3D Human Body Scanning and Personalized Version Generation Model in Garment CAD System

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Abstract: - With the increasing demand for clothing comfort and personalization among consumers, traditional clothing design methods based on standard sizes are no longer able to meet market demands. This study focuses on the application of 3D human scanning technology in computer-aided design (CAD) systems for clothing, as well as the development of personalized shirt pattern generation models based on this technology. By using high-precision 3D human body scanning equipment to obtain human body data, combined with advanced image processing and data analysis techniques, precise extraction of human body feature points has been achieved. By utilizing this feature point information, a three-dimensional clothing basic model is constructed, and the model deformation technology is used to adapt to different body types. Finally, personalized two-dimensional shirt patterns are generated based on the particle spring model. This study not only improves the accuracy and efficiency of clothing design but also provides consumers with a highly customized wearing experience, providing new ideas and methods for the intelligent development of the clothing industry.

Key-Words: - Clothing CAD system, 3 D body scanning, personalized version, generation model, custom clothing, body size measurement.

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1 Introduction

In the fields of clothing CAD, virtual fitting on the internet, and 3D human animation, there is a problem with 3D reconstruction of human models. With the development of virtual reality technology [1], human body models have been increasingly applied in many fields, and the demand for personalized 3D human body models is becoming stronger. Personalized products are designed to meet the different needs of different users [2], so personalized design is a design method that can meet individual requirements. With the improvement in living standards [3], [4], [5], people's demand for personalized products is also increasing. Therefore, research on personalized design has become increasingly important, and personalized design has become a trend in the development of enterprises. Setting up personalized design experimental teaching in mechanical and related majors plays an important role in meeting the needs of social development [6], [7].

Domestic and foreign researchers have carried out a lot of work and achieved fruitful research results. Firstly, accurate 3D human body scanning and model reconstruction are the foundation for achieving human body shape analysis in clothing plate making. The popularity of 3D scanning equipment provides a convenient technical approach for 3D reconstruction of human body shape models, and geometric analysis, model registration, and reconstruction of human body 3D models are the most important steps [8], [9], [10]. The human body model obtained through 3D scanning is usually a scattered grid structure, and the vertices and grids usually do not have the semantic properties of human geometric features [11]. The work of grid registration is mainly to achieve intelligent human body model development through parameterized reconstruction of spline curves and surfaces, and integration of triangular patches, so that the model can be directly modified and edited intelligently, and the reconstruction of the human body model can be achieved by directly editing the relevant parameters of the human body shape. It is expected that the model will maintain its shape, posture, and resolution unchanged during the editing and reconstruction process [12], [13]. Further work is to construct a composite model with bone, skin, and soft tissue simulation functions based on the physiological properties of the human body [14], [15], [16]. In addition, color depth (RGBD) cameras provide a low-cost solution for human body modeling [17], which can obtain a large amount of 3D human body data more conveniently, but requires solving the problem of low-quality point cloud data processing.

2 Human 3D Scanning and Feature Point Extraction

2.1 Data Acquisition of Human 3D Scanning

Using 3D scanners to obtain accurate human surface models is the basis for accurate measurement of human versions and personalized customized plate making [18], [19]. The commonly used scanners include a special human scanner, handheld scanners such as Atec, Smart, etc., as well as a fast scanning system based on a depth camera. In this paper, the SmartScan F6 handheld scanner is used for human scanning. The device is based on the principle of multi-angle stereo vision and ECHO software to perform three-dimensional point cloud reconstruction and registration of three-dimensional point cloud model, as well as triangular grid generation and data processing operation [20].

Figure 1 shows the scanning device and the reconstructed 3D human model using it. According to the requirements of personalized version generation, the upright and mildly expanded posture is used to scan a single human body. The scanning time of the device is about 30 s, the 3D model contains vertex color information. After denoising and simplified grid processing, a single human model includes about 100,000 vertices of 150,000 triangular grids.

