

Reproduction of Intangible Cultural Heritage by Virtual Costume Design Based on Digital Texture Rendering Algorithm

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Abstract: Intangible cultural heritage (ICH) is a valuable cultural wealth of the nation, carrying the genes of Chinese civilization and manifesting the aesthetic pursuit and spirit of the nation. Considering the technical needs of image texture rendering enhancement, a texture rendering algorithm based on fuzzy clustering is designed from the two aspects of fuzzification processing and image fuzzy enhancement. According to the four virtual clothing technology characteristics, it is proposed to use Marvelous Designer 3D virtual software to construct a virtual clothing model, and explore the effectiveness of the model in this paper from multiple dimensions. Among the 35 sets of comparison data between the virtual clothing effect and the real clothing effect, 31 sets of data are equal, corresponding to a correct rate of 88.57%, i.e., the model in this paper has excellent effectiveness. In addition, when the experience feeling index in the virtual clothing model is raised by 1 quantitative value, the corresponding quantitative value of the effect of intangible cultural heritage reproduction is raised by 0.124 units, which reflects the facilitating effect of virtual clothing design on the reproduction of intangible cultural heritage.

Keywords: fuzzy clustering; texture rendering algorithm; virtual clothing design; non-heritage

1. Introduction

As an important part of regional culture and intangible cultural heritage, traditional clothing carries multiple cultural connotations such as history, religious beliefs, social structure and natural environment [1-2]. However, with the process of globalization and modernization, the status of traditional clothing has gradually declined, and especially the younger generation has a weakened sense of identification with it, making it face the dilemma of inheritance [3]. In the diversified modern society, combining traditional clothing with digital intelligence technology can inject soul and depth into virtual clothing. Virtual clothing is a three-dimensional garment expressed in digital form in virtual space, generated by simulation through modern digital computer technology such as 3D virtual software technology, which is a synthetic image or video synthesized after comprehensive consideration of factors such as clothing layout, fabric material, shape and human body movements, as well as the form and changes when wearing clothing [4-6]. In order to meet the demand for cultural diversity, the integration of traditional and virtual clothing design and innovation becomes crucial. This process requires collecting a large amount of information, observing real-life trends and fashion trends, and at the same time figuring out the characteristics and needs of the virtual characters, so as to create a perfect virtual character image [7]. This innovation is not only simply moving real clothes to the virtual world, but also requires creating a unique virtual clothing experience by integrating digital technology and creative design [8].

With the rapid development of computer hardware, digital-based rendering technology has been widely used in the fields of gaming, film and television in order to obtain images with great realism [9-10]. The field of rendering is an important subfield of computer graphics, which is the study of displaying and computing graphics, representing and building models, managing and manipulating graphical data, and using graphical information for interactive operations on specific scenes [11-13]. While rendering is the technique of visualizing graphics and outputting a 2D or 3D virtual scene as an



image, the development of rendering is closely related to the development of graphics [14]. Rendering from the rendering speed is divided into real-time rendering and offline rendering, the game because of the need to meet the real-time, generally use real-time rendering, and film and television in order to pursue a stronger sense of realism, will use offline rendering to do some special effects, etc. [15-16].

Virtual costume design not only plays a key role in the development of regional culture, but also has an important significance for the inheritance of intangible cultural heritage, and the promotion of the integration of traditional costumes and digital technology is an effective way to realize its revival [17-18]. By using three-dimensional virtual costume display technology, researchers have realistically reproduced historical and ethnic costume artifacts, effectively solving the problem of difficult preservation and dissemination of costume artifacts. The digital texture rendering technology helps to increase the public's cultural interest in traditional costumes and enhance the recognition and identity of the value of intangible cultural heritage. The development of virtual clothing meets the basic requirements of the public's cultural needs and needs to have more creative innovation and technological revolution [19].

Currently, there are a large number of reports on the research of virtual clothing, according to the retrieved literature on virtual clothing most of the research focuses on the design process of virtual clothing, human body fit, traditional clothing recovery, etc. [20-21]. Hou et al. [22] conducted a study on the basis of virtual clothing based on the human body fit, established a 3D model of the human body through linear regression equations, and designed virtual clothing with better performance in terms of fit and design time according to the user's body type. The designed virtual clothing has a better performance in terms of matching and design time. Yu et al [23] mastered the basic features of A-Ma culture and clothing through literature analysis and used them to establish a standard female body model, and then accurately simulated the 3D virtual production process of A-Ma clothing by using CorelDraw X4, PEACE CLOTHING CAD software and CLO 3D software. Sabina et al [24] used simulation technology in a virtual fitting environment to design a virtual clothing pattern for the actual body type of the subject, and used a variety of methods to evaluate the clothing pattern design, which realized the perfect correspondence between the virtual clothing design and the subject. Spanlang et al [25] designed a virtual clothing system that automatically collects data such as customer dimensions and body markings through a 3D scanner, and its on-board Kawabata evaluation module ensures proper fabric virtual draping behavior, which can quickly provide customers with virtual clothing that meets their requirements.

