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Digital Inheritance of Traditional Mongolian Robes of the Nayman Tribe

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Abstract
The Mongolian robe is the crystallisation of the wisdom of Mongolian people after a long period of social practice and one of the intangible cultural heritages of humanity. With the gradual disappearance of the nomadic lifestyle in the steppe, it is not easy to protect and pass on traditional Mongolian dress culture and traditional handicraft technology. This study used the digital twin concept to construct a digital twin to try on clothes for a model in a virtual environment, to realise a mirror image presentation of the target physical entity, and to use effective modern technology to protect and pass on the traditional clothing. The experiment used an AlphaM4 3D body scanner to obtain a 3D human body model, as well as reverse engineering technology to process the initial data, such as noise reduction, streamlining, hole patching and smoothing to build a personalised human body model. The traditional black cotton robe of the Nayman tribe researched in the field was mapped by the planar structure design method, and its structure and 2D samples were recovered. A 3D model of the traditional cotton robe of the Nayman tribe was established based on 3D simulation technology to achieve a 3D virtual display effect, enable better dissemination and inheritance, and give a new vitality to non-heritage clothing in the digital era. The research results can provide fresh ideas and technical support for the digital estate and development of other traditional costumes, as well as contribute to the construction of digital resources for intangible cultural heritage.

Keywords
Mongolian robe restoration, 3D body modelling, digital twin, digital inheritance.

1. Introduction

As a unique branch of Mongolian costume, the traditional Mongolian robe of the Nayman tribe is essential to Chinese minority costumes. With the gradual fading of the nomadic lifestyle of the grasslands, the use of Mongolian costumes by various tribes has changed, leading to a gradual decrease in the styles and types of costumes, and some exquisite traditional Mongolian costumes have been damaged. In contrast, along with the gradual decline or disappearance of conventional handicraft techniques, inheriting and preserving Mongolian costume culture has become challenging(Peng C N, 2021; Naregle, 2022), hence new inheritance paths must be explored.

Digital modeling of clothing and the virtual try-on method can present the realistic original appearance of traditional Mongolian robes and are also essential means to realize personalization and virtual try-on, which have received much attention from scholars. There are two types of research on the digital modeling of clothing. The first type uses 3D scanners to scan the dressed human body and thus obtain a model of the garment(Duan L, et al., 2019). Virtual clothing fitting is achieved by using motion and bone capture sensors(Adikari S B, et al., 2020), RGB-D sensor systems(Xu W, et al., 2019; Varshney N, et al., 2010), or ArtecStudio handheld scanners(Tang X M, 2019). The sensors are mounted on specific human body parts to capture the motion trajectory. The virtual garment can also move with the captured human motion stream, allowing users to interactively experience the virtual garment fitting effect in a realistic environment. Michael B. Holte scholars proposed a method for creating digital garments based on a virtual fitting room by scanning real clothes using RGB-D sensors and then creating digital garments with the garment modeling software MarvelousDesigner2(Holte M B, 2017). Rui Li scholars used a 3D scan-based modeling approach to cut garment pieces from the scanned garment point cloud using a cut-loop algorithm, reconstruct the garment pieces from the point cloud, and perform virtual stitching to generate a garment model(Li R, 2017). Zorah Laehner et al. proposed a new method to create accurate and realistic garment deformations from actual data capture, consisting of two modules working together in an original framework to represent the global shape deformation and surface details of the garment with high fidelity(Lahner Z, et al., 2018). The advantage of this garment modeling method is that it can capture the garment model in real time according to human movement. Still, it is usually superficial processing of the garment model, with a poor sense of embodiment and high cost at the joints and details of the garment pieces.

The second type is to generate a blank base model of the garment, then carry out the parametric adjustment of the fabric to determine the number of voids, and finally realize the deformation of the control points to establish a personalized garment model with different fabric effects. For example, Meng Tiancui scholars used the mass-spring model to create a physical model of the three-dimensional fabric. They solved the numerical integration of the fabric system with the verlet integration method to realize the simulation of the deformation movement process of the material being

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pulled up and released. Also, they used VS2010 as the development platform to establish a virtual fitting system based on anthropometry, which can realize the simulated garment's creation process and the garment's dynamic deformation process(Meng T C, 2018). By using the virtual try-on software CLO3D, Huang S. et al. used a garment deformation algorithm based on human input to deform the garment model by adjusting the basic structure according to the mechanical properties of textile materials to present the physical characteristics of the virtual garment more realistically (Huang S & Huang L, 2022). The model built by this method pursues similarity in shape and is more professional in the physical simulation of fabric collision, with higher precision and a more realistic effect on the fit of clothing and the human body. For this reason, this paper chose the method of generating a billet base-fitting garment model directly from the human body model. It implemented the virtual simulation of the Mongolian robe model on the already established human body model using CLO3D software. In the field of garment restoration and digital twinning, Qianqian Yu and other scholars(Yu Q & Zhu G, 2023)seamlessly transitioned from 2D pattern restoration to 3D through a detailed simulation process of garment pattern restoration using an autonomous 3D scanning system and an offline point cloud generation algorithm, combined with a laplacian mesh deformation algorithm to perform conformal transformations on the neighbouring vertices of the moving vertices. The experiment finally measured six 3D garments, revealing the absolute deviation between the model and the actual clothes, and mapped out a fast way to achieve digital restoration and 3D virtual presentation of Hakka cardigans. QingzhuYe scholars(Ye Q, 2023)aim to build a digital collection and database of traditional clothing, which is convenient for the digital dissemination and application of conventional clothing. They developed a code symbol assembly method to provide a unique number for each piece of clothing, which is easy to identify, classify and record. They created a metadata construction scheme for traditional clothing.

This study aimed to explore the digital inheritance path of the traditional Mongolian robe by collecting Mongolian robe specimens through field research and analyzing their material composition, structural characteristics, and production process. Using the concept of digital twin technology, we used 3D body scanning technology and 3D modeling of clothing to construct its digital twin and explore the degree of completeness of the replication of the appearance of the virtual Mongolian robe and the authenticity of its try-on effect to achieve a mirror-image presentation of the target physical entity. In order to prove the feasibility of this research programme and provide a technical basis for the virtual display and personalised customisation of national costumes, the research results can be used in the fields of digital museums, digital restoration of garments, and virtual fitting technology, which provides a novel perspective on the digital revival of traditional costumes and a valuable addition to contemporary methods of preserving traditional costumes.