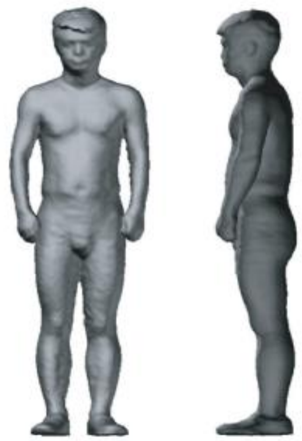
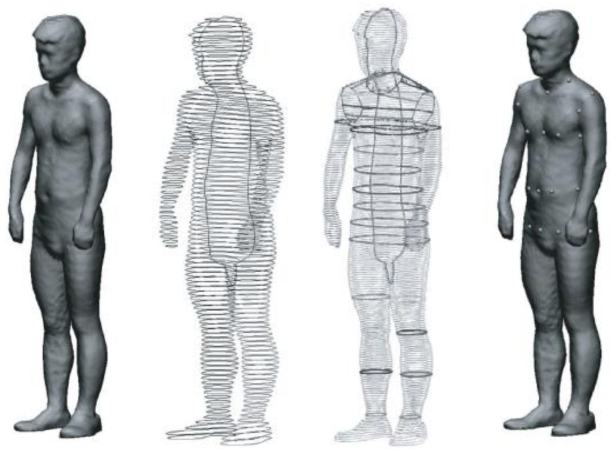


Fig. 1: Example of the device and scanning model for 3D human scanning

2.2 Characteristic Point Extraction of Human 3D Model

Geometric analysis and feature extraction are conducted on the generated human model. The model adopts the standard upright posture. In the world coordinate system defined in this paper, the x axis is taken as the vector direction from the left hand to the right hand, the why axis of the vertical upward direction, and the front of the body is the axis. The geometric feature extraction steps are: first using the layer cutting method, With tiny layer interval steps dZ=10 mm, Scan the area where the 3D model is located, Obtain the sequence of section curves for the 3D model and the horizontal cross section: then perform the geometric analysis of each section curve, Fit to extract the symmetry center, Arrange the center points of the horizontal section curve sequence in order, To obtain the sagittal cross-section curve, As shown in Figure 2 (b); According to the geometric features of the sagittal plane, we extracted the waist point, hip circumference point, front and back neck points, Combining the cross-section curves of each level and the curvature characteristics, the left and right lateral line, chest circumference line, waist circumference line and hip circumference line were extracted, As shown in Figure 2 (c); Finally, the feature set K, Including 31 characteristic points in the collar, chest, waist, hip, hem, left and right shoulder circumference, As shown in Figure 2 (d), Chest circumference, waist circumference, circumference, including posterior middle, posterior right, right posterior, right, right front, anterior right, anterior middle, anterior left, left anterior, left, left posterior and posterior left, The layout of the feature points follows the overall layout of the longitudinal front and back midline, left and right side stitches, front and back princess lines and the transverse circumference curve in the garment plate making.



(a) Scan model (b) section curve (c) feature curve (d) feature point

Fig. 2: 3D scan model analysis feature extraction

3 Personalized Model Shirt Version Generation

3.1 Construction of the Basic Model of 3D Clothing

Shts usually include clothing body, sleeve, collar, and several accessories, among which the compatibility closely related to personalized customization is mainly reflected in the version structure of the clothing body, while other parts can be parameterized according to the body version. Therefore, this paper focuses on solving the production problem of the shirt body version based on scanning mannequins. The shirt body version includes the front, back, and shoulder pieces, which are divided by the front center line, the shoulder line, and the transverse dividing line. For this purpose, a 3D basic model of clothing similar to the plate-making human body structure was constructed, as shown in Figure 3. The main body is divided into a lower trunk and upper shoulder, The trunk part uses the horizontal level of the grid structure, the shoulder with a number of interconnected quadrangle grid structures, the grid structure and 2.2 defined characteristic line and characteristic points, including the longitudinal midline, right and left suture, princess line, sleeve line, etc., and transverse collar line, chest line, waist line, hip line, bottom line and shoulder line. The overall model is divided into several large quadrangle grids, each large quadrangle grid area is subdivided into smaller quadrangle grids, and the last quadrangle grid is divided into triangular grids by diagonal. The vertices of the 3D grid model of the 3D clothing base version to cover the human body shape characteristic points defined in Section 2.2, which is the key to realizing the deformation of the grid model in the following steps.

