



Sketch based garment modeling on an arbitrary view of a 3D virtual human model*

Yu-lei GENG¹, Jin WANG^{††1}, Guo-dong LU¹, Zheng LIU^{1,2}, Gang CHEN³

⁽¹⁾State Key Lab of CAD & CG, Zhejiang University, Hangzhou 310027, China)

⁽²⁾Department of Garment, Jiaxing University, Jiaxing 314000, China)

⁽³⁾Department of Mechanical Engineering, Zhejiang Textile and Fashion College, Ningbo 315211, China)

[†]E-mail: dwjcom@zju.edu.cn

Received Mar. 5, 2010; Revision accepted Sept. 28, 2010; Crosschecked Jan. 31, 2011

Abstract: This paper presents a new approach for modeling a virtual garment intuitively and simply by sketching garment style lines. The user sketches directly onto the surface of 3D virtual human from arbitrary viewing directions, and the 3D garment suited to the virtual human can be created automatically. First, a distance field based allocation algorithm is proposed to find the 3D point which has the shortest given distance to the virtual human along the view direction. Then, the 3D style lines are generated by transforming from the 2D strokes on the human model and all the garment pieces are recognized from the 3D style lines. Finally, the 3D garment model is constructed by using the angle and offset based interpolation and Delaunay triangulation. In addition, we propose a body feature based template reusing method to fit the 3D garment to different virtual human models. The method can be adapted to designer habits and improve the usefulness of garment design. Examples show that the method is useful and efficient.

Key words: Sketch-based interfaces, 3D garment modeling, Distance field, Garment style template

doi:10.1631/jzus.C1000049

Document code: A

CLC number: TP391.72

1 Introduction

In the garment computer-aided design, the 3D modeling method is becoming more popular because of its intuitiveness, fitness, and realistic perception. More and more studies focus on designing a garment directly onto a 3D scanned body.

McCartney *et al.* (2000) represented the garment as a set of panels offset from the body surface. The garment panels were created around a static mannequin body. Kim and Kang (2002) divided the human model into four panels, and adopted a stereovision-

based algorithm to generate the garment surfaces. Wang *et al.* (2003a) separated the laser-scanned body into six parts, and then reconstructed the garment surface by connecting the human body slice vertices where they intersected with each part on the horizontal cutting plane.

Although the methods above can generate a 3D garment surface, the garment style is basically fixed and only a few parameters can be controlled. Therefore, this kind of method cannot match the user's design habit and the design inspiration would not be well used.

With the development of a sketch based method, applications in garment computer-aided design have been studied to improve the design intuitively and practically. The sketch based garment design can be classified into 2D and 3D methods.

Using 2D methods, Wang *et al.* (2003b) specified a garment sketch through a 2D stroke and then used a subdivision method to refine the garment mesh.

[†] Corresponding author

* Project supported by the National High-Tech R & D Program (863) of China (No. 2009AA04Z103), the Project of Public Technology Research in Industry (No. 2010C31001), the Research Fund for the Doctoral Program of Higher Education of China (No. 20100101110025), and the Natural Science Foundation of Ningbo City, China (No. 2010A610117)

© Zhejiang University and Springer-Verlag Berlin Heidelberg 2011

Turquin *et al.* (2007a; 2007b) allowed the user to draw an outline of the front and the back of the garment contours on a mannequin, and then used a distance field around the mannequin to generate garment surfaces. Decaudin *et al.* (2006) used the same method to generate garments and added seam lines during sketching garment contours to generate patterns. Zhang *et al.* (2009) constructed a 3D garment model from a sketched garment contour drawn in a 2D plane and mapped the 2D sketch to a 3D garment using the relative position between sketched garment contour and the outline of human projection.

Although the above methods have accomplished sketch based garment modeling, the design process is still on a 2D projection in the front or the side view; that is to say, the garment contour is 2D. The z -axis information is lost in the transformation from 2D to 3D. Although several algorithms have been adopted to estimate the z -axis value, the estimated value cannot be the real goal of the designer. It causes a difference between the design result and the design goal. In addition, these methods confine the garment contour design to the front or the side projection plane, while the design details in other view directions are lost. All these problems make it hard to design a complex garment.

For 3D methods, Lu *et al.* (2004) used a 3D interactive ball to allocate point position, and designed the garment piece according to the control points. A 3D garment design was obtained, but only garment pieces were shown, while the interactive method was inconvenient and professional hardware was necessary. Bae *et al.* (2009) designed a 3D sketch based system which sketches a 3D curve similar to 'paper and pen', but it is hard to apply to garment design systems because of the close relationship between garments and virtual human models. Wang *et al.* (2010) offered freehand drawing tools to enable designers to specify styling curves on the mesh surface of a reference model design. The mesh surface of the reference model is duplicated and trimmed into separate 3D mesh pieces by the styling curves, making the design more convenient and flexible, but the styling curves must be attached to the reference model surface.