Decaudin et al [26] proposed a novel virtual garment design system that first draws and sews garments on 2D sketches of the user's silhouette mapped on a virtual human body, then calculates the distances around the mannequin in order to convert the sketches into 3D surfaces, and then the system automatically assembles each 3D panel to form complete virtual garments. Wang et al [27] designed a virtual clothing display system using CLO3D and HTML5. CLO3D helps designers to design virtual clothing according to user requirements, and then the system displays the virtual clothing design process to the online media, which provides feasible technical support for the digital transformation of the apparel industry. Zhu, X et al [28] started from the perspective of virtualized display of clothing design, and chose to conform to the user's personality of clothing color scheme and fabric to form a personalized Clothing style, and then through Unity3D and VR technology developed personalized clothing 3D customization system for user 3D face scanning, clothing style design and other virtual clothing design process.

In addition to this, Meng et al [29] considered the human body model as an ellipsoid and surrounded the ellipsoid using recursive optimization, and at the same time introduced four types of user interaction operations for pre-positioning and virtual sewing of the virtual fabric, and proposed a dynamic model of fabric that simplifies and integrates with fabric simulation, which effectively improves the quality of the virtual design of the fabric. Lungu et al [30] investigated the Romanian cultural heritage by collecting patterns on traditional clothing combined with digital technology and CAD-CAM-CAE methods for production, the collection of more than 100 kinds of traditional patterns drawn with vector graphics software Corel Draw, selecting different processing methods to ultimately apply the pattern on the material of the furniture for evaluation and analysis. Peng [31] systematically analyzed the trend of application of virtual simulation in the teaching of apparel technology majors, and from a Clothing technology teaching point of view pointed out that the advantages of the application of virtual simulation technology, which helps teachers to carry out the practical teaching of clothing design based on virtual simulation technology.

Realistic rendering techniques are well developed, and various rendering techniques have emerged in the apparel field to optimize apparel texture transformation. For example, He et al [32] used 3D modeling and rendering techniques to optimize the traditional garment texture conversion, using parallax mapping to project the fabric texture mapping onto the surface of the garment model and constantly updating the illumination parameters to obtain the optimal garment illumination effect, and then using the minimum

average filter to eliminate the edge curves of the garment image to achieve a high-quality texture transfer. Adabala et al [33] used the fabric texture mapping and horizontal maps to combine syntactic representations of textile information files and procedural thread textures. bi-directional reflection distribution function and level maps, combined with the textile information file in the syntactic representation and program thread texture to build a clothing rendering model, while using a multi-texture approach to meet the real-time constraints, the example proves the effectiveness of the model in the clothing texture dressing. Wu et al [34] in order to solve the rendering technology in the fiber level fabric model on the application of the high cost of the problem, to put forward a suitable for the graphics processor, and the study shows that this method can achieve real-time rendering of fiber fabrics and maintain high frame rate of the image in the presence of shadows or occlusions. Zhu, H et al [35] proposed a rendering model for randomly generating sequin positions, and studied the optical properties of four special fabrics, namely, metal-wire hybrid fabrics, sidelight fabrics, laser fabrics, and glitter fabrics, and through texture data, the rendering results of the proposed method are close to the real situation.

In order to realize the image texture rendering and enhancement, use the fuzzy clustering algorithm to carry out the blurring processing and enhancement of the image, and finally design a texture rendering algorithm based on fuzzy clustering. From the characteristics of virtual clothing technology, using the texture rendering algorithm in this paper to obtain 2D clothing pattern coloring work, which is imported into the Marvelous Designer 3D virtual software. Then the virtual sewing, after sewing, according to the experimental needs to add the corresponding fabric, stitching, pattern and other materials, and adjust the properties of the material, so that the pattern in the virtual effect of the garment is more realistic, thus constructing a virtual clothing model. After verifying the algorithm and model, the regression analysis in the statistical analysis method is utilized to explore the role of virtual clothing design in relation to the reproduction of intangible cultural heritage.

2. Virtual Clothing Design Based on Texture Rendering Algorithm

2.1. Texture Rendering Algorithm Design

2.1.1. Fuzzification

Blurring the image, transforming the image from the grayscale domain to the fuzzy domain, firstly needs to set a suitable fuzzy affiliation function. In order to better describe the grayscale information of the image, the S function is chosen as the fuzzy affiliation function in this paper:

$$S(x, y, z, g) = \begin{cases} 0, & g \leq x \\ \frac{(g-x)^2}{(y-x)(z-x)}, & x \leq g \leq y \\ 1 - \frac{(g-z)^2}{(z-y)(z-x)}, & y \leq g \leq z \\ 1, & g \geq z \end{cases} \quad (1)$$

where g is the image gray value information, x , y and z are the three parameters of the fuzzy affiliation function, respectively, and x and z denote the two peak gray values with the smallest and largest probability in the gray histogram. The value of y is related to the information entropy of the probability distribution of the gray values, and the information entropy of the probability density distribution of the grayscale in the target part and the background part of the image is defined as respectively:

$$H_1(i) = -\sum_{i=0}^t \frac{p_i}{p_t} \ln \frac{p_i}{p_t} \quad (2)$$

$$H_2(i) = -\sum_{i=0}^N \frac{p_i}{1-p_t} \ln \frac{p_i}{1-p_t} \quad (3)$$

where p_i denotes the probability of occurrence of a gray value of i ; t is the selected threshold, which is defined as:

$$t = \arg \max \{H_1(i) + H_2(i)\} \quad (4)$$

N denotes the number of binary grayscale pixel units, and p_t denotes the sum of probability distributions within the selected grayscale threshold:

$$p_t = \sum_{i=0}^t p_i \quad (5)$$

The grayscale threshold t is the parameter y of the fuzzy affiliation function. According to the constructed fuzzy affiliation function, the blurring of the image can be completed, and the segmentation of the image object and background can be realized through the information entropy calculation.