2. Methods

Based on this paper's research content and methodology, a research technology roadmap was developed (see Figure 1).

2.1. 3D body scanning

Three-dimensional human body scanning experiments were conducted using experimental equipment for the AlphaM4 three-dimensional human body scanner. The kit consists of the AlphaM4 three-dimensional human body scanner hardware system and Alpha3d Studio digital human body automated measurement software system, which can be completed within 7 seconds of the human body scanning, generating virtual three-dimensional scanning images and real-time in the terminal interface output of the AlphaM4 Bodyscan software system. The subject was a 20-year-old Mongolian man from Nayman Banner, Tongliao City, Inner Mongolia Autonomous Region, with a height of 160 cm and weight of 52 kg. The 3-D body scanning experiment was conducted according to the dressing and standing posture requirements in ISO 20685 "3-D scanning methodologies for internationally compatible anthropometric databases".

2.2. Point cloud data processing method

Geomagic Studio, a reverse engineering software, processed the point cloud data from the 3D body scanner for noise reduction, simplifying, hole filling, and smoothing to obtain a characteristic human model. The processing process is divided into five stages: point cloud processing, encapsulation into polygons, polygon stage, modeling stage, and output model. The flow chart is shown in Figure 2.

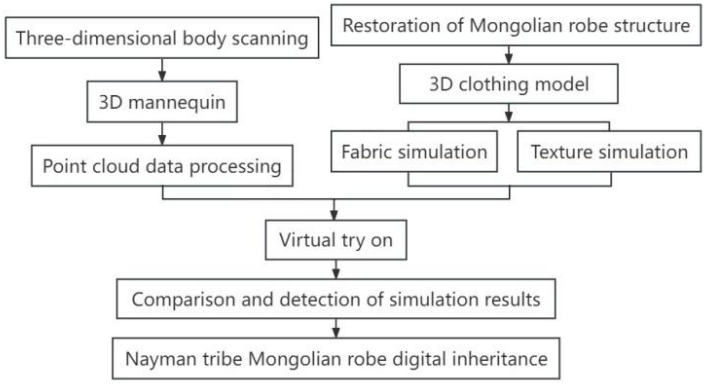


Fig. 1. Technology roadmap

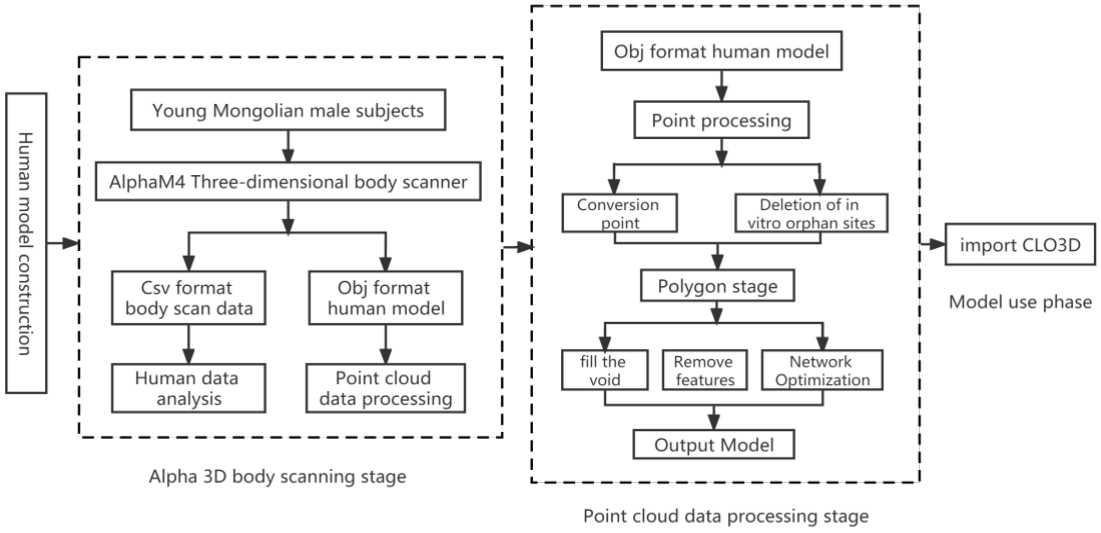


Fig. 2. Flow chart of point cloud data processing



Fig. 3. Physical picture of traditional Nayman tribe cotton robe

2.3. Cotton robe modeling method

2.3.1. Description of the cotton robe sample

Through field research, a precious black traditional cotton robe, the owner's daily wear in winter, was obtained from the village of Hamatai on the eastern boundary of Huanghuatara Township, Nayman Banner, Tongliao City, Inner Mongolia Autonomous Region. The specimen was purely handmade in around 1949 and is a classic representative of the cotton robe of the Mongolian Nayman tribe (see Figure 3). The outer fabric is black plain cotton, and there is no decoration on the body. The style features a typical round corner standing collar, even sleeves, and broken seams; one Chinese frog at the neckline, one on the flap, and three on the side seams (Figure 3a); interrupted seams on the front, back, and middle of the robe (Figure 3b); the front piece right placket is a typical asymmetric structure; the inner placket has a pocket 18.5cm long and 13.5cm wide; and the inner skirt is shorter 5cm than the outer coat (Figure 3c). There are slits on the left and right sides, and a circle of removable beige-white cloth is sewn at the cuff and neckline of the robe (Figure 3d). The whole body of the cotton suit adopts quilting technology, and the front and rear sides of the garment pendulum are spliced.

2.3.2. CLO3D modeling method

The visualised 3D garment virtual presentation software CLO3D was used to recover the cotton robe sample in 3D. The software can realise 3D garment design and plate making and has been widely applied in garment design and production, which can effectively improve the efficiency of garment drawing. ETCAD recovered a 2D sample of the cotton robe, and the processed 3D human body model (obj format) and 2D sample of the cotton robe (dxf format) were imported into the CLO3D platform for 3D recovery.

