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Parametric Body Model Generation for Garment Drape Simulation

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Abstract: A parametric body model generation system has been developed. Using various mathematic and geometric algorithms of this system, a three-dimensionally scanned human body can be converted into a resizable body model. Once a parametric body model is formed, its size and shape can be modified instantaneously by providing appropriate anthropometric data. To facilitate the subsequent pattern arrangement process for garment drape simulation, a bounding box generation algorithm has been developed in this study. Also the model can be converted into a set of parametric surfaces that it can also be used for three-dimensional garment pattern design system.

Keywords: Parametric body model, Parametric surface model, Drape simulation, Automatic pattern arrangement, Three-dimensional pattern design

Introduction

The applications of computer aided design (CAD) and manufacturing (CAM) technology has become an obvious trend in many fields of industry recently [1]. For the garment manufacturing industry, a significant amount of automation has been achieved mainly by using two-dimensional CAD systems [2,3]. However, a radical innovation is taking place recently that such two-dimensional CAD systems are evolving steadily into three-dimensional ones [4-7]. Many researchers have worked on the development of three-dimensional garment CAD systems including the fabric drape simulation system based on the mechanical analysis of fabric behavior, and three-dimensional direct pattern generation from three-dimensional human body models [8-13]. One of the most important features needed for the development of an integrated three-dimensional CAD system is to design a functional human body model. Usually, a simple three-dimensional object modeling technique has been applied to generate a human body model. However, it is possible nowadays to model a human body directly from the three-dimensional body scan data because whole body scanners become affordable at an acceptable cost thanks to the advances in non-contact measurement technology [14-17]. However there are some problems in such a scanned body model that a new model must be scanned whenever a different sized human body model is required, although the shape of each human body does not differ largely. Another problem is that it is unsuitable for the garment drape simulation where a large amount of collision treatment is required, because the data size of such a model is usually very large. The third problem is that as the scanned body model is composed of a series of triangular elements, it is impossible to draw arbitrary shapes including garment patterns on it easily.

In this study, a parametric body model generation system has been developed to overcome such difficulties. The parametric body model has many advantages over a static body model. One is that the shape and size of the model can be changed easily that no more scanning is necessary as long as the overall shape of a newly required model does not differ largely from that of the original one. Another is that the data size of the model is significantly reduced so that it became suitable for the use in the garment drape simulation. The third is that as the surface of body model may be turned into a set of parametric surfaces, arbitrary shapes can be drawn easily on it for the generation of three-dimensional garment patterns. One more advantage is that the optimum bounding boxes can be defined around the body model that can be used for the automatic spatial pattern arrangement function of the garment drape simulation system. The use of bounding boxes has a striking effect for the garment drape simulation because the spatial arrangement of the pattern pieces around the body model is one of the most time consuming and human dependent procedures. As described above, the parametric body model developed in this study can be applied for many fields including the three-dimensional garment CAD systems.

Preparation of 3D Body Data

As the three-dimensional whole body scanners become available at an affordable cost, researches based on the three-dimensional quantitative human body data also have become more and more popular recently. The three-dimensionally scanned body models are used in the field of garment drape simulation. However, there are some problems in using the scanned raw body model. Firstly it is not so efficient because of the large data size of the models. Secondly, a new body model must be scanned whenever a new model is needed. Therefore, a resizable model is required, which is initially generated from the three-dimensional body data and further