2.1.2. Image blurring enhancement

In order to realize the image texture rendering and enhancement, the texture information needs to be extracted and processed. The fuzzy affiliation function can be used to map the texture information to the fuzzy domain as well, realizing the texture blurring process.

The initialization of fuzzy clustering clustering conditions are determined according to the image itself and the requirements of the image texture rendering effect, the more the number of clustering centers, the stronger the image enhancement effect. The smaller the clustering cost threshold e , the better the texture rendering effect, but the algorithm complexity is also higher.

After the fuzzy clustering iterations, the fuzzy affiliation of the texture is calculated:

$$u_{ij} = \left(1 + \frac{g - g_i}{F_d}\right)^{-2} \quad (6)$$

where g denotes the gray value of the texture; g_i denotes the clustering center of the gray value of the texture; and F_d denotes the threshold value, which takes the value of the gray value when the fuzzy affiliation is equal to 0.5.

After texture fuzzy mapping, a collection of fuzzy mappings for the whole image can be obtained. The fuzzy enhancement of the image using fuzzy enhancement factor can realize the segmentation of the target and background regions of the image and enhance the detail rendering of the image texture. The fuzzy enhancement method can be defined as:

$$u_{ij} = T^m(u_{ij}) = T(T^{m-1}(u_{ij})) \quad (7)$$

where T denotes the fuzzy enhancement factor; m denotes the fuzzy enhancement index is performed, and the size of m can be determined according to the actual enhancement needs.

The traditional fuzzy enhancement factor is calculated by using nonlinear transformation:

$$T(u_{ij}) = \begin{cases} 1 - 2(u_{ij})^2, & 0 \leq u_{ij} \leq 0.5 \\ 1 - 2(1 - u_{ij})^2, & 0.5 < u_{ij} \leq 1 \end{cases} \quad (8)$$

From Eq. (8), it can be seen that when $0 \leq u_{ij} \leq 0.5$, the fuzzy enhancement factor decreases with the increase of fuzzy affiliation; when $0.5 < u_{ij} \leq 1$, the fuzzy enhancement factor increases with the increase of fuzzy affiliation. Therefore, the contrast between the target region and the background region can be enhanced to a larger extent.

In order to further enhance the rendering effect of image texture, this paper proposes an image enhancement method designed based on the contrast between image affiliation and texture affiliation, then the fuzzy enhancement factor is defined as:

$$T(u_{ij}) = \frac{|S_{ij} - \bar{u}_{ij}|}{|S_{ij} + \bar{u}_{ij}|} \quad (9)$$

where S_{ij} denotes the fuzzy affiliation of the target region of the image; and \bar{u}_{ij} denotes the mean value of the local texture fuzzy affiliation of the image, which is defined as:

$$\bar{u}_{ij} = \frac{\sum_{m=i-w/2}^{i+w/2} \sum_{n=j-w/2}^{n=j+w/2} u_{mn}^2}{\sum_{m=i-w/2}^{i+w/2} \sum_{n=j-w/2}^{n=j+w/2} u_{mn}} \quad (10)$$

where w denotes the edge length of the selected texture localized region.

The value of the fuzzy enhancement index is related to the degree of change of fuzzy affiliation in the region, if the trend of fuzzy affiliation change in the region is relatively smooth, the fuzzy enhancement index can be set slightly larger, which can be defined as:

$$m = m_{\min} + \frac{(E_n(i, j) - E_{n_{\min}}) \times (m_{\max} - m_{\min})}{E_{n_{\max}} - E_{n_{\min}}} \quad (11)$$

where $E_n(i, j)$ denotes the degree of change in fuzzy affiliation within a region, which is defined as:

$$E_n(i, j) = - \frac{\sum_{m=i-w/2}^{i+w/2} \sum_{n=j-w/2}^{n=j+w/2} \varphi_w(m, n) \times \lg(\varphi_w(m, n))}{\lg(w \times w)} \quad (12)$$

where $\varphi_w(m, n)$ is a parameter related to the information entropy of image fuzzy affiliation, which is defined as:

$$\varphi_w(m, n) = \frac{f(i, j)}{\sum_{m=i-w/2}^{i+w/2} \sum_{n=j-w/2}^{n=j+w/2} f(i, j)} \quad (13)$$

where $f(i, j)$ is:

$$f(i, j) = u_{ij} \times H_1 \times H_2 \quad (14)$$

Then equation (7) can be rewritten as:

$$u_{ij} = T^m(u_{ij}) = u_{ij} \left(\frac{|S_{ij} - \bar{u}_{ij}|}{|S_{ij} + \bar{u}_{ij}|} \right)^{m_{\min} + \frac{(E_n(i, j) - E_{n_{\min}}) \times (m_{\max} - m_{\min})}{E_{n_{\max}} - E_{n_{\min}}}} \quad (15)$$

After fuzzy enhancement of the image, fuzzy inverse transformation is performed on it to get the set of gray values of the texture enhanced image.