Fig. 3: 3D clothing base version model

3.2 Deformation of the 3D Clothing Foundation Model

This paper adopts the rigid deformation algorithm to realize the deformation from the standardized 3D model of the basic clothing to the personalized clothing model. The algorithm is a kind of triangular grid deformation algorithm based on the Laplacian coordinate system, based on the principle of linear quadratic energy minimization optimization to meet the constraints of the geometric model, the algorithm can keep the model of local geometry details, and has high computing efficiency, in computer graphics, machine vision, geometric modeling, and other fields are widely used.

The triangular grid representation based on the Laplacian coordinate system is the basis of achieving preserved rigidity. For any vertex $v\ i\ x\ i$ in the triangular grid V containing N vertices, $y\ i$, z with which the vertex with the connection relationship

is,$v_i(x_i, y_i, z_i)\, v_j(x_j, y_j, z_j), j \in N(i), i, j\, v_i$, the triangular grid representation based on the Laplacian coordinate system is the basis of preserving the rigidity, For any vertex in a triangular grid V containing N vertices, The vertex with a connection relationship is, Is the Serial number, The details of the vertices can be described by the discrete Laplacian operator (discrete Laplacian operator) defined on their adjacent triangular grids, The vector connected to the central position of all discrete points connected to it, among, The vertices, respectively; And its surrounding vertices, The x-coordinate value of, For the weight of the vertices around the vertex, Uniform weight can be used.

$$v_i v_j, j \in N(i)\, l_i = \sum_j^{N(i)} \omega_{ij} x_j - x_i\, x_i, x_j v_i v_j \omega_{ij} v_i \sum_j^{N(i)} \omega_{ij} x_j = 1$$

Based on the basis of the Laplacian describing the local details of the model, the sum of the differences of the corresponding points between the models before and after editing is minimized, and the minimized objective function as shown in (1):

$$\mathrm{f}(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3, \cdots, \mathrm{x}_\mathrm{n}) = \sum_{\mathrm{i}=1}^{\mathrm{n}} \left\| \left(\sum_j^{N(i)} \omega_{ij} x_j - x_i \right) - \mathrm{l}_\mathrm{i}' \right\|^2 \quad (1)$$

In the formula, l_i'is the Laplacian at the point i on the preediting model, which represents the detailed information at the point before editing. The matrix form of the above formula is defined as M, which satisfies the following conditions as shown in (2):

$$M_{ij}\begin{cases} 1, i = j \\ -\omega_{ij}, \text{I and j are connected} \\ 0, \text{other} \end{cases} \quad (2)$$

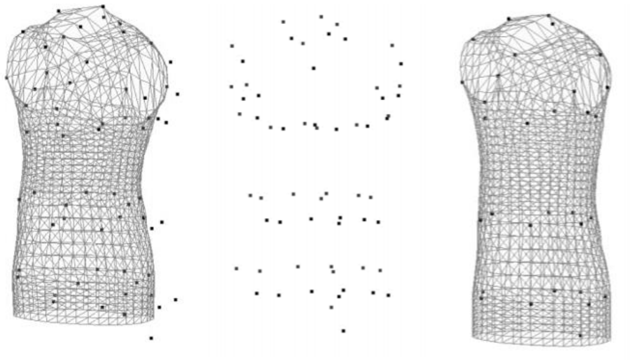
When several new vertices u_k'=P are specified as the position limit condition to be met, P_K is the k th fixed point, construct the column vector B as shown in (3):

$$B_i = \begin{cases} P_K - u_K, \text{end} \\ l_i', \text{other} \end{cases} \quad (3)$$

Then construct and solve equations for V (x, y, z) coordinate values $MV = B$.

A new grid with new coordinate values is obtained. v'.