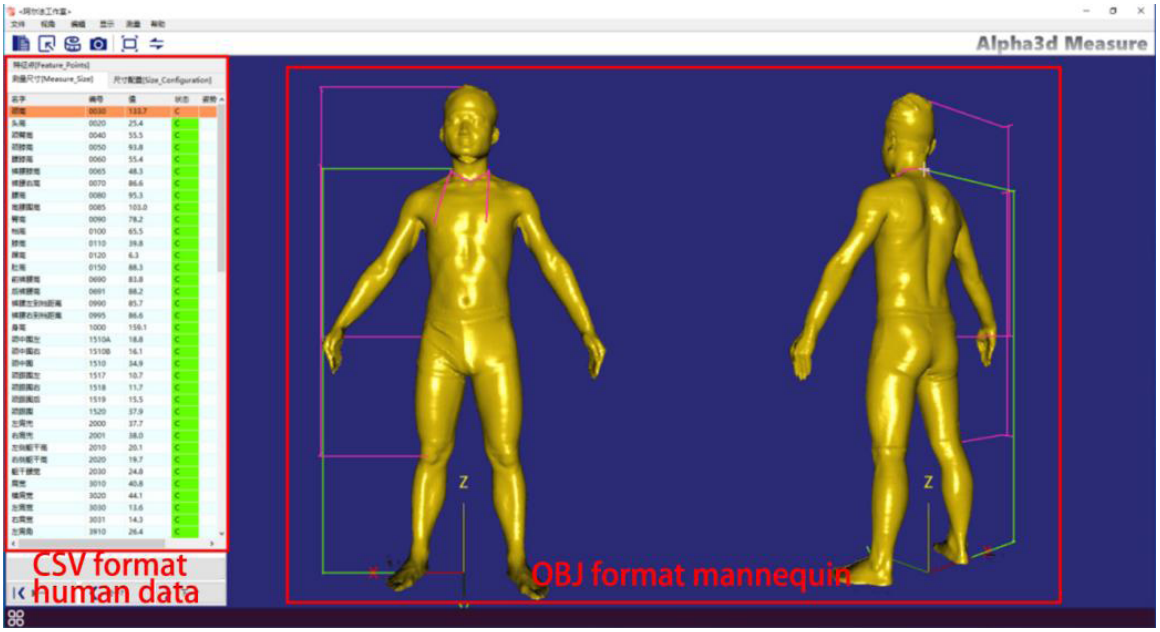
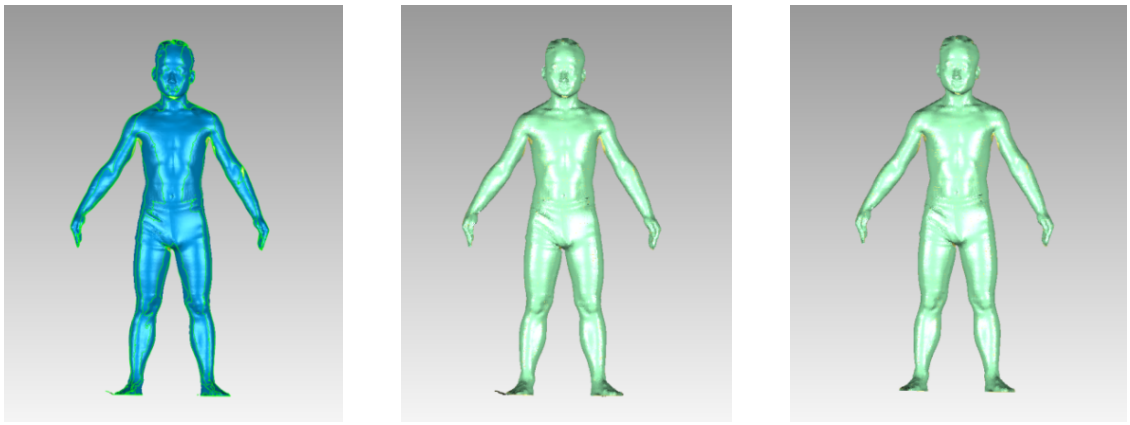


Fig. 4. human body scan after the completion of the interface



a. three-dimensional body scan mannequin b. conversion points c. removal of in vitro orphan points

Fig. 5. Point cloud data processing process

3. Results and discussion

3.1. Personalized human modeling

3.1.1. Model Acquisition

The human model was obtained by 3D body scanning and exported to the OBJ format, and the data were exported to the CSV format, as shown in Figure 4.

3.1.2. Point Cloud Data Processing Results

The point cloud data processing process is shown in Figure 5. When the human body is scanned, it will scan parts outside the human body (Figure 5a), thus it is necessary to convert the model to points, separate these point bundles (Figure 5b), and remove externally isolated points and unconnected items from the principal point cloud (Figure 5c).

Noise points are frequently introduced into the data during the scanning or digitizing process. The rough, non-uniform appearance of the surface model is considered "noisy data" due to slight vibrations in the scanning equipment, measurement laser diameter errors, or surface roughness, so noise should be reduced. There are four sampling methods in Geomagic Studio: unified sampling, curvature sampling, grid sampling, and random sampling. In this experiment, the unified sampling method was used to consistently reduce the number of points on a flat surface, but with a specified density to reduce the number of points on the surface, which is also the most common sampling method.

After encapsulating the human model with the point cloud data (Figure 6), the polygonal phase begins. As shown in Table I, the polygon phase requires filling the model's voids, "removing features" from the uneven parts, and optimizing the mesh. Each piece of the model is treated differently when filling the holes. The holes on the underarm and crotch surfaces