2.2. Virtual Clothing Technology Features

With the development of the Internet, virtual technology penetrates into the clothing industry at a rapid speed, and virtual clothing technology comes into being. Virtual clothing technology is the technical realization of the process of clothing design, production, simulation and display with the help of digital technology, and has four virtual clothing technology features. Specifically as follows:

2.2.1. Advanced

Virtual clothing technology is the cross technology field of information technology field and clothing field, the high-speed development of digital technology for virtual clothing to achieve high-precision simulation effect to bring the possibility of the clothing industry has brought great commercial value. So that the clothing industry in the design, production, display, marketing and other aspects of the greatly increased investment and reliance on digital technology, subverted the traditional mode of operation of the fashion industry. In addition, the technical scope between the two fields is becoming blurred, industry personnel not only need to master the knowledge of apparel pattern making, sewing process, etc., but also need to skillfully operate the digital technical software. In the future, clothing designers, print designers, pattern makers, 3D designers will become more and more fuzzy job division, the structure of jobs will be unavoidable changes with the promotion of new technologies.

2.2.2. Simulability

Virtual clothing technology has an extremely strong simulation performance. The simulation effect of virtual fabric directly affects the simulation state of virtual clothing, and plays a crucial role in the fit of virtual clothing. Virtual clothing technology can accurately simulate the physical properties of real fabrics, parameterize the drape of fabrics, and realize the simulation state of different kinds of fabrics, such as woven, knitted, leather and so on. On this basis, virtual clothing technology can accurately simulate virtual samples, including sewing process, pattern process, flush color, accessories and other details. In addition, it can also create a natural and realistic simulation environment, which is convenient for the display and sale of virtual clothing.

2.2.3. Efficiency

Virtual apparel technology can shorten apparel development time. The traditional apparel production chain generally goes through a series of procedures such as quarterly planning, design drawing, 2D pattern making, material preparation, sampling, sample alteration, sample finalization, and so on, and this traditional apparel R&D and design process most directly restricts the production efficiency of the apparel industry. Through the production of 3D samples can save the correction of physical samples, saving time and cost. In addition, virtual clothing software is a bridge between clothing designers and clothing pattern makers to make the communication between designers and pattern makers transparent and clear, to reduce the problem of unequal and incorrect product information, and to improve the hit rate of sample clothing. Therefore, with the help of virtual clothing technology can be real-time reformatting, multi-party online collaboration, the establishment of 3D resource library, greatly enhancing the efficiency of apparel research and development, so as to put more energy on improving product innovation and quality.

2.2.4. Sustainability

Virtual garment technology reduces sample production, material costs and transportation costs. The environmental pollution and waste of the traditional apparel supply chain is a growing problem, and many socially responsible apparel companies are beginning to transition to sustainable fashion. The use of virtual apparel technology can minimize carbon footprints and pollution in the production process while taking into account design and development needs. Often companies face high costs in implementing sustainable operations, but virtual apparel technology replaces a portion of the sample material production with a digital process that reduces costs and increases efficiency, taking sustainable fashion a step further. In addition, it supports people to fully express their personalities and fashionable dresses in social networks and virtual worlds, breaking social media users' habit of showing off their physical fashion consumption, thus reducing the problem of excessive waste caused by fast fashion consumption.

2.3. *Virtual Clothing Modeling*

Starting from the virtual clothing technology characteristics from the previous section, the texture rendering algorithm above is used to obtain the 2D clothing pattern drawing work, the 2D clothing pattern samples are imported into Marvelous Designer 3D virtual software, and then virtually sewn, and after sewing, according to the experimental needs to add the corresponding fabrics, sewing threads, patterns, and other materials, and to adjust the attributes of the materials, so as to make the pattern in the clothing virtual effect More realistic.

2.3.1. Modeling software

Clothing modeling is mainly done through various types of 3D modeling software, mainly in two forms: one is modeling using general-purpose 3D modeling software, such as, Maya, 3dsMax, Poser, etc [36]. The other is modeling using professional 3D clothing software, such as, Marvelous Designer, CLO3D, Optitex and Physan DCSuite.

Marvelous Designer can simulate and show the vivid and natural dynamic effects of 3D fabrics, and the simulated dynamic effects are more natural, three-dimensional and vivid than other 3D virtual software of the same type. At the same time, the user can be flexible through the material library, selective adjustment of the required fabrics and patterns, thus greatly improving the design efficiency. The software supports obj, fbx, almbic and other formats, can realize the three-dimensional virtual model of the dynamic fashion show, its shortcomings lie in the clothing two-dimensional paper drawing function and professional CAD clothing plate making software is relatively weak, and its mode of operation and the daily use of common clothing design software, the use of the pre-need to learn in order

to be proficient in the operation.

Compared with Maya, 3ds Max and other three-dimensional modeling software, Marvelous Designer is able to generate garment models closer to the real state of the garment structure paper samples by virtue of two-dimensional. Compared with Physan DCSuitex and other 3D apparel design software, Marvelous Designer integrates 3D virtual human body, 2D paper pattern design and 3D virtual sewing technology together, so that you can draw 2D paper patterns and conduct 3D virtual fitting on a single operating platform. Marvelous Designer's fabric fabric virtual system is more complete, with better virtual effect. The fabric fabric virtual system of Marvelous Designer is more perfect, the virtual effect is better, the system has strong dynamic display and video recording function, and the effect of the presented 3D garment model is more realistic. Therefore, this paper chooses to use Marvelous Designer as the three-dimensional clothing virtual software.