In practice, the rigid-preserving deformation algorithm finds the new position of each vertex of the model by minimizing the function representing the difference in the surface details of the model before and after editing under the condition of satisfying the set new position of some vertices. The original grid connection structure remains unchanged, and a new triangular grid model is generated. Firstly, the Laplacian coordinate system is calculated from the 3D model of the basic garment version to construct the energy constraint matrix, using the feature points of the 3D model of the basic garment version related to the human body as the constraint points before and after the deformation, the feature points of the model are the position of the new coordinates of all vertices of the whole model based on the energy minimizing constraint, so as to realize the deformation of the 3D model of the basic garment version to the process and result of deformation as shown in Figure 4. The deformed model has the same grid structure as the original model, has a similar geometry to the personalized human scanning model, and maintains the approximate human body size characteristic points and the grid topology. Both the model and feature points to be treated here maintain the same coordinate system alignment state, therefore, the rotation transformation factor in deformation is not used. Specifically, the body size-related constraint K is the 31 feature points described in Section 2.2.



(a) The source model feature point (b) the feature point control (c) the target model feature point

Fig. 4: 3D clothing model deformation based on feature point constraints

3.3 Two-dimensional Model Generation based on the Mass-Spring Model

The particle-spring system model has an important role in geometric deformation, which achieves the balance between internal and external forces, so as to realize the purpose of model geometric deformation and optimization. It has simple construction, high computational efficiency, and is widely used in rigid and flexible object simulation. This paper proposes a garment plate leveling algorithm based on the particle-spring system, three-dimensional clothing plate constructs a spring model, then force the model constraint in the two-dimensional plane, specified several fixed point constraints, when the model reaches the internal stress balance, the two-dimensional shape compared with the original three-dimensional model, the minimum deformation energy, the two-dimensional figure is considered to be the optimal leveling result of the three-dimensional model, as shown in Figure 5. Given the 3D shape of the triangular grid, the 3D model peak is the particle m, with the triangle grid edge as the spring connection s as the 3D state edge as the spring length: in the leveling process, with the X plane constraints, the vertex z value set to 0, time integration of particle-spring model iteration, when the system in the X plane to steady state, the overall internal energy is minimum, is that the three-dimensional graphics, virtual spring using fixed elastic coefficient k=1.

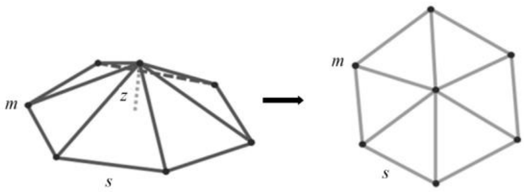


Fig. 5: The 3D graphic leveling based on the physical model

4 Results and Analysis

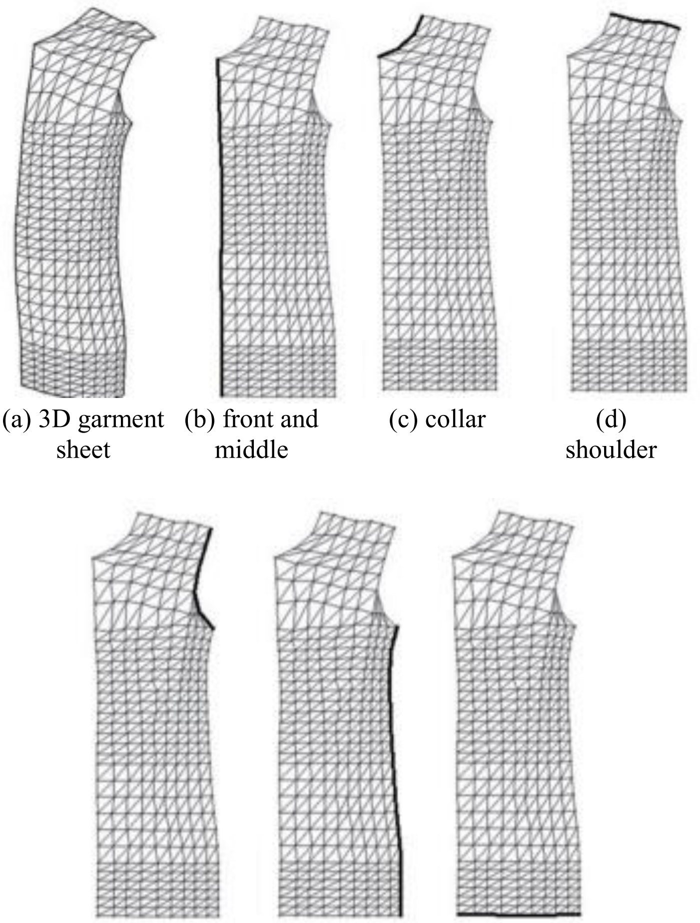
In order to realize the above algorithm, using the VS Studio development environment C + + language and OpenG, the graphics library developed a prototype system based on a 3D model, and the experimental test of shirt version generation was carried out on the ordinary PC. The results of the version were calculated and analyzed separately, in addition, the resulting garment version was made for the fitting experiment.

