The restoration of garment heritages based on digital virtual technology: A case of the Chinese pale brown lace-encrusted unlined coat

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ABSTRACT – REZUMAT

The restoration of garment heritages based on digital virtual technology: A case of the Chinese pale brown lace-encrusted unlined coat

Garment heritages are commonly missing evidence of restoration because of their age and complex preservation environment. Traditional restoration methods rely on the subjective experience of restoration personnel. Its restoration results are difficult to achieve accuracy and objectivity, exposing precious cultural relics to the risk of irreversible secondary damage. Taking the Pale Brown Lace-encrusted Unlined Coat as an example, this study puts forward a method of garment heritages restoration based on digital virtual technology. After fully researching the garment background information, we used deep learning and virtual twin technology to draw and cut the garment pieces, arrange and sew the garments, and complete the stained patterns. The results show that our method can restore the original appearance of the heritages relatively well, providing a new method reference for the inheritance and digital transmission of traditional garment heritages.

Keywords: *digitization, garment culture, deep learning, heritage restoration, pattern complement, virtual twin*

Restaurarea patrimoniului vestimentar pe baza tehnologiei virtuale digitale: Un caz de jachetă necăptușită cu dantelă de culoare maro pal confecționată în China

De obicei, patrimoniului vestimentar îi lipsesc dovezile de restaurare din cauza vechimii și a mediului de conservare complex. Metodele tradiționale de restaurare se bazează pe experiența subiectivă a personalului de restaurare. Rezultatele restaurării sale sunt dificil de atins cu acuratețe și obiectivitate, expunând relicve culturale prețioase la riscul de deteriorare secundară ireversibilă. Luând ca exemplu jacheta necăptușită cu dantelă maro pal, acest studiu propune o metodă de restaurare a patrimoniului vestimentar bazată pe tehnologia virtuală digitală. După ce am cercetat complet informațiile anterioare despre articolele de îmbrăcăminte, am utilizat învățarea profundă și tehnologia modelării virtuale pentru a desena și a croi piesele, a aranja și a asambla articolele de îmbrăcăminte, a construi tiparele. Rezultatele au evidențiat că metoda noastră poate restabili corespunzător aspectul original al patrimoniului, oferind o nouă metodă de referință pentru moștenirea și transmiterea digitală a patrimoniului vestimentar tradițional.

Cuvinte-cheie*: digitalizare, cultura vestimentară, învățare profundă, restaurarea patrimoniului, construcția tiparelor, model virtual*

INTRODUCTION

Cultural heritage is a precious carrier of historical and cultural information. The restoration and display of cultural relics are of key significance to the preservation and transmission of history and culture.

Unearthed cultural relics are often accompanied by varying degrees of deterioration. Due to the lack of accurate and reliable restoration evidence, for the same cultural relic, different periods and different restoration personnel may produce different restoration results, which is not conducive to determining its true historical appearance. To ensure the requirements of "minimum intervention" and "reversibility" in international conservation guidelines, digital virtual technology has become an important auxiliary tool in the restoration of cultural objects. In recent years, some progress has been made in the field of virtual heritage restoration. Digital photogrammetry, laser scanning, 3D modelling, and artificial intelligence have been used in the literature for heritage restoration studies. Hou et al. proposed a virtual restoration method for complex structural heritages based on multi-scale spatial geometry and applied it to the virtual restoration of the Thousand-Hand Bodhisattva in Dazu Country. The adaptive adjustment of their skeleton line extraction algorithm improves the centrality and topological relationships of the skeleton lines of the heritages, solving the problem of difficulty in discovering the logic of complex heritage geometry in the restored evidence [1]. Arbace et al. propose a recombination hypothesis of the fragments for formulating and evaluating reorganization hypotheses in digital space. This is expected to reduce the operational complexity of the restoration work and avoid the risk of further deterioration of the heritage [2]. The degree of wear and tear and restoration resistance of different categories of cultural relics vary greatly because of their different materials and organizational structures. Garment heritages are mostly composed of cellulose and protein materials. Its polymer chains are susceptible to fracture by external environmental influences. This brings great difficulty for its long-time underground preservation, physical restoration work and display transportation. Researchers mostly focus on the restoration of costume artefacts from the perspective of sewing processes and chemical treatment techniques. Ferrari Martina explored the possibility of using gellan-immobilized enzymes of bacterial origin (Bacillus alpha-amylase) to obtain a satisfactory starch removal from a damaged archaeological tunic-shroud from the Turin Egyptian Museum (Italy), without altering the original yarns or textile fibres [3]. Janpourtaher et al. analysed the materials of Songket sarong from the 19th century by using Field Emission Scanning Electron Microscopy and Energy Dispersive Spectroscopy to experimentally improve the stability of textiles and developed a method for the preservation of acid-free paper properly covered samples [4]. However, there is little literature that discusses a systematic approach to the restoration of garment heritages based on digital virtual technology in a full process. Based on this, the digital virtual restoration of garment heritages becomes more important [5]. The diversity of materials, the complexity of the organization, and the strong relevance of the aesthetic and social humanities behind the garment heritages all pose significant challenges to the virtual restoration of garment heritages [6]. We try to use digital virtual technologies such as virtual twin and deep learning to participate in the multi-step work of assisting in the restoration and display of garment heritages and provide theoretical references for the preservation and transmission of traditional costume culture.

