimensions of 250cm x 200cm, large enough to completely cover camera's filed of view, as shown in Fig. 2.b). Fabric used was not professional green background fabric; some considerations explained in next section have to be followed. Camera used was Canon Power shoot A560 digital camera with 7.1 Mpixels sensor, with capability of recording videos of VGA (640 x 480 pixels) resolution at 30 frames per second. Hama Gamma 74 camera tripod was used for correct camera placement in the setup. Personal computer was used for image processing and data analysis, with the following configuration: Core 2 duo processor @ 2.66Ghz, 2GB of RAM, Microsoft Windows XP SP3 operating system. All image processing and data analysis tasks were done on Matlab 2006 software package (Mathworks 2006). Because of use of optical measurement device, area between subject and camera, including the complete cameras sight has to be cleared of any visible obstacles. Another mandatory requirement was adequate lighting conditions required to achieve best possible results with the given equipment. Soft and well placed light sources would create high quality image of subject on camera, without sharp shadows on the background or uneven lighting of a subject. Best result are achieved using professional studio lighting equipment, but even daylight with help of few ceiling neon lights or small reflectors removed shadows and uniformly lighted subject and background.

3.2 Measurement setup

As mentioned in the previous section, one vertical surface was covered with the uniform green fabric using a specially prepared mechanical construction, as shown in Fig. 2.



a)

b)

Fig.2, Measurement setup: a) with the calibration board, b) with the subject

Camera was placed on a tripod about tree meters from the background keeping measurement plane parallel to the camera's image plane. Camera was vertically rotated in order to optimize utilization of a camera sensor.

Before measurement, calibration board was placed on the ground in the vertical position 50cm from the background, as shown in Fig. 2.a). Full explanation of calibration process is given in the section 3.4. After calibration completed, subject was instructed to stand in front of the background in the place where calibration board was placed before. This is important, because calibration is done for only one plane, if subject moves from that plane calibration and all results obtained after are invalid.

3.3 Measurement process

Four different measurements were done on three subjects. First measurements were used for hand, forearm and upper arm segment length estimation while last measurement was used for a body segments volume and mass estimation. In this work, for the purpose of testing and method validation, only anthropometric parameters of hand, forearm, and upper arm were considered. Video of subject's rotational movements was required for the process of determination of body segment's length, which is explained in the section 4.2. Similar procedure was used for the body segments volume estimation, where only one high resolution image was required. Poses and movements of the subject for all four measurements are shown in Fig. 3. During arm length measurement, subject was instructed to stand still, oriented perpendicular to the camera's image plane with his sagittal plane parallel to the image plane. When instructed, subject started to rotate his arm in the shoulder, where all other distal joints were fixed and segments kept in parallel, so the maximum length of linked segments was achieved.

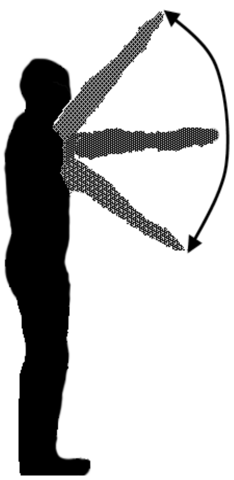
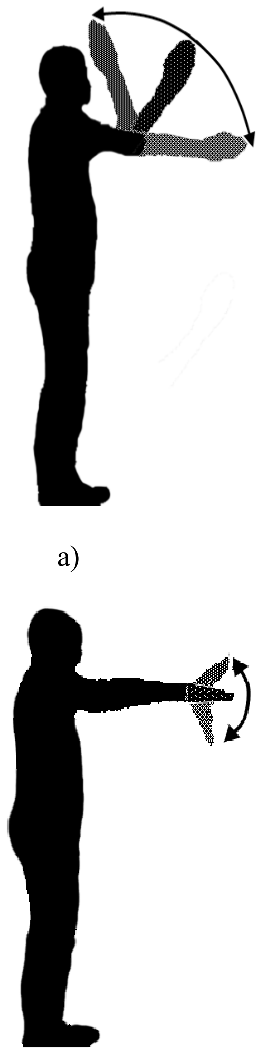