The leveling process of the 3D plate to 2 D plate will lead to local deformation of the model. The degree of deformation is an important indicator to measure the effect of the pattern expansion algorithm. In the DV model, the area of 3D version and the two-dimensional version. The 3D model of the left anterior coat is shown in Figure 6 (a). The six edge curve segments (front and middle, collar, shoulder, sleeve hole, side seam, bottom edge) shown in Figure 6 (b)-(g) are selected for calculation and comparison. Table 1 (Appendix) shows the results of the calculation and comparison. It can be seen that the geometric deformation of the model in the expansion process is limited to a low range, indicating that the expansion process produces a small deformation, which ensures the accuracy and effectiveness of the expansion algorithm.

The shirt version is a symmetric structure, and the version generated in this paper is on the left; the garment version is generated according to the scanning model, including the front, shoulder, and back pieces. The sleeve piece, collar, and accessories are applied by parameter template.

Figure 7 shows the unfolding process of the front, shoulder, and back slices of the shirt. Figure 7 (a) shows the 3-dimensional model, Figure 7 (b) is the 2-dimensional model after the algorithm expansion in this paper, and Figure 7 (c) is the two-dimensional paper sample.

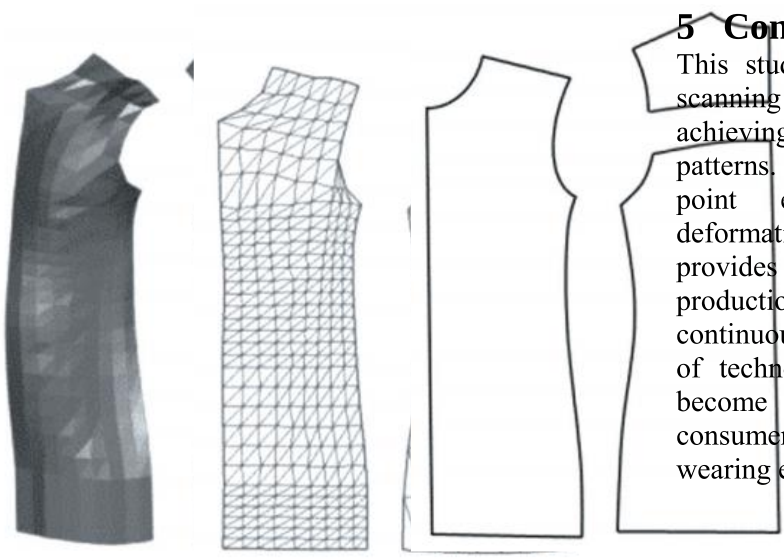
According to the two-dimensional garment model extraction edge curve, extract the characteristic points for linear and curve after the graph, the graph is the zero loose base close to the human body, according to the easing design requirements, superposition at the characteristic point offset $x\ i$, $x\ y$ to achieve the purpose of increasing the loose, increase the zero loose base generated by standard template model and the offset between the standard type garment.


(a) 3D garment sheet (b) front and middle (c) collar (d) shoulder

(e) sleeve hole (f) side seam (g) bottom edge

Fig. 6: Schematic diagram of the edge curve segment of the left front coat piece

According to the experience of men’s shirt plate making, with the manual measurement of the net body size parameters as the benchmark, the combination of chest circumference is about 13 cm, the collar, and relaxation is 2 cm, the total shoulder width is 1-2 cm, the coat length is added according to the overall height of 43%-44% calculation, the sleeve length is about 3 cm. The combination described in this paper means that the shirt has a good matching degree with the human body, with no obvious loose or bad folds, and no obvious restrictions on movement, as shown in Table 2 (Appendix).