GARMENT HERITAGES ANALYSIS

The tomb of Huang Sheng of the Southern Song Dynasty is known as “the treasure house of ancient Chinese silk” and is one of the most important physical evidence of the Chinese Maritime Silk Road [7, 8]. In October 1975, a stone tomb with a triple earthen structure was discovered in Fuzhou, China. The right side of the tomb is relatively well preserved, and its owner is named Huang Sheng. Huang Sheng's tomb yielded 480 pieces of funerary objects, including 354 pieces of costumes and silk fabrics, making it the largest known tomb of silk fabrics from the Song Dynasty. The garment heritages from Huang Sheng's tomb provide important physical information for people to understand the garment culture and textile skills of the Southern Song Dynasty. One of the most representative garment items among the excavated cultural relics is Pale Brown Lace-encrusted Luo Unlined Coat with light texture, exquisite patterns and exquisite craftsmanship [9].

Garment form

The culture and art of the Song Dynasty occupy a pivotal position in Chinese history. Influenced by Neo-Confucianism, the philosophical theories and literary thoughts of the Song Dynasty tended to be rationalized. People's aesthetic thinking also developed in the direction of pragmatic simplicity. The costumes of the Song Dynasty were fashioned with subtlety, and women's clothing emphasized the femininity of gentle, sensible and elegant [10]. The main dress forms in Song Dynasty are “robe”, “coat”, “undershirt”, “pants” and “skirt”. Among them, “coat” has an unlined coat and a thick coat. The length of the unlined coat is equal to or slightly longer than the upper body. It was worn with two lapels hanging down and was a common dress for noble women at home or when they went out.

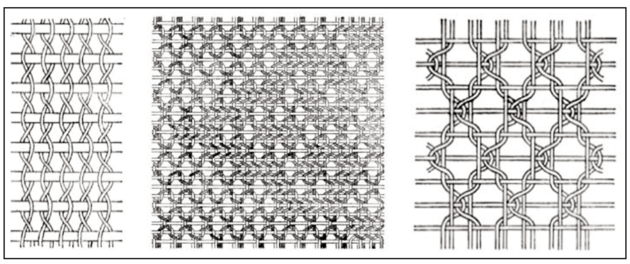
The Pale Brown Lace-encrusted Luo Unlined Coat is light brown overall. It has no buttons or ties on the collar and lapels. The length of the garment is 73 cm in both front and back, and the hemline reaches the middle of the thigh when worn on the upper body. The sleeves of the entire garment are straight, the hemline hangs down, and the collar is connected to the lapel, making it a straight one. The outer edge of the unlined coat near the neck is sewn with an additional layer of the short collar, which is overlapped and sewn on top of the original collar. Such a structure can increase the collar's fastness and also serve as a decoration. The large lapels are embroidered with peony, hibiscus, camellia and lotus patterns, and the small lapels are made with gold paint to make the patterns more gorgeous and exquisite. The overall colour of the garment is fresh and elegant, reflecting the elegant and harmonious aesthetic interest of Song Dynasty silk clothing. The Pale Brown Lace-encrusted Luo Unlined Coat is shown in figure 1.