Fig.3, Subject movements during arm length measurement



a)

b)

Fig.4, Subject movements during a) forearm length measurement, b) hand length measurement

Video of described movement was recorded and prepared for analysis. Similar procedure was followed for the forearm and palm length measurement; subject was placed in the same position and similar pose, his arm horizontally extended, as in Fig 4. Subject started to make rotational movements in elbow or wrist; all proximal segments are fixed, while all segments after observed joint were following that joint's rotation. As before, video of that movement was recorded and prepared for analysis. For the last measurement subject was facing camera with his frontal plane, placed as before but in slightly different pose. Subject was instructed to copy pose of Leonardo's Vitruvian man, with his legs and arms extended as shown in Fig. 1. In this pose, good distinguishing of limbs from body trunk is achieved which would simplify image processing algorithm that is dealing with detection and separation of body segments.

3.4 Camera calibration

In order to obtain accurate results, some camera and setup properties have to be considered. Precisely positioning of camera in setup, with its image plane parallel to the background plane is difficult task. Also, slight misalignment of camera with horizontal plane has to be considered too. To deal with the mentioned problems, camera has to be calibrated using one of the camera calibration techniques [19]. For process of calibration we used simple calibration board with the size of 60 cm width and 80 cm height. Board was placed in the vertical position, parallel and 50cm distant from the background plane, as shown in Fig. 2.a). With camera set up and fixed in desired position, in which will remain till end of the measurement process, one image of background with calibration board was taken. Goal of calibration process was to eliminate geometric distortion caused by the imperfect camera setup and to transform image with undefined pixel information to the image where position of each pixel in known in coordinate system, and described by metric system. Calibration process was done using technique based on Projective transformation. Projective transformation is a linear transformation on homogenous 3-vectors represented by a non-singular matrix (1)

$$\begin{pmatrix} x_1' \\ x_2' \\ x_3' \end{pmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} \quad (1)$$

Or in short (2)

$$x' = Hx \quad (2)$$

Position of minimum four selected points on image is required to be compared with their real positions in local coordinate system, that four points are edges of our calibration board [20,21]. Algorithm is capable of calculating transformation matrix, which transforms all pixels from original image to calibrated transformed image, where every pixel in final image is equal of 0.2mm in size and that image could be used for size measurements. Calculated calibration matrix is valid for all images that were taken in the same camera setup, if camera or measurement plane moves, calibration is invalid.

4 Image processing and analysis

Video and image measurement data were obtained using digital camera. Video data was edited using VirtualDub video editing software, while only sequences of interesting movements were extracted and prepared for future analysis. Goal of image processing part used in this work is to extract subject's silhouette with the highest quality possible from the background with the given equipment. Extracted silhouette will be used in future analysis procedures as the only input data required for obtaining body anthropometry parameters.

4.1 Chrome key technique

As a backbone for our image processing procedure, chrome key technique was used. Chrome key technique is well known and simple technique used for the years in the 7.th art for object extraction from video sequence in specially prepared conditions [17]. Technique is based on distinguishing objects color data from the background's color data which is known and not changing during sequences. Technique presumes that object is colored differently, if possible complementary to the background color. Best and today commonly used solution is to use green background color, Bayer Masks in CCD sensors uses two green pixels while only one blue and red pixel is used allowing better representation of green colored objects in image.