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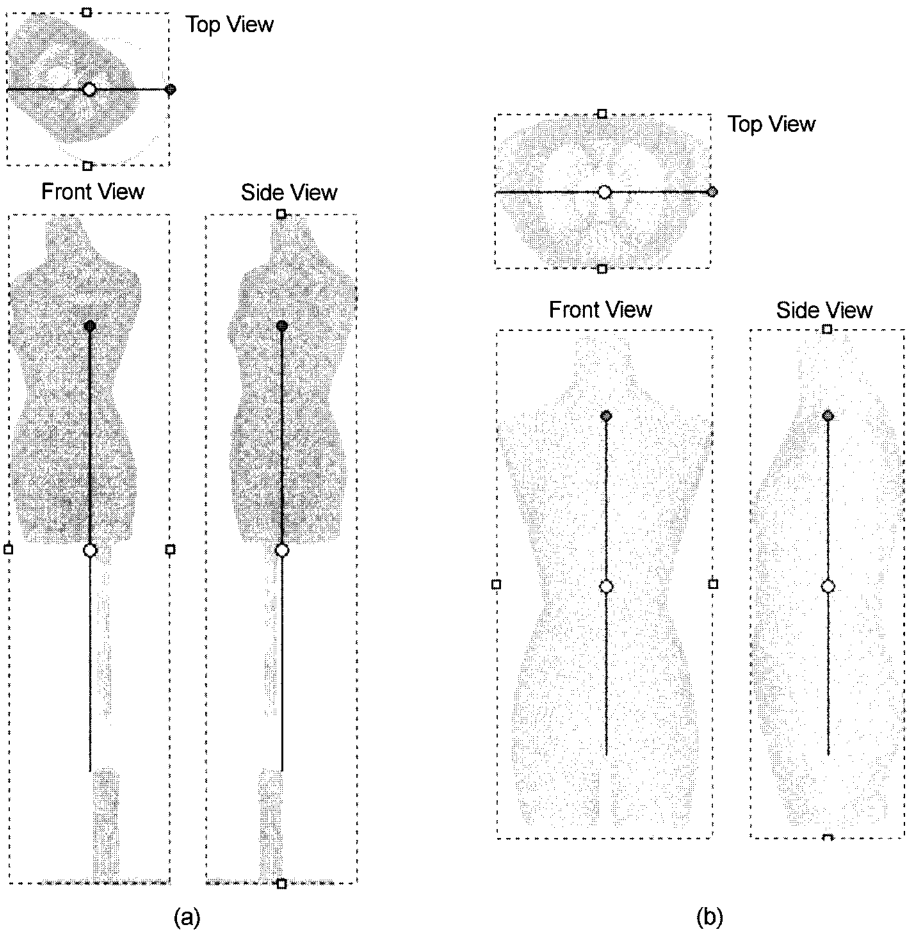


Figure 1. Example of three-dimensional body data manipulation: (a) Initial body model and (b) Aligned and cropped body model.

can easily be reshaped and resized. In this study, a parametric body model was generated based on the three-dimensional body data obtained using general whole body scanners. The type of scanner does not matter in this study as long as the scanner supports the '*.iv' data format which is one of the most famous data types for three-dimensional objects.

When scanning a mannequin instead of a real human body, some useless parts like a stand may also be included as shown in Figure 1(a). Also the scanned model may not be properly aligned along principle axes for some reasons. In this study, user can realign the model through axis control and crop the useless portion of the model easily using an intuitive interface system as shown in Figure 1(b).

Formation of Parametric Body Model

Extraction of Body Cross Sections

A parametric body model is generated using the shapes of some specific cross sections of the three-dimensional body data. With this method, the shape and size of the model can be changed either by reshaping each cross section or by changing the vertical location of each cross section. In this study, the cross sections at neck top, neck bottom, shoulder, armhole, armpit, bust point, waist, abdomen, hip, and thigh are used for model generation. The location and horizontal

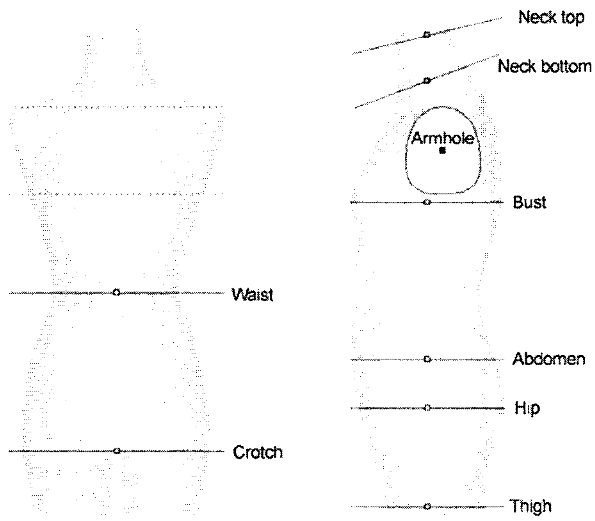


Figure 2. Definition of body cross section.

inclination of each cross section can be defined using a simple interface system as shown in Figure 2. The initial location of each cross section is obtained from respective statistical anthropometric data.

