3D Clothing Fitting Based on the Geometric Feature Matching

Zhong Li [1, 2, 3], Xiaogang Jin [2], Brian Barsky [3], Jun Liu [1]
1. Department of Mathematics and Science, Zhejiang Sci-Tech University, Hangzhou, China, 310018
2. State Key Lab of CAD&CG, Zhejiang University, Hangzhou, China, 310058
3. Computer Science Division, University of California, Berkeley, CA, USA, 94720
lizhong@zstu.edu.cn

Abstract

The 3D clothing fitting on a body model is an important research topic in the garment computer aided design (GCAD). During the fitting process, the match between the clothing and body models is still a problem for researchers. In this paper, we provide a 3D clothing fitting method based on the feature point match. We firstly use a new cubic-order weighted fitting patch to estimate the geometric properties of each vertex on two mesh models. Feature points are then extracted from two models and a new matching function is constructed to match them according to curvature and torsion. We interactively select several key feature points from two limited feature point sets to compute the transformation matrix of the clothing model. Finally the second match is performed to achieve the precise match between the clothing and body models. The experimental results show that our 3D clothing fitting method is simple and effective.

1. Introduction

With the rapid development and popularity of the online garment shopping, the 3D clothing fitting has become a hot topic in the garment CAD. During the online garment shopping, customers not only hope to see the 3D effect of the apparel, but also want to know whether the apparel fits them or not. An effective method is to provide the customer with a specific 3D graphical body model (called an avatar) and display the selected clothing on this avatar [1].

Recently, the virtual garment fitting has gotten broad attention for researchers. The early method is to paste the 2D clothing pictures onto the 2D body model. This method is simple, but it fails to the interactive display. For the 3D clothing fitting, they usually build up a body model using the geometric method, and then map the texture of clothing to the corresponding part of the body model. The problem is that it lacks of the realistic fitting effect [2]. Some improved methods create more realistic clothing models based on the physical modeling [3], and perform the garment fitting according to the seaming forces attracting to pieces of cloth [4]. Because the physical garment modeling is some complicated and takes too much implementation time, this process sometimes influences the real-time effect of the virtual clothing fitting. Currently, another popular clothing fitting method is based on the interactive operation for the mesh models. They interactively choose feature points from the given garment and body models, then match them and save the positions of two models for the further display. This approach enhances the realistic display of the garment. The problem is that too many interactive selections from the point cloud data influence the efficiency of the clothing fitting while too fewer selections bring us the difficulty for the accurate match. For the match of the garment and body models, reducing the interaction operation and obtaining the precise matching algorithm are still the challenges for researchers.

In this paper, we present a new 3D garment fitting method. We firstly search feature points on the clothing and body models and match them by constructing the matching function, and then several key feature points are interactively selected from the limited feature point sets to compute the rigid transformation matrix for the clothing model. Finally, we perform the second match to adjust the garment fitting on the body model.

2. Related work

The related work of our 3D garment fitting includes the estimation of differential geometric properties on the mesh models, the extraction of feature points from the mesh models, the feature point match between two mesh models and the matrix construction for the rigid transformation.

The estimation of differential geometric properties of each vertex on the mesh model is the basic operation during our 3D clothing fitting process. For the normal vector estimation, there have been many existing methods [5]. The curvature estimation is mainly divided into two categories. One category is to approximate curvatures by formulating a closed form for differential geometry operators [6]. The other category involves fitting a local surface [7]. Torsion is an important invariant value for the rigid transformation. But it seems to get little attention on the mesh models [8]. In this paper, we will introduce the principal geodesic torsion and apply it for the mesh model match.

For fitting the clothing on a body model, one important step is the feature point extraction from two mesh models. Here the feature points include the ridges and the valleys. The feature point is normally obtained by the approximation of discrete principal curvature and the principal curvature derivative about the principal direction [9]. These feature points can be detected by constructing the local fitting surface, or by other numerical approximating methods [10].