2.3.2. Modeling process

The garment modeling process based on Marvelous Designer is divided into three stages: pattern pre-preparation, garment structure drawing and model production. First of all, using the texture rendering algorithm designed for the above to complete the pattern drawing work, and then after the clothing structure drawing, the pattern, clothing structure drawing need to be imported into Marvelous Designer in the format of jpg, dxf, respectively, to prepare 3D clothing model, to women's non-heritage clothing as an example to illustrate. The virtual fitting system of this software has good compatibility with other apparel CAD software, and it can import and open and add the apparel structure drawings in dxf format, and carry out the virtual sewing of apparel according to the apparel process, so as to get the virtual fitting effect of 3D apparel. In the 3D virtual window, you can not only intuitively view the overall effect of clothing worn on the model, but also effectively and carefully view the reasonableness of the clothing structure diagram, in which the 3D human body model can be scanned by a 3D scanner to scan the 3D dimensions of the real model after the import, you can also use the software to adjust the model size editor to adjust the virtual model's dimensions, sizes, and greatly meets the demand for personalized clothing customization. The demand for personalized clothing customization is greatly satisfied.

3. In-depth probing analysis

3.1. Algorithm Validation Analysis

In order to verify the superiority of texture rendering algorithm based on fuzzy clustering on the virtual design of clothing, this paper carries out simulation experiments with a large number of clothing images. The experimental environment is Matlab R2018a, CPU frequency is 2.60GHz, memory is 16GB, and the operating system is Windows 11. Here a few intangible cultural heritage costume images are selected as examples for algorithm description and comparison. The specific process is as follows:

3.1.1. Evaluation indicators

Assuming that the time consumption for texture rendering the i th ICH costume image is t_i , the time consumption for sending the texture rendering result of the i th part to the server from the client j is $k_{i,j}$, the number of processors is n , and the total time is T , the ideal texture rendering time is G . Obviously, the ideal texture rendering time is the average of all node texture rendering time and communication time, and in the case that each processor is fully loaded at all times, the ideal texture rendering time G is the single process texture rendering time divided by the number of texture rendering nodes. The specific calculation formula is as follows:

$$G = \frac{\sum (t_i + k_{i,j})}{n} \quad (16)$$

And the total time required for texture rendering of ICH costumes T is determined by the maximum node time consumption and the maximum inter-node communication time. The specific calculation formula is as follows:

$$T = (\max(k_{i,j}) + \max(t_i)) \quad (17)$$

In the texture rendering process of ICH costumes, the image is divided into m parts, $m > n$ when a

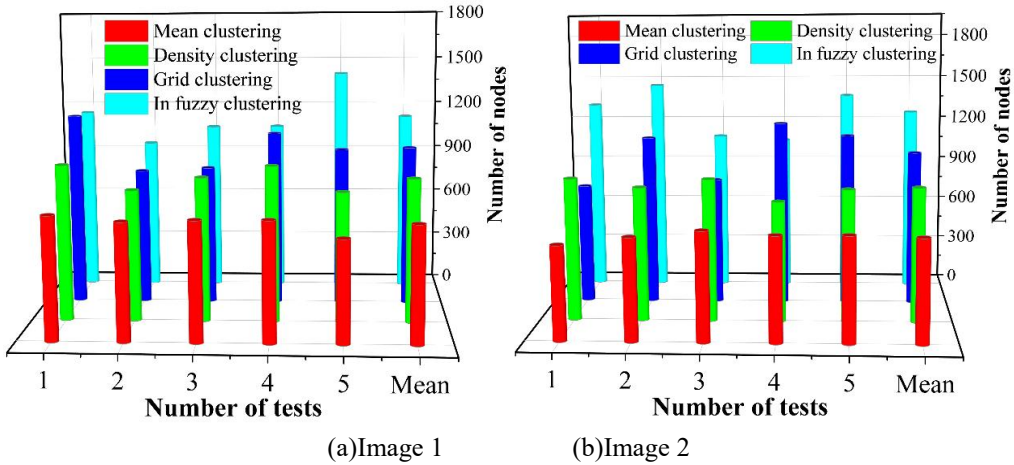
node has finished rendering a part of it, it will receive from the server the texture rendering task of the row of ICH costumes, then the rendering time conforms to the following equation. Specifically:

$$T = \frac{m \cdot k + \sum t_i}{n} + \frac{\varepsilon}{m} \quad (18)$$

It can be seen that the larger the m , the smaller the error caused by the imbalance $\frac{\varepsilon}{m}$, but it will bring about an increase in the $m \cdot k$, meaning that it causes more time to be consumed.

3.1.2. Analysis of experimental results

In order to better reflect the effectiveness of this paper's algorithm in the texture rendering task of intangible cultural heritage costumes, the mean clustering algorithm, density clustering algorithm, and grid clustering algorithm are set as control algorithms, and the superiority of this paper's algorithm in the virtual design of costumes is verified by comparing the numerical values of different algorithms' evaluation indexes. Four images of intangible cultural heritage costumes are selected as the objects of this experiment, image 1 is the Yi costume scene image, image 2 is the Miao costume scene image, image 3 is the Tujia costume scene image, and image 4 is the Gelao costume scene image. The analysis of the number of image texture rendering nodes of different algorithms is shown in Fig. 1, and the analysis of the image texture rendering time of different algorithms is shown in Fig. 2, where (a) ~ (d) are Image 1, Image 2, Image 3, Image 4, respectively. based on the number of algorithmic texture rendering nodes and texture rendering time in Figs. 1~2, it can be seen that the fuzzy clustering-based texture rendering algorithm outperforms the mean clustering algorithm and density clustering algorithm, grid clustering algorithm. In the Yi ethnic costume scene image, fuzzy clustering (number of texture rendering nodes: 1135, texture rendering time: 248s) > mesh clustering (number of texture rendering nodes: 996, texture rendering time: 345s) > density clustering (number of texture rendering nodes: 884, texture rendering time: 463s) > mean clustering (number of texture rendering nodes: 707, texture rendering time: 562s), the same law is shown in the Miao clothing scene image, Tujia clothing scene image, and Gelao clothing scene image, which will not be expressed in detail. In summary, the number of texture rendering nodes and texture rendering time of different algorithms show that the algorithm of this paper is superior in the texture rendering task of intangible cultural heritage costumes, which not only verifies the effectiveness of the algorithm of this paper, but also provides a solid theoretical foundation for the subsequent design of virtual costume models.



