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# Anthropometric body modeling based on orthogonal-view images

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## ABSTRACT

This paper presents an efficient and convenient method for creating an anthropometric model of a real person. First, 3D surface body models based on orthogonal-view photographs are reconstructed, and then skeletal systems for the reconstructed models are matched. A total of 26 anthropometric data items are measured using the surface and skeletal models. Some anthropometric data are measured directly on the deformed surface models, whereas others are estimated from the matched skeletal systems by kinematic analysis. A comparison of the anthropometric data from the reconstructed model with data from the corresponding real person demonstrates that the methodology proposed in this paper has high efficiency and precision. These models will satisfy consumer demand for higher product personalization and therefore product comfort, and they are likely to be widely used in future ergonomic research.

*Relevance to industry:* A convenient and efficient method to create individual anthropometric models is proposed. These models will help people create their own anthropometry databases and satisfy their demand for higher product personalization and therefore product comfort. The industrial applications include mass customization, computer-aided drafting, online custom-made design, and ergonomic evaluation.

## 1. Introduction

An anthropometric model is a digital human model (DHM) built on anthropometric data measured under defined poses. Such models are used to analyze the ergonomic performance of a proposed product (Duffy, 2009; You and Ryu, 2005). Current ergonomic software packages, such as JACK (Demirel, 2006), ErgoForms (Dreyfuss, 2001) and PeopleSize 2000, are based on statistical descriptions of human variability and lack the ability to build models for specific individuals. With the increasing popularity of ordering custom-made products via online shopping, people are paying more attention to the usability of a product for themselves. Therefore, a single convenient method for creating individual anthropometric models and helping customers measure their own body size has broad applications in the fields of internet shopping, virtual try-on systems, industrial design, and healthcare.

Anthropometry modeling methods are classified from scanners and photographs. Allen et al.(Allen et al., 2002, 2003) created a static and dynamic model using a point cloud and sparse marks with a 3D body scanner. Baek et al. (Baek and Lee, 2012) extracted anthropometric data from a real person using a range scan, deformed the template model using these data, and then reconstructed the 3D detailed model. In the research of Thomassey and Bruniaux, a reverse methodology using scans of a reference body and garment enabled the evaluation of the overall 3D ease of the garment (Thomassey and Bruniaux, 2013).

The 3D whole-body scanning method is the most accurate method for obtaining body shape information, but the technology is highly complex and difficult for the typical customer to understand (Nadadur and Parkinson, 2013). A feasible solution to this problem is for customers to create their own 3D models from 2D photographs. Hilton et al. and Lee et al. reported a robust method for establishing a model of an individual person with orthogonal photographs (Hilton et al., 1999; Lee et al., 2000; Magnenat-Thalmann et al., 2011; Zhu et al., 2013). They extracted the silhouettes from 2D images and deformed the 3D unified models by adding this detailed information. Free-form deformation (FFD) is the deformation algorithm currently used to morph DHMs because

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it can retain the continuity and characteristics of the human body (Kasap and Magnenat-Thalmann, 2007). Zhu et al. (Zhu et al., 2013) adopted a new deformation algorithm-composite triangle (CT) FFD that can minimize distortion and closely resemble the geometrical shape of the control mesh. However, compared to the scanning method, orthogonal modeling has a lower accuracy and lower fidelity of detail simulation (Simmons and Istook, 2003). Therefore, in the present paper, the global and local deformation methods are adopted sequentially to improve accuracy. Our modeling method aims to model a specific person and not a statistical crowd. Then, a skeletal system is matched to each deformed model, and anthropometric data are measured from these models to enable the construction of a large-scale ergonomic database.

## 2. 3D digital human body modeling

### 2.1. Defining characteristic points

To determine the relationship between the 2D images and 3D surface model, the characteristic points must first be defined. Consider the frontal view images of the photograph in Fig. 1 as an example, which show binary image processing (Gabarra and Tabbone, 2005) and silhouette extraction. Such images must be taken under the conditions of a simple background, even lighting and form-fitting clothing. The focal plane must be parallel to the coronal or sagittal plane as accurately as possible when taking the front and side photographs.

For 2D body silhouettes, the characteristic points include three types of points: extreme, primary and secondary. There are seven extreme points in the extracted 2D silhouettes: five in the front picture and two in the side picture. These are denoted with triangular symbols in Fig. 2(a) and (b) and are the maximum or minimum points along two axis directions on the 2D silhouettes.