After acquiring the feature points from the clothing and body models, we need to obtain the match relation of them between two models. Besl and Mckay presented a classic iterative closest point (ICP) matching algorithm [11]. It has to know the reliable initial match values. Another matching method is based on the principal components analysis (PCA) [12]. For the object match with the different geometric shape and topological structure, above methods are hard to get satisfactory match results. Recently, some researchers constructed the local shape function or the shape descriptor to match objects [13, 14].

After getting the match relation of feature points on two mesh models, we can use the least squares method, ICP or other registration methods to obtain the rigid transformation matrix.

3. 3D clothing fitting on the body model

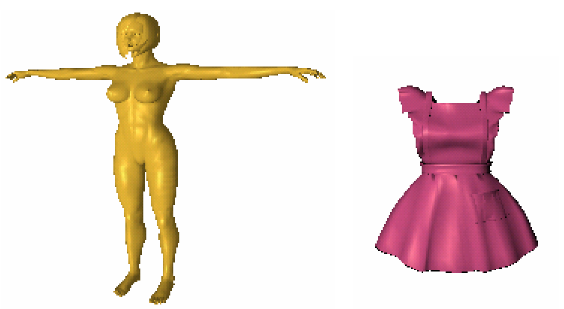


Fig 1. A woman mesh model and a clothing mesh model

The main idea of our clothing fitting algorithm is that we firstly construct the local fitting patch to estimate curvature and torsion of each vertex on body and clothing models which are shown in Fig 1. Secondly we use the feature extraction method to obtain the feature points. Thirdly we build up a matching function based on curvature and torsion to match similar feature points and interactively acquire several key feature points from both models. Finally, we calculate the transformation matrix according to pairs of key feature points.

3.1 Geometric property estimation of each vertex on both models

Before extracting feature points from the garment and body models, we need to estimate curvature of each vertex on both models, which may influence the final matching precision.

Recently, Razdan and Bae [7] presented a curvature estimation method based on the weighted bi-quadratic Bézier patch. As we know, curvature is related to the second-order derivatives and the third-order surface is a better fit to the shape of a local area. Here we construct a new weighted bicubic Bézier patch to estimate the geometric properties of each vertex. A bicubic Bézier surface is written as

$$B(u,v)=\sum_{i=0}^{3}\sum_{j=0}^{3}B_{i,3}(u)B_{j,3}(v)b_{ij}, \quad u,v\in[0,1],$$

where $B_{i,3}(u)$, $B_{j,3}(v)$ are the Bernstein basis functions and b_{ij} are the Bézier control points which form the Bézier control net.

We should compute the parameters (u_i,v_i) of vertex p_i and other fitting points at first. Here we take the vertex p_i and the vertices in its 2-ring neighborhoods as the fitting point. For p_i, its approximate normal vector N is computed by the arithmetic average of all the normal vectors of its neighboring triangles. We create a tangent plane which is vertical to N and set p_i as the origin of its coordinate system. Then we construct a local Cartesian coordinates in this plane. The direction from one projected point to the vertex p_i is set as the x-axis and one vertical direction as the y-axis. All fitting points are projected in this plane and the coordinates of all projected points are enclosed by a min-max box. This min-max box is finally scaled to $[0,1]^2$. The coordinates of projected points in this range are regarded as the corresponding parameters of fitting points. If some projected points of vertices in the tangent plane coincident or some lines connected by two adjacent projected points are self-intersecting, we change another fitting point as the origin of the coordinate system to calculate a new tangent plane or replace fitting vertices in the 2-ring neighborhood by vertices in the 1-ring neighborhood to avoid these situations.