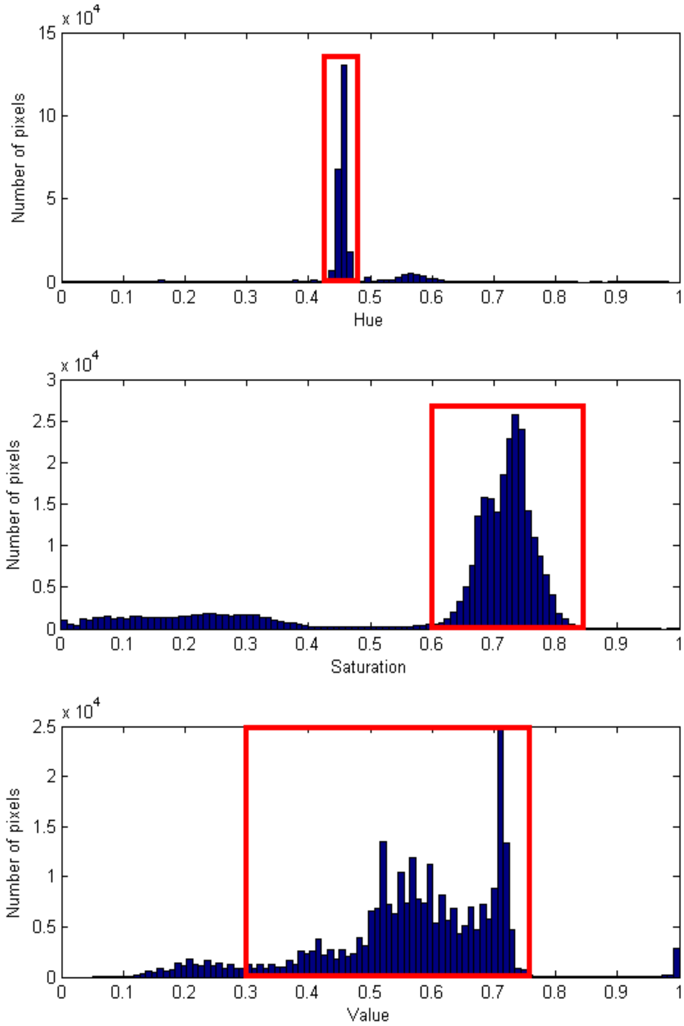


Fig.5, Image's Hue, Saturation and Value histograms.

Original video frame was represented in RGB (Red Green Blue) color space by array of pixels, where each pixel, green, red, and blue respectively, can take one value in range [0-255]. Image was then transformed from RGB to HSV (Hue Saturation Value) color space, which is more powerful in describing variations of a single color (hue), [12]. Background's HSV values were obtained by analyzing image's histograms, while image used for this process could be any one from original video sequence. In Fig.5 are shown histograms for image's Hue, Saturation and Value with marked values for background pixels. It is clearly visible form the first image that background pixels could be easily detected by using only image's Hue channel, where histogram for background pixels is most narrow. In contrary, histogram of image's Value channel has more uniform distribution and could not be used for efficiently detection of background pixels. Saturation channel is not informative enough to be solely used for background detection, but algorithm that uses both Saturation and Hue channels in its process showed satisfactory results. Range of background HSV values, in histograms represented with windows must be chosen carefully to cope with problems that could arise during measurements. Changing lighting conditions during longer measurement and shadows on background with darker values as the background are most common, but other problems like imperfections of background material (e.g. fabric perforations) exists and must be considered. As explained in section 3.4, all frames were transformed in perspective so that all pixels match with their real values in measurement plane. Next step was to remove all background pixels from the original frame, subject's silhouette and small number of non-background pixels was left after removal. All remaining objects, including noise were indexed and counted for number of containing pixels, largest of them all was a subject's image. Extracted object was then binarsed and using operations of binary image enhancement, small imperfections of binary image were repaired. Finally, binary image of subject obtained this way was prepared for future analysis.

4.2 Segments length estimation

Our method of estimation of body segments lengths is based on analysis of a short video sequence. As mentioned in section 3.3 short sequence of rotational movements for each analyzed segment were recorded. As only information of moving body part is required for our analysis, still body parts have to be removed from original frames. This is achieved by analyzing all video frames obtained in section 4.1, all pixels with value 1 (binary image) during video sequence are presumed to be part of subjects still body parts (e.g. Trunk) and are removed (value 0) from all frames. Result of this process is a series of binary images containing motion of subjects moving body segments. Next step is to estimate position of joint about which rotational movements was preformed. This is achieved by analysis of subject's silhouette; position of joint in image obtained in this way is imprecise estimation required for future process of precise joint position calculation. All frames were analyzed again and searched for most distal point in each frame, where distance from estimated joint position and endpoint is greatest. That endpoint is in fact (e.g. for arm movements) tip of the middle finger, while positions of all endpoints during recorded video sequence create form of a half-circle as shown Fig. 6.