Once all the locations and inclinations of cross sections are defined, the shape of each section can be extracted from the body model. The plane equation for target section can be described as equation (1) when the normal vector and height of the section is v and h, respectively.

$$v_x x + v_y y + v_z z = h \tag{1}$$

As the body model is composed of triangular elements, each section can be defined as the set of intersecting points between the plane and each side of elements. Assuming that the two end points of a side of an element to be $p_1(x_1, y_1, z_1)$ and $p_2(x_2, y_2, z_2)$, the side has an intersecting point on the plane if the two points satisfy equation (2).

$$(v_x x_1 + v_y y_1 + v_z z_1 - h) \times (v_x x_2 + v_y y_2 + v_z z_2 - h) < 0 \tag{2}$$

In this case, the coordinates of the intersecting point I can be obtained using equation (3).

$$p = \overrightarrow{p_1 p_2} = (x_2 - x_1, y_2 - y_1, z_2 - z_1),\ k = \frac{v \cdot p_1 - h}{v \cdot p}$$
$$I_x = kp_x + x_1, I_y = kp_y + y_1, I_z = kp_z + z_1, \tag{3}$$

Some examples of cross sections extracted using this method are shown in Figure 3.

Circular Fitting of Cross Sections

As shown in Figure 3, each cross section has arbitrarily dispersed. The shape of each cross section can roughly be considered as a closed loop and the position of each point can be described with two parameters, one is the distance r between the point and section center and the other is the angle θ between the x-axis and the line connecting the section center and the point. Once all the points are sorted with respect to their θs, the relationship between θ and r can be approximated using Fourier series expansion as shown in equation (4). With this method, the shape of each section can be fitted through a single continuous curve rotating in counterclockwise direction and the position of a point $P(\theta)$ can be obtained using equation (4).

$$a_n \cong \frac{1}{n\pi}\left[-\sum_{s=1}^{m} j_s \sin\frac{n\pi}{L}\theta_s - \frac{L}{n\pi}\sum_{s=1}^{m} j_s' \cos\frac{n\pi}{L}\theta_s\right]$$
$$b_n \cong \frac{1}{n\pi}\left[\sum_{s=1}^{m} j_s \cos\frac{n\pi}{L}\theta_s - \frac{L}{n\pi}\sum_{s=1}^{m} j_s' \sin\frac{n\pi}{L}\theta_s\right]$$
$$j_i = \frac{r_{i+1} - r_{i-1}}{2},\quad j_i' = \frac{j_{i+1} - j_{i-1}}{2} \tag{4}$$
$$r(\theta) = r_0 + \sum_{s=1}^{m}(a_i \cos i\theta + b_i \sin i\theta),$$
$$P(\theta) = (r(\theta)\cos\theta, r(\theta)\cos\theta)$$

where, n is the number of terms in Fourier series, m is the number of points, j is the primary jump, and j' is the secondary (differential) jump.

There is a variety of cross sectional shapes for a body model as shown in Figure 3. However, the shapes of most garments are convex so that the garment may generally cover the concavities of the body, except for some special garments where the exact fitting is required. Therefore, the final shape of desired model depends on the curve fitting method for each cross section. With this method, convex

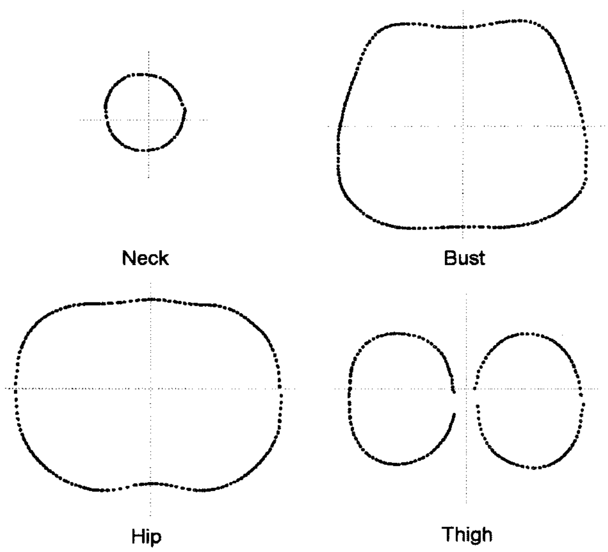


Figure 3. Examples of the shapes of extracted cross sections.

