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Computer-Aided Design AND APPLICATIONS

3D Personalized Human Modeling and Deformation Technology for Garment CAD

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Abstract. According to the design requirements of garment CAD system, this paper summarizes and analyzes the flow, characteristics and existing problems of existing human modeling algorithms, and proposes a 3D human modeling method based on section ring calculation, and realizes the dynamic modeling of human body driven by joint points. Firstly, the human body shape is classified to create a 3D human body shape template library. On the basis of extracting feature points and feature lines of the human model, the relationship between the size change and the feature points is calculated by using simple linear scaling ratio. Through the mathematical modeling of chest curve, waist hip curve and longitudinal datum line, the fitting curve results which reflect the curve characteristics and are convenient for subsequent clothing deformation are obtained. The algorithm is simple and efficient. It can not only accurately reproduce the surface static characteristics of the original scanned human body, but also change the dynamic characteristics of the human body interactively, which can meet the basic requirements of the human body model in the process of fashion design.

Keywords: Garment CAD, human modeling, human deformation, 3D model.
DOI: https://doi.org/10.14733/cadaps.2021.S3.23-33

1 INTRODUCTION

Human body model is more and more widely used in many fields, and the demand for personalized three-dimensional human model is also increasingly strong. With the appearance of 3D scanner, realistic 3D model can be obtained [1]. This kind of fine measurement technology is completely unnecessary compared with the application of low precision requirements. People try to deform and edit the characteristic three-dimensional human body models according to the parameters of human height, weight, chest circumference and waist circumference [2]. The key problems are as follows: (1) the establishment of feature human body model. The human body model generated by 3D scanner only has simple coordinate information of points and topological relationship between points, and lacks corresponding with key parts of human body. And its large amount of data, whether for computer storage or network transmission is a great challenge. Therefore, it is necessary to build a human model with semantic features. (2) Feature human model editing. Due to the complexity of human body shape and irregular change of human body shape, simple geometric transformation cannot be carried out.

3D human modeling and deformation technology can be divided into three categories: surface modeling method based on skin and bone, body modeling method based on physical characteristics and hierarchical modeling method based on anatomy. Among the three methods, the surface model method only considers the skin layer and bone layer, which can fully describe the geometric information and topological relationship of the human body. The hierarchical modeling method based on anatomy is to decompose the human body into bone layer, muscle layer, fat layer and skin layer to achieve a more realistic effect from the perspective of physiology and physics [3]. In order to make the matching error of a small number of newly input real human body data smaller, the coverage of human body data in the body database is wider and more comprehensive, the personalized human model synthesized is closer to the real human body information of input users, and the reconstructed human body quality is better [4]. In the database construction stage, Wang scanned the whole-body data of 250 subjects in three-dimensional, and used the statistical analysis of body shape change characteristics and their correlation with some body sizes [5]. Chen and others choose to use a small number of standard human body as the representative for three-dimensional scanning [6]. The feature points and characteristic lines determined by the simplified human body model obtained by scanning the standard human body are aligned with the actual key points before scanning, and the initial section line and contour line of clothing obtained by processing the human body feature information are finely adjusted. Kaixuan used facial and body feature points on the front, back and side images to synthesize 3D human body in computer, and then based on parametric modeling, the 3D human body was modeled through the deformation of template body [7].

Based on the above analysis, the curved body model based on skin and bone can better meet the requirements of garment CAD, not only can maintain the human body characteristics, but also has high efficiency. In this paper, the modeling method proposed by the project team is used to generate the standard surface human body model with topological rule mesh simplification by modeling the scanned human body data of standard standing posture and the scanning data of human platform (part of human body). The model with the same topological structure is built into the standard human body database, which provides the basic human body model support for garment CAD. In the actual clothing design process, it is often necessary to use different size, different posture and different local body shape as the design reference, although different human body models can be obtained by reconstructing different human body scanning data. However, the process of getting the original scanned human body is rather complicated, and it is impossible to get every model from the original scanning data through direct modeling. However, by deforming the standard human body model, the required human body model can be obtained quickly and easily.