(a) 3D coating (b) 2-dimensional clothing film (c) A 2 D paper pattern

Fig. 7: The unfolding process of the front, shoulder, and back slices of the shirt

Usually, the fit of a shirt is based on the objective evaluation of size parameters such as collar, shoulder length, chest length, and sleeve length and the subjective evaluation of the visual effect of actual wearing. To test the fit of samples, using the main size parameters used for comparative analysis, including chest, width, collar, shoulder length, and sleeve length, such as five size parameters, the experiment model (model) for manual measurement, the human body manual body size, 3D model measurement, manual relaxation, plate making method with relaxation and the final sample measured size for comparative analysis, as shown in Table 3 (Appendix).

After inputting the standard clothing model and the personalized human model, the feature point detection, model deformation, and version generation are automatically realized through the corresponding algorithm, so as to ensure the efficiency of the version generation. The development and operation test of the prototype system described in this paper are completed on an ordinary PC. The computer is configured with Intel Core i5 10400F processor, 16 G memory, and AMD6700 graphics card. The program does not use parallel computing processing. The geometric information of the model and the processing running time of each module of the system are shown in Table 4 (Appendix).

5 Conclusion

This study successfully applied 3D human body scanning technology to a clothing CAD system, achieving automatic generation of personalized shirt patterns. Through steps such as 3D scanning, feature point extraction, model construction and deformation, and 2D pattern generation, this study provides a new technological path for customized production in the clothing industry. With the continuous advancement and deepening application of technology, personalized clothing design will become more popular and convenient, bringing consumers a more comfortable and fashionable wearing experience.

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APPENDIX

Table 1. Comparison of deformation calculation between 3D and 2 D garment chip models

Parameter	Front middle/mm	Neck/mm	Shoulder/mm	Hollow/mm	Latasuture/mm	Base/mm	Area/mm2
three-dimensional length	657.0	122.3	135.1	195.9	531.2	219.2	144339
two dimension length	652.8	122.1	135.3	196.6	528.3	219.6	144353
deformation rate /%	-0.64	-0.15	0.17	0.37	-0.53	0.18	0.01

Table 2. The sets and mode of the edge of the edge

Edition feature points	Deviant/cm	The offset mode
Front shoulder point	1	Extend along the shoulder line
The anterior thoracic lateral point	3	Offset x coordinate values
	-1	Offset y coordinate values
The anterior bottom side point	3	Offset x coordinate values
	-1	Offset y coordinate values
Back shoulder point	1	Extend along the shoulder line
The posterior bone side point		Extend laterally
The posterior thoracic side point	3	Offset x coordinate values
	-1	Offset y coordinate values
The posterior bottom side point	3	Offset x coordinate values
	-1	Offset y coordinate values

Table 3. Comparison of the main size parameters of the type fit

Project	Chest Measurement	Neckline	Shoulder breadth	Long clothes	outside sleeve
Manual body size	89	40	45	64	53
3D model measurement dimensions	88	40	44	56	54
Handmade plate plus relaxation	13	2	2	0	3
This paper’s method adds the amount of relaxation	12	0	2	10	3
The measured size of this sample garment	100	41	43	66	57

Table 4. Geometric information of the model and the processing running time of each module of the system

Enforcement and processing process	performance period/s
Analysis of body size feature points (31 body size feature points, about 93,800 vertices, 171.000 triangle faces)	22
3D model preserves rigid deformation (1177 vertices, 2232 triangle surfaces)	12
3D version leveling (10,000 iterations) (50 vertices of shoulder piece, 72 triangle surface)	3
3D leveling (10000 iterations) (120 vertices, 198 triangles)	5
3D leveling (10000 iterations) (310 vertices, 531 triangles)	9
2-D version post-processing	1

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)
The author contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest
The author has no conflicts of interest to declare.