Research on the Technology of Mass Customization of Clothing

Qianqian Sun and Xiaodong Sun

Abstract—**The COVID-19 pandemic challenged the garment industry dramatically which will accelerate the garment industry to turn to technology of mass customization for it offers digital online options. This paper reviews the mass customization technology of clothing from the aspects of intelligent pattern-making technology, virtual garment prototype technology and the evaluation of apparel fitness. By surveying the technologies in order to establish a ground true rules for the mass customization platform so that suitable for all clothing categories, and the pattern-making standards which could fit different body types. And finally, by experiments of different digital garment prototype on different body types to establish the rules for generating virtual prototype and evaluated fitness of virtual garment on different body types.**

Index Terms—**Garment mass customization, rules for digital production, intelligent pattern-making, virtual garment prototype, evaluation fitness of virtual garment prototype.**

I. Introduction

The traditional clothing industry is challenged greatly by the COVID-19 pandemic. The garment companies have to shift business to the online one. The artificial intelligent promoted mass customization of garment could provide online options for the clothing industry. And the mass customization of garment could also fulfill the requirement diversity and personality of customers. Therefore, mass customization of clothing is an inevitable trend in the development of the clothing industry [1]. The mass customization (MC) reduces the cost of customization, and improves production efficiency greatly. The MC could effectively solve the great inventory problem in traditional clothing industry. The MC is less dependent on the pattern maker, and can shorten the production cycle. The MC can automatically make patterns and cut clothes. The MC can not only meet individual needs but also reduce subjective errors and realize mass production.

The first section of this paper analyzes the technology of intelligent pattern making. The second part discusses the virtual try-on criteria for different body types through virtual garment prototype experiments. The third part establishes the evaluation criteria of digital garment prototype by virtual pressure experiments. Those will benefit the MC process of the clothing industry.

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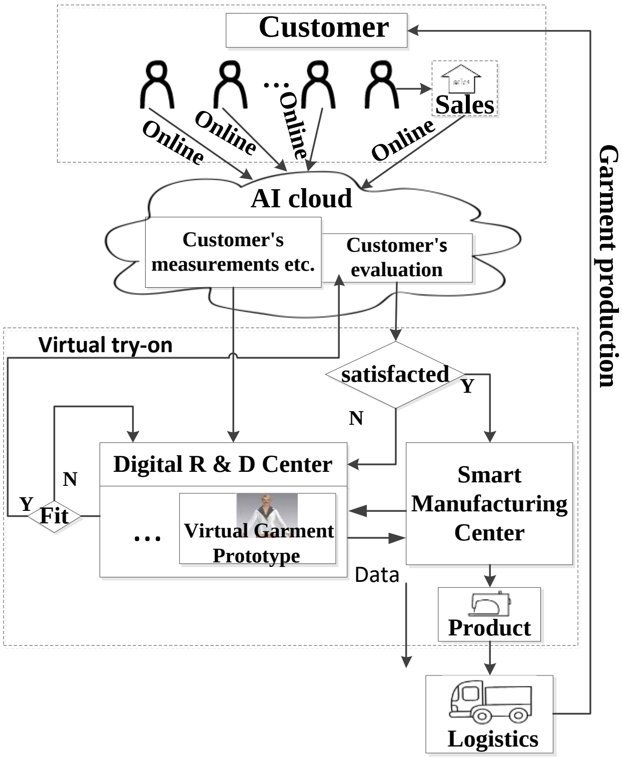

Fig. 1. The process of mass customization.

II. Key Technology of Intelligent Mass Customization

Mass customization (MC) can realize multi-user personalized customization. The MC uses AI cloud and intelligent manufacturing technology for mass customization of personalized clothing. Fig. 1 shows the process of mass customization. Mass customization requires intelligent technology, such as intelligent measurement, smart pattern-making, intelligent sewing to generate virtual garment prototype and smart virtual fitting evaluation. Fig. 2 shows the key technical process of mass customization.

A. Smart Pattern Making

Intelligent pattern making is to intelligently generate the pattern for the size and body shape of the individual. It can realize the automatic generation of patterns of any category and any body shape. However, the traditional manual pattern making requires sufficient experience of the pattern maker. It is not possible to make personalized patterns based on individual bodies. Therefore, a large number of researchers conduct related research on intelligent patterns generation. There are two methods for generating smart templates: 2D pattern making and pattern making by flattening of 3D body.