2 DESIGN OF 3D HUMAN MODELING SYSTEM

Aiming at the problem of low surface information positioning accuracy of the artificial human body containing a large amount of real human body information used in the clothing interactive system, the artificial human body is reconstructed. Combined with the rendering function of the 3D production software, the 3D production software is used to render the simulated human body containing real human body information, add the available information for surface measurement, and then import it into the interactive system as a research medium for 3D clothing CAD [8]. The main process of reconstruction of 3D clothing CAD simulated human body includes: scanning and processing simulated human body data; implementing fixed-point and positioning technology on the simulated human body imported by the interactive system; rendering the simulated human body; importing the built interactive system to display and experimentally verify the efficiency [9]. As shown in Figure 1. The human body modeling has gone through the steps of feature point feature size acquisition, data preprocessing, model value point calculation, surface reconstruction, surface splicing and display. On the basis of this main process, if you want to realize the parametric modeling function or the human body animation effect, you need to return to the two steps of model value point calculation or feature point and feature size acquisition to recalculate the body surface points.

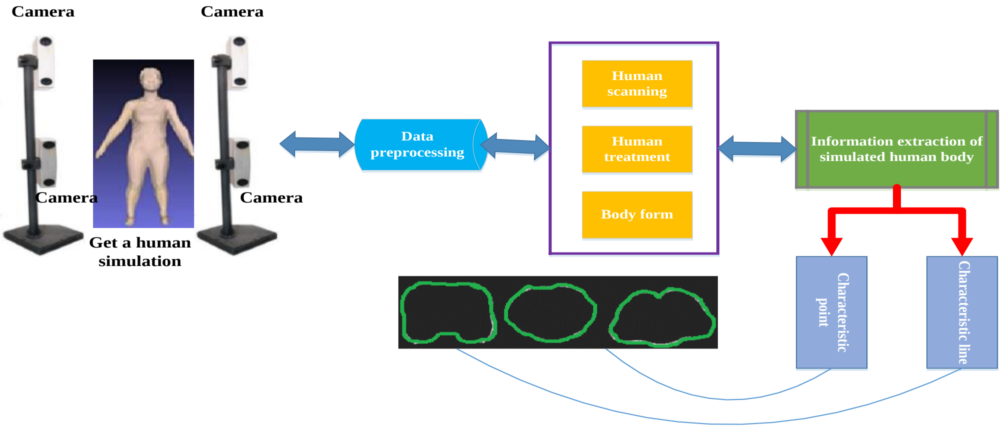

Figure 1: Flow of 3D human modeling system.

2.1 Feature Extraction of 3D Human Model

2.1.1 Preprocessing of 3D human body model

The three-dimensional human body model used in this paper is downloaded from the three-dimensional model website, which is designed by the three-dimensional modeling software. It uses point, line and surface to express the geometric information and topological structure of the model. It has simple structure, can represent any topological surface, rendering is convenient, and the approximation accuracy of smooth surface is controllable. Due to the different sizes of 3D models and different definitions of coordinate systems, it is necessary to standardize and preprocess the acquired 3D models.

The 3D model is imported into 3dsmax software and exported to obj file format for storage after coordinate adjustment and size adjustment. The center of obj model used is located at the coordinate origin, and the coordinate system meets the right-hand rule. The human body's horizontal direction to the right is the positive X-axis direction, the vertical upward direction of the human body is the positive direction of the z-axis.

2.1.2 Human feature point and feature line extraction

At present, there is no universal feature point positioning standard in the clothing industry. In this paper, the key feature points include scapular points, left and right axillary points, and perineum points, which are used to divide the human body model. The pre-marking of these key feature points is manually marked by importing the 3D human body model into the 3Dsmax software [10]. Through the marks of these 4 points, the three-dimensional human body model is divided into six parts: head, left and right arms, torso and left and right legs. Ordinary feature points are used to calibrate the plane where the feature line of the human body is located, and to calculate the size information of the three-dimensional human body. In this article, we only discuss the three-girth information of the human body's chest girth, waist girth and hip girth. Therefore, it is necessary to find out the characteristic points related to the three-girth information. These characteristic points include nipple point, waist girth point and hip apex. In addition, there are some fixed anchor points, which are used as apex constraints in the process of human body reconstruction, including head vertices, left and right shoulder points, left and right sole points, and left and right-hand tips.