In this paper we propose a sketch based garment modeling method on a 3D human model. After the designer has sketched style lines on virtual human

models in arbitrary view directions, the 3D garment fitted to the virtual human model can be created automatically. First, the human distance field is computed and stored using an octree construction, and the shortest point fast allocation method is studied, based on which, the user sketches style lines on the human body, and the 3D style lines are generated automatically according to the distance field and human model shapes. Finally, the garment surface is generated by using angle and offset based interpolation and the Delaunay triangulation method for all the garment pieces constructed using the 3D style lines. In addition, reuse of the method is studied to dress garments to different virtual human models.

2 System overview

The following are some terminologies related to our method: (1) Distance field, which saves the shortest distance from a set of points to the virtual human body. We use distance field to locate the 3D points that have the given shortest distance from the virtual human along a certain view direction. (2) Style line, a curve that is an approximation of the user stroke. The style lines determine garment shapes. (3) Garment piece, one closed area constructed using several style lines. The garment is constructed using several garment pieces. (4) Style template. The garment style information is encoded to a template according to human features to recreate a garment for different virtual human models.

This paper presents a method for modeling a 3D garment by sketching style lines on virtual human models. In contrast to existing methods where the sketching process is constricted to the front or back view, the user can sketch style lines in arbitrary view directions. According to the distance field, the human model shape, and the view direction, the user's 2D strokes are transformed into 3D style lines and the 3D garment can be generated using the 3D style lines.

The method we propose is performed in three main steps. The design interface is shown in Fig. 1a. First, the user sketches on a virtual human from the desired view direction according to the design request and operational convenience (Fig. 1b). Subsequently, the system follows the process of feature detection and smoothing treatment, and then removes noise

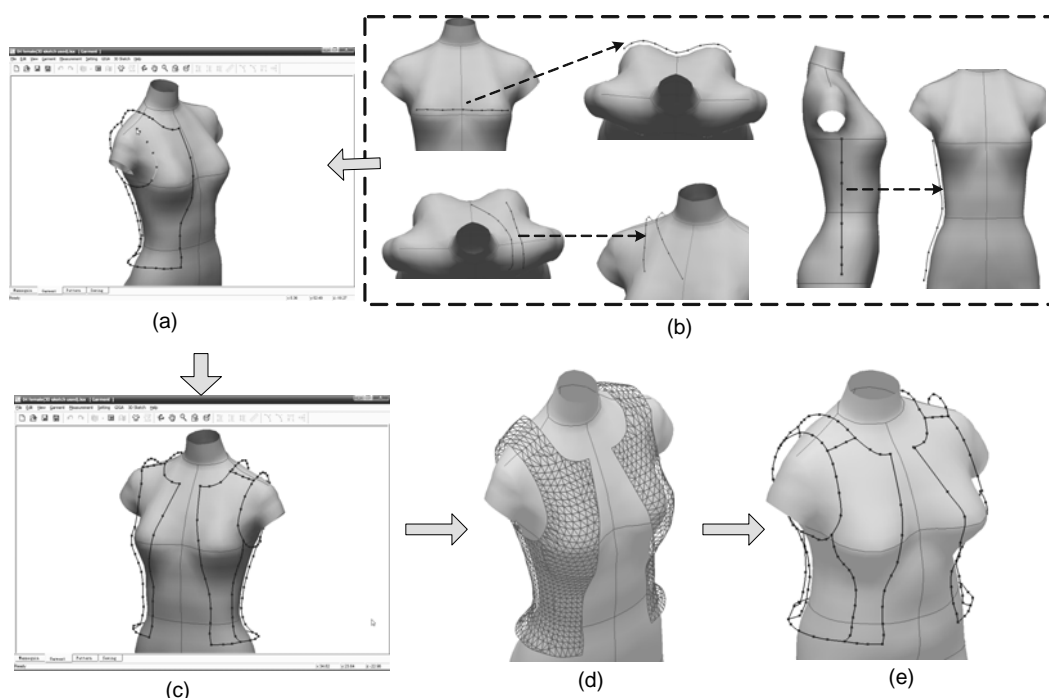


Fig. 1 Algorithm framework for modeling a 3D garment by sketching on an arbitrary view

(a) The interface of style lines sketching; (b) Sketch style lines in different view directions, with the left figures showing the design status of sketching style lines on the human model and the right figures showing the shape of 3D style lines generated automatically according to the human model shape; (c) The style lines of a designed garment; (d) Garment mesh; (e) Redressing the garment to different human models

after one stroke has been completed to form a cubic B spline. Several modification methods are offered to the user. When the user completes the whole design process, the system obtains the whole garment style lines at the same time (Fig. 1c). Then, the system recognizes the garment pieces and interpolates the inner points, and adopts a Delaunay triangulation to generate the garment piece mesh. Finally, all the garment piece meshes are merged to form a whole garment surface (Fig. 1d). Reusing the method, we fit the garment to different human models to improve the design efficiency. As shown in Fig. 1e, the garment is automatically fitted to another human body after adjustment.

