

## ON THE SEGMENTATION OF SCANNED 3D HUMAN BODY MODELS

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Analysing the human body in three-dimensional (3D) space is becoming more and more popular due to the large number of available 3D scanning solutions. Using 3D body models enables detection of many different body parameters which cannot be assessed using 2D images only. Once a 3D body model is generated, it is usually segmented so that specific body parts can be further analysed. In this paper we propose a new approach to the segmentation of the human body. Our anthropometry-based approach can successfully segment various body-types into six main segments – head, torso, left and right arm, and left and right leg. The proposed method has been tested successfully on standard benchmark models and on 3D point cloud data acquired from a low-cost 3D scanner.

**Key words:** *anthropometry, human body segmentation, SL scanning system*

### Introduction

Advances in 3D scanning technologies for the purpose of creating a human 3D body model give us the possibility of analysing the human body in its true three-dimensional form. Observing all three dimensions, instead of only two, enables better automatic anthropometric measurements, detection of changes in the body shape, pose estimation, etc.

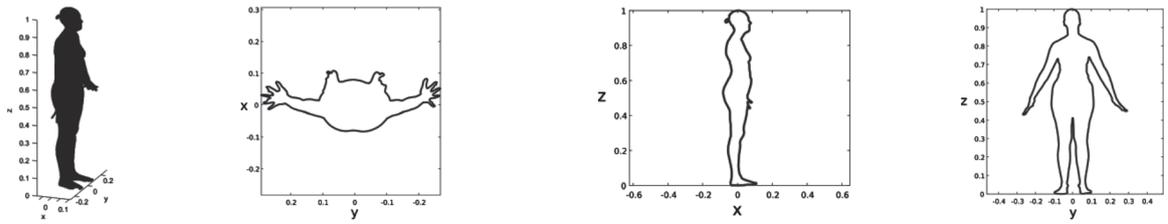
Several types of imaging techniques can be used in 3D full body scanning systems. The most popular are laser line (LL) and structured light (SL) systems, but multi-view camera systems and millimetre waves are also used in specific cases (Daanen and Ter Haar, 2013). LL scanners and SL scanners can both give an accurate and dense 3D reconstruction, but laser-based scanning time is usually above ten seconds while SL systems (the approach we used) can acquire data in only a few seconds, depending on the system setup (Petković et al., 2016). The shorter data acquisition time is advantageous for individuals who have difficulty in standing still. Often 3D full body scanners are used for anthropometric measurements which may be used in a wide range of applications, for example in medicine (Giachetti et al., 2015), sport (Daanen et al., 2016), and in the garment industry (JoonWoo et al., 2014). The scanners also have applications in kinematic movement analysis (Mahnić et al., 2014). In many of these applications the measurements must be on specific parts of the human body and thus the acquired data must be segmented into the different body parts.

There are two main approaches in human body segmentation (Werghi, 2007). The first approach is for segmentation of the body in an arbitrary posture and is usually done using feature extraction techniques, clustering or fuzzy logic. The second approach deals with models in a standing position with arms and legs slightly separated from the body, and here the segmentation is usually based on anthropometric information and/or topological analysis.

In this paper we use the second approach. We first explain our method of segmentation and then we apply it to some standard benchmark human body models downloaded from the internet. Subsequently we apply our method to data acquired using our own low-cost SL-based 3D scanning system.

### Methods

We propose an approach that segments the human body into six body parts – head, torso, left arm, right arm, left leg and right leg – and which is based on the analysis of the anthropometric body characteristics. Due to a possible misalignment of the scanning system and the scanned human body, the first step is aligning the 3D model with an appropriate coordinate system using the first three principal component vectors calculated using PCA (principal component analysis) of the point cloud. A coordinate system aligned with these vectors is chosen such that the x-axis is positive running from posterior to anterior, the y-axis from right hand to left hand, and the z-axis from the feet to the head. The origin of the coordinate system is on the horizontal plane through the soles of the feet (the lowest point of the body) and at a point directly below the centre of mass of the body. The model is isotropically scaled so the maximum height is normalized to 1 (Fig. 1a). Then the body can be divided into the required sections by employing anthropometric knowledge about ratios of body parts and total height. In the segmentation process we use body projections in 2D planes (Fig. 1b-d) but we combine those 2D projections to obtain the final segmentation in 3D space.