Fig. 1. Pale Brown Lace-encrusted Luo Unlined Coat

Garment fabrics

Huang Sheng's tomb is located in Fujian Province, on the southeast coast of China. This area has a warm climate and abundant rainfall, which is suitable for growing mulberry trees and raising silkworms. It is one of the important silk-producing places in Chinese history. Pale Brown Lace-encrusted Luo Unlined Coat is a pure silk fabric. It is light in texture but strong in structure, comfortable and breathable. The extremely high level of weaving technology has allowed it to remain flat and the yarn straight for over 800 years without weft slanting.

Silk fabrics can be classified according to their tissue structure. The tissue fabric formed by twisting yarn is collectively referred to as Luo. Luo fabrics are divided into plain Luo and jacquard Luo. The plain Luo contains two warp-twisted plain Luo and four warp-twisted plain Luo. The jacquard Luo is divided into two warp-twisted jacquard Luo, three warp-twisted jacquard Luo and four warp-twisted jacquards Luo. The fabric of the composite collar of the unlined coat is two warp-twisted plain Luo, which is light in texture and moderately sparse. Its organization is shown in figure 2, *a*. The fabric of the large body piece of the unlined coat is the four warp twisted flower roving, which has different mesh sizes and resembles a fish net, as shown in figure 2, *b*. The unlined coat uses the four warp twisted leno at the big and small lapels. Four warp threads form a twisted group, and each of the four warp threads is circulated. Its left and right neighbouring groups are interwoven with large pores, which is very suitable for embroidery craft. Its organization is shown in figure 2, *c*.



a ***b*** ***c***

Fig. 2. Unlined coat fabric organization illustrations: *a* – two warp twisted plain Luo; *b* – four warp twisted jacquard Luo; *c* – four warp twisted plain Luo

Garment patterns

The dress patterns before the Song Dynasty were relatively abstract. The popular scrolling grass patterns and composite flower patterns of the Tang Dynasty could not find direct prototypes in nature. A large number of natural images appeared in the garment patterns of the Song Dynasty. This aesthetic interest was largely due to the prevalence of literati painting in the Song Dynasty. The objects of literati painting in the Song dynasty were mainly flowers and birds in gardens and courtyards, which were lifelike and highly realistic. At the same time, people in the Song Dynasty took thinness as their aesthetic orientation. This aesthetic orientation was expressed in the dress patterns, which formed the main body of slender, dynamic plants and animals and the expression technique of mainly dots and lines. Song people loved flowers, and this is often recorded in historical materials. Song people's love for flowers led to the prevalence of floral clothing patterns. The patterns appearing in the Pale Brown Lace-encrusted Luo Unlined Coat are all based on flowers and floral combinations, such as the use of peony, lotus, hibiscus and camellia floral combinations representing the four seasons at the lapel. Such a choice of subject matter was very popular in the paintings of the Southern Song Dynasty. The four seasonal flowers represent the rotation of the four seasons and symbolize the endless cycle of life rhythm. The flowers are in various postures, such as upward, downward, front and side, and the leaves are zigzagged and rolled. In terms of pattern organization, the four types of flowers are combined into a basic unit extending up and down in a bipartite continuous organization. The creator arranges the layout of flowers and branches and leaves according to the rectangular pattern boundary and the growth pattern of plants. The overall effect of the pattern is clear, balanced and rich in content.

Garment colour

The Confucian policy of the Song rulers had a great influence on the social characteristics of Song garment colours. Compared with the gorgeous and complicated colour characteristics of the Tang Dynasty, Song Dynasty clothing reduced the use of highly saturated colours and began to advocate light and simple colours. Men's clothing in the Song Dynasty was mainly in dark colours, and women's clothing was mainly in low-saturation plain colours. Soft colours such as violet, goose yellow and light green were commonly used in the colour scheme of garments, reflecting the aesthetic pursuit of tranquillity and simplicity [11]. After observing and comparing the unlined coat with other Song Dynasty costume items in kind, picture materials and restoration cases, we made restoration-oriented adjustments to the colours of the unlined coat. The colour recovery-oriented adjustment mainly includes the enhancement of pattern colour saturation and contrast, the normalization of main fabric colour difference, and the weakening of decay traces, as shown in figure 3.

