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Research on the Application of Digital Modeling Technology to the Innovative Design of Traditional Ethnic Clothing

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Abstract This study takes digital modeling technology as the core and explores its application in the innovative design of traditional ethnic clothing. By integrating particle dynamics model, triangular mesh delineation algorithm and dynamic feature point co-tracking technology, three major modules of fiber fabric simulation, garment-human body motion co-tracking and immersive virtual interaction system are constructed. Experimental validation shows that the fabric simulation method based on 3D mesh convolution outperforms the traditional physical simulation and deep learning model in terms of Hausdorff distance error (2.381 mm for flag, 5.318 mm for teapot, 5.343 mm for hanging cloth) and time consumption (3.62 s for flag, 2.84 s for teapot, 3.31 s for hanging cloth), and the efficiency of vertex extraction is improved by 40.5%, which significantly reduces the computational cost. Factor analysis further extracted the three core evaluation factors of "fabric characteristics", "sample structure" and "dynamic effect" (cumulative variance contribution rate of 90.17%). The results of subjective evaluation by users show that the page layout (4.35~4.88 ratings by ordinary users and 4.78~4.94 ratings by administrators) and the comprehensiveness of functions (4.27~4.84 ratings by ordinary users and 4.57~4.88 ratings by administrators) of the virtual interactive display system are highly recognized. The research results provide highly efficient technical support for the digital heritage and innovative design of ethnic costumes, with both theoretical and applied values.

Index Terms particle dynamics modeling, triangular mesh partitioning, dynamic feature point cooperative tracking, traditional ethnic clothing

I. Introduction

Traditional national costume is an important form of national culture, which has the characteristics of both material culture and spiritual culture [1], [2]. However, with the rapid development of social economy, national culture has been influenced, eroded and assimilated in the social environment, gradually showing marginalized characteristics, and national costumes are facing the dilemma of being lost [3]-[5]. Under the role of information technology, the protection and promotion of national culture has a new direction [6]. Digital innovation design for traditional national costumes is the main means to ensure the cultural vitality of national costumes, expand cultural influence and strengthen the role of cultural protection, and it is also the necessary way [7]-[9].

From the point of view of national costume culture protection, there is a serious shortage of technical input in China, especially for ethnic minorities that are relatively concentrated in the distribution area, the technical force that can really be invested in cultural protection and cultural development is very limited, and some of the means of cultural protection stays in the aspect of image data retention [10]-[13]. Whether it is the collection of cultural phenomena or cultural dissemination, due to fragmentation and unsystematic, greatly affecting the vitality of cultural development [14], [15]. In recent years, with the continuous development of science and technology and the continuous updating of the clothing industry, digital modeling technology has gradually become a hot topic in the innovative design of traditional ethnic clothing [16]-[18]. Digital modeling technology, is a comprehensive technical system that generates, displays and manages the whole process of clothing design and other information through the computer, through the introduction of digital modeling technology, traditional ethnic clothing can realize the information management of the whole life cycle of apparel design, which not only improves the efficiency of the design and production of traditional ethnic clothing, but also enables the clothing industry to be more environmentally friendly and sustainable development [19]-[22].

This research centers on three core modules, namely fabric simulation, dynamic feature tracking and virtual interaction system, to realize the precision, dynamization and immersion of dress design through multidisciplinary cross-methods. Aiming at the complex fabric structure and texture characteristics of traditional national costumes, a fiber fabric simulation method based on particle dynamics and triangular mesh division is proposed. The interweaving process of warp and weft yarns is simulated by particle dynamics model, and the light and shadow details of fabric surface texture are restored by combining with OpenGL lighting algorithm. The triangular mesh delineation technique is introduced to refine the mesh delineation of the fabric based on the Delaunay mesh rule, and the redundant points are eliminated by the point set construction and region optimization algorithm to ensure the physical stability of the mesh model. Secondly, we combine dynamic feature point interpolation and SVD decomposition algorithm to construct a cooperative tracking model of clothing and human body movement, and propose a personalized 3D clothing perception model based on dynamic feature point interpolation. The mapping relationship between the dynamic feature point set of the human body and the dynamic feature point set of the clothing is constructed by marking multi-point features in the key areas of the human torso and limbs. Further, the SVD decomposition algorithm is used to align the coordinates of the point set matrix and optimize the tracking error by combining with the bone spacing constraints, so as to realize the accurate response of the garment to the human body movement. On this basis, we design a 3D scanning apparel virtual interactive display system with scene roaming, collision detection and multimodal interaction functions, in which the scene roaming module is operated by “arrow + WASD” composite keys and mouse perspective control to realize the free exploration of the user in the virtual exhibition hall. The collision detection algorithm simulates the real obstacle avoidance logic to avoid the penetration phenomenon and enhance the sense of immersion. The interaction function is based on giving the model rigid body attributes, integrating collision detection script and multimodal resource loading. It enables users to deeply participate in the digital experience of dress culture and realize the digital inheritance and innovative experience of national dress culture.

II. Research on dynamic simulation and virtual interaction technology of national costumes based on digital modeling

II. A. Research on fiber fabric simulation and simulation algorithm

II. A. 1) Fabric fabric simulation

Fabric organization consists of two mutually perpendicular yarn systems woven in a certain pattern to form a fabric. The warp and weft yarns are defined as yarns that are sequentially arranged horizontally and vertically. The warp and weft yarns are woven in a certain way, and the intersections that occur during the weaving process are called organization points. The process of fabric formation can be described as the interweaving of warp and weft yarns, that is to say, the weft yarns are lifted and lowered according to a certain law, and during the lifting and lowering of the weft yarns, the warp yarns pass back and forth through the weft yarns according to a certain law. And the place where the warp and weft yarns intersect forms the organization point. Weft yarns covered in the warp yarns on the intersection is called the weft tissue point, the warp yarns covered in the weft yarns on the intersection is called the warp tissue point, which is in accordance with a certain law of the warp tissue point and weft tissue point is displayed on the fabric, the number of times, and the number of times of the cycle determines the fabric in the texture of the complexity of the performance. The higher the number of cycles, the higher the complexity of the texture, and vice versa. The number of warp yarns is determined by the number of warp yarns used in a cycle, while the number of weft yarns is determined by the number of weft yarns used in a cycle. Within a cycle, different organizations can again be classified according to the number of points of warp and weft organization, the warp-face organization and the weft-face organization. Where the warp face organization means that the number of dimension fabrics is less than the number of warp fabrics, while the weft face organization is just the opposite. And when the number of warp and weft fabrics is the same it is called the same face organization.