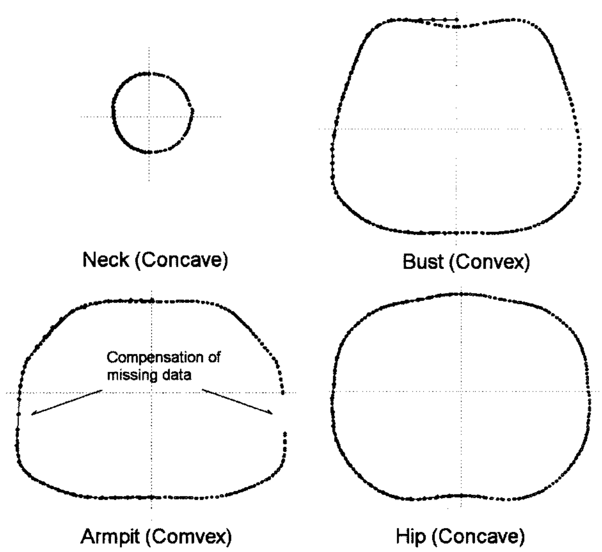


Figure 4. Examples of the circular fitting for selected cross sections.

Table 1. Controllable parameters for a parametric body model

Girth/Length	Height	Sleeve
Neck	Neck	Length
Shoulder	Shoulder	Shoulder Angle
Bust	Armpit	Elbow Angle
Waist	Bust	Cuffs Attenuation Ratio
Abdomen	Abdomen	
Hip	Hip	
Thigh	Crotch	
Leg Length	Thigh	

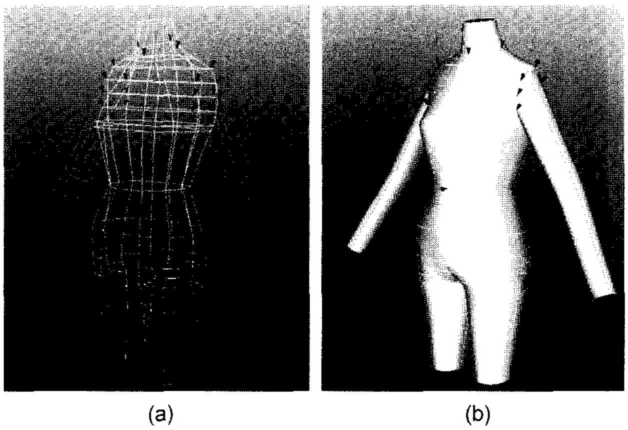


Figure 5. An example of parametric body model: (a) Structural frame and (b) Surfaced model.

curve fitting was performed using the well-known Graham convex hull generation method and the results of circular fitting are shown in Figure 4.

Deformation of Body Model

In this study, eight primary cross sections and a number of auxiliary cross sections were used for the definition of a body model and the shape and size of the model can be changed by resizing and relocating each section considering the final desired geometry. Each body part was generated by sweeping those cross sections. Also the shape of armhole curve and several parameters were used to define sleeves of which the shoulder angle as well as the elbow angle can be controlled freely. Some major landmarks are automatically generated on respective cross section. Controllable body measurement parameters are listed in Table 1 and the structural frame and surfaced model of a parametric body is as shown in Figure 5.