We choose the clustering algorithm to perform colour analysis on the pre-processed garment images. The clustering algorithm can divide and merge intervals by calculating the distance between samples. We create five colour intervals based on the clustering algorithm and improve the quality of the interval partitioning by translating the different intervals through a circular positioning technique. To achieve the desired effect, the clustered colours were batch normalized and averaged based on the calculated colour distance values. The image cluster partition of

Fig. 3. Contrast of colour repair-oriented adjustment of unlined coat

Table 1

UNLINED COAT COLOR CLUSTERING ANALYSIS					
Colour	**Pale brown**	**Dark brown**	**Dark green**	**Black**	**Gold**
Impression Cluster Partitioning					
Percentage (%)	59.93	24.19	6.58	5.76	3.54
RGB	109/74/45	88/58/32	69/62/54	36/30/27	157/97/47

5 groups of images was set to consist of all colours within 10 pixels. The results of the unlined coat colour analysis were obtained by clustering as shown in table 1. The RGB (Red, Green, Blue) represent the colours of the red, green and blue channels. The RGB values of the five colours were extracted for subsequent colour recovery research.

From the analysis results, the overall colour of the unlined coat is even. The main colour of the garment is pale brown, with a light and elegant floral pattern, showing a quiet charm. A large dark colour was chosen as the base colour for the lapel pattern of the unlined coat. The light green branches and leaves and the golden flowers are set off by them to get a stately and elegant artistic expression of natural elegance.

Garment craft

The tomb owner, Huang Sheng, as a ruling class and nobleman of the Song Dynasty, spared no effort in the pursuit of perfection in her burial garments, from the choice of fabric to the design of a pattern on the cuffs. The costumes unearthed in Huang Sheng's tomb are extremely elaborate. Embroidery and golden paint were used on the unlined coat to make the pattern effect richer and more decorative.

Embroidery was used extensively on the lace of the unlined coat. Embroidery is used for the petals, stamens and leaf outline edges on the large lace pattern. The high level of embroidery makes the embroidery surface flat and precise, with a strong sense of three-dimensionality. The complex and expensive golden paint craft was used for the small lapels of the unlined coat. The garment maker dipped a patterned wooden plate into the gold paint and then printed the outline of flowers and leaves directly onto the thinly stencilled and ironed silk fabric. The width and thickness of the golden paint print depend on the strength of the wood panel used. The adhesion of the gold paint has weakened with time and some of the golden paint patterns have now fallen off [12].

RESULTS

Garment heritage restoration

With the maturity and popularity of digital technology, the virtual twin is showing an increasingly important role in garment development and display. Several companies have developed fully functional digital virtual garment development and display software platforms. These software platforms allow for varying degrees of human modelling, garment piece drawing, garment sewing, wear testing, and 3D display of finished garments. The open functionality and editable parameters of such software platforms provide effective support for the digital restoration of garment heritages. Such mainstream software platforms include CLO 3D from CVF in Korea, Optitex from EFI in the U.S. and Style 3D software from Lingdi Digital Technology in China. We chose the Style 3D software platform, version V4.8.405, which has a more complete digital repository and greater ease of use, for the restoration of the garment heritages in this study through a functional comparison.

Body model building

People in the Song dynasty admired the image of a slender and beautiful woman, and there are numerous descriptions of women's slender bodies in Chinese Song Poems. Such aesthetic standards for women of the era were widely practised among noble women who did not have to undertake heavy physical labour. The skeleton of the tomb owner, Huang Sheng, is well preserved. Based on the skeleton data, it can be deduced that Huang Sheng's height in his lifetime was about 160 cm. Based on the physical characteristics of women in the Song Dynasty, we fine-tuned the data for the Chinese GB/T1335.2-2008 clothing size women's A body type corresponding to 160 cm height, and the results are shown in table 2. The adjusted data was input into the Style 3D software platform for virtual body modelling (figure 4). The dimensions of the virtual body and the arrangement of the joints were set concerning standard specifications. We set the virtual human body in a stand-

Table 2

MODEL BODY PARAMETERS							
Item	**Height**	**Arm length**	**Neck circumference**	**Shoulder width**	**Bust**	**Waist circumference**	**Hip circumference**
Value (cm)	160.0	50.5	33.6	39.4	84.0	68.0	90.0

ing position with arms outstretched to facilitate the subsequent fitting of the garment, as shown in figure 5, a.

Garment structure restoration

According to the comparison of physical measurement and related information, we compiled various dimensional data of the unlined coat, as shown in table 3. Based on the structure of the garment and the information on each dimension, we draw up the shape diagram of the unlined coat, as shown in figure 4.