3 Stroking 3D garment style lines

3.1 Allocating points in the 3D space

In the user stroke process, to allocate the 3D point that has the given shortest distance away from the virtual human along a certain view direction, we adopt a rapid search algorithm with adjusted step length. At first, we define a set of 3D grid points

that are around the virtual human in the given resolution. For each grid point, we use octree storage structure to store the shortest distance from the human body model. The octree is constructed using the following steps:

Step 1: According to the 3D grids around the human body, we find the maximum vertex P_{\max} and the minimum vertex P_{\min} , and then construct a bounding box AABB using P_{\max} and P_{\min} as the diagonal vertex (Fig. 2a).

Step 2: The AABB box is divided into eight sub-square boxes, each of which can be recursively decomposed until the decomposition meets the final conditions.

Step 3: Calculate the shortest distance for each sub-box vertex and store it to the octree structure.

The distance field is computed once for each virtual human body and saved as a file. At the beginning of garment design, the distance field is loaded from the file.

When we search for the point with the given shortest distance d from the virtual human in direction V , the following steps are adopted (Fig. 2b):

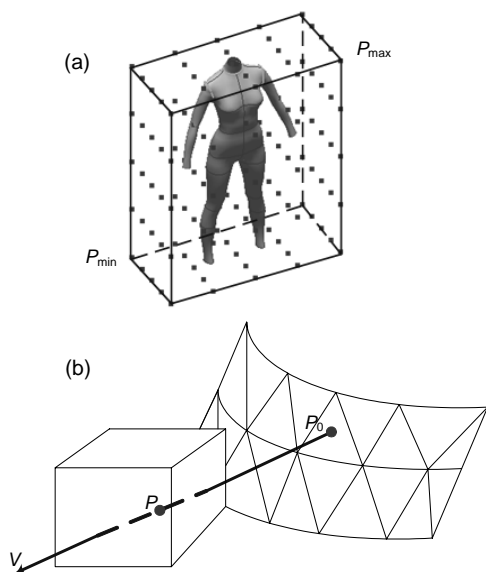


Fig. 2 Allocation of a 3D point

(a) Distance field division; (b) 3D point search

Step 1: Initialize parameters T , P , V , D , d , and δ . T is the search step length; P is the current search point; V is the search direction; D is the given shortest distance; d is the shortest distance between the current search point and the human body; δ is the allowed error value. Let $P=P_0$, P_0 is the intersection point of the view direction and human mesh.

Step 2: calculate d , $d=f(P)$, $f(P)$ is the function to calculate the shortest distance between P and the human body. Owing to the octree storage structure of the distance field, it is easy to obtain the shortest distance by tri-linear interpolation.

Step 3: if $|D-d|\leq\delta$, P is the desired point, stop; else, go to Step 4.

Step 4: if $d<D$, $P=P+VT$, $T=2T$, go to Step 2.

Step 5: if $d>D$, $T=T/4$, $P=P-VT$, go to Step 2.

3.2 Three-dimensional style line generation

When the user draws a 3D sketch, the system captures the mouse movement on the body surface to obtain a sketch line (Fig. 3a). A set of 2D points captured during the mouse movement can be transformed into a 3D point P_m . V_{dir} is the view direction. P_b is the intersection point of the line that passes P_m along V_{dir} and the human body. Using the algorithm mentioned in Section 2.1, with P_b being the initial search point and V_{dir} the search direction, we can obtain the desired point P_s , which has the given shortest distance from

the virtual human. P_s is the searched point of the sketch line.

In the mouse movement, each mouse position can generate a 3D point having the given shortest distance. The sketch line can be obtained by connecting these 3D points successively. Fig. 3b is a sketch line stroked by the user.

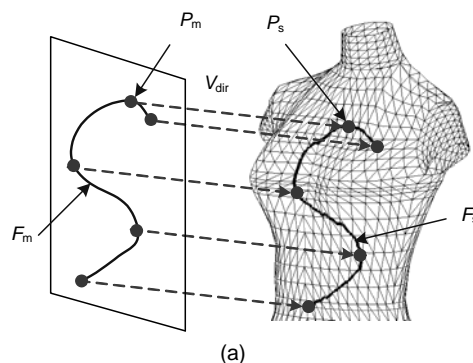


Fig. 3 Generation of the 3D sketch line and style line
(a) User stroke on the human body; (b) Sketch line; (c) Style line

Factors such as irregularity of stroke motions and variations in the drawing style can lead to low quality of the data. To overcome these problems, we use two steps to obtain the refined 3D style line. First, we resample the user stroke points. Then we use a B spline curve to approximate the user input.

In the resampling process, we use Igarashi's routine (Igarashi *et al.*, 1999). When there are too many points close together, we simply ignore some points. If the distance between the previous point and the current point is less than 10 pixels, we ignore this point. This simple process creates points further apart from each other, and appears to have no substantial impact on the results.