After the key feature points are marked, the human body can be divided into several sub parts according to the coordinate position of the key feature points, and then the corresponding common feature points can be found. Because the chest circumference, waist circumference and hip circumference are all located in the trunk part of the human body, only the body feature points can be found in the trunk part. Because the human body is symmetrical, the left half of the human body is taken as an example to illustrate the steps of finding human feature points

- In the left half of the human body, the point with Z coordinate of 0 and the maximum X coordinate is the waist point, and the horizontal plane of the waist point is the plane of the waist line feature point (Z coordinate 0 represents the two-dimensional side contour curve of the human body, and the minimum x represents the concave point position of the trunk side contour line).
- The point with the largest Z coordinate value is found below the shoulder blade point and above the waistline point, which is the milk apex point, and the horizontal plane of the breast apex point is the plane of the chest circumference point feature point.
- Finding the point with the smallest Z coordinate below the waist point and above the perineum point is the hip vertex, and the horizontal plane of the hip vertex is the plane of the hip line feature point.

2.2 Human Body Model Baseline Curve Fitting

The human body's torso is the most important part of the clothing dressing effect. Its structure is the most complex in the human body. It is composed of the chest and the waist and hips. The shape of the breast can determine the characteristics of the person's gender, age, and the shape of the waist and hips. With diversity, these characteristic parts determine the shape of a person, and the shape of a person directly determines the effect of clothing. Therefore, the shape of the key parts is the decisive factor for the fitting effect of the clothing. Computer methods are used to automatically analyze and extract the feature information related to the body's torso and clothing. However, because the feature data is extracted from the discrete point cloud collection of the human body, the extracted "curve" is actually a discrete point cloud collection. In order to better control the shape of clothing, these discrete point clouds must be fitted into a continuous curve. The chest and waist and hip sections are the characteristic parts of the human body, and their cross-sectional shapes have their own inherent characteristics. This paper introduces a mathematical model of the bust and waist-hip curves to fit the waist section curve, and uses mathematical methods to fit the human body longitudinal reference line. The fitting curve reflects the basic characteristics of the human body baseline, and enables the originally irregular human body lines to be controlled by mathematical models. This part is an important processing process, which can obtain important data driving the deformation of the clothing, and is a key part of connecting the human body and the clothing.

The left and right sides of the chest are symmetrical. After separating from the middle, the two sides can be fitted with two symmetrical ellipses. Along the central axis, the upper and lower recessed parts of the chest are respectively fitted with two ellipses tangent to the two symmetrical ellipses in the middle. That is, the mathematical model of the four ellipses A, B, C, and D in Figure 2(a)(b) can be established.

This kind of chest curve modeling method can be used to realize the following functions:

1) The bust curve is represented by a regular ellipse model to realize the parametric control of the curve, which is convenient to establish the corresponding relationship between clothing points and human body curves;
2) The concavity and convexity of the curve can be adjusted according to the tightness of the garment, which reflects the body shape characteristics and integrates the clothing characteristics, which has a good effect.

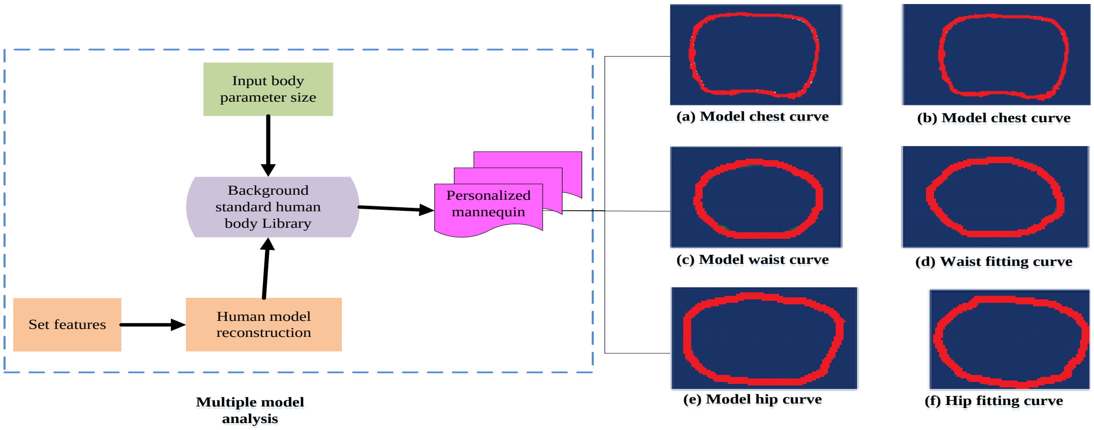

Figure 2: Fitting curve of chest, waist and buttock of mannequin.