(a) 3D body model (b) yx-plane projection (c) xz-plane projection (d) yz-plane projection

Figure 1: Human body model in the chosen coordinate system (a) and contours of its 2D projections (b-d).

The head is segmented in the yz-plane. We modified the approach used by Wen et al. (2012). We observe the top 25% of the body, i.e. the interval  $z=[0.75,1]$  on the normalized model in the chosen coordinate system. By taking a horizontal cross-section at  $z=0.95$  of the body contour in the yz-projection plane, two auxiliary points on the head section are created: *TR* (top-right) and *TL* (top-left) as shown in Fig. 2. Points *TR* and *TL* are connected to another set of auxiliary points (*BR* and *BL*) which are located as the lowest points of the observed contour section. The neck points (*NR* and *NL*) which are used to segment the head and neck from the rest of the body are determined as the contour points that are farthest (in the corresponding body side) from the *TR-BR* and *TL-BL* lines respectively. Approximations of the acromion points (*AR* and *AL*) are determined as the points that are farthest (in the corresponding body side) from the *BR-NR* and *BL-NL* lines respectively. These approximations of the acromion points will be used later for the separation of the arms from the torso.

The armpit points are detected in the yz-plane projection following the approach proposed by Wen et al. (2012). For the complete segmentation of the arms we propose using yx-projections of the body to define segmentation lines that separate the arms from the torso. Starting from the contour slice at  $z=0.9$  and using a slice step  $\Delta z=-0.005$ , we analyse the contours of each slice between  $z=0.9$  and  $z=0.35$ . Let  $c(x, y)$  be the contour function of the observed slice. We propose using an indicator function ( $y$ ):  $f(y) = \begin{cases} 1, & \exists x \ c(x,y) = 1 \\ 0, & \text{otherwise} \end{cases}$ . The section of the indicator function that is equal to zero is the section where the arm is separated from the torso. The middle point of that section is used as the “arm separation point” at the observed slice. Final lines that separate the arms from the torso are the lines that connect arm separation points for each arm across all observed slices combined with the lines that connect the armpit points and the acromion points (Fig. 3).

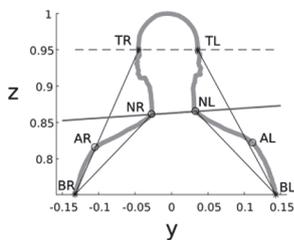


Figure 2: Segmentation of the head from the torso.

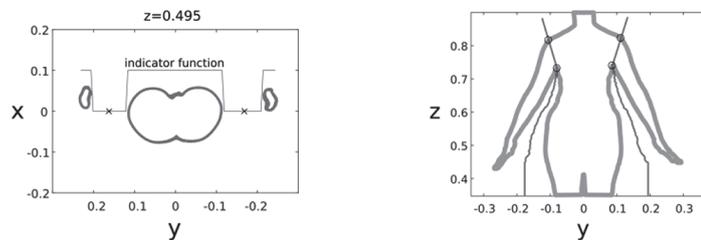


Figure 3: Segmentation of arms. Left: An example of the indicator function. Right: Final segmentation of arms.

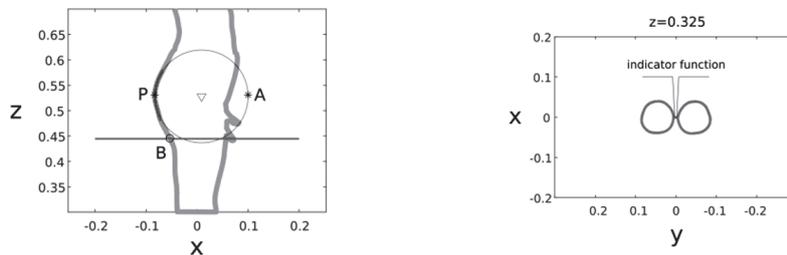


Figure 4: Segmentation of legs using analyses in the (a) xz-projection plane and in the (b) yx-projection plane.

