An undamaged pattern generation method from 3D scanned garment sample based on finite element approach

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ABSTRACT – REZUMAT

An undamaged pattern generation method from 3D scanned garment sample based on finite element approach

The purpose of this study is to propose a new method to achieve pattern generation from garment sample without damage. The non-contact three-dimensional (3D) scanner was employed to get the point cloud data of garment samples. The Bowyer-Watson algorithm was used to implement Delaunay triangulation for surface reconstruction. The finite element (FE) approach was employed to achieve the consideration of the fabric properties in surface development. The proposed method was demonstrated to effectively realize the pattern generation of 3D sample clothes with fabric properties without damaging the garment samples, and to be suitable for different clothing styles and fabrics. Compared with traditional methods, the proposed method has higher accuracy (2.21% higher on average) and better stability.

Keywords: *3D scanned garment, fabric properties, finite element, pattern generation*

O metodă de generare a tiparelor fără deteriorare dintr-un articol de îmbrăcăminte scanat 3D, bazată pe abordarea cu elemente finite

Scopul acestui studiu este de a propune o nouă metodă pentru a genera tipare din articolul de îmbrăcăminte fără deteriorare. Scanerul tridimensional (3D) fără contact a fost folosit pentru a obține conturul punctat al articolelor de îmbrăcăminte. A fost utilizat algoritmul Bowyer-Watson pentru a implementa triangularea Delaunay, pentru reconstrucția suprafeței. Abordarea cu elemente finite (FE) a fost utilizată pentru a lua în considerare proprietățile materialului textil, în dezvoltarea suprafeței. S-a demonstrat că metoda propusă realizează în mod eficient generarea tiparelor pentru articolele de îmbrăcăminte 3D, ținând cont de proprietățile materialului textil, fără deteriorarea acestora și că este potrivită pentru diferite stiluri de îmbrăcăminte și materiale textile. În comparație cu metodele tradiționale, metoda propusă are o precizie mai mare (în medie cu 2,21% mai mare) și o stabilitate corespunzătoare.

Cuvinte-cheie*: îmbrăcăminte scanată 3D, proprietăți ale materialului textil, element finit, generare de tipare*

INTRODUCTION

Nowadays, clothing sample processing (processing according to the garment samples given by customers) is one of the important sources of customer orders in the garment industry. What pattern making technology has become the most important method adopted by garment manufacturing enterprises is obtaining patterns from garment samples. To obtain patterns from garment samples, professional pattern makers, with years of experience, are required to manually measure garment pieces after splitting garments into pieces or directly measure the garments. The measurement is to analyse its garment structure and obtain the data of the size, radian, and angle. According to the obtained data, clothing patterns are made by experience. After repeated trial and error, the new garment made with this pattern is similar in shape to the target sample. On the one hand, this process is highly dependent on professional pattern makers, and the experience of technicians will also affect the obtained garment patterns [1]. It seems a nicer choice to use digital means to replace traditional processes. On the other hand, for high-end clothing, precious clothing collections, or protective cultural relics, if they need to be reproduced or recreated, the traditional method of samples to patterns will cause irreversible damage [2] and inaccurate measurement. The non-contact 3D scanning technology can obtain the depth information of garment 3D modelling more accurately without damaging the sample [3, 4]. The digital means of obtaining patterns from garment samples include scanning, surface reconstruction, and surface development. Depth information needs surface reconstruction to get a 3D garment model. The Bowyer-Watson triangulation algorithm [5] for surface reconstruction is not restricted by spatial dimension, and its implementation is simpler. 3D scanning only obtained 3D modelling information of garments, but different fabrics would have an impact on the production of the garment pattern [6]. In the surface development process, accurate patterns may not be obtained if only depth information is considered without fabric parameters [7].

The finite element method has been employed to study the fabric compressibility [8] and impact properties of fabrics [9]. The finite element (FE) algorithm can help to couple the properties of the material to the entity for bra design [10]. Any three-dimensional surface can be flattened into a two-dimensional plane by increasing the force [11]. Therefore, the combination of three-dimensional scanning technology and finite element approach can realize the non-destructive pattern generation of sample garments with fabric parameters.