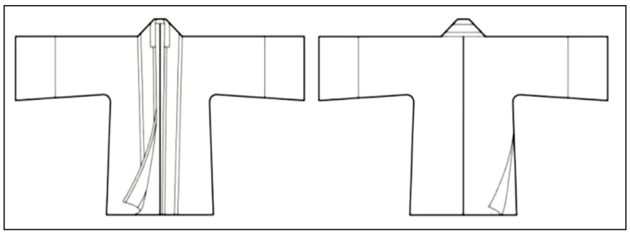


Fig. 4. Shape diagram of garment

The unlined coat cut pieces and data are stored in ".dxf" file format by Fuyi CAD software and then imported into Style 3D software for digital virtual garment placement and sewing. Correct and reasonable placement of the garment pieces and correspondence between the sewing threads are the keys to the smooth sewing of the garment. Errors such as tilting and reversing the garment pieces may lead to incorrect dressing and stitching. We finally determined the placement of the garment pieces as shown in figure 5, *b* after many times of garment piece placement, comparison debugging and simulation experiments. The part of the garment structure that is not ideal for wearing can be adjusted in time in the simulation state to ensure the integrity of the overall garment structure.

Garment pattern restoration

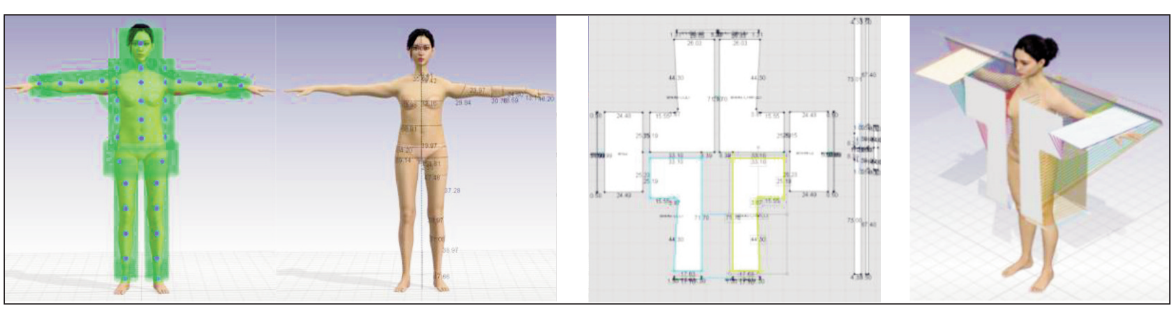
The logic of the geometric layout of the damaged part of the heritage is a key issue in the restoration of the heritage. Judgments based solely on the subjective experience of restoration workers tend to result in one-sided restoration results. The development of deep learning techniques provides effective methods for image remediation topics including heritage damage remediation. GAN works differently than most deep learning models that work serially. GAN does not require a variational lower bound but generates results directly by sampling noise. It is used by researchers for pattern complementation and creation [13]. In this study, we build a logical complementary model of garment heritages pattern defacement layout based on GAN to assist in pattern restoration.

Insufficient annotation samples, specification and style diversity of garment heritage patterns are significant challenges for training compared to most other image complementation training objects. Given such limitations, we propose a globally and locally consistent GAN for garment heritage line drawing completion, which assists in manual pattern restoration. For the machine algorithm to better understand and distinguish the structure of the pattern from the defective part, we manually outline and label the initial image. We distil the structure of the complete part of the original pattern and present it as a line drawing. We mark the defective areas of the pattern in the form of black blocks. For the problem of small samples of garment heritage patterns, we did sample augmentation on the dataset samples. We perform random flip, brightness or contrast adjustments in the present range to achieve the sample augmentation. The amplified data set samples are fed into the batch normalization algorithm for quality and specification harmonization. The trainability of the dataset is greatly improved

Table 3

DIMENSIONAL DATA OF THE UNLINED COAT

Item	Clothing length	Through-sleeve length	Waist width	Sleeve sleeve edge	Cuff width	Sleeve edge width	Front hemline width	Back hemline width	Hem edge width	Small lapels width	lapel lace width	Collar edge width
Size (cm)	73.0	133.0	47.0	25.0	25.5	0.5	48.0	52.2	1.3	1.5	4.3	2.5



a *b* *c*

Fig. 5. Virtual model and garment cutting piece position placement: *a* – virtual model joint point arrangement position and parameters; *b* – flat cutting piece of the garment; *c* – 3D placement of garment cutting piece