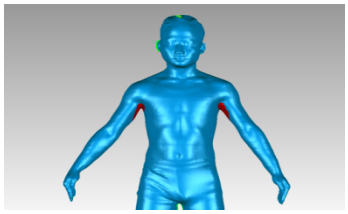
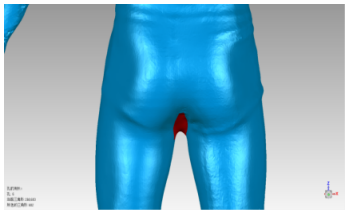
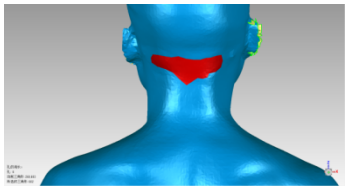
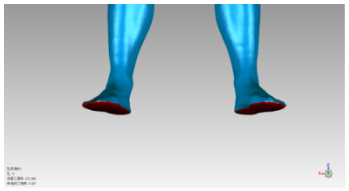
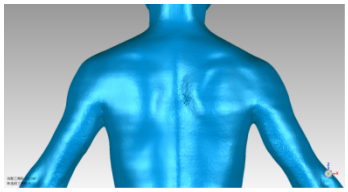
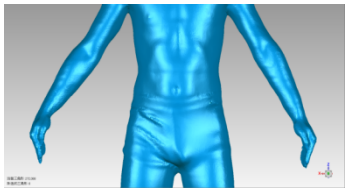
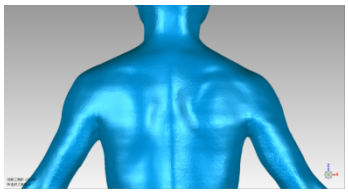
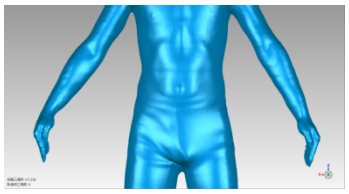
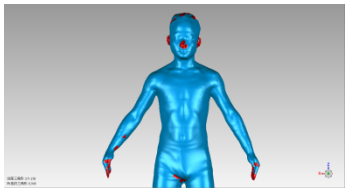
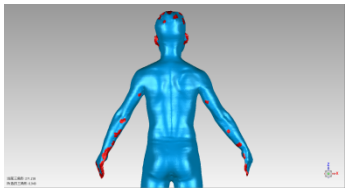
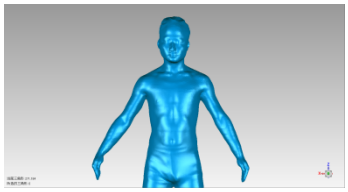
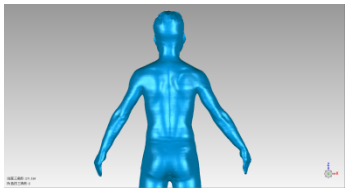
Processing method		Treatment area diagram and before-and-after comparison diagram	
Fill hole	„Curvature" filled individual holes		
	„Flat" filling of individual holes		
Remove features	Before the removal of features		
	After the removal of features		
Grid optimization	Before grid optimization		
	After grid optimization		

Table 1. Polygon stage processing method

are at an acute angle, and a new mesh must be specified to match the curvature of the surrounding mesh; therefore, "curvature" is used to fill individual holes. The holes on the back of the head and the soles of the feet are relatively flat, so a "flat" is used to fill the individual holes. "Remove Features" is a command that quickly removes lumps and indentations from objects. Network optimization allows the entire polygon mesh to be further optimized and tuned, automatically detecting and repairing defects in the polygon mesh.

When the polygon stage is completed, the model can be exported. The processed human model is shown in Figure 7.

3.2. Analysis results of the cotton robe structure process

3.2.1. Results of structural analysis of cotton gown

The main structure of this cotton robe is based on cross coordinates, thus forming an overall "continuous body with sleeves" state under the action of a "cross-shaped plane structure." The cross-shaped plane structure is shown in Figure 8.

According to the physical and measured dimensions, a structure drawing was made (Figures 9a, 9b), and sample corrections made to the structure drawing to extract a cutting sample (Figure 9c).

By studying the structural restoration of the specimens, we can find that the samples are made within the framework

of the "cross-shaped plane structure," using the structure of the width of the jointed sleeves to realize the concept of "respecting things and being frugal." The design principle that "the width of the cloth determines the structural form" and the thrifty means of "complementing the corners of the pendulum" and "splicing into vessels" are strong evidence of thrift awareness.

3.2.2. Cotton robe process analysis results

For this cotton robe adopts, a quilting process was adopted. The quilting line plays a role in fixing cotton wadding pieces to prevent the wadding from gathering into a block after washing and affecting the warmth and durability. As shown in Figure 10, the vertical line spacing of quilting is 7-8cm. The fabric treated by the quilting process can visually reduce the expansion of thick fabric or down fabric but also increase the three-dimensional effect of the material by controlling the thickness of the sandwich, forming a unique bumpy feeling to the touch.

The steppe's unique natural environment creates water scarcity, hence clothes are seldom washed. The Mongolian people often ride horses to graze, therefore cuffs and collars are often worn, and thus a removable fabric block 41cm long and 8cm wide is sewn on the cuffs and collars, which also promotes the traditional virtue of thrift of the Chinese people, as shown in Figure 11.

3.3. Simulation results of an asymmetric structure

Import the virtual model in OBJ format in CLO3D and adjust the scale size and axis conversion to try on the model, as shown in Figure 12, for the virtual mannequin of the subject in the CLO3D interface.

Figure 13a is imported into the CLO3D interface as a DXF-formatted cotton robe 2D sample. The sample arrangement plays a decisive role in the success of the garment simulation (Figure 13b). The location of the model needs to be tested several times to match the corresponding parts of the human body. The results of the sample arrangement are shown in Figure 13c.

