Automatically Constructing Skeletons and Parametric Structures for Polygonal Human Bodies

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Abstract We present an approach for automatically creating skeletons and controllable parametric structures for polygonal 3D human models. In this method, anatomical feature points of a human body are automatically extracted firstly. Secondly, a skeleton model is constructed based on those feature points. Thirdly a parametric wire frame with controllable structure is constructed by sweeping along the skeleton. And finally the human model is approximated with multi resolution sweep surface.

Keywords *skeleton, parametric structure, sweep surface*

1 Introduction

Virtual human plays an important role in the area of computer graphics with many applications. In the past 30 years, researchers have investigated various techniques for representation and deformation of human body. This research area still remains one of the most difficult and challenging problems.

As summarized by Magnenat-Thalmann et al[1], existing methods for human modeling can be classified into three categories: creative approaches [2,3], reconstruction [4,5] and example based modeling [6,7].

Creative methods are usually anatomy-based, which can simulate underlying muscles, bones, and generalized tissue. However, these modelers require a relatively slow production time. Reconstruction approaches build 3D human models automatically by scanning existing shape. The disadvantage of these techniques is that it is very difficult to automatically modify the reconstructed models to different shapes according to the user's intends. Example-based shape modeling technique is a good alternative to overcome this disadvantage. However example-based methods require a same parameterization of all examples.

One major contribution of this paper is automatically establishing a skeleton and a controllable parametric structure for a polygonal human model. It can be used as the pretreatment for example-based modeling. Our method is motivated by recent work of Wang who proposed a feature based parameterization method with Gregory patches for scanning human data [8]. Our method is based on polygonal human model, and it is more robust to automatically construct skeleton on the human model with noise points. Hierarchy-based strategy is adopted to make the processing of skeleton construction more efficient. Multi resolution sweep surface is constructed to approximate the human model surface.

Another major contribution of this paper is that, our method takes the influence of model structure on the human deformation into consideration [12]; therefore our method fits for both human modeling and human animation.

The remainder of this paper is organized as follows. In section 2, a skeleton of a human model is constructed after automatic detecting feature points on a 3D polygonal human surface. In section 3, feature sections along skeleton curves are extracted to set up the parametric wire frame of a human model, and multi resolution sweep surface is constructed to approximate a human model. Applications and analysis are presented in section 4. The paper is concluded in section 5.

2 Skeleton construction

The objective of skeleton construction is to subdivide the human model into several feature parts, so that we can construct parametric structure separately in each feature part. Also the skeleton makes the human model animatable.

To construct the skeleton, we first extract the feature points near the joints on the human model surface based on human anatomy, and then we get the joints by intersecting proper plane through the feature points. Skeleton curves are finally obtained by link those joints. In our method, we assume that the input human models are in a standing state facing the screen with their armpits and crotches visible.

2.1 Strategy for feature points extraction

The strategy of automatic extraction of feature points is hierarchy-based as follows:

Firstly, we extract the calvaria point, finger points, toe points, armpit points, crotch point and neck point. The last four points are key feature points, proper plane through those four points separate the human model into six major parts: head, torso, two arms and two legs, as shown in figure 1. Arm parts and torso part are connected at the armpit points; leg parts and torso part are connected at the crotch point; torso part and head part are connected at the neck point. We name those feature points as class I (CI for short) points.

Secondly, in each major part, we extract the points with anthropometric semantic, including chest point, waist point, elbow points, wrist points, thigh points, knee points and ankle points. Proper plane through those feature points can further subdivide the human model into several sub-regions, as shown in figure 2. We call those feature points as class II(CII for short) points. The CI and CII feature points determine the skeleton of a human model, which will be detailed late.

Feature points of class III(CIII for short) are located in sub-regions, as shown in figure 3, including under-breast point, pelvis point, middle upper arm points and so on, those feature points indicate the major surface change in their corresponding regions.