In the approximating process, we adopt the control point adjustment method (Yang *et al.*, 2004) to generate B spline curves for approximating the user

strokes. First, initialize a B spline curve L_{spl} with feature points P_i as the control points to approximate the user stroke points. The feature points can be obtained by applying Li's method (Li *et al.*, 1994). Then calculate the error with a square distance minimization method for each segment of L_{spl} . If a segment of L_{spl} has a large error, then add a control point to this segment. If there is a redundant control point, remove it. Once the L_{spl} control points have been updated, error calculation will be applied again to produce a new approximated B spline curve. This procedure is repeated until a satisfactory result is obtained. Fig. 3c is a refined style line.

3.3 Modification of 3D style lines

Convenient modification operations are provided to design the garment details more accurately (Fig. 4), including:

1. Extend: take one of the endpoints of S_1 as the start point to stroke a new sketch; the new sketch is merged to a new style line.

2. Break: take one of the non-endpoints of S_1 , P_1 , as the start point to stroke a new sketch line S_2 , and S_1 is broken by P_1 ; or move the endpoint of S_3 to P_2 , by which S_1 is broken.

3. Merge: move the endpoint of S_2 to the endpoint of S_1 and merge S_1 , S_2 into a whole style line.

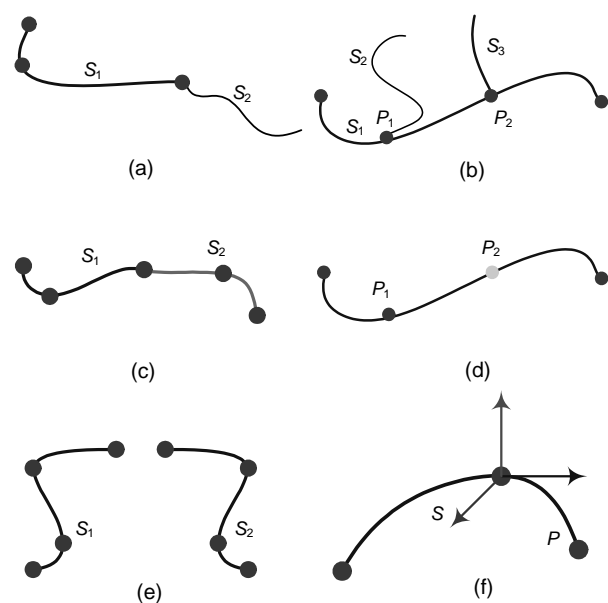


Fig. 4 Three-dimensional style modification

(a) Extend; (B) Break; (C) Merge; (D) Add/Delete control points; (E) Mirror; (F) Adjust the offset value

4. Add/Delete control points: delete the control point P_1 or add the control point P_2 .

5. Mirror: S_2 is generated according to the vertical mirror of S_1 .

6. Adjust the offset value: a local 3D coordinate axis is offered to guide the point moving in any direction to adjust the offset value from the virtual human.

According to the final requirement, the modification can be divided into fixed distance modification and non-fixed distance modification. The fixed distance modification keeps the offset value unchanged in the modification process (Figs. 4a–4e). If the designer wants to control the style line when it has a different offset value from the given one, e.g., not very close to the body, we use a method similar to Wang *et al.* (2005)'s method to modify the style line in the 3D space (Fig. 4f).

4 Generating the garment mesh

4.1 Obtaining garment pieces from style lines

A whole garment consists of several garment pieces, each of which is a closed area with several style lines as its boundary. The garment piece can be defined as $GP = (\{L_i\}, M, T)$, where $\{L_i\}$ is the boundary style line, M is the mesh of this garment piece, and T is the texture information of this garment piece. As shown in Fig. 5a, style lines L_1 , L_2 , L_3 , and L_4 construct one garment piece, and the texture mapped to this garment piece is as shown in Fig. 5b.

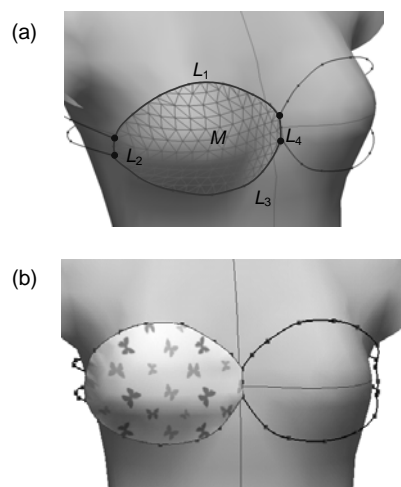


Fig. 5 Garment pieces

(a) A garment piece; (b) Texture of the garment piece

To obtain all the garment pieces from style lines, we adopt the loop detection method (Wang *et al.*, 2001) to find all the closed areas in style lines. Because of the limitation of the search algorithm, user interaction may be needed to delete the non-garment piece areas.