The structural characteristics of the yarn are simulated using particles and the dynamics are used for yarn simulation. After obtaining the warp and weft yarns, the warp and weft yarns are interwoven according to the arrangement of the fabric to obtain a fabric organization cycle, and then the simulation of the fabric structure style is realized by methods such as tiling. In order to get a more realistic fabric effect, OpenGL lighting algorithm is used to add lighting factors to the simulated fabric, and the specific implementation process is shown in Figure 1.

II. A. 2) Fabric fabric meshing

In order to realize the physical simulation of the fabric, it is necessary to establish a physical model of the obtained fabric cloth, analyze the force of the fabric, and construct a mechanical simulation model of the fabric. For the fabric simulated in this section, the triangular mesh construction algorithm is utilized to mesh the fabric clothing piece and improve the triangular mesh.

(1) Constructing point sets for a given area

Delineate the boundary of the fabric, and construct a point set in the given region of the fabric to lay the foundation for the construction of the triangular mesh. The construction of point set in a given area is based on the following rules, and the method of point distribution is shown in Fig. 2.

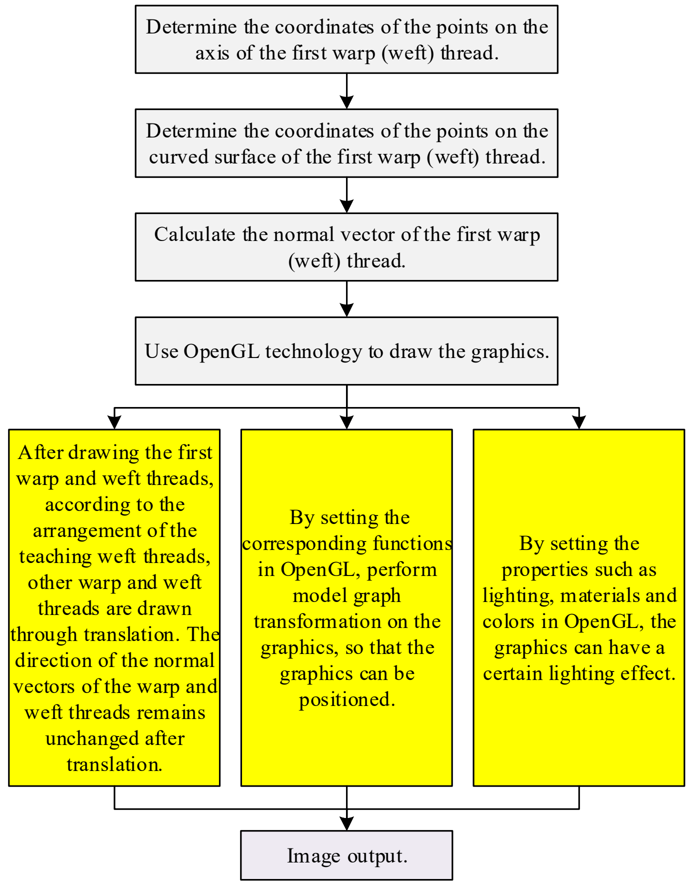

Figure 1: Fiber simulation process

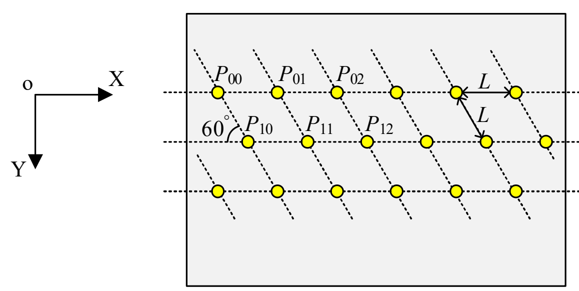

Figure 2: Point layout method

Specify the point at the upper left corner of the rectangle as the origin, X axis refers to the horizontal direction to the right, Y axis downward vertical direction, the specific method of laying points is as follows:

Starting from the upper left corner, the points are laid out sequentially row by row, assuming the first point $P_{00}(x_0, y_0)$.

The points in the first row are $P_{00}, P_{01}, P_{02} \cdots P_{0n}$ in that order, then the horizontal coordinates of the point $P_{0i}(0 \le i \le n)$ are

$$x_{0i} = x_0 + i \times L \tag{1}$$

The vertical coordinate is

$$y_{0i} = y_0 \tag{2}$$

Horizontal coordinates of the first point P_{10} in the second row

$$x_{10} = x_0 + L/2 \tag{3}$$

The vertical coordinate is

$$x_{10} = y_0 + \sqrt{3}/2 \times L \tag{4}$$

Then the horizontal coordinates of the i th point $P_{1i}(0 \le i \le n)$ in the second line

$$x_{1i} = x_0 + i \times L + L/2 \tag{5}$$

The vertical coordinate is

$$y_{1i} = y_0 + \sqrt{3}/2 \times L \tag{6}$$

Therefore, the horizontal coordinates of the point $P_{ij}(0 \le i, j \le n)$ in row i, column j are shown in Eq:

$$x_{ij} = \begin{cases} x_0 + j \times L, & j = 0 \ or \ j \ is \ an \ even \ number \\ x_0 + j \times L + L/2, & j \ is \ an \ odd \ number \end{cases} \tag{7}$$

The vertical coordinate is shown in Eq:

$$y_{ij} = y_0 + i \times \sqrt{3}/2 \times L \tag{8}$$

The second step is to remove the redundant points in the given region, and there are two methods to determine the redundant points in the region.

The first one is to define the point outside the outline of the clothing piece as a redundant point, and the judgment method is to define the point to be judged as the end point, and make a horizontal ray to the right with the end point as the starting point, if the intersection point of the horizontal ray and the outline of the clothing piece is an odd number of points, the point is judged to be inside the outline of the clothing piece and is not a redundant point, and if it is an even number of points, then it is a redundant point, and it is necessary to remove it. The judgment method is shown in Figure 3.