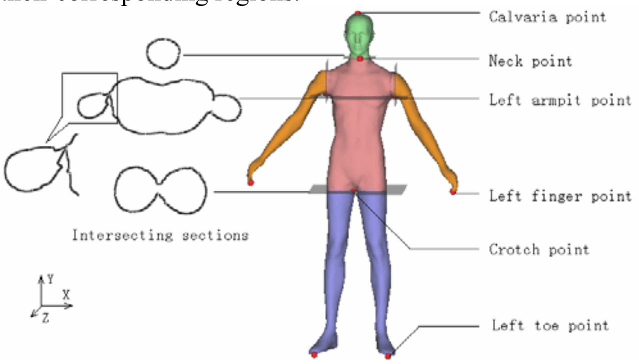


Fig. 1 Class I feature points

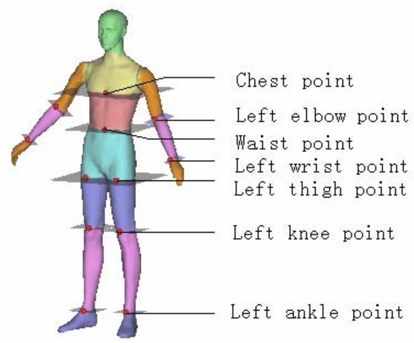


Fig. 2 Class II feature points

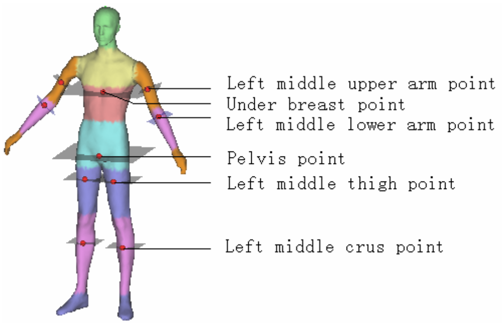


Fig. 3 Class III feature points

2.2 Detailed method for feature points extraction

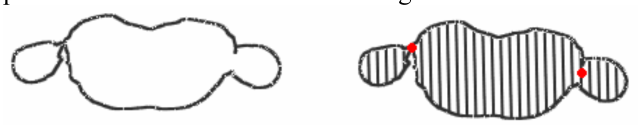
During the extraction of feature points, the calvaria point, two finger points and two toe points are extracted by detecting the vertices with minimal or maximal coordinate. For instance, the left finger has the minimal value along Y axis in neighboring region of the vertex with the maximal value in X axis. The most difficult and most important feature points to be extracted are the armpit points and crotch point. To automatically extract them, we use some planes to intersect the human model, as shown in figure 1, and the feature points are near the turning points on the 2D contours.

For the armpit points, we intersect the human model with horizontal planes from its 3/4 height upside literately. Once the intersecting section breaks into two loops, we stop the iteration. And assume the armpit points locate in the previous intersecting section, near the left and right turning points of the intersecting section. To extract the turning point, Wang [8] used an angle-based method, i.e. if an angle formed by three adjacent points is smaller than a threshold, then it is a turning point. It is the case with the premises that there are no noise points on the human model. However, in most scanning models, noise points exist, as shown in the section near armpits in figure 1. If we directly use Wang's method, error may occur. Here, we proposed an alternative way to robustly extract feature points. We firstly scan the intersecting section with rays parallel to Z axis to get pairs of sampling points. Then, we compute the distance of each pair. We chose the two pairs with minimal distance on the right and left side of the center of the intersecting section. And set the middle point of each pair as the left or right armpit point. As shown in figure 4, with this method, we can robustly extract the armpit points, as shown in red point in figure 4. And we use this method to extract the crotch point similarly.

When the armpit points are extracted, we intersect the human model with two planes containing the armpit points respectively with their normal parallel to X axis to get the shoulder points. The shoulder points are those points with maximal value in Y axis on the intersecting section, as shown in figure 5.