4.2 Angle and offset based interpolation

Before generating the garment mesh, the garment pieces should be interpolated to obtain the inner points. Garment piece interpolation points have special requirements. First, the interpolated points should have a certain offset value from the virtual human so that the garment can obtain fit surfaces. Second, the interpolation points should be evenly distributed to obtain better mesh quality. The interpolation method based on angle and offset can meet these requirements well (Fig. 6).

The interpolation operation in height position y is as shown in Fig. 6b. O is the center point of the cross section of the human body in y . P_0 and P_n are the intersection points with garment piece boundaries and the horizontal plane. Q_0 and Q_n are the intersection points of vectors OP_0 , OP_n and the human body mesh, respectively. α is the angle between OP_0 and OP_n . The angle step length is α_{step} . d is the given offset value from the virtual human. h_1 , h_2 are the offset values adjusted by the user. The interpolation has the following steps:

Step 1: Initialize OP_i with OP_0 .

Step 2: Let OP_i rotate an angle of α_{step} ; then the angle between OP_i and OP_0 is α_i .

Step 3: If $\alpha_i > \alpha$, stop; else, go to Step 4.

Step 4: Calculate the intersection point Q_i of vector OP_i and the human body mesh.

Step 5: Calculate the offset value d_{offset} at angle α_i , $d_{\text{offset}} = h_2 + (h_1 - h_2)\alpha_i/\alpha$.

Step 6: Take Q_i as the start point, and along vector OQ_i , search for the point P_i whose shortest distance from the virtual human is d_{offset} , so P_i is the interpolation point at angle α_i . Go to Step 2.

For a garment piece, we interpolate in a set of y values according to a height step from the top to the bottom of the garment piece boundary. It is possible that more than one interpolation range needs to be used in a height. All the inner points can be obtained after the complete interpolation process. The points in Fig. 6c are the interpolation points of the garment piece.

4.3 Garment mesh generation with Delaunay triangulation

A Delaunay triangulation method is used to generate a garment mesh. However, the triangulation of 3D points is complex and it is hard to ensure high mesh quality. As is known, the mesh is created using geometric information and topologic information. In Section 4.2, the mesh vertices have been interpolated. Also, taking into account the garment geometric shape, we can project these points into a cylinder and expand it. Triangulation is performed on a 2D plane and the topologic information can be obtained. Mapping the topologic information to 3D geometric information, the 3D mesh can be generated. A garment piece mesh is shown in Fig. 6d.

The mesh topology of garment pieces is separated, and all the garment pieces need to be merged to generate a complete garment mesh. Through triangulation, the topological structure of the garment piece has been obtained, provided that the two-garment-

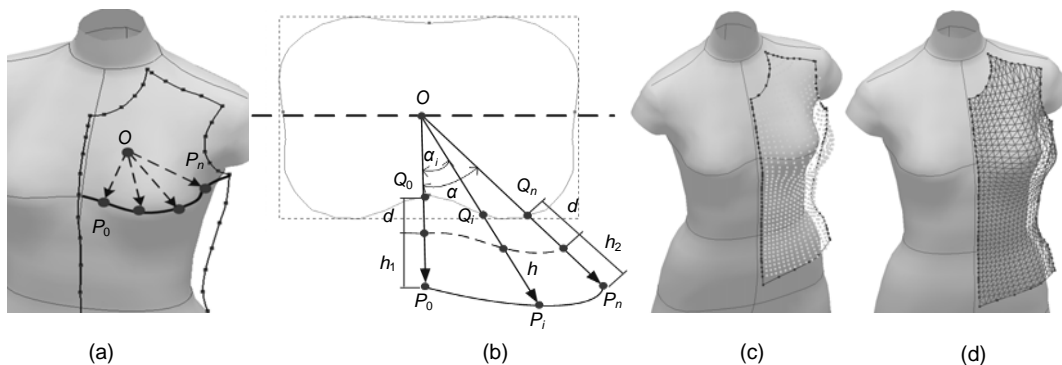


Fig. 6 Points interpolation and mesh generation: (a) cutting the garment piece with a horizontal plane; (b) angle and offset based interpolation; (c) interpolation points; (d) mesh generation

piece mesh vertex and topology information are merged. However, the points on the common boundary are duplicated. Therefore, we must first identify the boundary to remove the duplicate boundary points, and then follow the merging process. Fig. 7 shows the merging process for trousers. There are eight pieces in total. Fig. 7d is the merging result.

5 Three-dimensional garment style template

Due to the diversity of human bodies, the garment design result will not be suitable for all other human bodies. As shown in Fig. 8b, the garment is designed for the human model in Fig. 8a; it is not suitable for the human model in Fig. 8b because of its different body shape and size. It is obvious that S_1 , S_2 , and S_3 have affected the body. To solve this problem, a human feature based garment template method is adopted to redress the garment correctly.