After obtaining the corresponding parameters (u_i,v_i) of vertex p_i and other fitting points, we build a linear equation system $Ax=B$, where

$$A=\begin{bmatrix} B_0^3(u_0)B_0^3(v_0) & B_0^3(u_0)B_1^3(v_0) & \cdots & B_3^3(u_0)B_3^3(v_0) \\ B_0^3(u_1)B_0^3(v_1) & B_0^3(u_1)B_1^3(v_1) & \cdots & B_3^3(u_1)B_3^3(v_1) \\ & & \vdots & \\ B_0^3(u_n)B_0^3(v_n) & B_0^3(u_n)B_1^3(v_n) & \cdots & B_3^3(u_n)B_3^3(v_n) \end{bmatrix},$$

$$x=[b_{0,0} \quad b_{0,1} \quad \cdots \quad b_{3,3}]^T, B=[p_0 \quad p_1 \quad \cdots \quad p_n]^T.$$

From this system of equations, the vector x is solved by the least squares method to determine the control points *bij*. However, the fitting surface sometimes does not reflect the local shape of each vertex. In order to describe the local shape more accurately, we add the adjusting matrix and factor to modify the system as follows

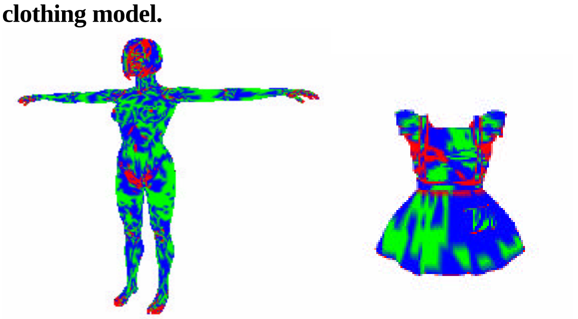
$$\begin{bmatrix} aA \\ (1-a)S \end{bmatrix}[x]=\begin{bmatrix} aB \\ 0 \end{bmatrix},$$

where A, x, B are defined above, the matrix S is added to make the control point distribution of the bicubic Bézier surface as uniform as possible. We find the following matrix is a good solution which means to minimize the second differences of the boundaries in the control net [15]

$$S=\begin{bmatrix} 1 & -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -2 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -2 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -2 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & -2 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -2 & 0 & 0 & 0 & 1 \end{bmatrix}$$

The factor a is in [0,1] and is adjusted according to the mesh noise density. When noise is dense, a is set lower, whereas, a is set higher. Normally it is set as 0.8.

(a). Mean curvature models of a woman model and a clothing model.



(b). Gaussian curvature models of a woman model and a clothing model.

Fig 2. Curvature models. (Red: high values; Blue: medium values; Green: low values)

For the modified system of equations, we also use the least squares method to solve the control points b_{ij}. For each p_i, its geometric property estimation is obtained by the corresponding point $B(u_i,v_i)$ on the local fitting surface $S(u,v)$. The mean curvature and Gaussian curvature on the point can be computed from the differential geometry formulas. Fig 2 is the mean curvature and Gaussian curvature models of the woman and clothing models.

We can also estimate the torsion property from this local fitting surface. Torsion, like curvature, is an important geometric property of the object's rigid transformation. For the point on the continuous surface, the torsion is normally measured by the geodesic torsion. Because the curve passing the given point on the surface is not determined, we generally compute the geodesic torsion according to some specific curves passing through the given point on the surface. One curve is the curvature line, but we know the geodesic torsion along the curvature line is zero from the differential geometry knowledge. Another curve is the torsion line, namely, the direction along the angle bisector of two principal directions. We know the geodesic torsion attains the maximum along the torsion line on the given point. Here we define it as the principal geodesic torsion. For the discrete mesh model, there is the similar torsion property. In this paper, we introduce the principal geodesic torsion and use it for our feature point matching. For the principal geodesic torsion computation, we have the following theorem.

Theorem. For the principal geodesic torsion $t_{\max}$ on the point of the surface, its value can be calculated by the mean curvature H and Gaussian curvature K, i.e., $t_{\max} = \sqrt{H^2 - K}$.