Parametric Surface Generation

Recently, the main trend of garment CAD system is migrating into three-dimensional system from conventional two-dimensional system. To design garment patterns directly from three-dimensional body, a special feature is required for a body model having various body informations. Arbitrary shapes including garment patterns can be drawn on its surface easily. As for the model shown in Figure 5, it is impossible because its surface is composed of mutually independent triangular elements. Therefore, a parametric surface generation algorithm was implemented in this study to make a functional surface model, which can be used for garment drape simulation as well as three-dimensional pattern design. The parametric surface used in this study is the Bézier surface on which any point can be referred easily using two parameters u and v, each of which ranges from 0 to 1. As each part of body can be roughly approximated as a cylinder, parameter u can be defined along its circumferential direction while parameter v along its axial direction. As each cross section is fitted with a continuous curve, control points for parametric surface can be defined easily. An example of the parametric surface model is shown in Figure 6(a) and an example of pattern drawing is shown in Figure 6(b). As shown in Figure 6, such a parametric surface body model can be used for three-dimensional pattern design process, which is another one of our research topics.

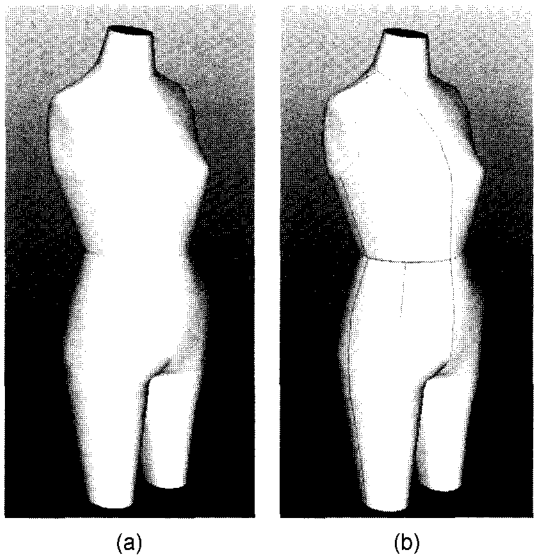


Figure 6. An example of parametric surface model: (a) Parametric surface model and (b) Pattern drawing example for bodice and slacks.

Bounding Box Definition

The primary goal of this study is the development of a deformable parametric body model for three-dimensional garment pattern design and garment drape simulation. Especially, one of the most difficult problems in garment drape simulation is the appropriate spatial arrangement of numerous pattern pieces around the body. However, it is a very difficult and time-consuming job for the user to arrange those pieces using only two-dimensional input devices. Therefore, the automation of this process is inevitable for the development of an efficient garment drape simulation system. In this study, an algorithm was developed to generate virtual cylindrical volumes, which tightly cover each body part called the bounding boxes. Once all the bounding boxes are defined for each body part, they can be flattened onto two-dimensional plane as all of them are developable surfaces. Then the user can easily arrange pattern pieces with respect to those boxes and the pieces will be arranged spatially through the inverse mapping of bounding boxes into their original three-dimensional forms. Using this method, numerous pattern pieces can be arranged automatically and appropriately without any interference with the underlying body model that the overall drape simulation time can be dramatically reduced. Examples of bounding boxes defined for each body part are as shown in Figure 7.

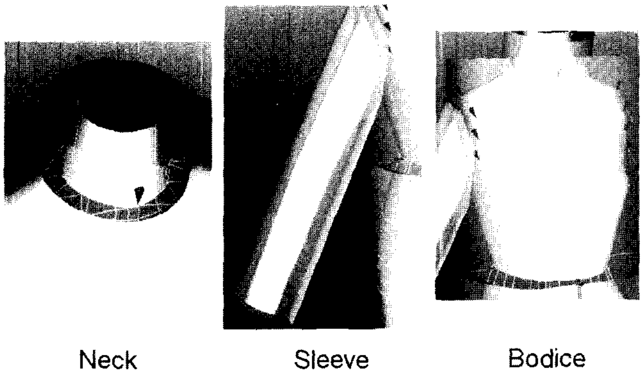


Figure 7. Examples of bounding boxes for various body parts.