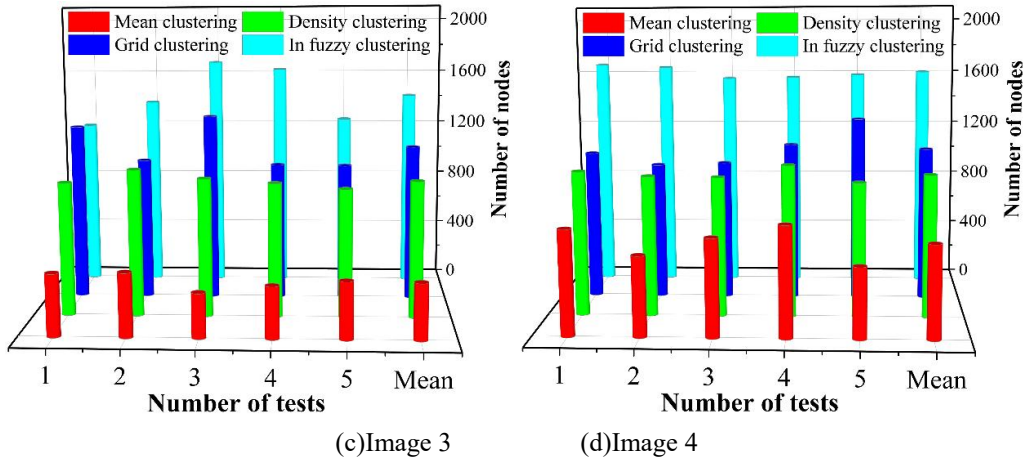


Figure 1. Analysis of the number of image texture rendering nodes.

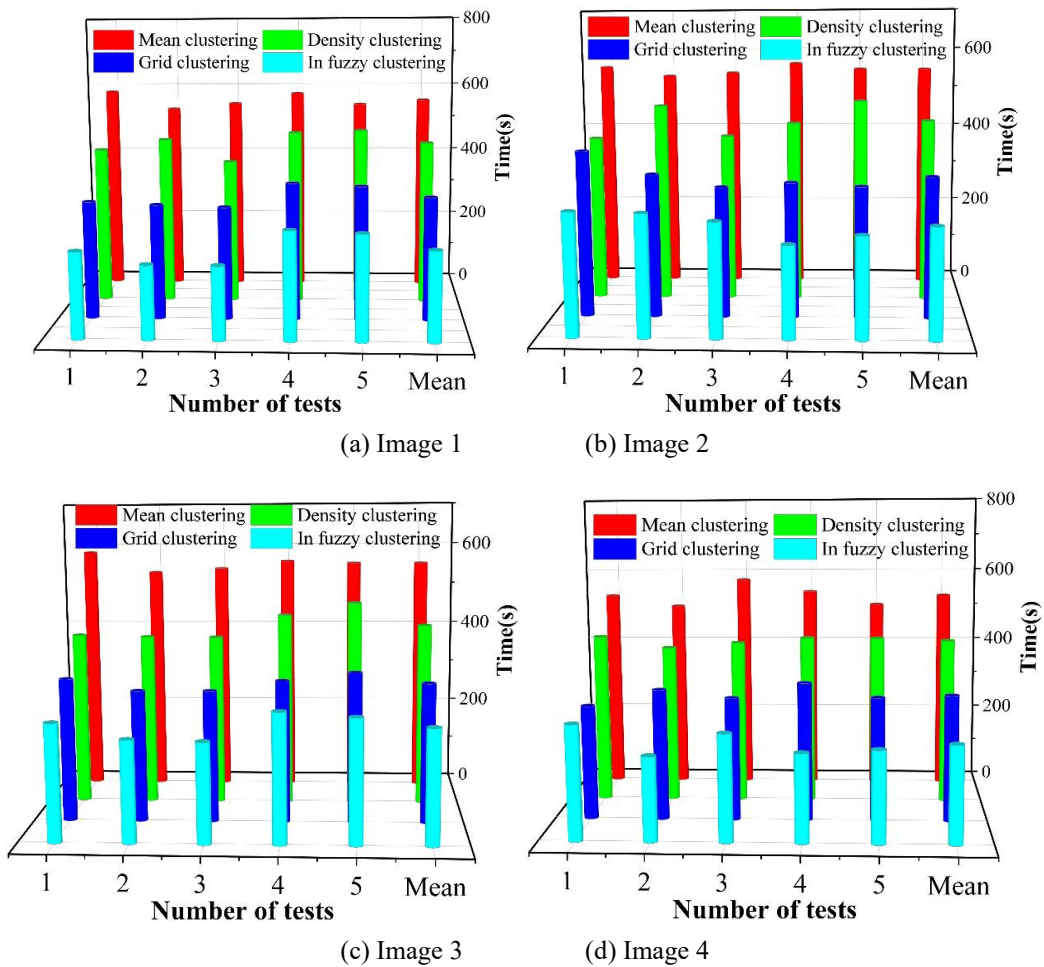


Figure 2. The rendering time of image textures for different algorithms.