The detailed proof is in Ref [15].

3.2 Feature point extraction from both models

We extract the feature points from the clothing and body models according to the curvature property. Here the feature points include the ridge and valley points. The feature point judgment is related to the calculation of curvature values and their derivatives [9]. For discrete triangular mesh models, we cannot explicitly calculate these derivatives on each vertex. Several estimation methods have been proposed to obtain the ridge point and the valley point. Here we use Stylianou's method [10] to detect these feature points.

3.3 The match acquisition of feature points from two models

For the 3D clothing fitting on a body model, the important operation is to match two models appropriately. Because the clothing and body models have the different geometric shape and topological structure, current ICP matching algorithms cannot get satisfactory results.

Recently, Gal and Cohen-Or [14] presented a new algorithm for the match of two similar objects or the local part match of objects. They constructed a matching function about curvature property and it considers not only curvatures of each vertex and its neighborhoods, but also uses the curvature variance in the neighborhood as the reference, they got a better match result for the local parts of an object or similar objects.

As we know, torsion is another intrinsic geometric property on the surface, but it has not gotten enough attention for the mesh processing. In this paper, we construct a new matching function based on not only curvature but also torsion

$$S = \sum_{p_i \in 1-ring} W_1 Area(p_i)[Curv(p_i)^2 + Tors(p_i)^2]$$

$$+ W_2 NC(p_i) VarC(p_i) + W_3 NT(p_i) VarT(p_i),$$

where $Area(p_i)$ is the sum of triangle areas of the 1-ring neighborhood of vertex p_i, $Curv(p_i)$ and $Tors(p_i)$ denote the curvature and the principal geodesic torsion on vertex p_i, $NC(p_i)$ and $NT(p_i)$ are the number of minimum(s) or maximum(s) curvatures and principal geodesic torsions in the 1-ring neighborhood, $VarC(p_i)$ and $VarT(p_i)$ are the curvature variance and the principal geodesic torsion variance in the 1-ring neighborhood, W_1, W_2 and W_3 are threshold values, here we set them to 0.33 respectively.

In the new matching function, we add the torsion property to get the reliable matching result from feature points between the clothing and body models, as shown in Fig 3. In the whole matching process, we also need to do some preliminary operations in advance. For example, in order to reduce the wrong match, we get rid of feature points on the head, hand and foot parts of the body model and exclude feature points on the edge of the clothing model. For the body model, we compute its centroids position, then judge whether the feature point needs to be matched by the distance between the centroids and the feature point. For the clothing model, the edge of the clothing model is judged by the number that the edge belongs to the triangle in the mesh model.

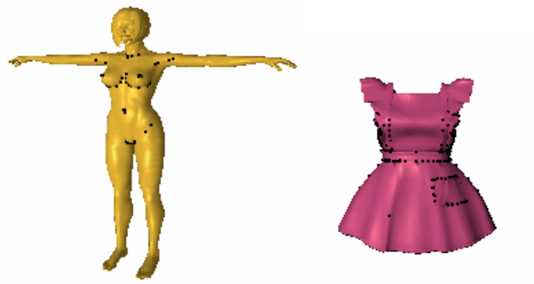


Fig 3. The feature point matching using the curvature and torsion property

Using the new matching function can get rid of redundant feature points between the clothing and body models. However, because of the shape complexity of the clothing and body models, the match relations of feature points are not always correct. We also know too many match relations of feature points will also influence the computation speed of the following transformation matrix. A compromising method is to interactively select several key feature points before the next rigid transformation matrix construction, as shown in Fig 4. Because the feature point relation is chosen only from the limited feature points sets instead of the huge cloud of vertices, the process is convenient.