In this work, the depth information (the point cloud data) was accurately obtained by 3D scanned samples to avoid damage to garment samples. Then, the surface was reconstructed by Delaunay triangulation based on the Bowyer-Watson algorithm. Also, as different fabrics were supposed to be considered, the surface expansion was conducted by the finite element approach. Finally, this novel method was compared with the traditional methods to demonstrate its superiority and was also carried out in different styles to prove its applicability.

MATERIALS AND METHODS

Materials

In this study, firstly, a cheongsam style [12] containing a dart, dividing line, sleeve, collar, and asymmetrical pieces was selected for the experiment. A plain-woven 100% Cotton fabric was utilized. The fabric parameters of the garment sample are shown in table 1.

Data acquisition of the garment

To obtain the 3D depth information of clothing, the garment was worn on the 160/84A female mannequin. Since the garment was made of soft material, the contactless high-precision hand-held 3D scanner [13] (Einscan-Pro2X, XianLin, China) with a precision of 0.1 mm, a scanning speed of 550,000 points/s, and a spatial point distance of 0.2 mm – 3 mm was employed. The scanning process is shown in figure 1.

The scanner needed to be rotated around the garment and keep a distance to scan the garment until the point clouds were obtained entirely. The Geomagic Design X 64 software was carried out to

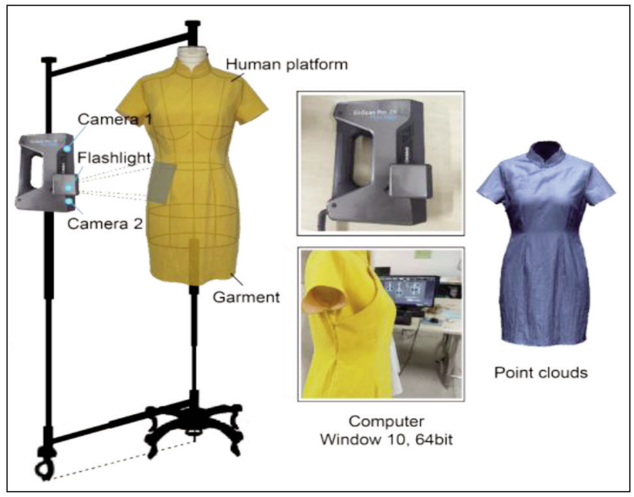


Fig. 1. Data acquisition

pre-process point cloud data, including coordinate system reconstruction, denoising, 50% sampling, and smoothing. The data was exported as a file in ASC format for subsequent processing.

Surface reconstruction and style segmentation

The point cloud data obtained by scanning was disorganized, and need to be triangulated by the Bowyer-Watson algorithm [14]. In figure 2, *a*, the spatial scattered point data and the adjacent points obeying the topology were connected to form a mesh structure so that the garment model was reconstructed. For the parts segmentation of style, as shown in figure 2, *b*, the 3D model was divided into *n* subfacets by over-segmentation [15]. Then the region fusion processing was carried out. Where the features were not significant, such as waist dart, underarm dart, and so on, the boundary needed to be adjusted manually. The garment parts were obtained. By parameterizing the surface of each garment component, the NURBS surface model was obtained by fitting NURBS surface pieces [16]. The data of the garment part was exported as a file in STP format.

Surface flattening to generate patterns

In this approach, surface development was implemented in NX Open C++ Software. As shown in figure 3, the finite element method was used to expand the surface.

Table 1

FABRICS PROPERTY OF A GARMENT SAMPLE					
Fabrics property	**No.**	**Value**	**Fabrics property**	**No.**	**Value**
Fabric content	P_1	100% Cotton	Weft bending rigidity (N/m)	B_2	5.0
Weave structure	P_2	1/1 Plain	Static drape coefficient (%)	F	41.08
Weight (g/m²)	m	138.6	Warp elastic modulus (MPa)	E_1	128.71
Thickness (mm)	h	0.443	Weft elastic modulus (MPa)	E_2	113.95
Warp density (threads/cm)	D_1	23	Warp Poisson's ratio	v_1	0.1532
Weft density (threads/cm)	D_2	24	Weft Poisson's ratio	v_2	0.1262
Warp bending rigidity (N/m)	B_1	6.0	Shear stiffness	G	2.24