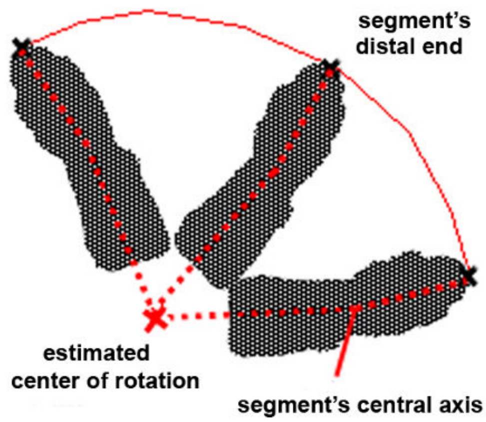


Fig.6, Center of rotation (joint center) of a moving body segment

Using circle points as a input data it is possible to precisely calculate center and radius using circle fitting technique by minimizing error described in equation (3) [20,21].

$$E(a,b,r)=\sum_i\left((x_i-a)^2+(y_i-b)^2-r^2\right) \qquad (3)$$

Where (a,b) is estimated circle center, (x_i, y_i) are circle points, and r is circle radius.

Circle origin obtained in that way is in fact position of center of rotation in joint, while radius is length of rotating segment. Repeating this process for each segment, as explained in section 3.3, all segments lengths are finally estimated.

4.3 Body segmentation

Input information for process of dividing subject's body in to the segments is single high resolution image of subject in Vitruvian man pose, as shown in Fig. 1, and segments lengths estimated by method described in previous section. High resolution image (7.1 Mpix) was used in stead of a VGA resolution image, in order to extract hi-quality subject silhouette that was used in later process of volumisation and creation of a segment's 3D model. Process of extraction of a subject from the background is similar as described in section 4.2, with the difference of larger input image size and consequently larger masks used for performing binary image enhancements operations. Next step is to search for five most distal points of subject's silhouette that are in fact endpoints of subject's extremities (middle finger of both hands and foot) and vertex. We have developed an algorithm for scanning and extracting subject's segments explained as follows: Each extremity was scanned starting from its endpoint trough the trunk with scanning line perpendicular to the extremity central axis, which was previously obtained using process of binary image skeletisation. After desired length of scanned segment was reached, scanned segment was extracted and process continues for next segment until trunk is reached, as shown in Fig.7, Only remaining object, after all extremities were extracted and removed from input image, was subject's trunk, in our work assumed to be rigid body segment and not further divided.

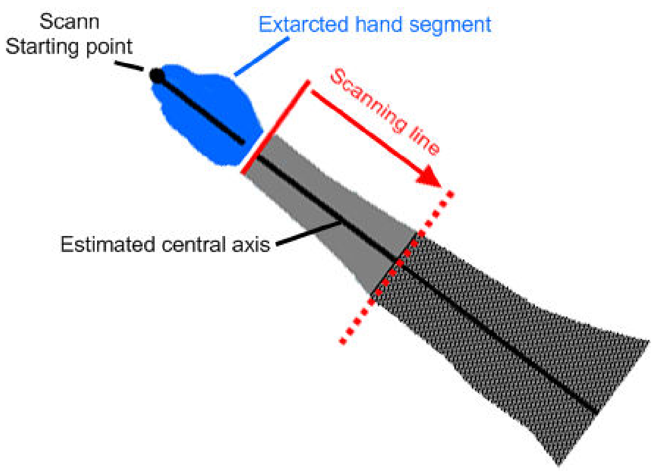


Fig.7, Segment scanning procedure

4.4 Calculation of segments volume and mass

In this work we assumed that segments of human body are homogenous bodies with constant density factor. Densities of body segment used in our work are taken from the literature and shown in Table 1. [1,7]. As all other surface scanning techniques, our technique do not have possibility to insight of segments mass and mass distributions, so mass of segments have to be calculated by multiplying segments volume with its density factor.