The neck point is extracted by cutting the human model with a plane parallel to XOZ plane above the shoulder points iteratively. The neck point is ideally on the section with minimal contour in the region of neck. However, in our experiments, we find that this criterion may fall to work because of surface noise. Indeed, we stop the cutting iteration when the difference of perimeter between the current section and previous section is smaller than a threshold. The neck point locates on the central front point of current intersecting section, as shown in figure 5.

Planes passing through armpit points with their normal parallel to X axis and planes passing through neck point and crotch point respectively with their normal parallel to Y axis divide the human model into six major parts as shown in different color in figure 1.



(a) Section near armpits (b) Scanning in Z direction

Fig.4 Extract armpit points

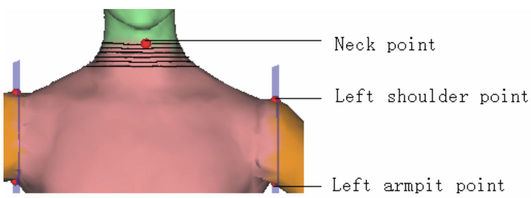


Fig.5 Extract neck point

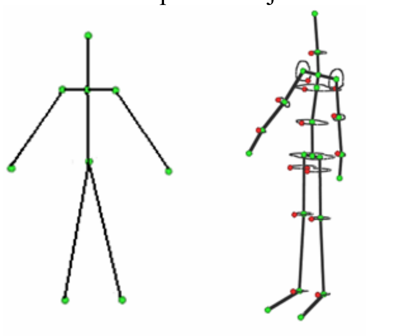
When CI feature points are extracted, an initial skeleton is established with the head point, armpit points, finger points, crotch points and toe points, as shown in figure 6(a). Based on anthropometry [13], CII feature points are detected on the intersecting sections perpendicular to the initial skeleton. For example, waist point locates on the section with maximal Z value on its back part among the sections between armpit points and crotch points. The back part of a section can be extracted by computing the dot product between the view direction (initially, (0,0,1)) and normal on points of the section. If dot product on a vertex is smaller than zero, then the vertex is on the back part of the section.

CIII feature points are extracted with the similar method as for CII feature points. Take pelvis points as an instance, pelvis locates on the section with minimal Z value on its back part among the sections between waist point and crotch point.

In our methods, CII feature points are extracted in corresponding separated body parts instead of the whole human model, therefore computation is reduced. Proper planes passing through the CII feature points further subdivide the human model into smaller regions as shown in figure 2, and CIII feature points are efficiently extracted in those smaller regions.

2.3 Skeleton

A skeleton is constructed with bones, as shown in figure 6. Two adjacent bones are linked on a joint. In the figure, joints are displayed in green spheres. A skeleton is constructed simultaneously during the extraction of feature points. We set the center of an intersecting section that corresponds to a feature point as a joint.



(a) initial model (b) final model

Fig.6 Skeleton

3 Parametric structure

Feature based parametric structures are fundamental for developing customized human models. Recent work of Yoon and Kim[9] show that, seep-based surface has many merits in shape deformation and animation of arbitrary 3D objects. Motivated by their work, in this section, we construct the feature based parametric structure in two steps. Firstly, a sweep-based wire frame with controllable structure of a human model is constructed, and then the human model is approximated with multi resolution sweep surface based on the wire frame.

3.1 Wire frame

Generally, human animation or deformation methods require a human model segment into head, torso, arms and legs. Therefore, we construct wire frame of each part separately, and then join them together with constrains. The detailed method is as follows.

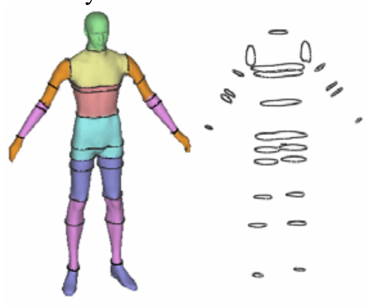
Firstly, key sections are extracted along the skeleton by intersecting some proper planes against a human model on the feature points, the normal of planes are perpendicular to the skeleton, as shown in figure 7. The key sections represent the boundaries and the major surface change of each part of a human model.