Segmentation of the legs is carried out by analysing xz- and yx-projection planes of the body segment in the interval  $z=[0.3,0.7]$  (Fig. 4a). In the xz-projection plane the legs are separated from the torso using the modified approach of Wen et al. (2012): first the most protuberant posterior point (*P*) on the contour is located and then a circle is fitted through a set of its neighbouring points (in the interval  $\pm 5\%$  of body height from the point *P*), using the least mean squares method. On the fitted circle, we create a virtual anterior point *A* such that  $(\overline{AP})$  is the circle diameter. All contour points below the point *P* are candidates for the final segmentation point that separates legs from the torso. We search for the point that represents the lowest point of the bottom. It, (point *B*), can be found as the point on the outline that is below point *P* and is

closest to the virtual point  $A$  on the fitted circle. For the separation of the left and the right leg we again propose using an indicator function  $f$  and projections of the body slices in the  $yx$ -projection plane. The indicator function can be considered a code word if we replace all consecutive repeating zeros with the code '0', and all consecutive repeating ones with the code '1'. The code word is then evaluated, starting from the slice at  $z=0.7$  where the code word is '10101' (because arms are separated from the torso due to the required standing position) and moving downwards using a slice step  $\Delta z=-0.005$ , until the indicator function eventually gives a code word of '101'. The midpoint of the first section where the code word of the indicator function becomes '101' represents the crotch point. By combining the separation points in the  $xz$ - and  $yx$ -projection planes, 3D planes for the separation of the legs from the torso are determined.

## Results

We first tested the proposed segmentation method on seven models from the 3D mesh segmentation benchmark (Chen et al., 2009) which met the requirement for an upright standing posture with arms and legs slightly apart. Fig. 5 shows that the segmentation for all seven models was successful.

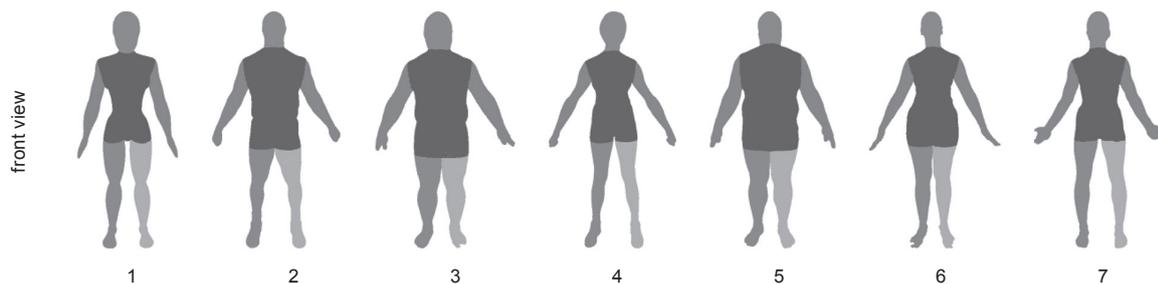


Figure 5: Front views of seven successfully segmented models from the (Chen et al., 2009) benchmark.

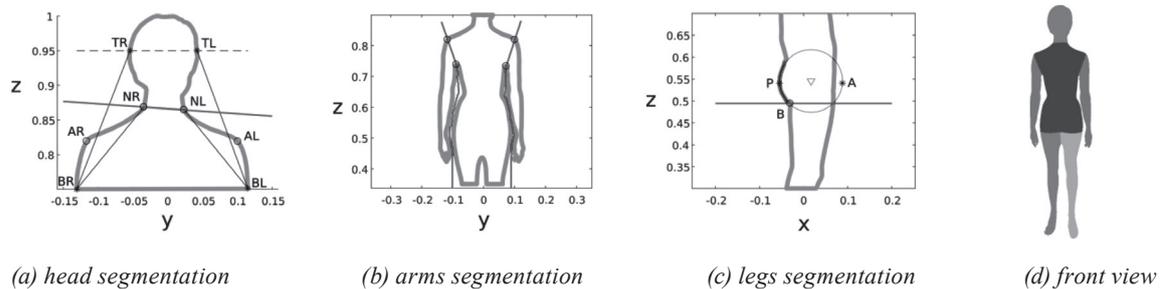


Figure 6: An example of the body segmentation for the mannequin model reconstructed using SL system (a-c) and the final segmentation from the front view (d).