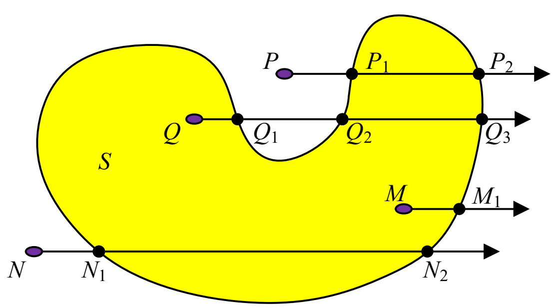

Figure 3: Illustration of discrimination methods

As shown in Fig. 3, the region is defined as S to determine whether the points N, M, Q, and P are in S or not in the given contour of the clothed piece, and the solid points in the figure denote the intersections of the rays derived from the endpoints with the boundaries of S, while the hollow points are denoted as the points for which the determination is to be made. As it can be concluded in Fig. 3, only the intersections of the rays of P and N with the boundary of S have an odd number of intersections, so it is determined that Q and M are inside the region, while P and N are outside the region.

In the determination process may occur just a point falls on the boundary of the delineation of the region, this point will be judged as redundant points, to be deleted.

The second judgment is when a point is very close to the boundary of the region, and for very close to the boundary of the situation set a threshold, the threshold will be controlled in the development of the range of step size, then all the points and the contour of the region of the contour point for the difference of the solution to the contour point of each point distance from the contour of the distance between the point, if the distance in the range of the threshold will be retained, and is no longer within the threshold range will be deleted.

(2) The basic principle of triangular mesh growth method

Triangular mesh has very good ductility and structural properties, which can perfectly triangulate the specified area, and the triangular mesh is constructed by triangulating the input set of discrete points according to the rules for constructing the mesh.

First, determine the given point set as $S=\{P_1,P_2,\cdots,P_n\}$. In S, find any point $P_i(1\le i\le n)$, and search for the nearest point P_j to point P_i, forming the initial growth edge of the triangular mesh e_1. According to the Delaunay triangulation rules, search through all the points in set S to find the optimal triangulation point P_k in the right region of e_1. Connect P_i and P_k, and P_j and P_k to form triangle t_1. Then, using P_i and P_k, and P_j and P_k as growth edges, continue to search for optimal triangulation points, repeatedly searching through the specified points in the area. Identify the optimal triangulation points; when the constructed triangles have utilized all the points in the designated area, the construction of the triangular mesh model is complete.

The method of determining the optimal grid point is to set the endpoints of the edges to be extended as A, B, and then find the point C in the set of points, so that the point where the value of L is minimized is the optimal grid point.

$$\begin{aligned} L &= 2\cos(\theta) \\ &= \left(|AC|^2+|BC|^2-|AB|^2\right)\Big/\left(|AC|\times|BC|\right) \end{aligned} \tag{9}$$

II. B. Collaborative Tracking Method for Garment-Life Dynamic Features

After completing the physical simulation and mesh delineation of the fabric structure, how to synergistically match the digitized garment model with the dynamic features of the real human body becomes a key issue. To this end, this section proposes a garment-real human collaborative tracking method based on dynamic feature points, which realizes the accurate response of the garment to human body movements through feature point interpolation and coordinate alignment techniques.

II. B. 1) 3D Clothing Perception Model Based on Dynamic Feature Points

The human skeletal model based on Kinect body sensing device acquisition can extract the position of human joints and recognize human body movements through skeletal points, but due to the limited number of skeletal points, it can not adequately match the changes of human limb movements. Therefore, in this paper, based on the 3D skeletal point features and silhouette features of human body sensing in Chapter 3, we use the midpoint interpolation method to mark multiple dynamic feature points on the key areas of the human body and clothing to construct a personalized 3D clothing perception model. In order to more accurately match the human body movement characteristics. The formula of the midpoint interpolation method is:

$$x_k=(x_1+x_2)/2 \tag{10}$$

$$y_k=(y_1+y_2)/2 \tag{11}$$

$$z_k=(z_1+z_2)/2 \tag{12}$$

where $(x_1y_1z_1)$ and $(x_2y_2z_2)$ are the 3D coordinates of the space points P_1 and P_2, respectively, and $(x_ky_kz_k)$ is the 3D coordinate of the point P_k in the line segment P_1P_2.

The set of human dynamic feature points $X\{X_1X_2\}$ is defined in the human body region, including a subset of human torso X_1 (red points) and a subset of human limbs X_2 (green points). Since a one-to-one correspondence is maintained between human body dynamic features and clothing dynamic features. Therefore, the clothing dynamic feature point set $Y\{Y_1,Y_2\}$ can be defined, which also includes the clothing torso subset Y_1 (red points) and the clothing limbs subset Y_2 (green points). In contrast to the Kinect skeletal model, this paper uses multiple feature points in the torso area and limb area to enhance the matching of garments to human features.

II. B. 2) Collaborative tracking of dynamic features in 3D garments

(1) Overall positioning of the garment

In 3D space, the coordinate alignment between two point sets can be expressed as a rotation plus translation transformation, i.e., it is realized by using rotation and translation matrices. The coordinates of feature points are extracted in X_t and Y_t to construct the point set matrices A and B, which represent the coordinates of the overall dynamic feature point sets of the human body and the garment, respectively, as shown in equation (13).

$$A=\begin{bmatrix}A_{1x} & A_{1y} & A_{1z}\\ A_{2x} & A_{2y} & A_{2z}\\ A_{3x} & A_{3y} & A_{3z}\end{bmatrix} B=\begin{bmatrix}B_{1x} & B_{1y} & B_{1z}\\ B_{2x} & B_{2y} & B_{2z}\\ B_{3x} & B_{3y} & B_{3z}\end{bmatrix} \tag{13}$$

The transformation of the point set matrix B to A can be expressed as equation (14):

$$A = R \times B + T \tag{14}$$

where R is the rotation matrix and T is the translation matrix. Through Eq. (14), the matrices B and A establish a correspondence and B can be transformed into A.

This article solves the matrices R and T by performing SVD decomposition on the covariance matrices B and A denoted as H. Here, H represents the correlation matrix of the coordinates between A and B, which indicates the correlation between the positions of the human body and the clothing model. By decomposing the correlation matrix, we find the mapping relationship from B to the coordinate system of A. The overall tracking process from B to A is shown in Figure 4:

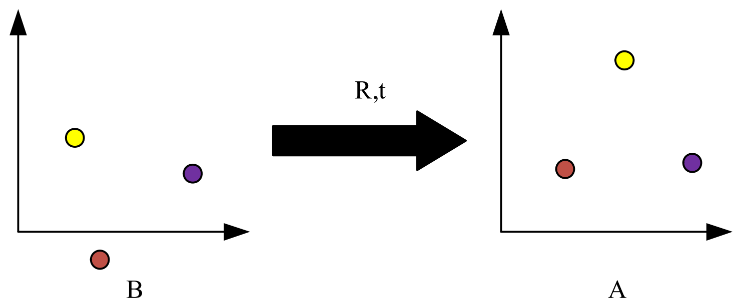

Figure 4: Point set tracking process

(2) Localized tracking of clothing

The predicted coordinates of local feature points are calculated by the SVD decomposition algorithm, and the constraints of the Euclidean distance between skeletal points and the error threshold are used to optimize the tracking accuracy for the feature points with large errors. Taking the arm joint as an example, the predicted spacing between the elbow and shoulder skeletal points is d_{pro}, and the formula is shown in equation (15):

$$d_{pro} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{15}$$

where (x_1, y_1, z_1) and (x_2, y_2, z_2) are the predicted coordinates of the elbow and shoulder skeletal points, respectively.