Secondly, we interpolate more sections between two neighboring key sections along the skeleton to make the human model more controllable, as shown in figure 7(b). Those sections are called as assistant sections. In a same region bounded by two key sections, we distribute the assistant sections evenly. The normal of planes containing the assistant sections are interpolated between two neighboring key sections. When we obtain sections in each human part, the whole sections of a human model is constructed, as shown in figure 7(c).

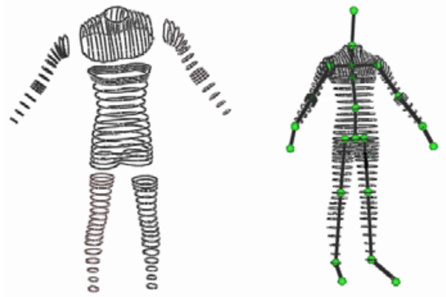
Finally, we add constrains of displacement and orientation on sections between two boundary sections $\mathbf{S}_s$ and $\mathbf{S}_e$ to construct the wire frame. Suppose $\mathbf{P}_i$ and $\mathbf{P}_{i+1}$ are planes containing two adjacent sections $\mathbf{S}_i$ and $\mathbf{S}_{i+1}$ between $\mathbf{S}_s$ and $\mathbf{S}_e$ respectively, and then we have

$$\mathbf{P}_{i+1}=\mathbf{R}(t)\,\mathbf{P}_i+\mathbf{d}(t) \qquad (1)$$

where $0\leq t\leq 1$, $\mathbf{R}(t)$ is a 3×3 rotating matrix and $\mathbf{d}(t)$ is 3×1 translating vector, $\|\mathbf{d}(0)\|=0$ and $\|\mathbf{d}(1)\|=\|C_sC_e\|$, C_s, C_e are the center of $\mathbf{S}_s$ and $\mathbf{S}_e$. Under equation (1), when we deform one section on the wire fame, it is conveniently to update the other sections, which makes human deformation or animation easy and efficient.



(a) key sections



(b) sections in each body part (c) wire frame

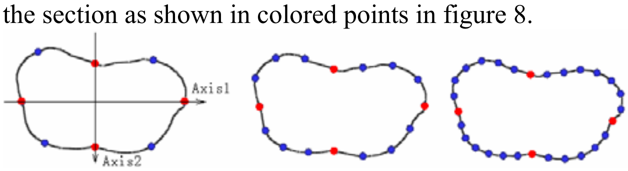
Fig. 7 Wire frame of a human mode

3.2 Multi resolution sweep surface

The shape of each human part is cylinder-like, so it is straightforward to adopt the method for creating surfaces with contours. Our approach for mesh generation has two steps: (1) extract vertices for contour curve on sections, and (2) surface construction from contours.

To sample vertices on a contour, Wang[8] proposed an angle-based method. In their method, angels on the contour center with other two end points as two adjacent sample vertices on the contour are equal. In this case, undersampleing problem may easy happen on the curves with high curvature. Other methods sample vertices using the curvature criteria, though they can approximate the surface shape well, the triangulation results with those vertices usually fall into low quality, which makes against human deformation or animation.

To create high quality of triangles, we extract the vertices for contour curve as follows. Firstly, according to the symmetry of human surface, we decompose a section into four parts by two orthogonal lines with their intersection fixed on the center of the section, as shown in figure 8. Secondly, each part is further decomposed into several sub-parts equidistantly. Then we get the vertices on the section as shown in colored points in figure 8.