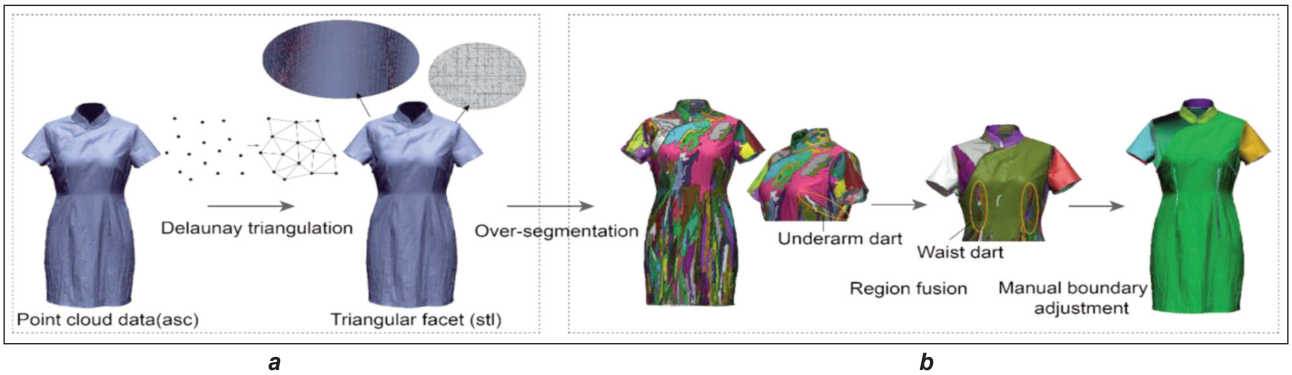


Fig. 2. Surface reconstruction and style segmentation: *a* – garment model reconstruction; *b* – segmentation of style

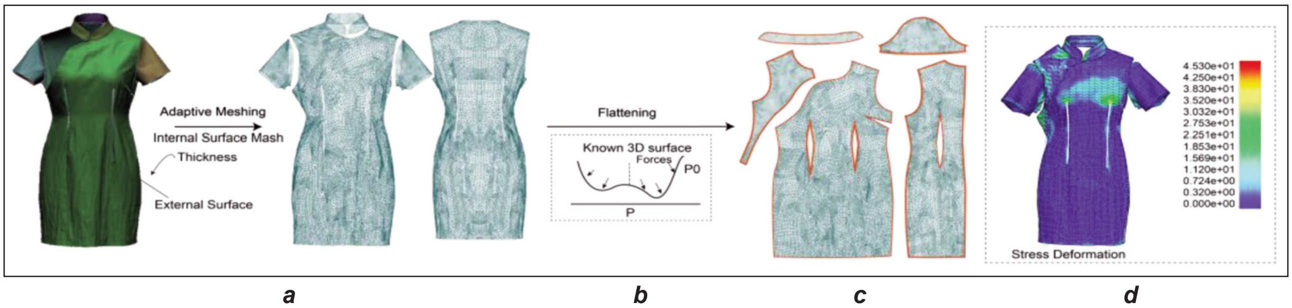


Fig. 3. Surface flattening based on finite element method: *a* – adaptive meshing; *b* – flattering; *c* – pattern generation; *d* – stress deformation

It was assumed that the soft fabric was a continuous homogeneous medium flexible sheet [17]. Thus, the parameters of fabric structure, such as weave structure P_2, warp and weft density D_1, D_2, could be ignored. The thickness h and the weight m were used to define the physical properties of surfaces. In figure 3, *a*, the internal surface was selected for adaptive meshing. As the garment fabric was regarded as an orthotropic elastic material, the surface was discretized based on the constitutive equation of the orthotropic elastic model [17–19]. The stress-strain relationship is the following:

$$\begin{pmatrix} N^{11} \\ N^{22} \\ N^{12} \end{pmatrix} = \begin{pmatrix} \frac{E_1}{1-v_1 v_2} & \frac{E_1 v_1}{1-v_1 v_2} & 0 \\ \frac{E_2 v_1}{1-v_1 v_2} & \frac{E_2}{1-v_1 v_2} & 0 \\ 0 & 0 & G \end{pmatrix} \times \begin{pmatrix} e_{11} \\ e_{22} \\ 2e_{12} \end{pmatrix} \quad (1)$$