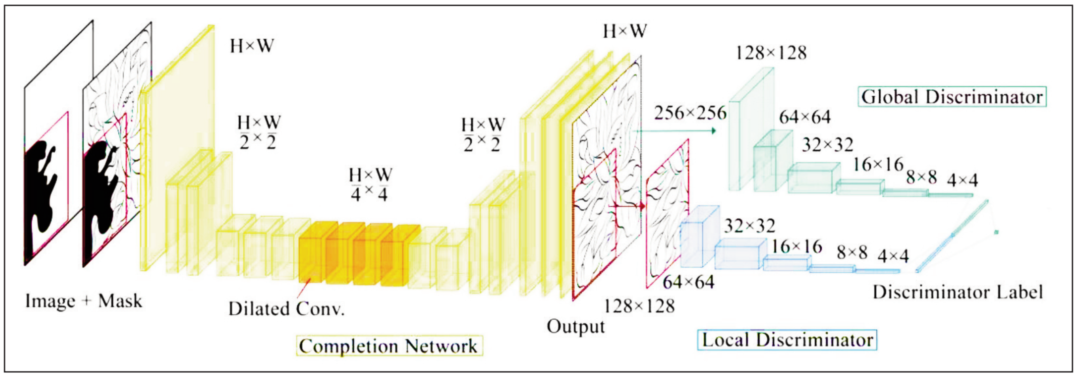


Fig. 6. The GAN architecture for line drawing completion

after image pre-processing by outlining, annotation, sample augmentation and batch normalization.

Following the manual line drawing step, we aim to complement the missing areas of the line drawing. The reason for not directly using an end-to-end pattern complementation network is that there are insufficient existing samples to fit this complex mapping. As an alternative, constructing a deep convolution network from the original defective line drawing to the complemented one is a compromise solution. We use H (height) to denote the height of the convolution layer and W (width) to denote the width of the convolution layer. Figure 6 depicts the globally and locally consistent GAN for line drawing completion [14]. The input of the GAN is the defective line drawing and its corresponding mask that is used to label the defective region and the output is a complemented line drawing. As a pre-processing, a constant colour is used to cover the completed region of the training input image, which is the average pixel value of the input image, before placing it into the network [15].

First, the completion network is a modified U-net which contains three down-sampling and up-sampling operations. Unlike the original U-net, the full convolution layers in the middle part are replaced by dilated convolution layers, which allows for increasing the area each layer can use as input. This is achieved by spreading the convolution kernels into the input map without increasing the number of learnable weights.

To discriminate the integrity of the images, global discriminators and local discriminators are used to further optimize the network parameters. The global discriminator is concerned with the harmony of the complemented image and the local discriminator is focused on the accuracy of the complemented details. The deep feature extraction encoder outputs the complemented image as a specified length label. At the end of the discriminator module, the outputs of two discriminators are fused by a concatenation layer to predict the probability of the image being real.

Let $C(x,M_c)$ denote the completion network in a functional form, with x the input image and M_c the completion region mask. For regular training, the weighted MSE (Mean Square Error) loss considering the completion region mask is used. The weighted MSE loss is shown below:

$$L(x,M_c) = \| M_c \odot (C(x,M_c) - x) \|^2 \qquad (1)$$

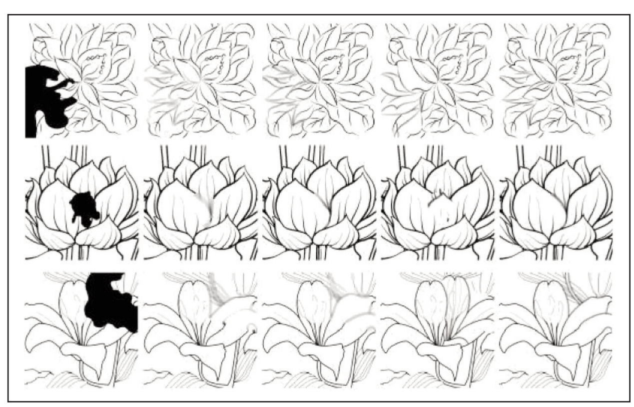
To estimate the complemented image, the context discriminators are treated as the GAN loss. This is the key part and involves transforming the standard optimization of the neural network into a min-max optimization problem, where the discriminator network is jointly updated with the complete network. For the network with one discriminator, the optimization equation is shown below:

$$\min(C)\max(D)\,\mathbb{E}\,[\log D(x,M_d) + \\ + \log(1 - D(C(x,M_c),M_c)] \qquad (2)$$

where M_d is a random mask and M_c – the input mask. Furthermore, the optimization equation of network with global and local discriminator is shown below:

$$\min(C)\max(D)\,\mathbb{E}\left[L(x,M_c) + \alpha\log D(x,M_d) + \\ + \alpha\log(1 - D(C(x,M_c),M_c))\right] \qquad (3)$$

In the training procedure, we first use the MSE loss function separately to train the completion network to make the network roughly converge. Then, the combined GAN loss function (L_{global} and L_{local}) is applied to fine-tune the network resulting in high accuracy. This helps stabilize the learning process. Image complementation results under the incommensurate loss function as shown in figure 7.



a *b* *c* *d* *e*

Fig. 7. Image complementation results under the incommensurate loss function: *a* – source; *b* – MSE; *c* – MSE+L_{global}; *d* – MSE+L_{local}; *e* – MSE+L_{global} + L_{local}

The line sketches patched by the machine algorithm are used as a logical reference to lay out the structure of the pattern in the defective part. By observing the logical details of the pattern around the defective part, we docked and organized the edges of the restored part. Then, we complete the restoration of the stained part and its embedding in the overall pattern by manually outlining, making the complete pattern both rational and beautiful. Based on the data results of the pattern units in the previous colour analysis section, we colour-fill the complete pattern structure. The pattern restoration result is shown in figure 8.

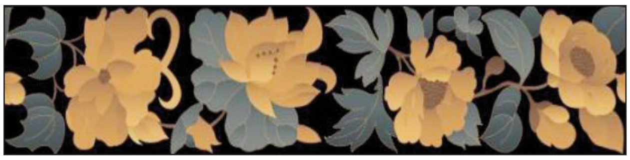


Fig. 8. Pattern restoration result

The craft texture of the pattern also plays a key role in the artistic expression of the garment heritage pattern. In this study, the craft texture restoration of the pattern is achieved by selectively adding mapping to the pattern and adjusting the parameters. The pattern of the large lapel is mapped with normal and displacement mapping and the pattern of the small lapel is mapped with metallic and transparency mapping in the Adobe Photoshop software. We import the craft texture effect into the style 3D software platform, overlay it in the edit bar and adjust the position of the texture so that it corresponds exactly to the original pattern. After several matching attempts, we determine the suitable intensity value for the normal map at the large lapel is 0.51, the suitable height for the replacement map at the large lapel is 0.2 mm, the suitable intensity value for the transparency map at the small lapel is 0.85, and the suitable intensity value for the smoothness map at the small lapel is 0.63. With this parameter, we obtained the pattern craft effect with the sense of light and shadow, bumpiness and texture. The pattern craft recovery method and effect are shown in figure 9.

Fabric restoration

The unlined coat is a typical Southern Song pure silk fabric with meticulous and tight organization, comfortable and breathable. The warp and weft density of the main fabric is 7214 roots/cm. The diameter of the warp thread is 0.4 mm and the diameter of the weft thread is 0.6 mm. The warp and weft density of the fabric at the lapel is 4840 roots/cm. The diameter of warp thread is 0.2 mm and the diameter of the weft thread is 0.4 mm. The warp and weft density of the fabric at the laminated collar is 3631 stitches/cm. The warp diameter is 0.15 mm and the weft diameter is 0.25 mm. Concerning the modern silk fabric properties and processing experience, we matched the three fabrics of the unlined coat with the silk fabrics in the database and fine-tuned the fabric property parameters [16]. The final fabric properties entered are shown in table 4 to facilitate the subsequent fitting of the garment.