Similarly, the true spacing of the elbow and shoulder skeletal points is denoted by d_{true}, and the formula for the difference between the predicted spacing and the true spacing is shown in Eq. (16), and the relative tracking error M is defined to denote the ratio between the difference between the predicted spacing and the true spacing of the skeletal points and the spacing of the skeletal points before and after tracking, and is calculated as in Eq. (17).

$$d_{(pro,true)} = \left| d_{pro} - d_{true} \right| \tag{16}$$

$$M = \frac{d_{(pro,true)}}{d_{(t-1,t)}} \tag{17}$$

where $d_{(pro,true)}$ denotes the difference between d_{pro} and d_{true}, and $d_{(t-1,t)}$ is the spacing between the elbow bone points before and after tracking. A tracking error threshold M_0 is set for control as well as iterative computation of R and T matrices to optimize the relative tracking error M.

II. C.Analysis and Design of Virtual Interactive Display System for 3D Scanning Apparel

On the basis of realizing the dynamic tracking of clothing, in order to further enhance the user's perception and interactive experience of traditional ethnic clothing, this section focuses on the design of the 3D virtual interactive display system, which builds an immersive digital display platform for ethnic culture through scene roaming, collision detection and multimodal interaction functions.

II. C. 1) Functional requirements analysis

Scanning dress virtual display system aims to reconstruct the original appearance of Han dress hall of Ethnic Museum of Beijing Institute of Fashion Technology on the computer screen through modern virtual reality technology, three-dimensional scanning and other technologies, so that the user can experience the dress appearance of Han dress hall in a close and diversified way. Through the visit to the existing entity Han dress hall and the analysis of the user's functional requirements, the main functions of the scanning dress virtual display system platform are divided into the following five parts:

(1) virtual scene display function: virtual display of three-dimensional scene model to restore the real showroom scene;

(2) Virtual dress display function: virtual scene roaming in the low-precision dress and a separate display of high-precision scanning dress model;

(3) UI design: design the guide interface: start from the interface layout, icon style, color matching to design an interface that conforms to the scene and has a certain visual appeal;

(4) Scene roaming: you can browse and watch freely and smoothly in the virtual exhibition hall, and you can click on an interested dress to watch it separately, with music as accompaniment and map navigation instructions;

(5) Interaction function: there are various ways to interact between people and exhibits, and you can view its corresponding introduction information, including pictures, text, video, audio, etc.. It can be easily modified when there are changes in text, pictures and models, by modifying the text content in the program and loading the required picture names and model names for replacement.

II. C. 2) Scene roaming

(1) Movement operation

The design of the movement operation is for position movement, while the perspective remains unchanged. Move by judging the user's key pressing situation. The traditional way to move the keyboard is through the four keys "W", "S", "A" and "D". In this article, the arrow keys " ↑ ", " ↓ ", "←" and "→" and the four letter keys "W", "A", "D" and "S" can all be used for movement operations. The up, down, left and right arrows on the keyboard have a small position range and are not related to other keys, which can reduce the probability of misoperation.

"W" and " ↑ " control the first-person object to move forward, and the camera moves in the direction of the negative axis of the Z axis;

"S" and " ↓ " control the first-person object to move backward, and the camera moves in the positive direction of the Z axis.

"A" and "←" control the first-person object to move to the left, and the camera moves towards the negative axis of the X axis.

"D" and "→" control the first-person object to move to the right, and the camera moves in the positive direction of the X axis.

(2) Rotation operation

Rotary operation is designed to change the position of the viewpoint does not change, the viewpoint changes to provide users with the ability to act with the scene, that is, the user's own viewpoint simulation, the user can make the viewpoint according to their own needs, so that the viewpoint converted to the place of interest. Using the left mouse button to control the rotation, hold down the left mouse button and drag the left slide perspective to the left, hold down the right mouse button and drag the right slide perspective to the right, hold down the left mouse button to move 360, the perspective of the original 360-degree conversion. The middle mouse button is used to control the change of view height, press and hold the middle button to move up, the view height increases, press and hold the middle button to move down, the view height decreases.

(3) Collision Detection

There are many obstacles in the process of movement. If there is no obstacle between the starting position and the end point, it can be a smooth straight line movement, but in order to make full use of the space in the Han Clothing Exhibition Hall, a number of booths are placed in the scene, and there are obstacles on the walking ground, such as exhibits, walls, booths, and benches for visiting and resting. In reality, if the linear path of movement is obstructed, people will choose to go around. In order to improve the real response to the roaming need for first-person and object collision detection, when the user walks forward and encounters an obstacle is not a direct penetration, but encounters a collision body to stay in place.

II. C. 3) Interaction design

Interaction is mainly realized between the user and the model, the user operates the model in the scene to read and display the resource information carried by the model. Interaction design and development involves three important steps, one is to give the object rigid body attributes, the second is to carry out collision detection, and the third is to add script components, which are the steps that must be completed before the output of the virtual interactive display system of traditional national costumes.

III. Digitization-based dynamic simulation verification of national costumes and evaluation of virtual interactive system

After completing the theoretical exploration of fiber fabric simulation, garment-real person dynamic collaborative tracking and virtual interactive system design in Chapter 2, this chapter comprehensively evaluates the practical effects of the proposed method from the multi-dimensional aspects of accuracy, efficiency and user experience through experimental verification and subjective user evaluation, to provide empirical support for the grounded application of the digital modeling technology in the innovative design of traditional ethnic clothing.