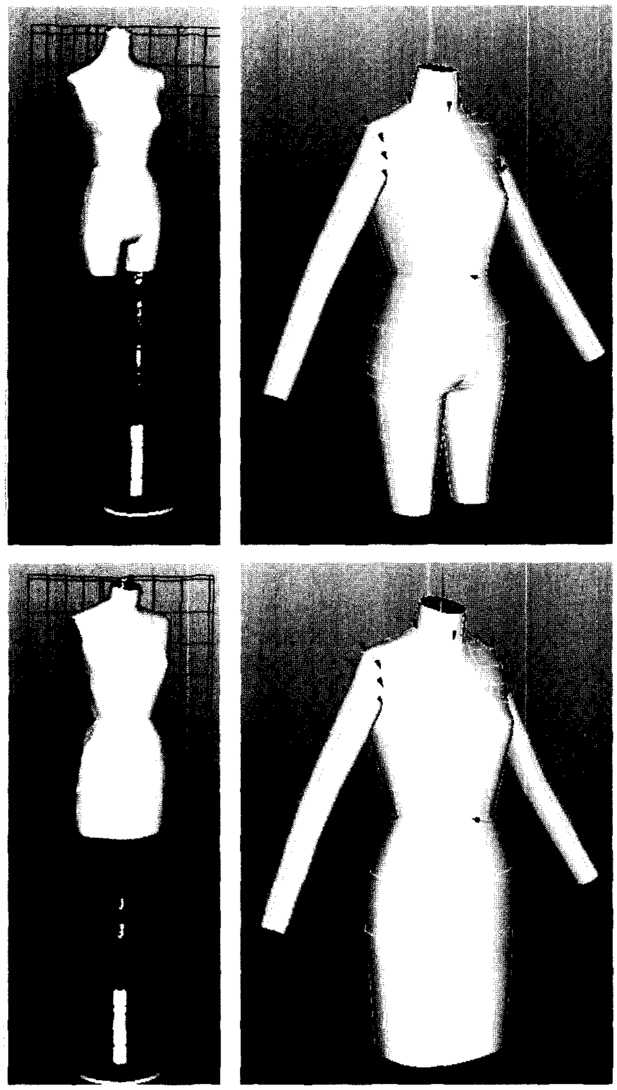


Figure 8. Example of originally scanned body and reconstructed parametric model.

Results and Discussion

Examples of three-dimensionally scanned body models and their corresponding parametric body models are shown in Figure 8. As the shape and size of a parametric body can be changed easily while maintaining the overall shape of its original model, a garment manufacturing company can keep its own model database obtained from scanning and converting