(a) 8 vertices (b) 16 vertices (c) 28 vertices

Fig.8 Section decomposition with multi resolution

The directions of the two orthogonal lines determine the arrangement of the vertices. To be convenient, we compute the direction of one line first, we call this line as principal axis, and then the direction of another line can be easily computed on the plane. The computation of direction of principal axis $\mathbf{D_p}$ takes the silhouette of a human model into consideration, and is computed as follows.

$$\mathbf{D_p} = \mathbf{N} \times \mathbf{A}_z \qquad (2)$$

where $\mathbf{N}$ is the normal of section, and $\mathbf{A}_z$ (0,0,1)is the direction of Z axis which parallels to the initial view direction, "×" means cross product. As a result, when we link all of the intersections between principal axis and sections of a human model, we can get the silhouette of the human model in front view, as shown in figure 9.

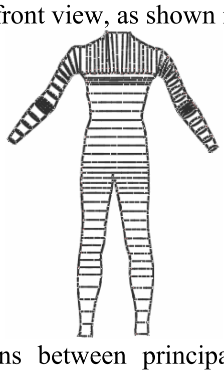


Fig.9 Intersections between principal axis and sections make the silhouette of a human model in front view

Our method can get evenly disturbed vertices on sections, as shown in figure 8, taking the section of chest for instance. Compared to angle-based method for decomposing a section proposed by Wang [8], our method synthesizes both the advantage of angle-based method and length-based method, as a result, the problem of undersampling on the parts with high curvature is reduced, and the shape quality of triangles formed with those vertices is high, as show in figure 13 and 15.

When we control the interval between two neighboring vertices on a section, we can get multi resolution vertices on the section, which makes it easy to construct multi resolution mesh for a human model surface.

After obtaining the vertices on contour curves, we can easily construct the surface of each part of human body with Meyers's method [10]. One technical challenge is how to combine the neighboring parts around the shoulder and the hip, where surfaces with different shape meet. We address this by creating a transition surface between two neighboring surfaces, as shown in figure 10. Our approach of creating transition surface can be divided into two steps: initial construction and optimization.

In constructing the transition surface linking arm, shoulder and torso parts, firstly we sew the surface of shoulder and torso by linking the vertices on the bottom boundary of shoulder surface and their nearest counterparts on the top boundary of the torso surface. As shown in figure 11(b), when we triangulation the vertices on chest section and the end points of shoulder sections, a triangle strip can be get, as shown in figure 10(b), and a closed loop containing the side boundary of a shoulder and part of chest section can also be gotten, as shown in figure 11(c). Secondly, we use this newly created closed loop L_n and the armhole section S_a to create a surface as follows:

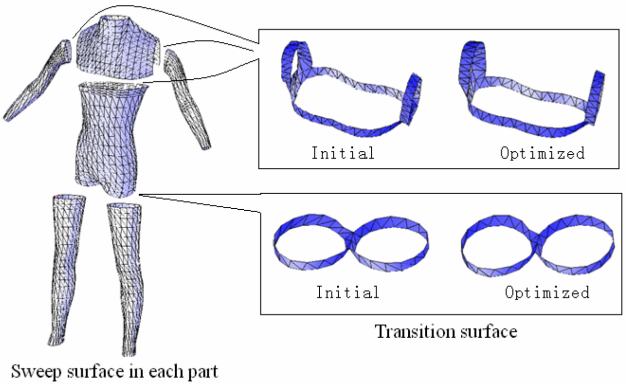
(1) Initialize the angle of each vertex on L_n and S_a by using polar coordinate, with the origin of the polar axis as the center of L_n and S_a respectively. The direction of polar axis is defined by equation(2), as shown in figure 11(c). Here the normal of L_n is defined as the normal on average plane of L_n.

(2) To a vertex v_i with polar angle α_i on S_a, we find a vertex v_j with polar angle β_j on L_n which has the minimal $|\alpha_i - \beta_j|$ to make a edge, as shown in figure 11(c). With this rule, we can initially create a transition surface as shown in figure 10.