5.1 Recognizing human feature points

According to the human feature information, we extract seven main feature points (Fig. 8c). A series of

horizontal cutting planes are used to intersect with the human body. By judging the intersection cross section geometric shape information, the feature points can be found. An alterable step method for plane cutting is adopted to speed up the recognition process.

The crotch point is the lowest point on the symmetrical plane; the waist point is in the cross section that has the shortest girth between the chest and hip feature points; the neck point is the most inward depression point on the symmetrical plane; the chest point is the most prominent point between the neck and the waist; the knee and the ankle points can be calculated using the proportions of the human body.

5.2 Garment style reuse with the template

Define a style line template $TL=(P, C_h, C_c)$. Here, $P=\{P_i\}$ denotes the 3D control points of the style line. $C_h=\{C_{hi}\}=\{(\lambda, idx_1, idx_2)\}$ denotes the relative height information between P_i and the adjacent body feature points. $C_c=\{C_{ci}\}=\{(\alpha, \sigma)\}$ denotes the rotational angle and offset of P_i on the horizontal plane passing by P_i . Thus, the whole garment style template can be defined as $TG=\{TL_i\}$. The following two steps form the template calculation with an encoding method:

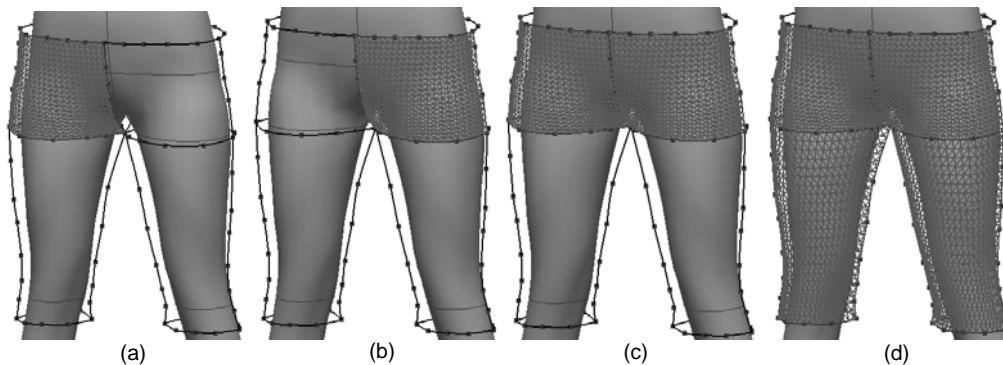


Fig. 7 Merging the garment pieces: (a, b) separate garment pieces; (c) merging two garment pieces; (d) whole garment

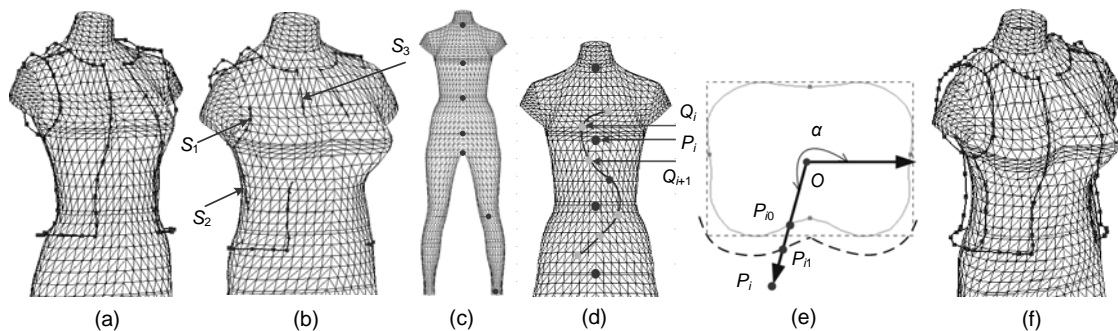


Fig. 8 Three-dimensional garment style template: (a) original style line; (b) redressing directly; (c) human feature; (d) encoding the height information; (e) encoding the angle and offset information; (f) redressing the garment

1. Encode C_h . According to the relative height relationship of the style line control point and the human feature points (Fig. 8d), we can obtain idx_1 and idx_2 . Let P_i be a control point on the garment style line, Q_i and Q_{i+1} be the two adjacent feature points, where λ is the proportion of P_i between Q_i and Q_{i+1} , and idx_1 and idx_2 are indexes of the individual control points in the feature point array.

2. Encode C_c . As shown in Fig. 8e, $P_i = P_{i0} + P_{i1}P_{i0} + P_iP_{i1} = f(P_i) + D(P_i) + E(P_i)$, where $f(P_i)$ is a function to obtain the intersection point of OP_i and the human body, $D(P_i)$ is the initial offset from the garment to the human body, and $E(P_i)$ is the interactive editing distance input by the user. $D(P_i)$ is a constant set by the user and $E(P_i)$ is the design information. Thus, we let $\alpha = E(P_i)$; α is the angle between P_i and the x axis.