where N and e are the stress and the membrane strain, respectively. The main parameters of the formula are explained in table 1. The relationship between bending moment and bending strain is the following:

$$\begin{pmatrix} M^{11} \\ M^{22} \\ M^{12} \end{pmatrix} = \begin{pmatrix} B_1 & \sigma_2 B_1 & 0 \\ \sigma_1 B_2 & B_2 & 0 \\ 0 & 0 & \tau \end{pmatrix} \times \begin{pmatrix} \chi_{11} \\ \chi_{22} \\ 2\chi_{12} \end{pmatrix} \quad (2)$$

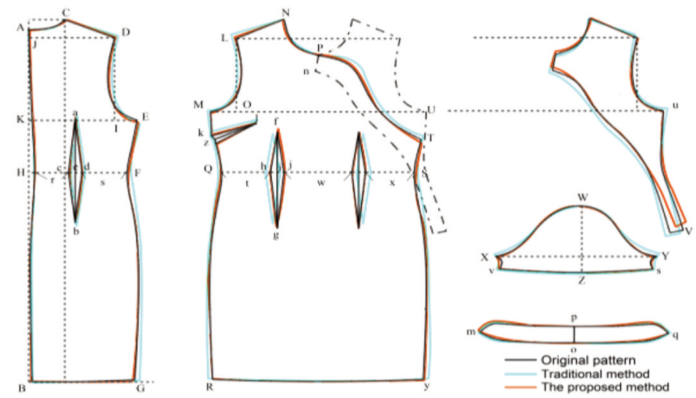
where M and χ are bending moment and bending strain, respectively, τ – the torsional rigidity, which could be calculated; α_1 and α_2 were parallel with Poisson's ratios, which were related to the anticlastic curvature. Because the anticlastic curvature of the thin woven fabric was minimal, α_1 and α_2 were assumed to be 0.

The known values were thickness h, weight m, elastic modulus E_1, E_2, Poisson's ratio v_1, v_2, bending rigidity B_1, B_2, and the initial stress and strain were 0. Besides, static drape coefficient F was also the one of fabric mechanical properties expression form, and could also be characterized by fundamental mechanical parameters, so F was not considered. It was assumed that the forming process was proportional loading. The finite element equation was established based on the deformation theory of elasticity and the principle of virtual work. Then the Newton-Raphson iterative algorithm was utilized to solve the problem. The position on the initial surface body P_0 and the final shape nodes P were obtained under certain boundary conditions. Finally, as shown in figures 3, *c* and *d*, the shape and size, stress, and strain of the flattening plane were obtained. Then smooth the curve appropriately and adjust the length of the piece to be consistent [19]. The area change ratio of patterns before and after adjustment was controlled within 0.1%. Finally, the pattern was imported into CAD software in DXF format. Employing the seam allowance given, lengthwise grain line and cut-outs marked, garment industrial patterns were generated.

RESULTS AND DISCUSSION

Comparison with traditional methods

To prove the superiority of the proposed method, this method was compared with traditional manual



PARAMENTERS OF PATTERN					
NO.	Pattern dimensions (cm)		NO.	Pattern dimensions (cm)	
1	Center back seam	$\widehat{AHB}$	17	Back armhole line	$\widehat{DE}$
2	Neck waist length	$\widehat{AH}$	18	Sleeve length	WZ
3	Shoulder width/2	JD	19	Sleeve width	XY
4	Front shoulder line	LN	20	Sleeve opening	vs
5	Back shoulder line	CD	21	Side seam opening position	$\widehat{uV}$
6	Bust line	MU+2KE	22	Front waist dart position	t
7	Waist line	t+w+x+2 (r + s)	23	Up front waist dart length	fi
8	Hem line	$\widehat{Ry}+2\widehat{BG}$	24	Under front waist dart length	ig
9	Side seam	$\widehat{EFG}$	25	Back waist dart position	s
10	Front neck hole	$\widehat{NP}$	26	Up back waist dart length	ae
11	Back neck hole	$\widehat{AC}$	27	Under back waist dart length	eb
12	Necklace line	$\widehat{mq}$	28	Waist dart width	Cd
13	Top collar width	po	29	Underarm dart position	Mk
14	Front armhole depth	LO	30	Underarm dart length	kl
15	Back armhole depth	DI	31	Underarm dart width	kz
16	Front armhole line	$\widehat{ML}$	32	Front edge	$\widehat{pT}$