We then used a SL system as a low-cost 3D scanning solution for obtaining a 3D reconstruction of a mannequin. Such a system requires only a projector and a camera which are calibrated. The projector shines a coded pattern onto the object surface and that projection is captured using the camera. After decoding the pattern on the captured image (or images), a triangulation method is used for computing 3D positions of the surface. In this work, we used a time multiplexing SL strategy using a pattern that is a combination of sinusoidal fringes and Gray code. This approach is a good choice when the object of interest is static and a dense 3D reconstruction is required. Our SL system is comprised of a DLP projector (Acer S1383WHne) and two cameras (PointGray Grasshopper3 23S6C) with Kowa LM8JCM lenses. The projector and cameras were mounted on a vertical pole with the top camera capturing the upper body, and the bottom camera the lower body. We were limited to only one scanning pole but by moving the pole around the mannequin and taking multiple scans, we obtained a full 3D body scan. The acquired point cloud was post-processed; it was first filtered in order to remove outliers and background points and then a Poisson surface reconstruction using MeshLab (Cignoni et al., 2008) was performed to ensure a uniform quality and point density. This data was then successfully segmented using our developed method. Fig. 6 shows the main segmentation steps (a-c) and the resulting body segmentation (d) of the reconstructed 3D mannequin model.

## Discussion

The proposed approach for the body segmentation is based on analysis of the 3D body model using a basic a-priori anthropometric knowledge of the human body. Our method uses anthropometric information to determine which part

of the full 3D body model (i.e. which intervals of the  $z$ -axis) should be analysed in order to segment a head, torso, arms and legs. Those intervals are chosen to be rather wide but even so the segmentation remained successful. Figs. 5 and 6 demonstrate that the proposed segmentation is successful for various body types, both on standard benchmark models and on data acquired with a low-cost scanner. A drawback of our approach is its sensitivity to outliers and the quality of the 3D reconstruction. This problem is usually avoided by using a high quality scanner, a good filtering and an adequate mesh (or point cloud) reconstruction. Some approaches (Han and Nam, 2011) successfully deal with the problem and correct the detected feature points (such as crotch and armpit points), if necessary, by conducting additional analysis and considering other shape characteristics of the arms and legs. Successful body segmentation allows further body analysis to be performed – segmented arms or legs can be individually used to calculate muscle circumference; a torso can be used to compute the waist circumference, or to analyse back shape and posture as shown in Figure 7.

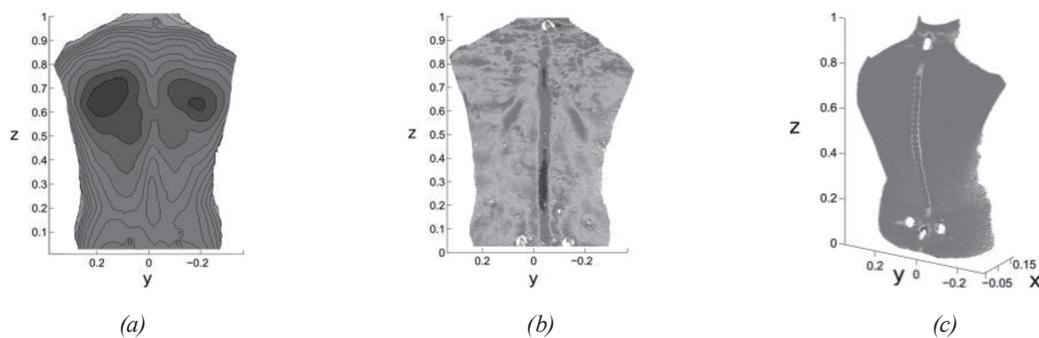


Figure 7: An example of the back shape analysis using a segmented torso. (a) Posterior torso depth map. (b) Back shape curvature analysis (mean curvature). (c) Detection of the spinal midline.

## Conclusion

In this paper we have presented an approach to 3D human body segmentation based on anthropometric information in order to segment a full 3D body model into six parts: head, torso, left and right arm, and left and right leg. We have shown that the proposed method successfully segments various body-types as long as the person is in standing position with arms and legs slightly separated. Also we have shown that there is no need for expensive LL scanners which are often used in the garment industry; a simple SL system using off-the-shelf components gives accurate and adequate 3D body reconstructions which can also be successfully segmented. After this basic body segmentation step, segmented parts can additionally be used for more detailed segmentation or for specific body-part analysis.

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