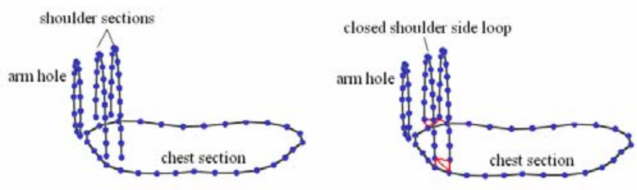
(3) The initial transition surface is further smoothed with edge exchange [11] as shown in figure 10.

In above method, all of vertices on the transition surface are shared with the arm, shoulder and torso parts, thus the transition surface stitch the three separated parts into one surface.

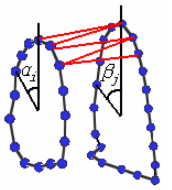
We use the similar method to create the transition surface linking torso and thighs. The major difference is that we insert an additional vertex between the two turning points on the crotch section to break the section into two closed loops, as shown in figure 12. With this pretreatment, the construction of transition surface between the torso and thighs becomes straightforward. The result is shown in figure 10. With the transition surfaces, the six separated body parts are combined into one surface, as shown in figure 13.



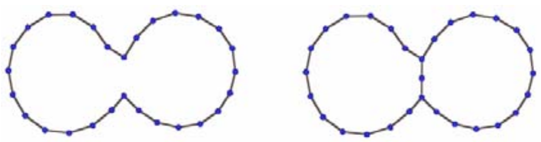
(a) Sweep surface in each part (b) Transition surface
Fig.10 Sweep surface of a human model



(a) initial sections (b) create shoulder boundary loop



(c) sew arm hole and shoulder boundary loop together
Fig. 11 Sections treatment in constructing transition surface combing torso, arm and shoulder



(a) initial crotch section (b) after disposure
Fig. 12 Crotch section treatment in constructing transition surface combing torso and thighs

4 Applications and analysis

According to the recent work of Yoon and Kim[9] and Hyun et al.[12], sweep-based surface has many merits in free form deformation than general polygonal mesh surface. In their methods, the most difficult and time consuming step in sweep-based surface deformation is to construct control sweep surfaces for deformable parts of an object [9]. In this paper, take 3D polygonal human model as input data, we present a natural and efficient way to automatically create multi resolution sweep-based surfaces for human models. For instance, to reconstruct a high resolution sweep surface on a man model with 23888 triangles, as shown in figure 13, the computational time is less than 1.5s on a PIV 1.5G Hz PC with 512M main memory. And the computational time of reconstructing the sweep surface of a female model with 60860 triangles is about 2s.

In our methods, the number of vertices on a section can be freely controlled, which makes it easy to create body structures with different shape quality, as shown in figure 13. And since the body structure is independent with the shape of human models, every human model reconstructed in this way is parameterized, which makes it easy to morph from one model to another, as shown in figure 14.

The reconstructed body surface can conveniently and efficiently deformed by editing the shape of sections on its parametric structure. And deformation region is easy to be controlled with constrains between sections provided by equation (1). As shown in figure 15, when we edit the waist section, the deformation of its neighboring sections between the chest section and the crotch section can be smoothly interpolated, since to each vertex on the waist section, its counterparts on the neighboring sections can be easily found in the parametric structure.

Furthermore, our methods can be used as the pretreatment of example-based human modeling, as those methods usually require a same parameterization of all examples [7].

Our methods can automatically construct the skeleton of a human model, which is very useful for generating articulated models without the interaction of the user, especially in animating scanned human models. In our methods, human surface vertices are located on sections which are obtained by intersecting planes along human skeleton, therefore the vertices can naturally combined onto the skeleton with the method proposed by Shen et al [14], which makes human deformation or animation efficient.

Based on the above applications and analysis, we can see that our methods has many merits both in human modeling and human deformation.