Fig. 4. Patterns and the parameters of the pattern

methods. The traditional manual method was to require professional pattern makers to measure the dressed sample garments manually, and then made patterns according to their own experience and understanding of the style. Three professional pattern makers, who basically have the same experience, skills, and knowledge, were invited to complete the experiment together. Figure 4 shows the original pattern of the sample garment (the black line), the obtained patterns by means of traditional method (the blue line) and the proposed method (the orange line). 1–32 parameters of the pattern are also shown in figure 4. Among these parameters, parameters 1–8, 12–13, 18–20 are the main control dimensions of the body, collar, and sleeves, respectively, which determines the accuracy of the main size. Parameters 28, 31, 32 are related to modelling design, which determines the design of some details of clothing.

The dimension of the obtained patterns and the original pattern were compared and analysed. To scientifically compare the accuracy of different pattern dimensions, in equation 3, the dimension change was expressed by the pattern dimension change ratio Y, which could be defined as:

$$Y = \frac{y_2 - y_1}{y_1} \tag{3}$$

where y_1 and y_2 are defined as the original pattern dimension and the obtained pattern dimension, respectively. The pattern dimension change ratio Y of 32 parameters of the pattern is shown in figure 5. The smaller the change ratio of the pattern dimension, the higher the accuracy of the pattern.

In figure 5, the pattern dimension change ratio Y of the traditional method is obviously higher than this of the proposed method. For the pattern parameters of Back armhole depth(15) and line(17), Sleeve length(18), width(19), and opening(20), Under front waist dart length (24), Up back waist dart length(26), Underarm dart length(30) and width(31), and Front edge(32), the traditional method has a higher ratio of change, that is, a lower accuracy. Because when dressing, these length dimensions measured manually need to contact the measuring point, resulting in fabric deformation and not enough accurate measurement. Manual measurements would cause dimensional errors due to factors such as human gestures and habits, so the non-contact measurement method could be more accurate. Figure 6 shows the average change ratio and variance of pattern dimensions of several methods. Compared with the traditional method, the average change ratio of pattern dimension generated by the proposed method (the FE approach based on 3D scanning) is