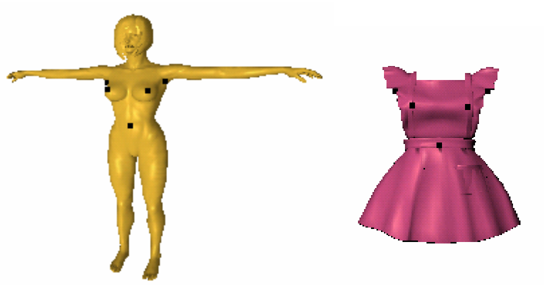


Fig 4. Key feature point acquisition from each model

3.4 The transformation matrix construction for the clothing model

Let B_i and G_i be the coordinate vector of the feature point on the body model and the corresponding feature point on the clothing model. After getting the match relations of key feature points between two models, all coordinate vectors from both models should satisfy the following coordinate transformation equation

$$\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_n \end{bmatrix} = R(q_x, q_y, q_z) \times \begin{bmatrix} G_1 \\ G_2 \\ \vdots \\ G_n \end{bmatrix} + T,$$

where n is the number of key feature points, $R(q_x, q_y, q_z)$ is a rotation matrix, T is a translation vector.

We apply these key feature points of two models for the above equation and minimize the following function

$$f = \sum_{B_i \in B} \left\| R(q_x, q_y, q_z) G_i + T - B_i \right\|^2 .$$

For this equation, we use the singular-value decomposition (SVD) method to calculate the matrix R and T which realize the rough match between the clothing and body models.

If there is the size difference between the clothing and body models, we perform the scaling operation before the rough match. The scaling value is calculated by comparing the difference between the corresponding feature point and each model's centroids. After the rough match, we also align the clothing model by the scaling operation until the clothing model covers the corresponding part of the body model appropriately.

In order to get the precise clothing match on the body model, we can do the second matching process. Namely, after obtaining the matrix R and T by the rough match, we calculate the new position of key feature points on the clothing model, then use above matching method to compute new R and T again.

4. Experimental results

We use VC++6.0 and OpenGL to implement our 3D virtual clothing fitting algorithm. Different body and clothing models are used to test the efficiency and robustness of our method. Fig 5(a) is the initial positions of a woman model and a short-sleeved gown model respectively. For two models which are in different coordinate systems and have no prescient relations, we use our algorithm to achieve the fitting effect of the clothing on the body model. Fig 5(b) is a woman model and a tight short skirt model. Fig 5(c) is a man model and a suit model. Fig 5(d) is a young man model and a T-shirt model. These clothing fitting results are realized by our feature matching method as shown in Fig 5. Table 1 lists the relevant data of the transformation matrix that makes the correct match of the clothing and body models during our experiment.

We compare our 3D clothing fitting algorithm to other existing methods. Popular method displays the clothing on the body model by the complicated interaction in advance while our algorithm uses fewer interactions from the limited feature point sets which is convenient and is suitable for different clothing and human models. Compared with the virtual clothing showing based on the physical clothing modeling and the seamed cloth fitting process, our feature matching method is faster and can be used in the real-time online clothing display. Compared to the traditional clothing display by pasting 2D pictures on the avatar, our garment fitting system permits the interactive and dynamic clothing display, which is suitable for the customers. Fig 6 is a set of clothing fitting on a woman model with different walking gestures.

(a). The short-sleeved gown fitting on a woman model

(b). The tight skirt fitting on a woman model

(c). The business suit fitting on a man model

(d). The T-shirt fitting on a young man model

Fig 5. The clothing fitting result of different models

Fig 6. The clothing fitting on a woman model with different walking gestures

Table 1. The experimental data for matching the clothing model and the body model