III. A. Comparative experiments of fabric simulation simulation based on 3D mesh convolution

III. A. 1) Experimental setup

For the proposed simulation framework based on 3D convolutional neural network to simulate the real yarn fabric folds, this paper compares and explores the various factors that affect the simulation effect. This experiment is realized under Linux system using python language, the hardware is 2.4GHz Intel Crei79700CPUo, 8*2GB dual-channel memory, and the graphics card model is NVIDIAGeForceRTX2070Super.

III. A. 2) Data set construction and parameterization

In this paper, the open source ARCSim system is used to complete the physical simulation. For the mesh provided by ARCSim, three fabric models such as a flag in the wind, a cloth in different positions on a teapot, and a hanging cloth are selected for the experiment. For the flag in the wind, one side of the flagpole is fixed and the wind and gravity are applied to make it flutter in the air, and by changing the size of the wind, a total of 10 sequences are formed, with 600 frames in each sequence and 6182 vertices per frame; for the cloth on the tea kettle, the rigid body of the tea kettle is fixed without moving, and the cloth which is only subject to the force of gravity is free to fall down to cover the tea kettle, and by changing the covering position (the spout, the handle, and the pot, etc.) and the size of the cloth (with no change in the number of vertices), a total of 10 sequences are formed. By changing the covering position (spout, handle and body, etc.) and the size of the fabric (the number of vertices remains unchanged), a total of 16 sequences are formed, each with 400 frames and 3020 fabric vertices per frame; for the hanging fabric, the fabric is fixed to a point so that it can hang down freely, and by changing the number of fixation points and the size of the fabric, a total of 18 sequences are formed, each with 1200 frames and 6570 vertices per frame.

For each of the three datasets, 70% of each training set is used as the training set and 30% is used as the test set.The length of the grid bounding box used in the experiments are between 0.6 and 1.5 units, gravity -9.8N/Kg, UV bending units are 0.5 each, UV tensile and compressive deformation units are both 50, the density is 0.005, and the thickness is 0. In spiral convolution, the setting of the fixed length L of 100 vertices as hyperparameters, and the size of storage table Rs is set to 50MB, and its storage form is sequential storage. In order to improve the computational efficiency, only one K-value calculation is performed for each local domain in the pooling operation.

Pooling in this paper is similar to the initial resizing of CNN images, where geometric mesh extraction helps to reduce the resolution and consequently the network capacity required for training, and reduces the runtime by a significant amount when using neural network upsampling, but in order to preserve the fabric details, only the vertices of the local domains with the smallest K-value are extracted until the number of vertices is less than 60% of the original number of vertices. For most experiments it is possible to produce visually smooth surfaces using only the L1 error, but in some cases the surface may be slightly uneven, so the normal error Ln is considered to improve the surface smoothness, and in rare cases the network produces smaller errors on most vertices but larger errors on a few vertices, and the addition of the L2 error removes these influences when a= 1, b=1, and c=0.02 the visualization is best.

III. A. 3) Comparison of quantitative experiments

Numerical experiments compare the difference in generalization ability with other methods, comparing methods that include a low-precision garment sampling-based physical simulation method, a multi-feature super-resolution network-based MFSR method, and a triangle mesh-based convolutional neural network method. Comparison of the four methods in terms of differences in simulation results includes the Hausdorff distance used to measure the simulated vertices from the initial vertices in each frame and the average elapsed time per frame, where the Hausdorff distance is used to characterize the degree of similarity between the two sets of point sets.

Comparison results of reconstruction error and time consumed for the test set on different datasets are shown in Table 1.The physical simulation method calculates the normal vector angle for the intercepted fabric frames and deforms the fabric according to the curvature magnitude, which can accurately measure the curvature degree of the surface in all cases, with small error distance and strong robustness, but the method is still essentially using physical simulation method, and the time consumed is still very high.The MFSR uses deep learning for fabric simulation, which is 12-14 times faster than the physical method, but the method converts a pair of high- and low-resolution meshes into corresponding images for simulation, which not only loses a large amount of mesh details during the conversion process, resulting in distortion during frame movement, but also takes too long to preprocess, which still adds to the time-consumption.

Table 1: Comparison of test set reconstruction errors and time consumption

	The flag in the wind		The cloth at different positions on the teapot		Hanging cloth	
	H/mm	T/s	H/mm	T/s	H/mm	T/s
Physical simulation	2.483	55.39	5.412	45.74	5.382	57.61
MFSR	3.476	4.07	6.484	3.42	6.021	3.82
Convolution based on three-dimensional mesh	2.527	3.88	5.812	3.55	5.532	3.70
The method of this article	2.381	3.62	5.318	2.84	5.343	3.31

Table 1 compares the Hausdorff distance reconstruction errors and average time consumed per frame for the four methods on the three datasets (flag in the wind, cloth on teapot, and hanging cloth). Although the physical simulation method has the smallest Hausdorff distance, 2.483 mm for the flag, 5.412 mm for the teapot, and 5.382 mm for the hanging cloth, its average per-frame elapsed time is as high as 55.39 s, 45.74 s, and 57.61 s, which is significantly higher than the other methods. It is because the physical simulation method calculates the normal vector angle on the intercepted fabric frames and deforms the fabric according to the curvature magnitude, which can accurately measure the curvature degree of the surface in various cases, with a small error distance and strong robustness, but the method still essentially uses physical simulation methods, and the time consumed is still very high.

The MFSR method accelerates the simulation through deep learning, and the time consumed is only 1/14 of the physical method, with 4.07s for the flag, 3.42s for the teapot, and 3.82s for the hanging cloth, but its Hausdorff distance increases significantly, with 3.476mm for the flag, 6.484mm for the teapot, and 6.021mm for the hanging cloth, and the MFSR method transforms a pair of high-resolution and low-resolution meshes into the corresponding images and then simulation, the conversion process not only loses a lot of mesh details, resulting in distortion during frame movement, but also the preprocessing time is too long, which still increases the time-consuming.

Although the 3D mesh-based convolution method also uses a convolutional neural network based on a triangular mesh, its reconstruction error and time-consumption are still higher than the method in this paper due to the fact that the time cost and simulation cost are not taken into account in the convolution and pooling stages. Its method outperforms MFSR in time-consuming flag 3.88s, teapot 3.55s, and hanging cloth 3.70s and error flag 2.527mm, teapot 5.812mm, and hanging cloth 5.532mm, but still slightly inferior to this paper's method. The method in this paper performs best on error flag 2.381mm, teapot 5.318mm, hanging cloth 5.343mm and time-consuming flag 3.62s, teapot 2.84s, and hanging cloth 3.31s through the optimized pooling strategy, and its Hausdorff distance is reduced by an average of 3.8% compared with the physical method, and the time-consuming is further reduced by 11%~17% compared with MFSR, which verifies its accuracy and efficiency in the of the physical method, verifying its double advantages in accuracy and efficiency.