Structural detail optimization

Based on the completion of the overall garment structure restoration, we optimize and adjust the structure details based on the feedback from the garment stress test. Traditional garment stress testing relies on the physical production of garments, and the number of stress test points is limited by the experiment. With the support of virtual twin technology, the stresses of the garment during wear can be calculated based on the garment

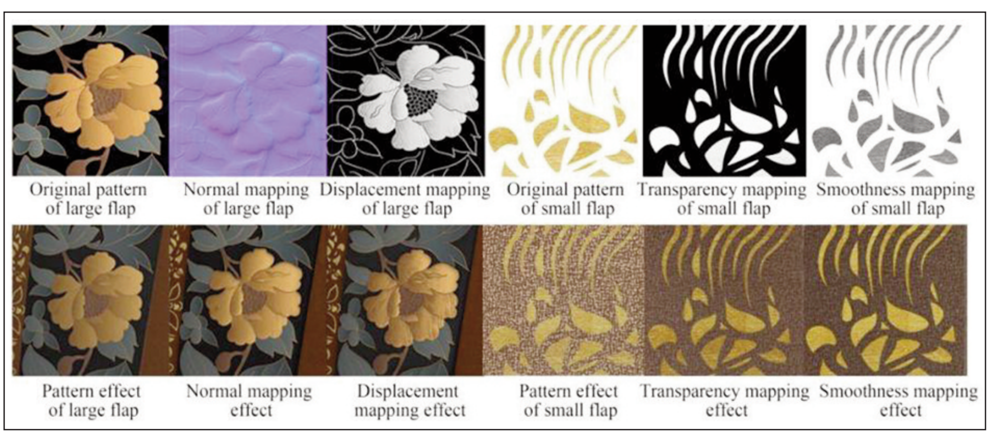


Fig. 9. Pattern craft restoration

Table 4

FABRIC PHYSICAL PROPERTIES								
Fabric	**Stretch weft**	**Stretch warp**	**Stretch bias**	**Bending weft**	**Bending warp**	**Bending bias**	**Weight (GSM)**	**Thickness (mm)**
Main fabric	0.00	12.48	7.92	7.00	8.10	7.70	160.10	0.10
Counterpane fabric	17.88	12.89	0.44	10.72	14.38	12.14	27.78	0.10
Conforming collar fabric	31.01	21.39	1.83	11.64	13.36	12.32	69.70	0.10

Table 5

STRESS VALUES AT CRITICAL POINTS									
Item	**Back cervical point**	**Lateral neck point**		**Arms**		**Frontal bust line point**		**Lateral hip line point**	
Number	1	2	3	4	5	6	7	8	9
Position	Medium	Left	Right	Left	Right	Left	Right	Left	Right
Stress value (kPa)	6.41	30.63	23.94	5.40	4.32	9.65	7.46	3.13	3.53

a *b*

Fig. 10. Three-dimensional display effect: *a* – stress distribution of unlined coat; *b* – garment restoration effect

structure, the model's body shape and the fabric properties. After entering these data in the Style 3D software platform, we can dynamically observe the stress distribution of the garment while it is being worn in a real-time visualization window. The unlined coat that completed the structure and fabric restoration in the previous paper was worn on the body of a simulated model of Huang Sheng's body type, and its stress test results are shown in figure 10, *a*. The overall stress distribution of the unlined coat is relatively uniform and all of them are in a non-stressed state below 40 kpa. The stress test data of nine representative structural points are shown in table 5. In summary, the recovered unlined coat structure does not require further detailed optimization adjustments in this session.to facilitate the subsequent fitting of the garment, as shown in figure 10, *b*.

The Pale Brown Lace-encrusted Luo Unlined Coat that has completed the restoration of structure, fabric, pattern, colour and technology is worn on the virtual model, and the restoration effect was completed as shown in figure 9, *b*.

CONCLUSIONS

This research proposes a garment heritage restoration method based on deep learning, virtual twin and other digital virtual technologies. We elaborate and analyse how digital virtual technology can intervene in the restoration of the structure, pattern, colour, and fabric of garment heritages, and practice restoration with the example of the Pale Brown Lace-encrusted Luo Unlined Coat from Huang Sheng's tomb in the Southern Song Dynasty in Fuzhou, China. As shown by the results, our proposed method can relatively well restore the original appearance of the garment heritages and meet the display needs of the public. However, there are some limitations in this study. The method proposed in this study has a relatively high requirement for the proportion of missing and damaged information on garment heritages, which will be focused on in our future work. We hope that this study will provide a theoretical reference for the restoration of garment heritages and help the inheritance of traditional costume culture.

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