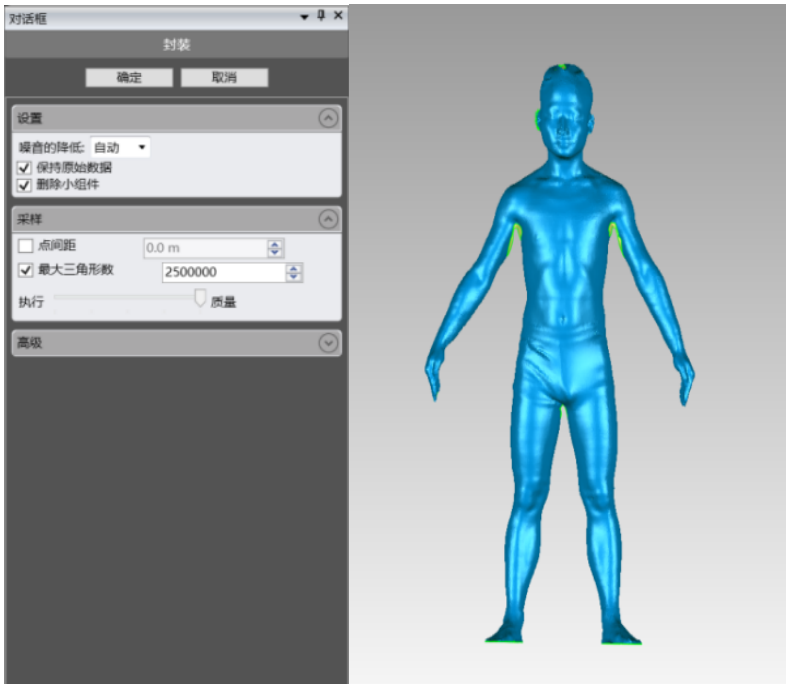


Fig. 6. Encapsulated point cloud data for the human model

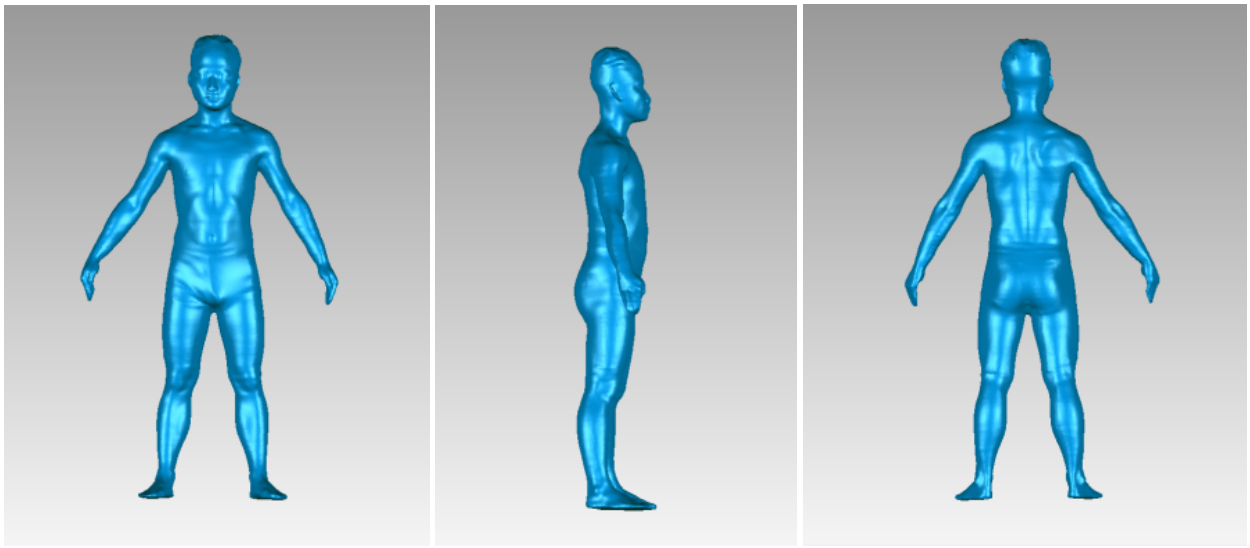
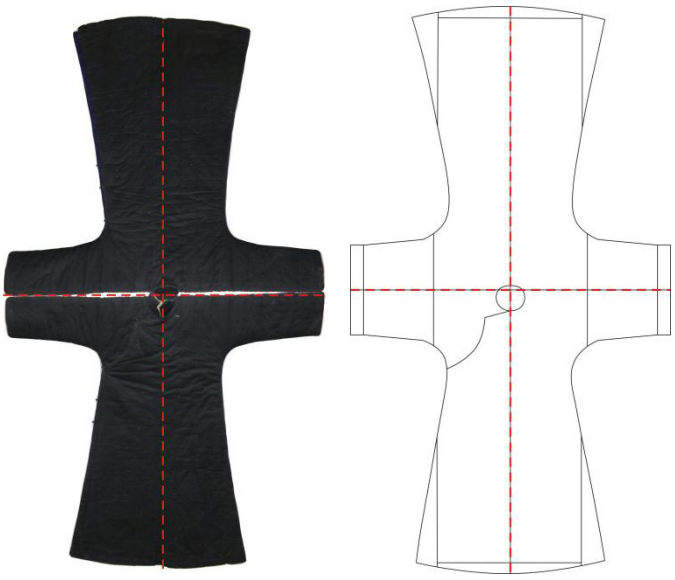


Fig. 7. Processed human model



The process of simulation of the traditional Nayman tribe cotton robe encountered the following two problems: One was the cross-even sleeve structure, that is, the front and rear body and sleeves are connected, resulting in the simulation not being possible by the human body model arrangement point taking into account the front and back body; the second was more cutting pieces and missing fragments for double fabric stitching; for the robe body vertical line quilting process simulation needs to be carried out; and the internal quilting needs cotton wadding filling. Hence, the simulation process often appears jammed, with samples passing through the mold, or in other situations.

Fig. 8. Cross-shaped plane structure

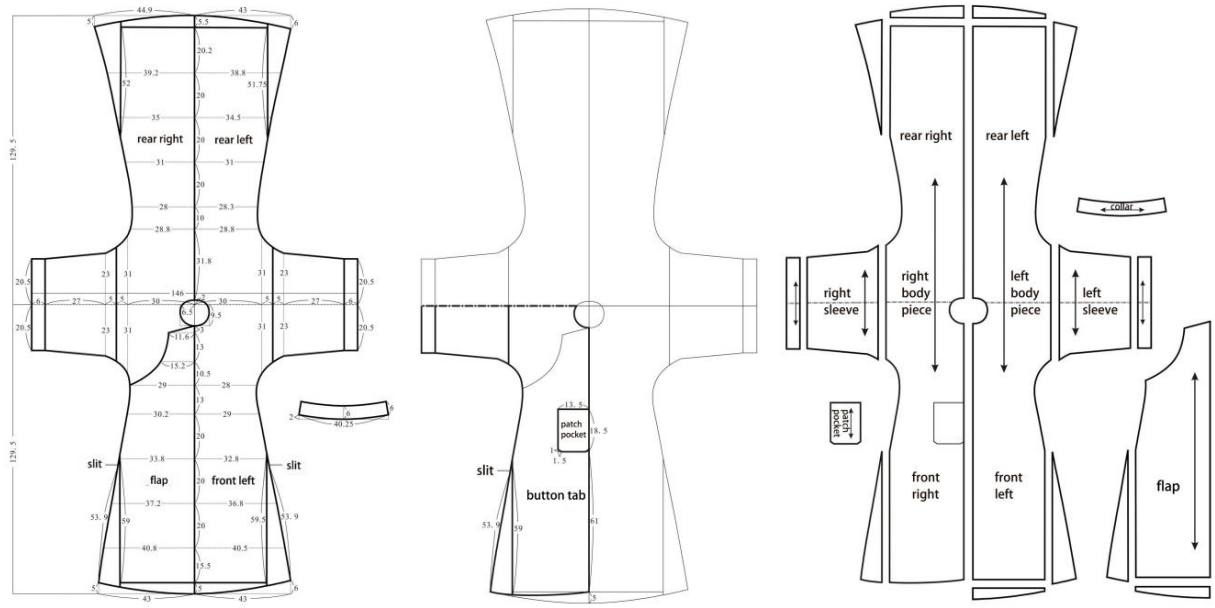


Fig. 9. Traditional Nayman tribe cotton robe structure sample diagram. a. Nayman cotton robe primary structure diagram b. Nayman cotton robe fly piece structure diagram c. Nayman cotton robe sample separation diagram