The number of simulated vertices of this paper's method is compared with the other three methods. The comparison results are shown in Fig. 5.

The number of simulated vertices for all methods was lower than the initial fabric vertex count (flag 5832, teapot 3011, hanging fabric 6905). The physical simulation method has a limited reduction in vertex count, 5640 for flag, 2892 for teapot, and 6793 for hanging fabric, and reduces the complexity only by a conventional mesh simplification strategy.MFSR has a significant reduction in vertex count due to the image transformation, 5407 for flag, 2791 for teapot, and 6438 for hanging fabric, at the expense of detail fidelity. The 3D mesh-based convolution method adopts a quadratic error edge folding strategy, and the number of vertices is further reduced to 4302 for the flag, 2665 for the teapot, and 6009 for the hanging cloth, but the number of remaining vertices is still high, and the simulation cost is high. The method in this paper calculates the local domain K-value by Gauss-Bonnet theorem, and prioritizes the extraction of low K-value vertices, and the number of vertices is significantly reduced to flag 3473, teapot 2547, and hanging cloth 5660, which is 40.5%, 15.4%, and 18.0% less than the initial number of vertices, respectively, and better than the other methods, and the number of flag vertices is reduced by 19.3% than that of the 3-D mesh convolution method. This result shows that the method in this paper significantly reduces the computational resource consumption through an efficient vertex extraction strategy while maintaining the simulation effect, and provides a feasible basis for real-time dynamic simulation.

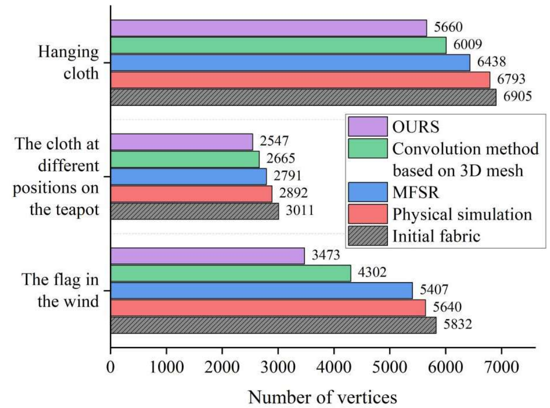

Figure 5: Comparison of the number of simulated vertices

III. B. Clothing model simulation effect evaluation

After verifying the model accuracy and efficiency advantage through the fabric simulation comparison experiment based on 3D mesh convolution, it is further necessary to systematically evaluate the simulation effect of the clothing model in order to explore its visual performance and dynamic characteristics in practical applications.

Taking the clothing model made in this paper as an example, various index data of the model effect are obtained through subjective investigation, and the evaluation index data are statistically analyzed, and the factor evaluation space is established, based on which the traditional national costume model made under the theoretical guidance of the cooperative tracking method based on the dynamic characteristics of the clothing - real people is specifically evaluated.

III. B. 1) Preliminary identification of evaluation indicators

The selection of virtual clothing simulation effect indicators under the theoretical guidance of basic clothing composition, clothing design and computer simulation has a certain scientific nature. There are four main elements of clothing composition, which are style, color, material and technology, while the three elements of clothing design are shape, color and material, which can be seen that the two have commonality. Among them, the style and modeling of the two refer to the basic shape of the garment, which is mainly composed of the external silhouette and internal details, including the design of the collar, placket, sleeves, pockets and other parts of the internal details; the color refers to the color of the garment and the color of the fabrics; the material refers to the drape of the fabrics and auxiliary materials, softness, shape retention, fabric texture, texture, and so on. In summary, 18 indicators are summarized as clothing silhouette, clothing style, collar structure, placket structure, sleeve structure, hem structure, hue, color saturation, color brightness, color combinations, fabric color, fabric texture, fabric luster, fabric texture, fabric thickness, drape, softness, stiffness, combined with the knowledge of computer graphics to increase the crease effect, perspective effect, static drape effect, static overall effect, dynamic texture. effect, perspective effect, static drape effect, static overall effect, dynamic swing effect, dynamic drape effect, dynamic overall effect and other 7 indicators, a total of 25 primary indicators.

Under the guidance of experts in the field of apparel and computer simulation, the following principles were followed for the preliminary screening: (1) only one of the indicators with very similar concepts was taken; (2) the indicators that could not be judged subjectively were deleted; (3) the indicators that were not representative enough were deleted or several indicators were synthesized to form one indicator.

The collar structure, placket structure, sleeve structure, hem structure are combined into the detail structure; the hue, color saturation, color brightness, color combination are combined into the fabric color; the fabric color and fabric texture, drape and stiffness are selected; the fabric texture and fabric thickness are combined into the thickness texture; the garment style, softness and dynamic overall effect are deleted; and other indicators are retained. Finally, 12 intermediate evaluation indicators were obtained as the evaluation items of the questionnaire.

III. B. 2) Correlation analysis of evaluation indicators

SPSS statistical analysis software was used to analyze the correlation between the scores of the 12 evaluation indicators. Correlation analysis refers to the analysis of two or more variables with correlation elements, so as to measure the degree of correlation between two variables, usually using correlation coefficients and scatter plots for correlation evaluation.

Analyzing the correlation of the 12 evaluation indicators and removing the indicators with particularly strong correlation can, to a certain extent, make the evaluation results more reasonable. The correlation coefficients obtained for the 12 indicators are shown in Figure 6.

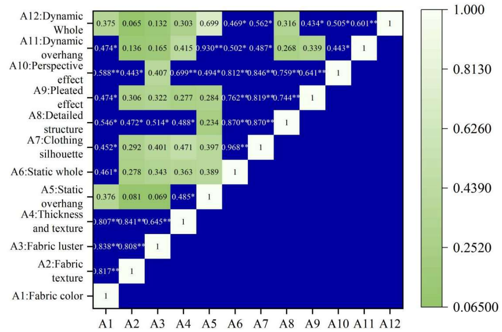

Figure 6: Pearson correlation coefficient analysis results of each index

The graph ** indicates that the null hypothesis can be rejected at a significance level α of 0.01; * indicates that the null hypothesis can be rejected at a significance level α of 0.05.