Table 1, Body segments density [7].

Segment	Density [kg/m^3]
Hand	1.16
Forearm	1.13
Upper Arm	1.07
Foot	1.10
Leg	1.09
Tight	1.05
Trunk	1.03
Head and Neck	1.11

As 3D computer model of body segment was used, final volume is expressed in number of volume elements called voxels, each 0.2 x 0.2 x 0.2 cm in size, as shown in equation (4)

$$m = V \cdot \rho$$
$$m = (0.2)^3 \cdot \rho \sum_i vox_i \qquad (4)$$

It is a difficulty to precisely estimate volume of a body from single 2D image, we have to devise an algorithm that would create 3D model of every body segment based only on a 2D input image with few assumptions that are described. It is common in computer added 3D modeling to describe 3D object by a series of geometric objects connected together and creating one large rigid object, Fig 8.

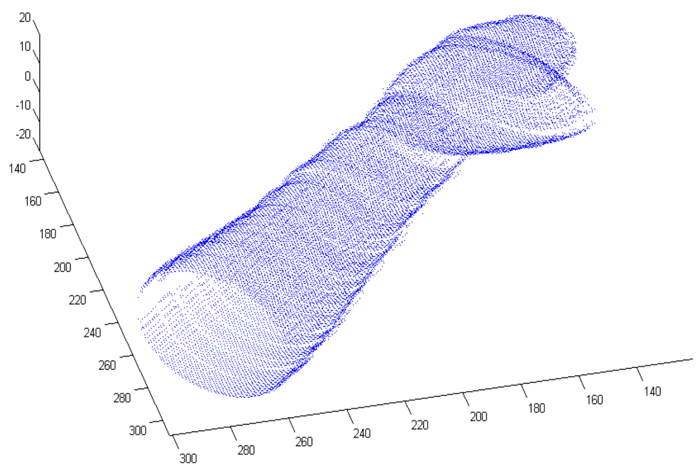


Fig.8, Hand and forearm modeled by series of ellipses

As basic building blocks for our model simple ellipses of different sizes and ratios were chosen. In our work, we presume that every body segment can be simply described as modification of an elliptical tube, where ratios of longer and shorter side of ellipse in tube's cross section is constant, but absolute size of ellipse can vary during tube's length [13, 22]. Ratios of ellipses shorter and longer side are in fact body segments height and widths are presumed to be constant for each segment of one population and are obtained experimentally. With the lack of any 3D measurement equipment this approach was essential in order to create approximate and personalized 3D model of a human body. Our method of segment volumisation is based on rule that a cross section of 3D body segment is equal with its 2D representation on which our 3D model is based.