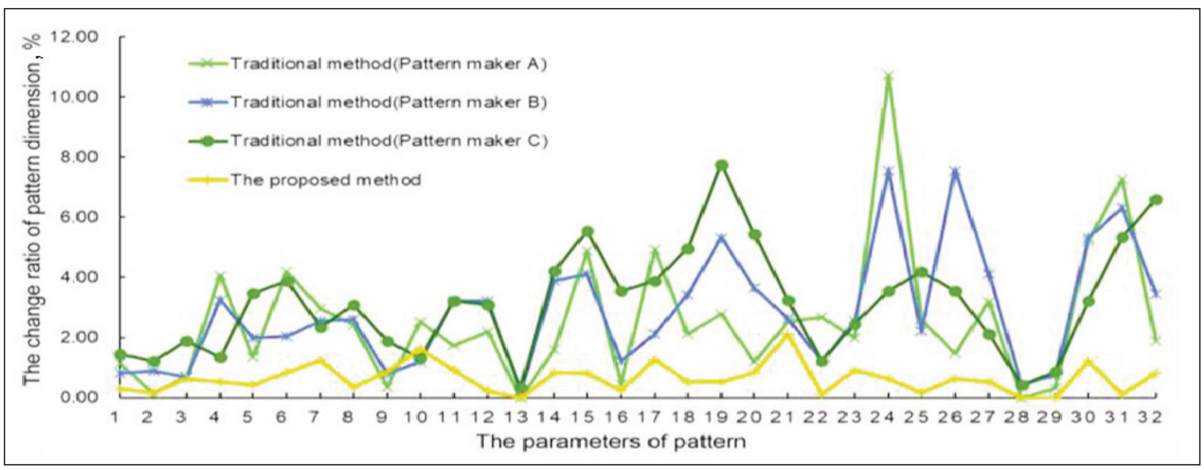


Fig. 5. The pattern dimension change ratio Y of 32 parameters of the pattern

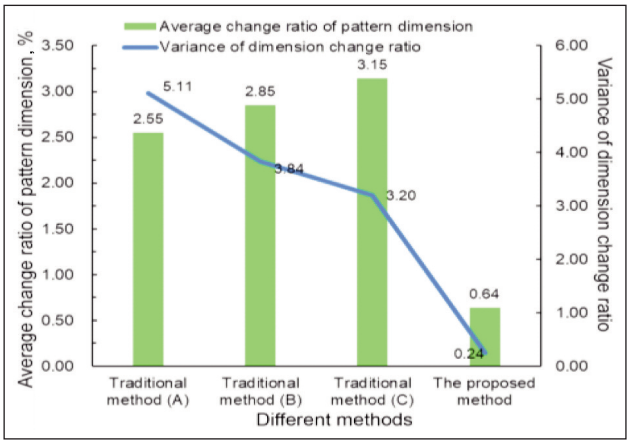


Fig. 6. The average and variance of pattern dimension change ratio

the lowest, which is 0.64%. According to the data in figure 6, the accuracy of the proposed method is 1.91%, 2.21% and 2.51% higher than that of the three traditional groups, respectively, with an average increase of 2.21%. So the proposed method has higher accuracy and better stability. This is because, in the process of data acquisition, a three-dimensional clothing shape can reflect the real shape of clothing better than a two-dimensional shape, while non-contact data acquisition can eliminate human errors to obtain the most objective three-dimensional data. As shown in figure 6, though these technicians have the same experience, skills and knowledge, the errors of different pattern makers are still different. This leads to larger errors and instability in pattern dimensions. The proposed digital method can obtain the garment pattern based on the FE method without damaging the sample garments and considering the properties of the fabric. So, accuracy and stability are the best.

The verification of garment similarity

Generated patterns were then recreated into garments. The similarity of the generated pattern shape was supposed to be verified by the shape similarity analysis between the original garment and the reproduced garment. Under the same shooting conditions, the sample clothes were worn on the female mannequin. After that, their front, side, and back photos with the size of 3456×3456 pixels were obtained. The similarity of modelling was analysed by MATLAB programming [21]. Figure 7 shows the procedure of the similarity analysis of shape.

Firstly, in figure 7, *a*, the background of the photo needed to be removed. The contour information was extracted by Fourier descriptor in figure 7, *b*. In figure 7, *c*, the similarity of modelling were compared employing Cosine similarity and histogram method. When the closer data of these two methods are to 1, the similarity is higher. *S* represents the mean values of these three views. The mean similarity *S* of the contour is 0.9801. The mean modelling similarity *S* of the Cosine distance and Histogram method is 0.9762 and 0.8714, respectively. Therefore, the high similarity indicates the rationality of the method.

Applicability to different styles of clothing

For different garment styles, the suitability of this pattern generation method needs to be demonstrated. As shown in table 2, the first style is wide-leg pants,

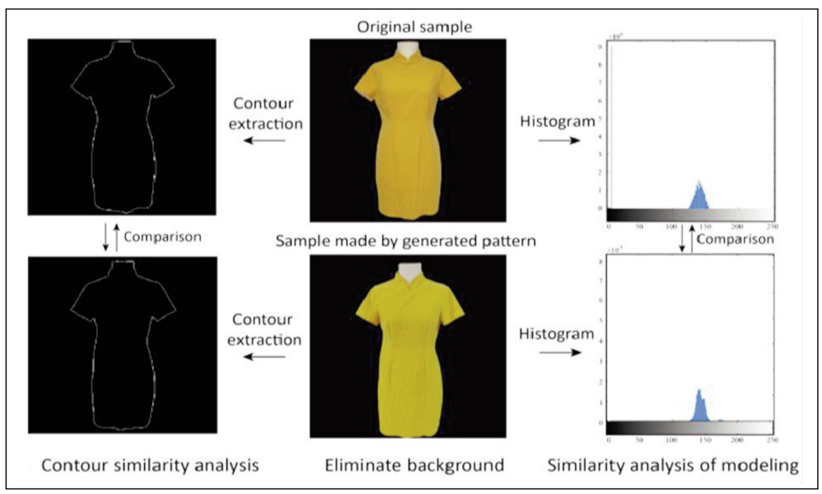


Fig. 7. Shape similarity analysis process: *a* – eliminate background; *b* – contour similarity analysis; *c* – similarity analysis of modelling