It can be known from Figure 6 that there is a very strong linear relationship between the "static overall effect" and the "clothing silhouette", and the corresponding correlation coefficient is 0.968. There is also a very strong linear relationship between the "static suspension effect" and the "dynamic suspension effect", with the corresponding correlation coefficient being 0.930. The probability P values of their correlation coefficient tests are all 0.000. When the dominant level p is less than 0.01, the null hypothesis of the correlation coefficient test should be rejected. Therefore, for judging the "static overall effect" and "clothing silhouette", and the "static drape effect" and the "dynamic drape effect", one of the two should be chosen.

III. B. 3) Establishment of final evaluation indicators

The matrix scatter plots of "static overall effect", "clothing silhouette", "static drape effect" and "dynamic drape effect" based on the data in the above figure are shown in Figure 7. It can be clearly found that in the units of "Static Overall Effect" and "Clothing Silhouette", as well as the units of "Static Drape Effect" and "Dynamic Drape effect", the vast majority of data points are concentrated around a straight line segment. This form indicates a strong positive linear correlation among the data. For the convenience of subsequent research, in this paper, the indicators related to "static" in "static overall effect", "clothing silhouette", "static drape effect", and "dynamic drape effect" are removed. The remaining 10 indicators are the final evaluation indicators for the clothing simulation effect.

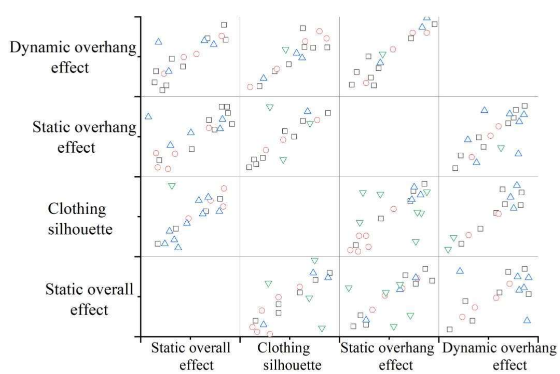

Figure 7: Scatter plot of matrix

III. B. 4) Experimental factor analysis

In order to find out the number of factors that can jointly influence the 10 evaluation indicators and the correlation degree between each factor and each indicator for the purpose of dimensionality reduction, so as to have a more comprehensive and complete understanding and grasp of the problem of evaluating the effectiveness of virtual clothing simulation, this paper adopts the exploratory factor analysis method (EFA) EFA) to obtain the correlation between the 10 indicator variants and a smaller number of factors (i.e., unobservable latent variables).) between these 10 indicator variants and a smaller number of factors (i.e., unobservable latent variables).

The Pearson correlation coefficients in Fig. 6 show that the PBP of the 10 evaluation indicators is generally greater than 0.3, which indicates that there is a strong correlation between these variables, and it is suitable for factor analysis. The KMO coefficient test and Bartlett's sphericity test of the data of 10 indicators using SPSS software show that: KMO=0.824>0.8, reaching the level of “good”, indicating that there is a common factor between the variables; Bartlett's sphericity test has a value of 167.23 (with 48 degrees of freedom), and the probability of significance is p=0.000, and the probability of significance is p=0.000. The value of Bartlett's test of sphericity is 167.23 (with 48 degrees of freedom), with a probability of significance of p=0.000<0.01, indicating the existence of a common factor between the overall correlation matrix. Thus, both KMO coefficient test and Bartlett's sphericity test indicate that the variables are suitable for factor analysis.

Based on the correlation coefficient matrices of the original variables, principal component analysis was used to extract the common factors. The results of factor analysis showed that there were three common factors with eigenvalues greater than 1. The fourth factor began to have an eigenvalue of less than 0.6, which explains the small contribution of the original variables, and therefore three subs were taken in the calculation.

The total variance of the original variables explained by the factors when taking 3 factors is shown in Table 2. As can be seen from Table 2, when taking 3 factors, the factors can explain 90.469%>85% of the total variance of the original variables, and overall the information of the original variables is lost very little, and the factor analysis is more satisfactory.

Table 2: Factors explain the total variance of variables

Factor	Initial eigenvalue			Rotate the sum of squares for loading		
	Total sum	Variance contribution rate /%	Cumulative variance contribution rate /%	Total sum	Variance contribution rate /%	Cumulative variance contribution rate /%
1	6.067	56.326	56.326	3.573	36.482	36.482
2	2.084	24.808	81.134	3.027	28.187	64.669
3	1.036	9.335	90.469	1.398	23.325	87.994
4	0.584	4.349	94.818			
5	0.485	2.658	97.476			
6	0.362	1.126	98.602			
7	0.213	0.743	99.345			
8	0.167	0.499	99.844			
9	0.064	0.132	99.976			
10	0.046	0.024	100.000			

III. B. 5) Factor analysis results

The factor loading matrix obtained after orthogonal rotation by the maximum variance method is shown in Table 3. This rotated loading matrix was ranked according to the magnitude of the factor loadings of the indicator items in each common factor. From Table 3: All factor loadings are greater than 0.78, and the common factor can explain more than 67.38% > 25% of the variance of the indicator variables. The Cronbach'sa coefficients for the 10 question items were 0.911 > 0.600, the internal stability and consistency of the factor constructs met the requirements, and the common factors could be named according to the common characteristics they contained.

Common factor 1 explains 36.293% of the total variance and consists of four items: "Fabric texture", "fabric color", "Fabric Gloss" and "Thickness Texture". It explains the relevant aspects of fabric characteristics in the model simulation effect and is thus named the fabric characteristic evaluation factor. The common factor 2 explains 31.023% of the total variance. It consists of four items: "Clothing Silhouette", "Detailed Structure", "Pleat Effect" and "Perspective Effect", describing the influence mode of the pattern structure on the simulation effect of the model. Therefore, it is named the pattern characteristic evaluation factor. The common factor 3 explains 20.117% of the total variance and consists of two items: "Dynamic Sag" and "Dynamic Swing". It is used to evaluate the effect of the dynamic model and is thus named the dynamic effect evaluation factor.