According to the curve of waist and hip, it can be represented by hyperellipse. The front and rear parts of the waist and buttocks are asymmetric, so the waist section ring is designed as the combination of the two hyperellipses. The calculation formula of hyperellipse is shown as followings:

$$\begin{cases} Y = [A + B\sin\beta] \times \cos(\beta) + y_0 \\ X = [C + D\cos\beta] \times \sin(\beta) + x_0 \end{cases} \tag{1}$$

Where A and D are the long and short semiaxes of the hyperellipse, B and C are the corresponding weighted coefficients, and Y and X are the center coordinates of the hyperellipse. Similar to the parameters of the chest curve, the key information can be obtained from the intersection coordinates of the section and the longitudinal curve. The eight intersection points of the cross section of the clothing control point P ', p' and the extracted 8 human body longitudinal clothing feature key lines are input as C 'point parameters. The parameter values in equation can be solved as follows:

$$\begin{cases} y = (L + R)/2 \\ x = (F + B)/2 \\ \omega = (L - R)/2 \\ b = F - x_0 \end{cases} \tag{2}$$

Where F and B are the short axis of the front and back semi hyperellipse respectively, L and R represent the Z-coordinates of the intersection points of P with the left suture ll and the right suture R respectively, and L and b represent the Z-coordinates of the intersection points L and B between P' and the front centerline F and the back centerline B, respectively.

The effect of waist cross section curve and super ellipse waist fitting curve is shown in Figure 2(c)(d). The effect of hip cross section curve and hyperelliptic hip fitting curve is shown in Figure 2(e)(f). Since the curve data points to be fitted in this paper are relatively scattered human body point cloud data, the Bezier curve fitting results have great defects. The B-spline curve can overcome the above difficulties. When the control points move, only part of the curve will be affected. In addition, its degree has nothing to do with the number of control points

(1) All data points in any vertical line are sorted according to y value, and the order is Q_0, Q_1, Q_2... Q_N;

(2) According to the mathematical expression of B-spline curve, the parameters of quadratic B-spline curve are calculated:

$$Q_i(s) = q_i G_{0,n} + q_{i+1} G_{1,n} + q_{i+2} G_{2,n} \tag{3}$$

$$Q(s) = \begin{bmatrix} s^2 & s & 1 \end{bmatrix} \frac{1}{3} \begin{bmatrix} 1 & -3 & 1 \\ -3 & 3 & 0 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} Q_0 \\ Q_1 \\ Q_2 \end{bmatrix} \tag{4}$$

(3) The parameter values of any segment of quadratic B-spline curve are calculated in turn, and the fitting results of human body modeling curve are shown in Figure 3.

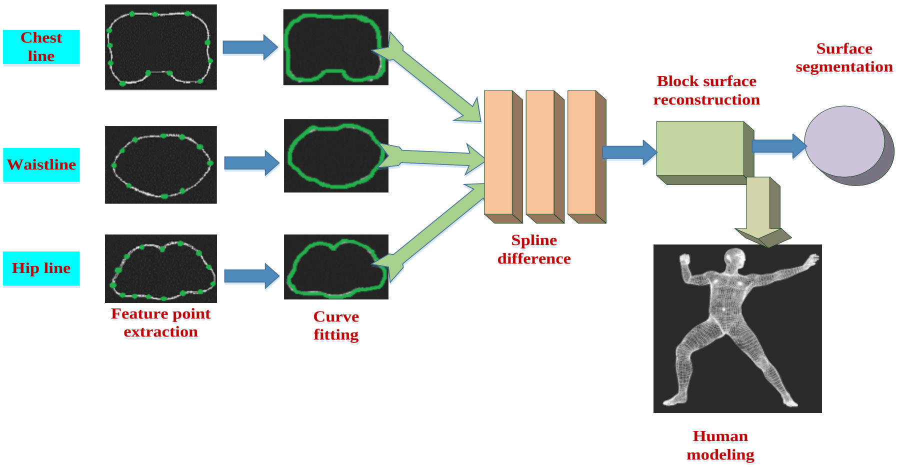

Figure 3: Curve fitting results of human body modeling.