For a garment, encode all the style lines and save the encoded information as the style template. When dressing the garment to a new target human body, we use C_h in the garment to calculate the new height

position of the style line control points and use C_c to rotate it to a proper position. Then according to the target human body feature, the style lines adjust to the new body size and shape. In Fig. 8f, the style template applies to the body successfully. In Figs. 9a, 9d, and 9g, some garment styles on some standing models were designed, and they can be generated automatically for other standing models or individual human models using our method (Figs. 9b, 9c, 9e, 9f, 9h).

6 Examples

The examples presented in Fig. 10 were drawn in a few minutes. A wide range of garments, such as skirts, shirts, trousers, and other less-standard garments, can be designed using our system. The users can easily become familiar with our system and express their creativity more directly.

In this work we hide the human model arms to make the design more convenient on the side parts of the human model. When designing sleeves, the arms

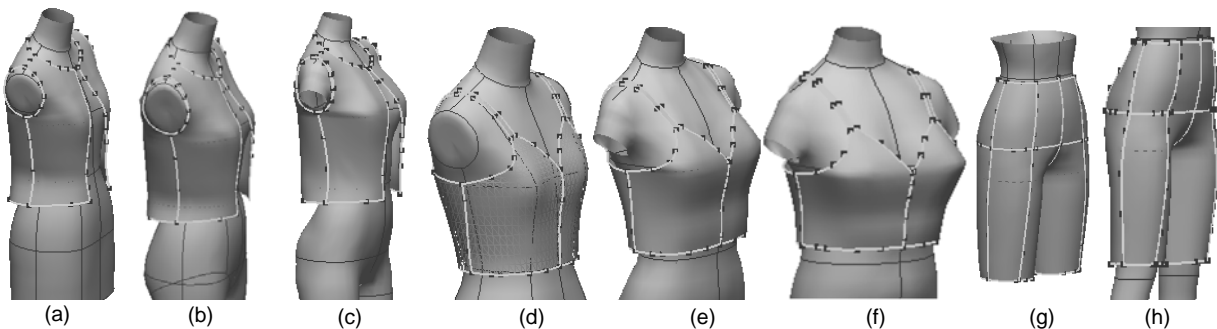


Fig. 9 Garment style reuse examples

Garment styles (a, d, g) on standing models can be generated automatically for other standing models or individual human models (b, c, e, f, h) using our method

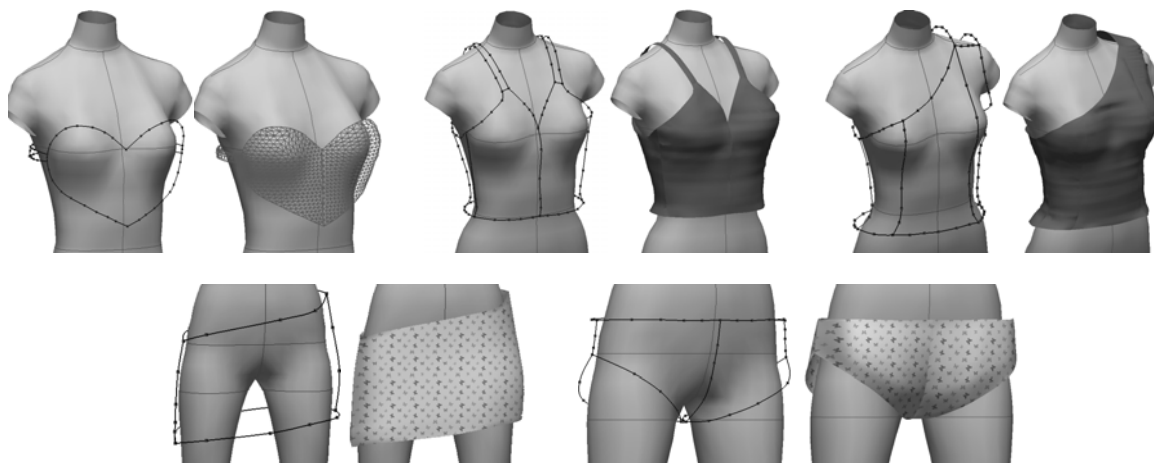


Fig. 10 Design examples

A wide range of garments, such as skirts, shirts, trousers, and other less-standard garments, can be designed using our system

can be shown. Because of the more complex requirement for sleeves, we use a hybrid method with sketch and parameters to design them. The detailed method was presented in Geng *et al.* (2009).

7 Conclusions and discussion

We have presented a way to design virtual garments using a sketch based method. The user can sketch garment styles in arbitrary view directions. The advantages of our method can be concluded as follows:

1. Realize 3D style lines in arbitrary view directions. In comparison with the system in which the user can stroke only in the front or side view, our system supports the user rotating the human model to a suitable view direction. In this way, the information of z-axis direction can be obtained accurately instead of being estimated, so that the design result is closer to the user's intent. Sketching in an arbitrary view direction also provides a convenient tool for the user to make more detailed and complex designs in the side part of a garment.