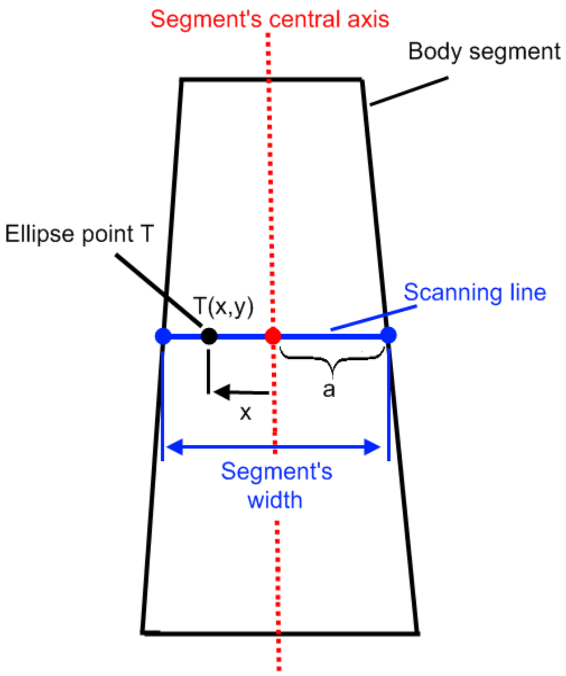


Fig.9, Top view of segments during scanning

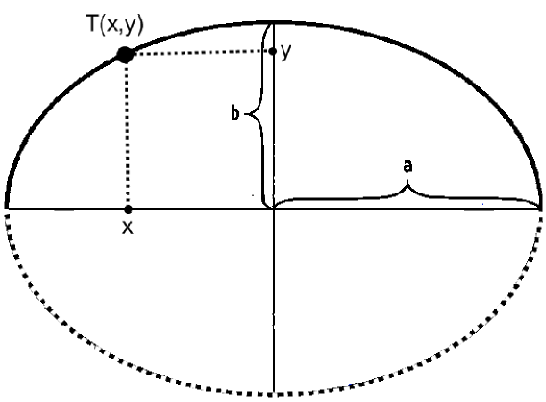


Fig.10, Ellipse as fundamental modeling object of our human 3D model

Segment that was extracted by methods described in section 4.3, its 3D image is rotated so that its longest side (segment's length) is parallel to the vertical axis. Rotated image is than analyzed by our algorithm, as described as follows: Procedure is similar as in section 4.2, segment is scanned with horizontal scanning lines perpendicular to the estimated segments central axis.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad (5)$$

$$y = b\sqrt{1 - \left(\frac{x}{a}\right)^2} \qquad (6)$$

Scanning lines could be described as top-view of our ellipses so the length of a line in every point of central axis (for every scanning line) between segments edges is equal with segment's width at given section, Fig 9. Ellipses describing our 3D model and shown in Fig. 10, are following ellipse equation (5), where x is distance between any point of scanning line and central axis and value y is calculated value and represents segment's height in a given point (6). Resulting object created with described procedure in one scanning line is half-ellipse, where full ellipse is created by simple horizontally mirroring half ellipse. Volume of our body segment is calculated by summing all voxels inside shell defined by ellipses. Finally, segments mass is calculated as described in beginning of this section, by multiplying segment's volume and density factor.

5 Results and discussion

In this section, results of an anthropometric measurement and estimation are shown, compared with other available methods, and discussed. Lengths of body segment were measured by most traditional method, using tape meter. Definitions of segment beginnings and endings and definitions of body key points required to correctly measure body segments length are found in the literature [4]. Manual measurements using a tape meter is considered to be most accurate and thus used as a referent measurement in this work. As mentioned in the introduction, manual measurement of body segments parameters has better repeatability than any other non-manual and automated measurement [5,6]. Second measurement was done using generalized anthropometry tables, where subject's height was used as the only input data in process. Segments lengths were calculated by multiplying full body height with segments length coefficients prepared in anthropometry tables [1,7]. Results of measurements and estimation by these two methods were then compared with our Computer Vision method, fully described in this work. All measurements shown in following comparison table were preformed on three healthy subjects, two males aged 24 (Subject 1) and 27 (Subject 2) and one female aged 24 (Subject 3) years. All subjects were Caucasian.

Table 2, Comparison of the results obtained by different methods

Length of the segment

	Body segemnts	Measured by meter	Anthrop. tables	Comp. vision
Sub. 1	Hand	20.0 cm	19.5 cm	19.5cm
	Forearm	28.0 cm	27.5 cm	26.5cm
	Upper arm	30.0 cm	34.0 cm	30.5cm
	Whole arm	78.0 cm	81.0 cm	76.5cm
Sub. 2	Hand	18.5 cm	19.0 cm	17.5cm
	Forearm	25.0 cm	25.5 cm	25.5cm
	Upper arm	29.0 cm	32.5 cm	27.0cm
	Whole arm	72.5 cm	77.0 cm	70.0cm
Sub. 3	Hand	18.0 cm	19.5 cm	18.5cm
	Forearm	28.0 cm	26.5 cm	24,5cm
	Upper arm	29.0 cm	33.5 cm	33.5cm
	Whole arm	75.0 cm	79.5 cm	76.5cm