3 HUMAN MODEL DEFORMATION ORIENTED TO SIZE AND POSE DRIVING

3.1 Size Driven Human Model Deformation

The basic principle of human model deformation based on section ring is to scale and move the section ring. When deforming, the 3D dimension information of the current human body model is extracted first, and the direct size driving the human body size deformation is obtained. After removing the influence of the error, the scale factor of the feature size is calculated by comparing the current size value with the size value input by the user. Because the surface shape between the two adjacent feature lines on the target feature line determines the size of the feature size, the size deformation of the human model can be realized by adjusting the surface shape of the part. Then determine the deformation datum of the human body section ring, and then traverse each section ring of the human body to determine the initial actual position of each section ring of the human body; finally, according to the scale factor of each characteristic size, the adjustment proportion and adjustment amount of each section ring of the human body are calculated, and the deformed section ring is obtained by adding the initial vector and the adjustment value. The algorithm flow is shown in Figure 4.

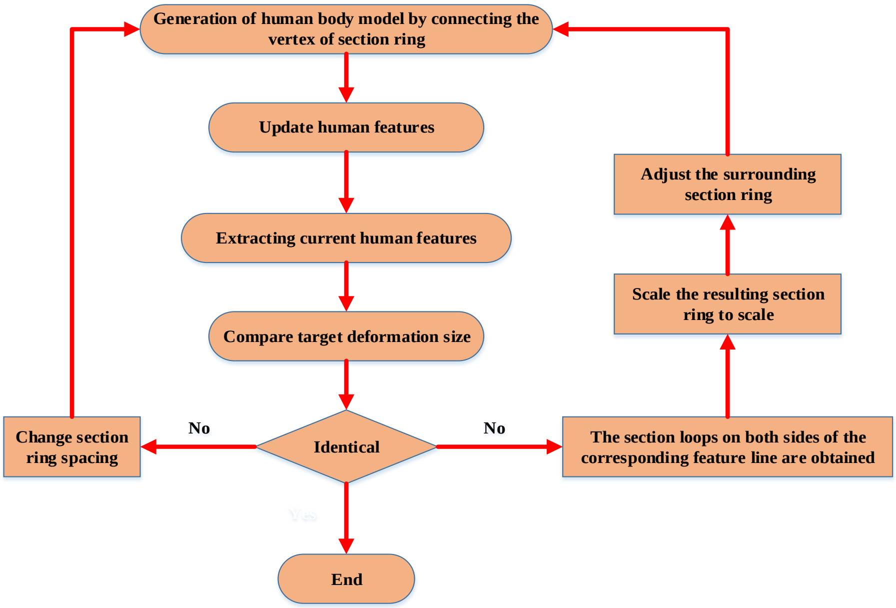

Figure 4: Human model deformation process based on section ring.

The human body is a rigid set connected by joint points, and the lines between the joint points of the human body and the adjacent joint points constitute the skeleton structure of the human body. Human body movement can be simplified as the movement of the human skeleton, and then simplified as the change of the position of the human joint points. Therefore, to simulate the motion of the human body, we must first determine the joint points of the human body. Based on the definition of feature points of the human body and the joints of the actual human body, we define a joint point for the whole body, including shoulder joints, elbow joints, wrist joints, skeleton joints, knee joints, manic joints, etc., as shown in the Figure 5. Most joint points are located at the junction of adjacent human body areas. For example, the shoulder point is located on the intersection of the shoulder area and the arm area. For such joint points, find the common section ring of adjacent sub-faces, then the center point of the section ring That is the desired joint point. Part of the joint points are located in the cross-section ring adjacent to the characteristic points of the human body, such as the sternoclavicular joint and the knee joint. Traverse all the section rings and find the section ring closest to the target feature point, then the center point of the section ring is the joint point. In addition, crotch joint points are crotch feature points. After confirming all the relevant nodes and connecting the adjacent joint points, the skeleton structure under the human body surface is generated.

3.2 Human Model Deformation Driven by Joint Posture

The characteristic size of human body is the basic factor in the whole clothing design process, some of which exist independently, such as chest circumference, waist circumference and other circumference dimensions, and the change of these sizes will not affect other size values.