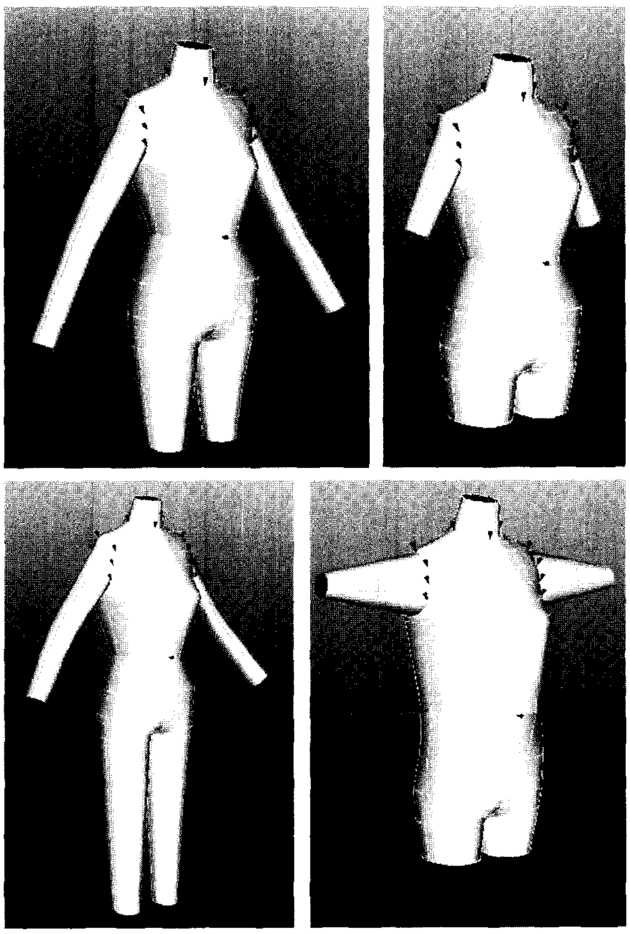
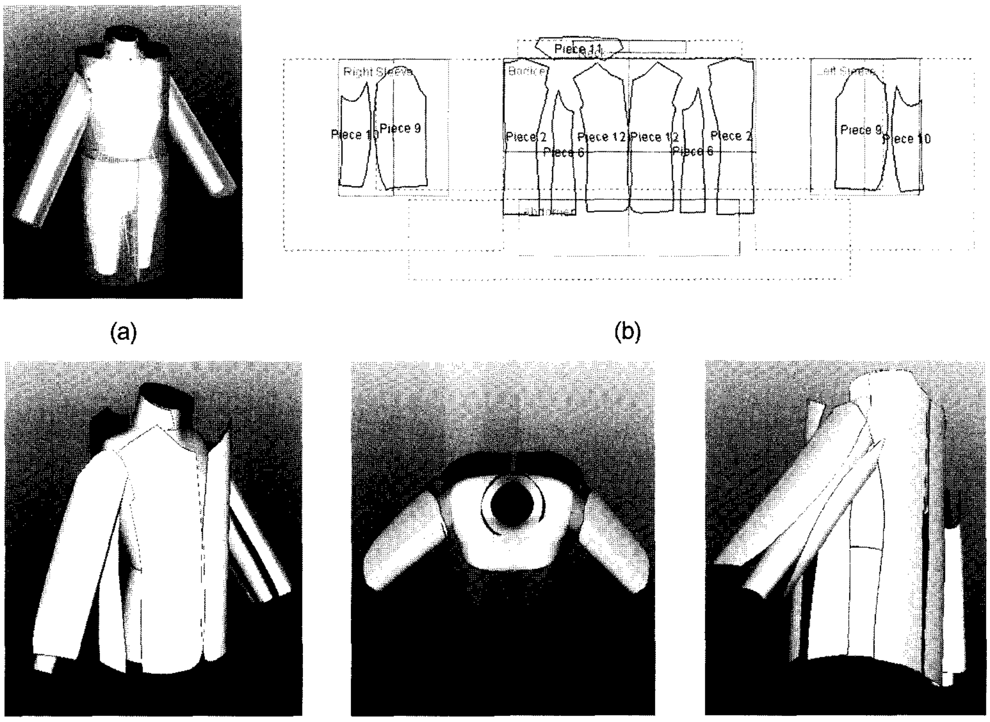


Figure 9. Deformation of a parametric body model.



(c)

Figure 10. Schematic diagram of spatial pattern arrangement using bounding boxes: (a) Bounding boxes defined around each body part, (b) Arrangement of pattern piece with respect to flattened bounding boxes, and (c) Inverse mapping of flattened bounding boxes for spatial pattern arrangement.

as many standard body models as possible.

As shown in Figure 9, a parametric model can have a variety of shape and the changes can be verified in real time on a general Pentium 4 1.3 GHz personal computer system through a fast calculation algorithm. Therefore, the effect of a certain parameter on the shape and size of the body model can be analyzed very quickly.

Bounding boxes can be automatically generated as shown in Figure 10(a). User can arrange numerous pattern pieces easily with respect to the flattened bounding boxes as shown in Figure 10(b) and the pattern pieces will be arranged around the body through the inverse mapping of bounding boxes as shown in Figure 10(c). The shape and size of bounding boxes are also changed according to the underlying body model in real time that changes can be verified instantaneously.

Conclusions

A parametric body model generation system has been developed. For this, a resizable body model was generated from the three-dimensional body scan data using various mathematic and geometric algorithms. The size and shape of body model can be changed easily and instantaneously using an intuitive user interface that any kinds of body models can be generated easily once a parametric body model is formed. Furthermore the surface of body model can be converted into a set of parametric surfaces. Arbitrary shapes can be drawn easily on it and therefore it can be used for three-dimensional pattern design system. Finally, tight fitting bounding boxes can be defined for a body model, which will be used in the automatic spatial arrangement of pattern pieces in the garment drape simulation system. The parametric body model has various application fields in the three-dimensional garment CAD system and it would be helpful to generate a truly practical system if such a functional body model could be refined by further researches.

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