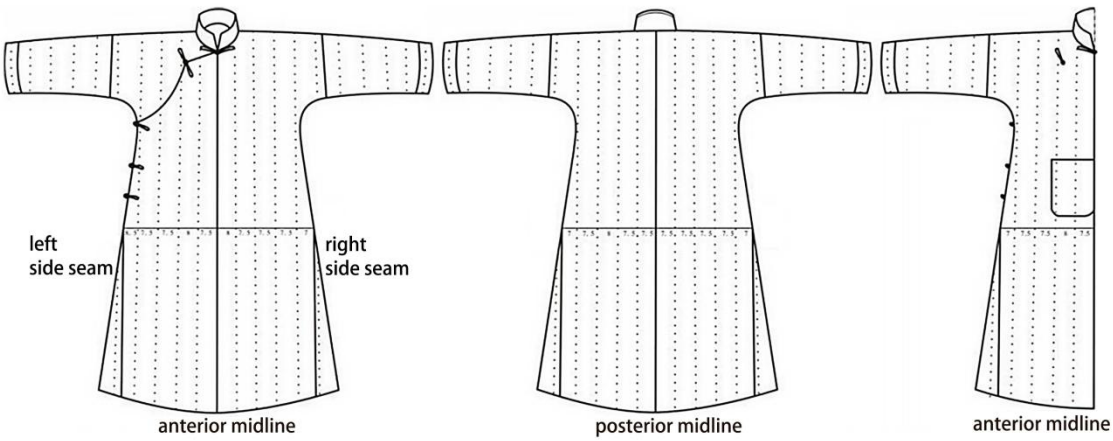


Fig. 10. Quilting and stitching diagram of a traditional Nayman tribe cotton robe. a.front, b. back, c. inner lining



Fig. 11. Traditional Nayman tribal cotton robe with removable cloth block

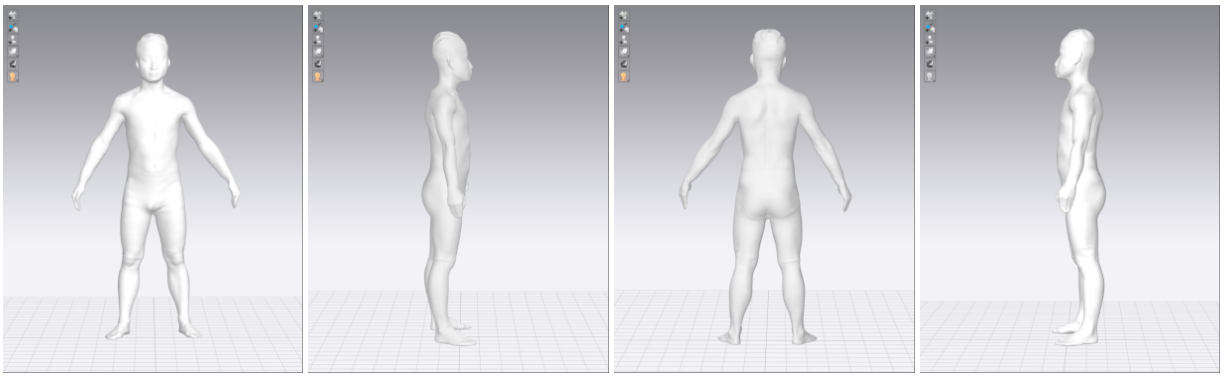


Fig. 12. Nayman tribe virtual mannequin

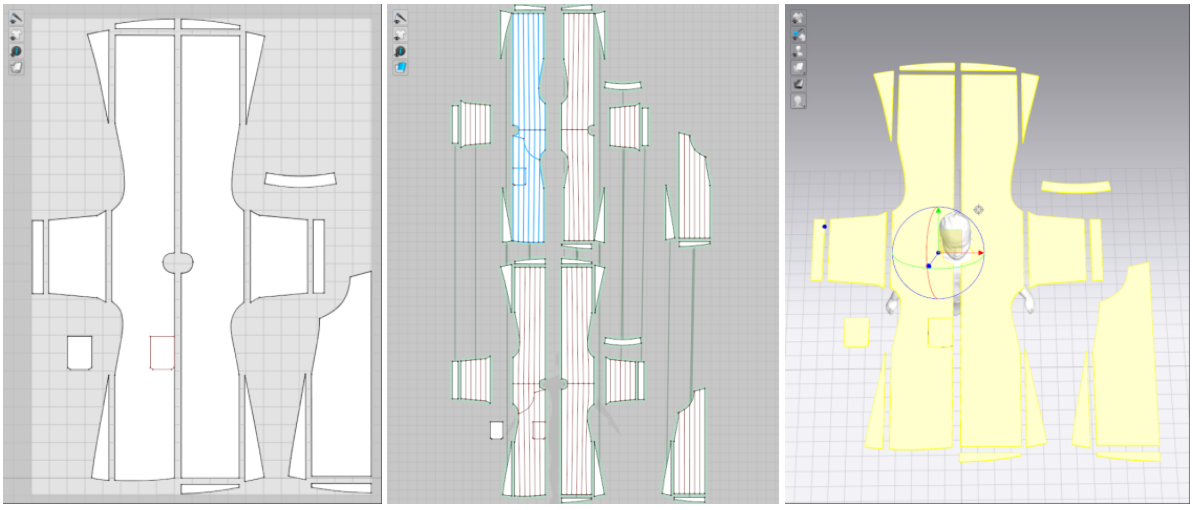


Fig. 13. Cotton robe sample arrangement. a.two-dimensional sample of cotton robe, b. sample arrangement, c. sample arrangement results