Experiment result	Rotation vector	Translation vector	Scaling vector
Fig 5(a)	(-0.1, -28.3, 22.1)	(-0.83, -1.53, -2.38)	(0.83, 0.82, 0.93)
Fig 5(b)	(0.4, -24.7, 23.9)	(0.69, -1.27, -1.98)	(0.89, 0.88, 0.89)
Fig 5(c)	(0.2, -20.3, 22.8)	(-0.10, -0.18, -0.28)	(0.81, 0.77, 0.83)
Fig 5(d)	(0.2, -20.1, 19.9)	(0.14, -0.26, -0.40)	(0.85, 0.72, 0.86)
Fig 6	(0.3, -24.9, 33.5)	(0.33, -0.39, -0.69)	(0.73, 0.78, 0.75)

5. Conclusion and future work

A 3D virtual fitting algorithm based on the feature matching is proposed in this paper. Our approach uses curvature and torsion to match feature points on the clothing and body models. Only few interactive selecting operations are needed to compute the rigid transformation matrix. The second match for the clothing model helps us achieve the satisfactory clothing fitting effect.

Currently, we still need a couple of interactive operations to select key feature points. How to achieve a completely automatic 3D clothing fitting will be our future work. Our current clothing fitting cannot deal with the deformable model and the animation state. How to combine our feature analysis with other modeling methods such as the physics-based method or the skeleton-based method to create a more realistic fitting performance is also the subject of our future work.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (Grant No.60533080), the Ministry of Education Key Program (Grand No.209051), the Key Technology R&D Program (Grant No.2007BAH11B03), the Open Project Program of the State Key Lab of CAD&CG (Grant No.A0913).

References

[1]Gillies M, Ballin D, Csaji B. Efficient clothing fitting fromdata. Proceedings of WSCG. 2004, pp.129-136.

[2]Goldenthal R, Harmon D, Fattal R, et al. Efficient simulation of inextensible cloth. Proceedings of SIGGRAPH 2007.

[3]Terzopoulos D, Platt J, Barr A, Fleischer K. Elastically deformable models. Proceedings of SIGGRAPH 1987, pp.205-214.

[4]Igarashi T, Hughes J. Clothing manipulation. Proceedings of the 15th annual symposium on user interface software and technology, Paris, France, 2002, pp.91-100.

[5]Hoppe H, DeRose T, Duchamp T, McDonald J, Stuetzle W. Surface reconstruction from unorganized points. Proceedings of the 19th annual conference on computer graphics and interactive techniques. 1992, pp.71-78.

[6]Taubin G. Estimating the tensor of curvature of a surface from a polyhedral approximation. Proceedings of ICCV. 1995, pp.902-907.

[7]Razdan A, Bae M. Curvature estimation scheme for triangle meshes using biquadratic Bézier patches. Computer-Aided Design. 2005, 37(14), pp. 1481-1489.

[8]Troyani N, Perez A, Baiz P. Effect of finite element mesh orientation on solution accuracy for torsional problems. Finite elements in analysis and design. 2005, 41(14), pp.1377-1383.

[9]Ohtake Y, Belyaev A, Seidel H. Ridge-valley lines on meshes via implicit surface fitting. ACM Trans. on Graphics. 2004, 23(3), pp.609-612.

[10]Stylianou G, Farin G. Crest lines for surface segmentation and flattening. IEEE Trans. Vis. Comput. Graphics. 2004, 10(5), pp.536-544.

[11]Besl P, McKay N. A method for registration of 3D shapes. IEEE Trans. on Pattern Analysis and Machine Intelligence. 1992, 14(2), pp.239-256.

[12]Moqhaddam B. Principal manifolds and probabilistic subspaces for visual recognition. IEEE Trans. on Pattern Analysis and Machine Intelligence. 2002, 24(6), pp.780-788.

[13]Maekawa K, Patrikalakis N. An algorithm for optimal free-form object matching. Computer-Aided Design. 2003, 35(10), pp.913-923.

[14]Gal R, Cohen-Or D. Salient geometric features for partial shape matching and similarity. ACM Trans. on Graphics. 2006, 25(1), pp.130-150.

[15]Li Z, Barsky B, Jin X.G. An effective third-order local fitting patch and its application. Proceedings of SMI'09, accepted.