3.2. Model validation analysis

3.2.1. Operational processes

First of all, use the fuzzy clustering-based algorithm to complete the 2D sample texture rendering of the semi-circular skirt, and export the 2D sample as a DXF file. Open the Marvelous Designer 3D virtual software, select the menu [Avatar]→[Avatar Style], the virtual body size dialog box pops up, according to the human stage data to adjust the size of the virtual body, the other dimensions are not modified. After

importing the DXF file, set the physical attributes of the fabric, and input the values of the attribute parameters as the attribute parameters of the software derived from the real fabric.

3.2.2. Analysis of parametric results

In the comparison of virtual and real clothing effects, considering the large gap between the specifications and pixels of virtual and real clothing in the process of acquiring images of bustle skirts, and because the front and back sides of the bustle skirts are basically the same, the model validation only compares the number of total ripples on the front, side, and right below, and also compares the angle of the front skirt spreading and the angle of the side skirt spreading, and the simulated bustle skirts and the real bustle skirts are compared with the parameters as shown in Table 1. Table 1. According to the table, it can be seen in 35 groups of comparison data when a total of 31 groups of data are equal, accounting for more than 85% of the total amount of data, the other groups of data with differences in the difference is very small, the maximum difference in the number of ripples is 2, the maximum difference in the angle of the skirt hem is 1 degree, most of them are concentrated in less than 1 degree, which indicates that the model simulation effect of the model in this paper is relatively satisfactory.

Table 1. Comparison of various parameters.

Sample	Semi-circular skirt	Number of ripples on the front (pieces)	Number of side ripples (pieces)	Number of ripples on the skirt hem	Front hem spread Angle (°)	Side skirt hem spread Angle (°)
1	Semi-circular skirt	4	2	6	14	17
	Simulate a semi-circular skirt	4	2	6	13	17
2	Semi-circular skirt	4	1	5	15	16
	Simulate a semi-circular skirt	4	1	5	14	16
3	Semi-circular skirt	6	5	6	11	13
	Simulate a semi-circular skirt	6	5	6	11	13
4	Semi-circular skirt	4	3	8	16	14
	Simulate a semi-circular skirt	4	3	9	16	14
5	Semi-circular skirt	5	4	9	12	12
	Simulate a semi-circular skirt	5	4	7	12	12
6	Semi-circular skirt	6	2	4	14	11
	Simulate a semi-circular skirt	6	2	4	14	11
7	Semi-circular skirt	5	1	8	14	13
	Simulate a semi-circular skirt	5	1	8	14	13

3.3. Impact of modeling on NRM reproduction

3.3.1 Questionnaire design and collection

The questionnaire consists of 3 main parts. First, the subjects were introduced to the concept of virtual clothing model, the wearing process, and the display of wearing virtual clothing videos and pictures. Then, aesthetics, technicality, perceived usefulness, perceived ease of use, experiential feeling, and non-heritage reproduction effect were measured respectively, and all the scales were from mature scales. Finally, respondents' age, gender, and familiarity with virtual costumes were counted. The questionnaire items were measured on a 5-point Likert scale: 1-5, with 1 indicating “strongly disagree/agree” and 5 indicating “strongly agree/agree”. 500 copies of the questionnaire were distributed on multiple platforms, including WeChat, Xiaohongshu, and Weibo, from August to September 2024, with a total of 500 copies. From August to September 2024, the questionnaires were distributed on multiple platforms such as WeChat, Xiaohongshu and Weibo, with a total of 500 questionnaires distributed.

3.3.2. Reliability and Validity Analysis

The results of the questionnaire reliability and convergent validity test are shown in Table 2. The data in Table 2 show that the Cronbach coefficients ($Cronch's\alpha$) of the variables measured in the questionnaire are all greater than 0.7, the factor loading coefficients are greater than the accepted value of 0.6, the combinatorial reliability (CR) is greater than the accepted value of 0.7, and the average variance extracted (AVE) is greater than the accepted value of 0.5, which verifies that the questionnaire has a good degree of reliability and convergent validity.

Table 2. Reliability and convergence validity tests.

Dimension	Item	Factor loading	$Cronch's\alpha$	AVE	CR
Aesthetic quality	Q1	0.839	0.827	0.655	0.838
	Q2	0.776			
	Q3	0.745			
Technical	Q4	0.835	0.789	0.586	0.806
	Q5	0.764			
	Q6	0.836			
Perceived usefulness	Q7	0.825	0.816	0.605	0.818
	Q8	0.834			
	Q9	0.754			
Perceived usability	Q10	0.706	0.827	0.626	0.829
	Q11	0.899			
	Q12	0.879			
Experience and feel	Q13	0.832	0.817	0.716	0.824
	Q14	0.799			
The effect of intangible cultural heritage reproduction	Q15	0.838	0.784	0.647	0.785
	Q16	0.885			

The results of the discriminant validity test of the questionnaire are shown in Figure 3, where X1~X6 indicate perceived usefulness, experiential feeling, non-heritage reproduction effect, perceived ease of use, technicality and aesthetics. The data in Figure 3 show that most of the AVE square roots are larger than the correlation coefficients between the variables, the correlation coefficient between the non-heritage reproduction effect and perceived usefulness is slightly larger than the AVE square root of perceived usefulness, and the correlation coefficient between the non-heritage reproduction effect and experiential feelings is also slightly larger than the AVE square root of the brand attitude, but the correlation coefficients of these two items are smaller than the AVE square root of the physical garments themselves, and this differentiated validity can still be accepted to a certain extent. The discriminant validity of the questionnaire is still acceptable to a certain extent. The above indicators together verify that the reliability of the questionnaire is good and can reflect the influence of the virtual clothing model on the effect of non-heritage reproduction.