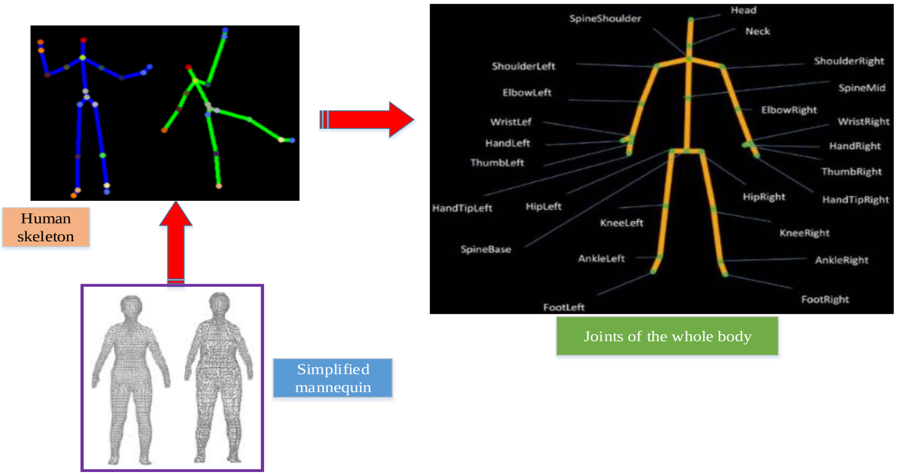

Figure 5: Acquisition and definition of human joint points.

However, some dimensions are interdependent, which shows that the current size value can be calculated by other dimensions, and the change of current size will affect other size values, which can be called dimension chain. The size chain of human body is a closed dimension group formed by interconnected dimensions. Each dimension in the closed dimension group is called the ring of dimension chain. Because the dimension chain is closed connected, there must be a ring in the dimension chain which is indirectly obtained from other rings, which can be called closed ring, and other rings are called composition ring. In this paper, the dimensions of the direct chain are divided into two categories: the dimensions of the direct chain and the dimensions of the chain which are not directly driven by the chain. The indirect size is determined by the direct size, which is a passive change in the process of human body deformation.

Since the human body model after modeling is composed of several parallel or cross section rings, and the clothing system does not require high fidelity of the human body surface, you can refer to the surface deformation method of the cross-section ring by changing the contour of each section. The direction, size and position can get the smooth deformation of human limbs and trunk skin. It should be noted that whether it is arm deformation or leg deformation, it is necessary to consider whether the deformed human body has self-intersection when deforming the joint points of the human body. If there is a phenomenon of self-intersection, then this deformation is actually invalid, and it will cause problems such as mesh damage. Now for the leg posture deformation, the angle is simply restricted before the deformation, and the angle is judged after the deformation. Since the system currently only requires simple posture deformation, it basically meets the constraints. If the system continues to improve and the attitude deformation requirements continue to increase, more detailed collision detection methods need to be studied. To obtain the deformed human body surface, it is necessary to regenerate the characteristic lines and three-dimensional dimensions of the human body to complete the dynamic modeling of the human body. The deformed human body retains the surface features and size information of the original model.

The human body deformation driven by the joint posture can meet the simple dynamic modeling requirements of the human body. Users can gradually adjust the deformation according to their needs to achieve the required posture of the human body. In fact, for the human body posture simulation required by the clothing CAD system, some commonly used human postures are usually used to investigate the stretch and contraction parts of the human body to determine the stretch and contraction area of the clothing, that is, to study the margin of human activity. At this time, it is a bit cumbersome to use joint drive to achieve posture matching through gradual deformation. If the system can pre-customize a series of common human postures, when deforming, through joint posture selection, the whole body can be directly deformed through the customized joint posture to achieve posture matching. In this way, not only is it easier to achieve posture matching, but it is also easier to achieve dynamic deformation between different postures and realize action simulation. On the one hand, it saves the user's time for posture design, on the other hand, it is convenient to carry out research on the activity margin of three-dimensional clothing.

4 ANALYSIS OF EXPERIMENTAL RESULTS

The development tool used in this paper is vs2018, the experimental environment is Intel (R) core (TM) i5 2.5GHZ, 16g memory.

Characteristic point	Traditional method	Method of this article	Error of traditional method	Error of this method
Left shoulder	(-4.7, 62.3, -4.4)	(-3.8, 62.5, -4.8)	7.96	8.58
Right shoulder	(3.4, 62.3, -4.5)	(4.7, 62.3, -4.4)	11.87	9.47
Waist	(6.8, 49.9, -2.6)	(3.7, 49.8, -2.9)	12.18	8.06
Left buttock	(1.5, 38.3, -4.1)	(1.9, 39.4, 2.5)	10.26	7.85
Right buttock	(3.7, 38.5, -4.8)	(6.8, 39.1, 2.2)	8.32	5.12

Table 1: The matching result of the algorithm to the target model fixed point.