Results from Table 2 showed that measurement using our CV system in 9 of 12 cases have similar or better results than results obtained using Anthropometry tables. In Table 2, method that was closer to the referent manual measurement is grayed, if both methods showed same results, both areas in the table are grayed. Experience during measurement showed us that even a small anomaly while making the predescribed rotational movements with body segments could result in a bad and false calculation of segments length. Small flexion of a joint that is assumed to be fixed during measurement could affect measurement results by dramatically reducing linked segments length. With this problem is mostly affected measurement of proximal segments length, where one or more distal segments are linked and could cause problems if not correctly fixed. This problem could be assisted by adding one or more cameras, if placed correctly in the scene would be able to detect unwanted flexion in joint, and recalculate correct segments length. Similar problem could occur, in this case result with overestimation of the segments length if complex joint are considered. On example, complex joints as shoulder is modeled as a simple 1DOF joint, while it is obviously that shoulder has more than one DOF. Small preparations of an algorithm are needed in order to detect unwanted joint movements, if detected measurement has to be repeated. As addition, rotational movements around shoulder joints were preformed in sagittal plane, and with limited range of rotation, that result in reduced error. In work [1] subject was fixed to the table while making rotational movements, this procedure complicates measurement and is in contrariety to our idea of a fast and simple measurement.

For the needs of our work, accurate measurement of a body segments masses could not be obtained with ease. As mentioned in introduction, body mass measurements are complicated procedures that require expensive and complicated equipment. Thus, as referent data for this work, data available from the anthropometry table were used. Segment mass coefficients obtained by our method were compared in Table 3 with anthropometry data [1,7]

Table 3, Comparison of a mass coefficients obtained by Anthropometry tables [7], and Computer Vision system

	$\frac{segment\ mass}{subject\ mass}$	
	Antroph. table [3]	Comp. Vision
Hand	0.006	0.006
Forearm	0.016	0.017
Upper arm	0.028	0.030
Foot	0.061	0.010
Leg	0.046	0.048
Tight	0.100	0.119
Head + neck	0.081	0.063
Trunk	0.497	0.495

Table 3 validate most of our results, grayed areas in table represent data that are comparable with referent anthropometry data. These results should be taken with a reserve, because even anthropometry tables' data were not individualized and could be invalid for particular subject. Estimations of foot and head + neck segment volume and mass using our 2D CV method showed bad and incomparable results. During measurement, subject foot was not orientated completely parallel to the measurement plane, thus correct volume estimation from single 2D image without adaptation in algorithm is difficult. In work of De Leva [4] foot segment was not considered because of similar problems in mass estimations. Another problem exists in estimating head volume, irregular shaped human head cannot be easy modeled by series of ellipses with constant ratios, and in this case some improvements of algorithm should be considered.

6 Conclusion

Method proposed and evaluated in this work showed to be promising, especially in situations where the fast measurement over large number of subjects is required.

As mentioned in introduction and results section, manual measurement using mechanical devices are more accurate with better repeatability and were used as a referent for segment length measurement comparison, but with great disadvantage of slow measuring time and complicated measurement. When compared with method that uses generalized anthropometry tables, results obtained using our CV method were better personalized thus showed to be promising for biomechanical applications. Problem of measuring foot and head + neck segment arise, to cope with this problem we propose modification of our method, where results obtained using CV will be checked with body model, an if considerable between expected and calculated data occurs, generalized anthropometry data will be used in stead of a calculated data. Another proposition would be use of one or more additional cameras that would offer better 3D model of a subject's body with depth perception. We assume that with less assumed data and more real measured data, calculation would give better results, and comparable to the results offered by the full body surface scanners.

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