For the first problem, the solution is to arrange the sample piece at the neck of the human body model, place it horizontally, and sew the front and back center lines of the body together first to prevent the sample piece from falling off during the simulation, attach the sample piece to the human body model after the simulation, and then carry out the next sewing step to prevent the sample piece from wearing the mold or sewing wrongly with the human body model (see Figure 14a). For the second problem, the solution is to arrange the sewing order between the cut pieces. First, sew the hem corner inserts on both sides of the hem of the cotton gown single layer fabric and the fabric piece of the bottom hem to the body of the garment, and then proceed to the next step (see Figure 14b). After the garment samples are sewn together, select all the panels and right-click "Clone layer (internal)." The two layers of fabric will be automatically stitched together, and finally the top stitches and internal cotton filling effect are set (see Figure 14c). This effectively avoids the stitching



a. Preliminary arrangement of sample pieces b. Single-layer fabric virtual sewing



c. Simulation of quilting and cotton wool filling effect d.Simulation of asymmetric structure

Fig. 14. Cotton robe virtual sewing process



Fig. 15. Lint filling simulation

simulation process, jamming, sampling through the mold, slice shedding, etc. The Nayman tribe's traditional cotton robe's asymmetric structure simulation effect is shown in Figure 14d.

3.4. Quilting process simulation results

As for this traditional cotton robe, a quilting process was used for the internal filling of cotton wool, there is a big difference in the embodiment of actual sewing and virtual sewing for the wadding treated by the quilting process. To simulate the effect of internal filling with cotton wool, the internal structure is first copied, and the pressure values of the inner and outer samples are set to simulate the effect of the cotton wool filling. As shown in Table II, the simulated impact the of cotton wool filling is achieved by adjusting different pressure values and thicknesses. After changing the parameters of the pressure and increasing the thickness several times, the pressure between the inner and outer samples needs to interact with each other to generate air, so that the inner and outer models bulge outward to achieve the effect of cotton wool filling.

As can be seen from the experimental results in Table 2, when the pressure value is adjusted to 4, the thickness is increased by 2 mm, and the positive and negative sides of the internal template are adjusted, the virtual effect of the internal cotton filling is the best (see Figure 15).

The quilting process is simulated by adding internal sewing threads to the body sample, as shown in Figure 16. After adding sewing threads for stitching, the top stitches are set, and the stitch spacing is adjusted to 10 mm to achieve the virtual effect of the quilting process.

3.5. Simulation results of the one-word button

The opening and closing of the Nayman tribal cotton robe uses three one-word buttons, but there is no one-word button in the button and buttonhole module in

		Pressure value		
		0	2	4
Increase thickness	0			
	2			
	4			

Table 2. Virtual effects of different values of air-filling simulation



Fig. 16. Quilting process simulation

CLO3D, therefore in order to simulate the realistic effect, in the button part a piece of cloth is used to simulate the one-word buckle effect, which can only play the role of decoration and does not connect the button and buttonhole. The one-word button simulation effect and one-word button pattern are shown in Figure 17.

In order to prevent the fly piece from falling off, the three Chinese frogs initially fixed at the fly piece were set with a 3 cm stitching thread to tie the buckle, then simulated afterward. After the completion of the sewing, a pendulum angle was inserted on both sides of the specimen, and the cloth pieces of the bottom pendulum were stitched together.

3.6. Fabric texture simulation results

This traditional cotton robe fabric is plain black cotton fabric. The texture is firm, and the surface is flat. It is lighter and thinner than cotton robe fabric, as well as being breathable, and comfortable. It is more lightweight, breathable and comfortable than other fabrics of the same size. It has better abrasion resistance and higher strength than other fabrics of the same size, the texture is even, and the front and back are the same, which makes it easy to undertake the embroidery process of the cotton robe.

A similar plain fabric (Muslin) is selected in CLO3D, the fabric's colour is set to black, and the fabric properties are adjusted as the material is more glossy and metallic. The reflective roughness is adjusted in the fabric properties panel to the mapping mode (intensity 50). The reflective intensity is adjusted to 15, which can reduce the fabric's glossy and metallic feeling to achieve the effect of the actual fabric's shiny surface. Table 3 shows a comparison of the impact of adjusting the fabric texture of the cotton robe.

3.7. Pressure test and effect demonstration

The pressure detection function is provided in CLO3D, which is mainly used to indirectly detect the garment's comfort through the force and margin size between the mannequin and the

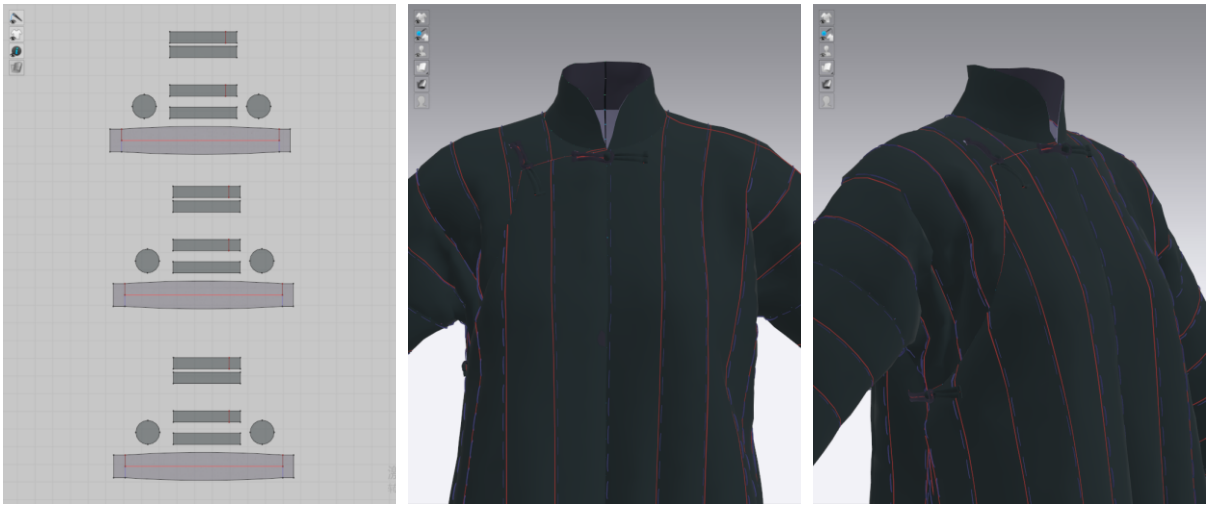


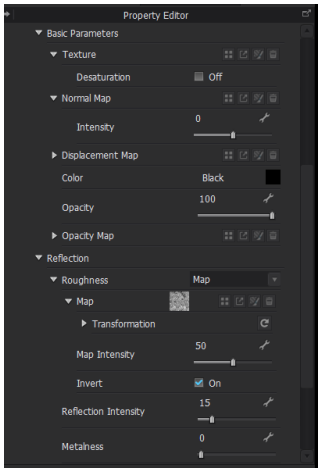
Fig. 17. One-word button sample and simulation effect