Table 3: Factor loading matrix

		Common factor		
		1	2	3
Common factor 1: Fabric characteristics	Fabric texture	0.937	0.121	0.025
	Fabric color	0.918	0.229	0.239
	Fabric luster	0.854	0.371	-0.018
	Thickness and texture	0.872	0.144	0.304
Common factor 2: Template characteristics	Clothing silhouette	0.197	0.813	0.293
	Detailed structure	0.274	0.852	0.069
	Pleating effect	0.396	0.859	0.177
	Perspective effect	0.243	0.764	0.404
Common factor 3: Dynamic effect	Dynamic overhang	0.236	0.112	0.891
	Dynamic swing	0.059	0.301	0.817

III. C. Subjective Evaluation of Immersive Ethnic Culture Digital Display Platforms

On the basis of completing the quantitative analysis of the simulation effect, in order to comprehensively assess the user experience of the virtual interactive system, this chapter further combines the subjective evaluation method to conduct user research on the immersive ethnic culture digital display platform in terms of the dimensions of the page design, functional layout and operation logic.

The evaluation of the platform is in the form of subjective evaluation, finding 20 traditional ethnic dress enthusiasts to evaluate the page style and page content of the designed 3D scanning dress virtual interactive display system, in which the page style mainly refers to the overall color tone, color matching and appearance design of the website; the page content is divided into two parts of the comprehensiveness and layout design, and comprehensiveness refers to whether the content of the webpage is comprehensive and rich, and whether the basic functions are Comprehensiveness refers to whether the content of the web page is comprehensive and rich, and whether the basic functions are realized, while the layout refers to the combination of different modules in the page and the framework design. The evaluation adopts the form of a five-point Likert scale, that is, each indicator is on a 5-point scale. Taking the rationality of page operation as an example, the experimenter needs to write down the score of each item based on their own judgment. Among them, 1 point indicates "very unreasonable", 2 points indicates "relatively unreasonable", 3 points indicates "average", 4 points indicates "relatively reasonable", and 5 points indicates "reasonable".

When the experimenters conduct subjective evaluations, they need to browse the website platform while filling out the subjective evaluation test form. The design of the test table is divided into two tables based on the running roles: ordinary users and administrators. Each table consists of two major parts: page style and page content, and is further subdivided into six sub-parts: "Color Tone", "Content comprehensiveness", "Content Layout", "Operation Necessity", "Operation convenience", and "Operation Logic". Among them, page style and content are the targeted functional modules. Based on the above conception, subjective evaluation questionnaires for the ordinary user role and the administrator role were designed. In the questionnaire, in addition to the scoring column, an autonomous suggestion column has also been added. The experimenters can write down their suggestions and opinions for a certain module. During the statistics, interviews and communication were conducted with the experimenters regarding the written suggestions, and the rectification opinions were recorded. Finally, the subjective evaluation forms of the 20 experimenters were collected, the average score of each indicator was calculated, and a line graph was made. The subjective evaluation results of the ordinary user role and the administrator are shown in Figures 8 and 9 respectively.

The role evaluation of ordinary users shows that ordinary users have a relatively high overall evaluation of the page style and content of the 3D scanning clothing virtual interactive display system. In terms of page style, the "tone" scores generally range from 4.15 to 4.46. Among them, the "Traditional Ethnic Costume Culture" module has the highest tone score, which is 4.46. The score of "Layout" was particularly outstanding, with all modules exceeding 4.35. Among them, the layout score of the "Academic Research" module reached 4.88, approaching a full score. In terms of the comprehensiveness of the content, the "Traditional Ethnic Costume Activities" module ranked first with a score of 4.84, indicating that users have the highest recognition of the completeness and richness of its display. Furthermore, the comprehensiveness and layout scores of the "User Center" module were both 4.55 and 4.60, slightly lower than those of other modules, suggesting that there might be room for optimization in this module.

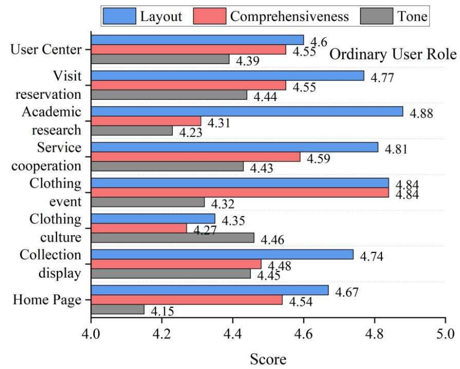

Figure 8: The page style and content evaluation results of ordinary user roles

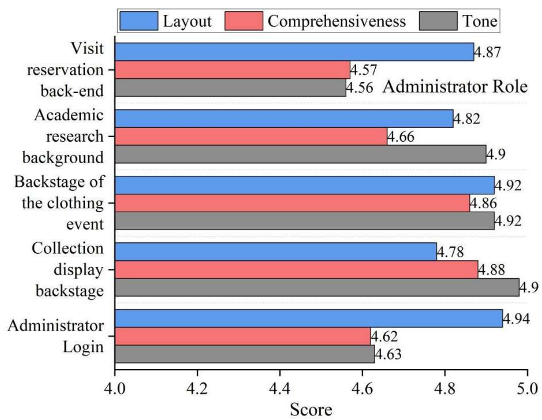

Figure 9: The page style and content evaluation results of the administrator role

In the evaluation of the administrator role, the evaluation of the background functions by administrators is generally higher than that of ordinary users, reflecting the professionalism and practicality of the background design. For instance, the color tone score of the "Collection Display Backend" reached 4.98, approaching a full score, and the layout score of the "Clothing Event Backend" was as high as 4.92, indicating that the administrator highly recognized the adaptability of the backend interface design. However, the comprehensiveness score of the "Visit Reservation Backend" is 4.57, which is relatively low and may reflect that the functions or information display of this module need to be further improved. It is worth noting that the layout score of the "Administrator Login" interface reaches 4.94, the highest among all modules, indicating that its operation logic and interface design meet the efficient requirements of administrators.

IV. Conclusion

In this study, a high-precision dynamic simulation and immersive interactive display of traditional ethnic costumes is realized by integrating particle dynamics, triangular mesh partitioning and SVD decomposition algorithm.

The fiber simulation model based on particle dynamics and triangular mesh partitioning reduces the Hausdorff distance error by an average of 3.8% compared with the physical simulation method, and the time consumed is reduced by 11%~17%; the vertex extraction strategy combined with the Gauss-Bonnet theorem reduces the vertex number by 18%~40.5%, which significantly optimizes the real-time simulation performance.

Factor analysis shows that dynamic drape (load 0.891) and fabric texture (load 0.937) are the core indicators affecting the simulation effect, providing data support for subsequent optimization. In the subjective evaluation of users, the average value of ordinary users on the system layout is 4.67, and the average value of administrators on the adaptability of background functions is 4.92, with a rating close to full marks. It confirms the practical value of its cultural display and educational dissemination.

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