5 Conclusion

In this paper, we present a natural and efficient approach for creating parametric structures of human models. Feature-based technique is adopted to automatically construct the skeleton of a polygon human model. Then the entire human model is subdivided into several parts. Multi resolution sweep surface with controllable wire frame structure are created separately in each part, and neighboring parts are combined with smooth transition surfaces. Our methods can automatically obtain the skeleton and parametric sweep structure of a human model, which makes following human animation and deformation very convenient.

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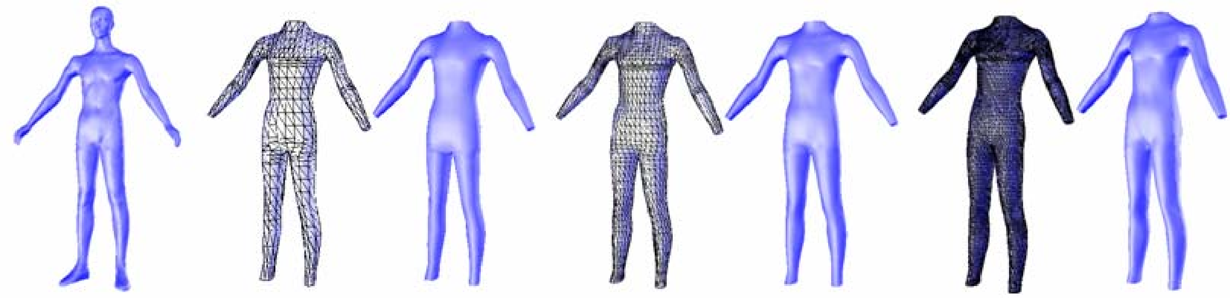
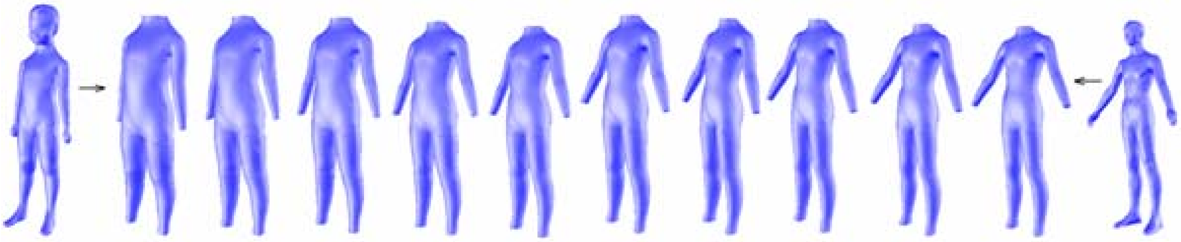


(a) input model (b) low resolution sweep surface (c) middle resolution sweep surface (d) high resolution sweep surface

Fig13. Control sample interval to get difference shape quality of sweep surface



(a) from a child/man to a man/child

(b) from a child/woman to a woman/child

Fig.14 Morph between different human bodies

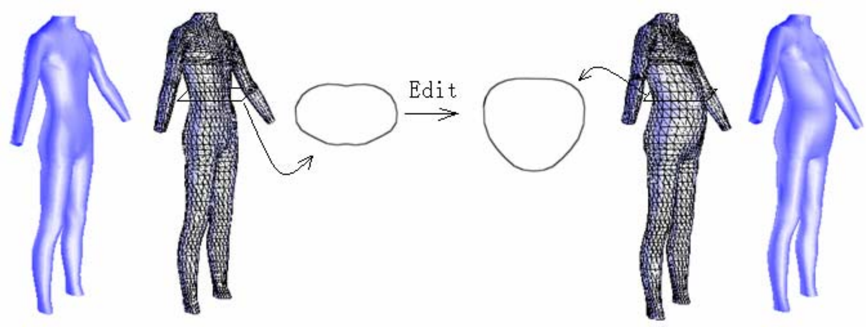


Fig15. Section-based surface deformation