The primary and secondary characteristic points are used to determine the segmentation of the human body. Except for the crotch point, their positions can be determined by referring to the standard body proportion of Chinese adults (GB, 1988). The primary points, denoted with x symbols in Fig. 2(a) and (b), divide the body into six parts: the head, left and right legs (including feet), left and right arms (including hands) and trunk. The secondary characteristic points, denoted with circular symbols, belong to and subdivide one part of body. For example, a leg can be divided into the thigh, calf and foot according to the secondary points. For the trunk, the secondary points define the breadth and depth of the bust, waist and hip in the front and side silhouettes of the body. Because the silhouettes of the arm are surrounded by the body's silhouette in side silhouettes, the secondary points of the arm are limited to the frontal projection.

To obtain the 3D individual model, the method adopted here deforms the template model. The template (Fig. 2(c)) is a surface model composed of triangle meshes and is divided into six parts, similar to Fig. 2(a) and (b). For the convenience of description, the silhouettes (Fig. 1(c)) from the 2D photographs are named $R2$, the silhouettes (Fig. 2(a) and (b)) from the 2D front and side projection of the 3D template are named $T2$, the 3D template model (Fig. 2(c)) is named $T3$, and the final 3D model of the real person is named $R3$.

### 2.2. Deformation of DHM

#### 2.2.1. Free-form deformation

In 1986, Sederberg and Parry (Sederberg and Parry, 1986) presented the FFD method, which uses the basic concept of embedding the object to be transformed into a frame with many lattices. With the action of the outer forces on the frame but not the object, the control frame produces deformation, and this deformation will pass to the object. FFD has the advantage of maintaining the continuity of closed surfaces after deformation. If $l$, $m$ and $n$ are the numbers of subdivisions along each of the three directions, $S$, $T$ and $U$, $l+1$, $m+1$ and $n+1$ are the numbers of control planes in the three coordinate directions, respectively, and $(l+1)\times(m+1)\times(n+1)$ is the number of control points. As shown in Fig. 3, the lattice is divided into 2 parts in three directions such that $l=m=n=2$. In total, there are 27 control points (black filled circles in Fig. 3).

Mathematically, the FFD is defined in terms of a tensor product tri-variate Bernstein polynomial. To impose a grid of control points $P_{ijk}$ on the parallelepiped, the deformation is specified by moving $P_{ijk}$ from their lattice positions. $P_{ijk}$ can be represented by Equation (1) as follows:

$$P_{ijk} = X_0 + \frac{i}{l}S + \frac{j}{m}T + \frac{K}{n}U \qquad (1)$$
$$(i=0,1,\cdots,l; \quad j=0,1,\cdots m; \quad k=0,1,\cdots n)$$

where $X_0$ is the original point of the coordinate under axis $S$, $T$ and $U$. The deformed position $X_d$ of an arbitrary point $X$ can be evaluated by the Bernstein polynomial $B$ as follows:

$$X_d = \sum_{i=0}^{l}\sum_{j=0}^{m}\sum_{k=0}^{n} B_{i,l}(s)B_{j,m}(t)B_{k,n}(u)P_{ijk} \qquad (2)$$

where $(s,t,u)$ is the original normalization coordinate of point $X$ that conforms to the conditions $0<s<1$, $0<t<1$ and $0<u<1$. The Bernstein polynomial can be expanded as

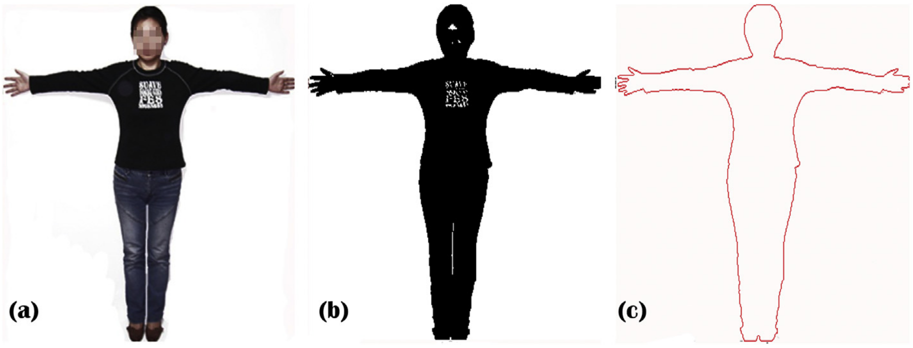

**Fig. 1.** Extraction of 2D silhouettes. (a) original image, (b) gray-scale image, (c) silhouette image.