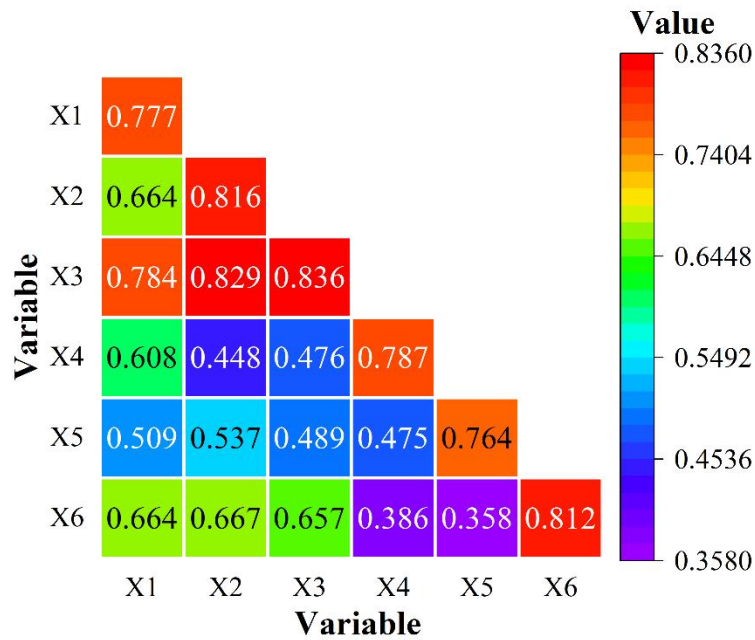


Figure 3. The results of the discriminant validity test of the questionnaire.

3.3.3. Statistical analysis

X1, X2, X4, X5 and X6 are set as independent variables, and X3 is the dependent variable, and regression analysis in statistical analysis is used to reveal the influence of virtual clothing model on the effect of non-heritage reproduction, and the results of regression analysis are shown in Table 3. Based on the data performance in the table, it can be seen that the indicators of perceived usefulness, experiential feeling perceived ease of use, technology and aesthetics in the virtual clothing model have a significant positive correlation on the effect of non-legacy reproduction, and its explanatory power is 0.794, and the mathematical role of the virtual clothing model on the effect of non-legacy reproduction is $X3=0.043+0.054*X1+0.124*X2+0.055*X4+0.099*X5+0.125*X6$. Taking Perceived Usefulness as an example, if the Perceived Usefulness index in the Virtual Clothing Model is increased by 1 quantitative value, the corresponding quantitative value of the non-heritage reproduction effect will be increased by 0.054 units, which fully demonstrates the relationship between the Virtual Clothing Model and the non-heritage reproduction effect.

Table 3. Regression analysis results.

Project	Non-standardized coefficient		Standardization coefficient	T-Value	P-Value
	B	Standard error	Beta		
Constant	0.043	0.0098		4.678	0.002
X1	0.054	0.0086	0.057	3.709	0.003
X2	0.124	0.0068	0.121	5.259	0.007
X4	0.055	0.0105	0.057	2.371	0.007
X5	0.099	0.0065	0.097	3.766	0.008
X6	0.125	0.0109	0.127	6.683	0.003
R ²	0.793				
Adjust R ²	0.794				
F	12.678				

4. Conclusion

With the rapid development of information technology, virtual reality technology has been gradually applied to the clothing design industry, which is of great significance to the reproduction and inheritance of intangible cultural heritage. In this paper, for the technical needs of image texture rendering enhancement, a texture rendering algorithm based on fuzzy clustering is designed, and with the help of the algorithm to complete the clothing texture rendering, the texture rendering samples are imported into the Marvelous Designer three-dimensional virtual software, and after a series of process operations, the

design of the virtual clothing model is finally completed. With the support of relevant data, the research program of this paper is analyzed in depth. The research results are as follows:

(1) In the texture rendering process of Yi clothing scene images, it is found that the fuzzy clustering performance is greater than the mean clustering algorithm, density clustering algorithm, grid clustering algorithm, and the number of texture rendering nodes and the time are 1135 and 248s, respectively.

(2) In the comparison between the virtual clothing effect and the real clothing effect, there are 31 groups of equal data in 35 groups of comparison data, and its correct rate is 88.57%, which indicates that the virtual clothing model designed in this paper has good application performance.

(3) Through the regression analysis in the statistical analysis method, it is understood that the mathematical role relationship of the virtual clothing model on the effect of non-heritage reproduction is: $X3=0.043+0.054X1+0.124X2+0.055X4+0.099X5+0.125X6$, which reveals the relationship between the virtual clothing model and the role of the non-heritage reproduction in the form of mathematical formulas.

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