2. Achieve the fitting garment surface generation method. By using the offset and angle based interpolation method, the garment piece inner points are well distributed and have reasonable distances from the human body according to the garment piece boundary line. Combined with the improved Delaunay triangulation method, the garment mesh is more associated with the human body.

3. Based on the 3D garment style template, we have achieved the design reuse of a 3D garment. The garment style template can match different human bodies according to body features, and thus inherit the originality and enhance the design efficiency.

There are still some problems. We are currently focusing on two directions of research. First, although we provide sketch based interaction, there is still no intelligent suggestion on guiding the user to make more creative works. Second, we will support 3D garment accessory construction to enrich the garment styles. Follow-up studies will focus on resolving these problems.

References

- Bae, S.H., Balakrishnan, R., Singh, K., 2009. Everybody-LovesSketch: 3D Sketching for a Broader Audience. Proc. 22nd Annual ACM Symp. on User Interface Software and Technology, p.59-68. [doi:10.1145/1622176.1622189]
- Decaudin, P., Julius, D., Wither, J., Boissieux, L., Sheffer, A., Cani, M.P., 2006. Virtual garments: a fully geometric approach for clothing design. *Comput. Graph. Forum*, **25**(3):625-634. [doi:10.1111/j.1467-8659.2006.00982.x]
- Geng, Y.L., Lu, G.D., Wang, J., 2009. Sketch-Based 3D Sleeve Modeling and Reusing Method for Garment CAD. World Congress on Computer Science and Information Engineering, p.711-715. [doi:10.1109/CSIE.2009.756]
- Igarashi, T., Matsuoka, S., Tanaka, H., 1999. Teddy: a Sketching Interface for 3D Freeform Design. SIGGRAPH, p.409-416.
- Kim, S.M., Kang, T.J., 2002. Garment pattern generation from body scan data. *Comput.-Aided Des.*, **35**(7):611-618. [doi:10.1016/S0010-4485(02)00081-7]
- Li, S.Z., Wang, H., Ang, T.H., Bey, K.M., 1994. Detection of corners on 3D space curves. *SPIE*, **2354**:339-346. [doi:10.1117/12.189102]
- Lu, Y.L., Hu, J.L., Li, R.Q., 2004. Design of 3D fitted garment pieces in a virtual environment. *J. Donghua Univ. (Nat. Sci.)*, **30**(5):53-59 (in Chinese).
- McCartney, J., Hinds, B.L., Seow, B.L., Gong, D., 2000. Dedicated 3D CAD for garment modelling. *J. Mater. Process. Technol.*, **107**(1-3):31-36. [doi:10.1016/S0924-0136(00)00695-6]
- Turquin, E., Cani, M.P., Hughes, J.F., 2007a. Sketching Garments for Virtual Characters. ACM SIGGRAPH, p.175-182.
- Turquin, E., Witter, J., Boissieux, L., Cani, M.P., Hughes, J.F., 2007b. A sketch-based interface for clothing virtual characters. *IEEE Comput. Graph. Appl.*, **27**(1):72-81. [doi:10.1109/MCG.2007.1]
- Wang, C.C.L., Chang, T.K.K., Yuen, M.M.F., 2003a. From laser-scanned data to feature human model: a system based on fuzzy logic concept. *Comput.-Aided Des.*, **35**(3):241-253. [doi:10.1016/S0010-4485(01)00209-3]
- Wang, C.C.L., Wang, Y., Yuen, M.M.F., 2003b. Feature based 3D garment design through 2D sketches. *Comput.-Aided Des.*, **35**(7):659-672. [doi:10.1016/S0010-4485(02)00091-X]
- Wang, C.C.L., Wang, Y., Yuen, M.M.F., 2005. Design automation for customized apparel products. *Comput.-Aided Des.*, **37**(7):675-691. [doi:10.1016/j.cad.2004.08.007]
- Wang, C.C.L., Zhang, Y.B., Sheung, H., 2010. From designing products to fabricating them from planar materials. *IEEE Comput. Graph. Appl.*, **30**(6):74-85. [doi:10.1109/MCG.2009.155]
- Wang, Y., Hu, S.G., Sun, W.N., Cui, X.F., 2001. Loop detection in 2D drawings based on node pretreatment. *J. Comput. Aid. Des. Comput. Graph.*, **13**(9):774-778 (in Chinese).
- Yang, H., Wang, W.P., Sun, J.G., 2004. Control point adjustment for B-spline curve approximation. *Comput.-Aided Des.*, **36**(7):639-652. [doi:10.1016/S0010-4485(03)00140-4]
- Zhang, Y., Sun, Z., Liu, K., Zhang, Y., 2009. A Method of 3D Garment Model Generation Using Sketchy Contours. Proc. 6th Int. Conf. on Computer Graphics, Imaging and Visualization, p.205-210. [doi:10.1109/CGIV.2009.58]