Then, we test the stability of the traditional method and the method in this paper under the selection of data points of different sizes. We randomly select 30, 50 and 100 data points in the vertex of the body triangle of the target model. Table 1 shows the matching results of the two algorithms at five feature points of the trunk when the selected data point is 50. Except for the left shoulder point, the matching error of the proposed algorithm is obviously smaller than that of the traditional method. This is an important improvement, because the accuracy of trunk feature points location plays an important role in limb position and human body linear skeleton extraction.

Figure 6 shows the positioning results of five trunk feature points under three different postures. It can be seen from the figure that the error of the standing model and running posture model at the feature points is larger than that of the sitting posture model at the feature points. This is because when the model is in the sitting position, the distance between the selected data points and the torso feature points is relatively small. At the same time, the error of feature points located by this algorithm is smaller than that of the traditional method under three kinds of human posture. Therefore, this algorithm can be used in different pose human models, and has better matching results of trunk feature points.

Based on the limb orientation features, the method in this part is also used to locate the limb feature points. Figure 7 shows the matching results of eight limb feature points under different models. The error of feature point positioning in coordinates is less than that in X and Y coordinates. This is mainly because the Z coordinate of the model does not have a wide range of X and Y coordinates. Furthermore, the relative errors of the three-dimensional coordinates are kept between (-0.05,0.05), which is much higher than the relative error range (- 0.1,0.1) in the traditional algorithm.

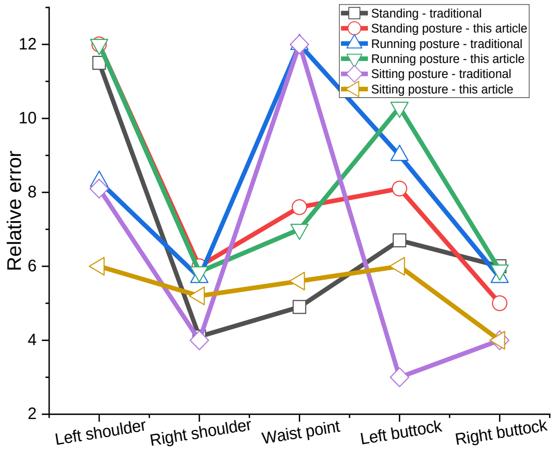

Figure 6: Algorithm comparison in different poses.

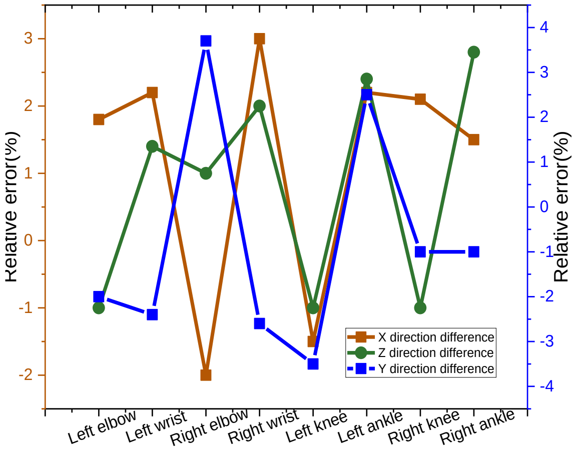

Figure 7: Error of extracting limb feature points.

5 CONCLUSION

A personalized human model construction method is proposed. The basic idea is to simplify a large number of 3D Scanned human body data with different feature sizes to obtain a series of human body models with consistent topology. In order to reflect the change of human body shape quantitatively, a shape factor attribute is introduced into human body data points to establish the relationship between human body data points and human body feature size. The calculation of shape factor is based on the simplified topology consistent human body model and corresponding feature size. According to the shape factor, the new human model is transformed into a reference human model. In addition, according to the special requirements of garment CAD for human body deformation, a multi factor driven human model deformation method is proposed in this paper. Through the driving factors such as size, posture and local shape, the method can quickly and accurately deform the standard human body model to obtain the required size, posture and body shape, so as to provide the basis of human body model for garment CAD.

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