Table 2

THE GENERATED PATTERNS OF DIFFERENT CLOTHING STYLES

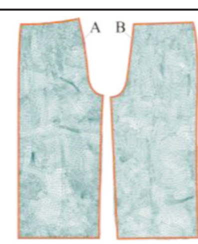
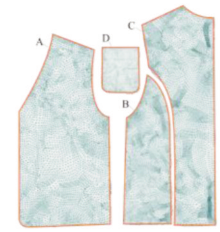
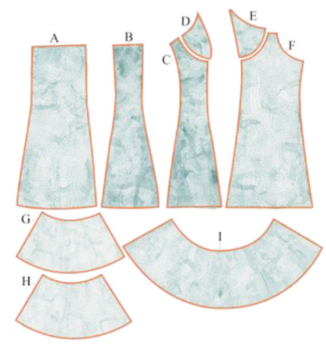
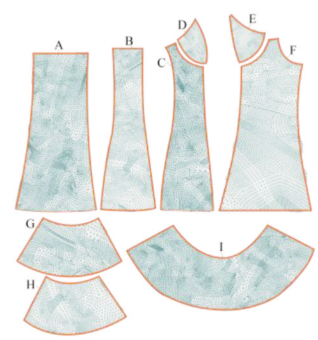
Materials	Sample garments	3D models	Generated patterns	Average change ratio of the pattern (%)
P_1 100%C B_2 15.33 P_2 Plain F 0.652 m 184.66 E_1 219.95 h 0.516 E_2 110.12 D_1 18 v_1 0.185 D_2 13 v_2 0.162 B_1 18.33 G 1.45			 	0.59

Table 2 (*continuation*)

Materials	Sample garments	3D models	Generated patterns	Average change ratio of the pattern (%)
P_1 100%C B_2 45.3 P_2 Twill F 0.487 m 510.66 E_1 383.09 h 1.89 E_2 179.16 D_1 51 v_1 0.152 D_2 37 v_2 0.127 B_1 62 G 0.82				0.73
P_1 100%C B_2 2 P_2 Satin F 0.178 m 128.3 E_1 221.8 h 0.269 E_2 140.5 D_1 44 v_1 0.312 D_2 92 v_2 0.207 B_1 3 G 0.21				1.54
P_1 100%C B_2 2 P_2 Satin F 0.178 m 128.3 E_1 221.8 h 0.269 E_2 140.5 D_1 44 v_1 0.312 D_2 92 v_2 0.207 B_1 3 G 0.21				2.23

the second style is a denim vest, and the third style is a one-piece dress. The green grid is the originally generated pattern, and the red edge is the shape after proper trimming.

The average change ratio of each pattern in table 2 is not more than 1.54 % (due to the limited space, the detail dimension is not shown here). The results show that this method applies to general skirts, trousers, and jackets. The 4th group was tested on a real human body with style 3, and the average change ratio of the generated pattern was 2.23%. Compared with the experiment of wearing the female mannequin, the change ratio of the generated pattern is increased. Because the circumference of the body (chest, hips) and posture will cause greater distortion of the fabric, and the breathing of the human body will cause errors in data acquisition.

CONCLUSIONS

In this study, under the condition of not damaging the garment samples, a new method to achieve pattern generation from garment sample with fabric properties based on a finite element approach was proposed. This proposed approach employed a non-contact 3D scanner for depth information acquisition of garment samples, Delaunay triangulation based on the Bowyer-Watson algorithm for surface reconstruction, and FE algorithm considering fabric performance for surface development. By comparing with the traditional methods, the proposed method proved to be more accurate and stable. Furthermore, this method applies to different clothing styles and fabrics, whether the garment for scanning is worn on the female mannequin or the real person.

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