(a) Effects before adjustment



(b) Adjusted effect



(c) Fabric properties

Table 3. Comparison of cotton robe fabric texture before and after adjustment



Fig. 18. Simulated cotton robe pressure distribution

virtual garment, and this function can see the pressure distribution of the garment in real time. The pressure distribution of the simulated cotton robe is shown in Figure 18, which expresses the size of the pressure through colour and value. Red to blue indicates that the fabric tensile strength is from strong to weak, and the sense of garment compression is from strong to weak. As can be seen from the figure, the pressure on the shoulders and collar is slightly higher, while the margin between the other parts and the human body is large, and the pressure is lower, which makes it easier to move around.

The final traditional Nayman tribal cotton robe simulated using CLO3D software is shown in Figure 19.



a. Front view b. Side view c. Back view

Fig. 19. Traditional Nayman tribal cotton robe model diagram



a. Front view b. Side view c. Back view

Fig. 20. Nayman tribe's traditional cotton robe physical try-on figure

The Nayman tribe's traditional cotton robe physical try-on figure is shown in Figure 20, through the same human body try-on in the virtual model and the accurate clothing comparison. From the static display comparison, the overall structure of the clothing, technology, fabric texture, and try-on effect is the same. Results of the comparison between the virtual model and the actual clothes are shown in Table 4. Therefore, the virtual model made by CLO3D can simulate the static effect of real clothes, which provides a new idea for the inheritance and development of traditional garments.

4. Conclusions

In this paper, 3D body scanning experiments were conducted, the essential characteristics of cotton robe specimens of the Nayman tribe were introduced, and the virtual simulation process of the detailed operation of the cotton robe specimens and the virtual design of the whole cotton robe were studied. The following conclusions were drawn from the above aspects of the study:

(1) The Nayman tribe's traditional cotton robe structure is typical of the round corner standing collar, right placket, one-word button, and front and back in the middle line broken seam. The robe production uses the structure concept of "the width of the cloth decides the position of the broken seam," makes efficient use of the fabric, and meets the specification requirements of the robe through the process of catching the sleeves, making up the corner hem, etc. The cuffs, collar, and other easy-to-wear parts have removable cloth block designs, reflecting the maker's "respecting things and being frugal" idea. The quilting process is characteristic of a cotton robe. The purpose is to fix the face, lining, and multi-layer fabric but also shape the appearance of the cotton robe with a unique bumpy feeling to the touch.

(2) The concept of digital twin technology was applied to transform the 3D-scanned young Mongolian man model into an OBJ format model that could be imported for use in CLO3D software through reverse engineering technology, to try on the model in the virtual environment to understand and give feedback on the state of the actual fitting of the physical entity on the information platform, and to build its digital twin. A mirror image

	Garment construction	Process structure	Texture of fabrics	Fitting effect
Actual clothes	Stretchy, criss-cross planar structure, one-piece with sleeves	The whole garment is quilted and has a one-word button closure.	The fabric is plain black cotton with a firm texture and a flat surface.	A-line silhouette for a more relaxed and comfortable fit, with less pressure between the garment and the body.
Virtual clothes	Complete restoration of the structure of the garment, cross-plane structure, one-piece with sleeves	The virtual effect of the quilting process and the cotton wool filling effect are realised, and the one-word button structure is restored.	The fabric is recovered from black plain cotton, adjusting the relevant properties and lustre so that it is infinitely close to the texture of the actual fabric.	The overall silhouette of the virtual fitting is consistent with the real thing, and the pressure test results are reasonable.

Table 4. Comparison results between the virtual model and actual clothes

presentation of the target physical entity was realized, and the establishment and representation of a virtual model of the traditional cotton robe of the Nayman tribe were achieved. The research results can provide technical support for the digital inheritance of conventional Mongolian costumes and lay the foundation for virtual fitting technology and personalized clothing customization.

(3) ETCAD software was used to draw a 2D structural sample of the classic style and combine it with 3D body scanning and reverse engineering modeling to obtain a virtual body model. The virtual sewing process was carried out by CLO3D software using an asymmetric structure modeling technique. In the virtual fitting of a cotton robe, after stitching the corner insert on both sides of the hem of the fabric and the cloth piece of the bottom pendulum with the clothing body, and then using the double-layer fabric stitching function in CLO3D, the lining stitched together with the fabric can be generated automatically, which can effectively avoid the problems of jamming, sampling through the mold, and so on.

(4) The quilting process simulation effect can be achieved by adding internal sewing threads to the body template, stitching the sewing thread, and then setting the top stitches. Through several experiments, it was found that the quilting process simulation effect is best when the stitch spacing is 10mm. The internal cotton filling effect can be realized by setting the pressure values of the internal and external templates. Through several experiments, it was found that when the pressure value is 4, the thickness is 2 mm, and the direction of the inner and outer templates is opposite, the filling effect of internal cotton can be realized.

(5) A cotton robe on a one-word button can be used to simulate the shape of the cloth block and will be placed on the cotton robe so that the cotton robe has only a decorative role and no actual opening and closing function buckle. Through the quilting process, internal cotton wool filling, a one-word button, and other details of the simulation, the display effect is closer to the real thing.

Our experimental results enabled the digital restoration of this garment through digital twin technology, demonstrating the feasibility of the technological route approach proposed. Still, the current 3D mannequin and garment model are only static displays. In future work, we will include dynamic presentations as part of the improvement to add realism. In addition, we will incorporate interaction design and try to improve the skeletal skin and facial structure of the mannequin to make the dummy more realistic and to increase the experiential effect while passing on the non-heritage culture.

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