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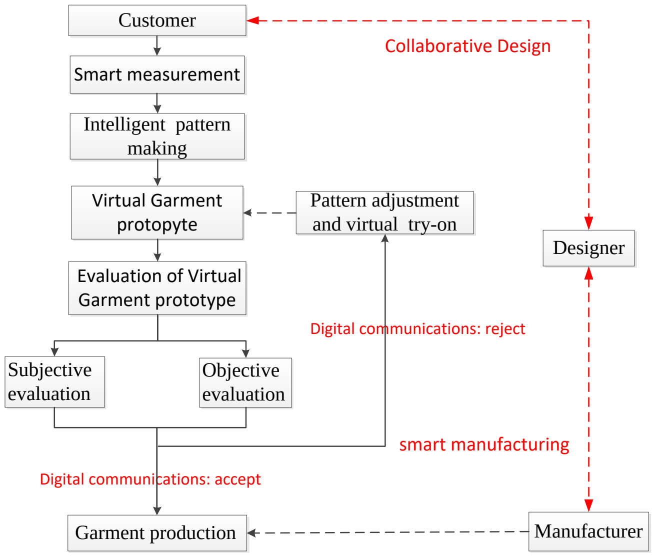


Fig. 2. Technical process of mass customization of garment.

The 2D pattern making methods are divided into parametric pattern-making[2],[3] and artificial intelligence pattern-making methods[4],[5]. Parametric pattern making depended on the corresponding relationship between the size and the pattern. The size and parameters need to be modified by the experience of the pattern maker. Artificial intelligence pattern making can replace the experience requirements of the pattern maker, but it requires a lot of experiments and patterns to fill the database. Pattern making by flatting of 3D body used surface flattening technology to process the human pattern or apparel pattern to obtain a 2D pattern. Liu, Kaixuan[6] and Kuzmichev, Victor E[7] used 3D flattening technology to compress the 3D human body into a 2D model. It is also very difficult to establish a human body model identical to the real human body. The relationship between the normal size and the pattern is not applicable to the body shape of the disabled. Table I shows comparison of intelligent pattern making methods. Neither method achieved true intelligent pattern-making and was suitable for simple version of clothing customization, such as suits, shirts, which cannot intelligently generate patterns for complex garments.

The differences between intelligent pattern-making and the existing intelligent pattern-making methods are: pattern-making speed, experience and accuracy. The intelligent pattern-making for the MC should be able to quickly generate patterns based on individualized body shapes, and automatically generate clothing patterns of different categories, such as Table II. There are still many challenges in existing pattern making methods. It is impossible to achieve personalized pattern making for different body types. Therefore, intelligent pattern-making technology requires intelligence generate personalized patterns and generate pattern-making standards for different body types. It can realize intelligent pattern-making of all body types, promoting the development of virtual prototype technology.

B. *Virtual Garment Prototype*

The authenticity of virtual garment must meet the requirements of real garment. It must realize online virtual try-on by customers to display real effects. It can solve the problems of repeated garment production, try-on and size modification of clothing customization. Table III shows comparison of real and virtual garment prototype. The traditional method needs to make a physical garment after obtaining apparel patterns. This model has a long production cycle and requires repeated trials and modifications on site. The cost of make a physical garment is relatively high and efficiency. However, the production of virtual garment

TABLE I: COMPARISON OF INTELLIGENT PATTERN MAKING METHODS

Methods	Category	Body type	Sizes	Disadvantages
Parameter pattern making	shirts[8], suit[3] pants, skirts[2],[9]	standard body	1-6、9、10、14-15、18、21、25-26	no accuracy apply the pattern
	dress[10]	fat body	1、4、9、15、25	
AI pattern making	shirts[6], suit[11] pants[12]	standard body	1-9、12-15、18、21、25	large training data, difficult to extract patterns
Pattern making by flatting of 3D body	pants, skirts[13],[14] prototype, suit[15] dress[16],[17]	standard body	surface flattening technology	missing body data, cumbersome data extraction
	prototype [18],[19]	scoliosis		difficulty in obtaining virtual models for the disabled

1-26：Bust, dress length, sleeve length, shoulder width, back length, neck circumference, upper arm circumference, cuff circumference, waist circumference, shoulder angle, shoulder slant length, chest width, back width, pants length, hips, upper length, feet mouth circumference, abdomen circumference, hip height, hip circumference, thigh circumference, inner and outer leg length, front and back girth length, back girth inclination, height, knee circumference

TABLE II: COMPARISON OF FUTURE AND EXISTING INTELLIGENT PATTERN MAKING METHODS

Pattern-making methods	Fast pattern making	Professional experience	Special body	Tight clothing	Loose clothing	Multiple styles	Accuracy
2D pattern making	×	√	×	×	√	√	×
Pattern making by flatting of 3D body	√	√	×	√	×	×	×
The MC method	√	×	√	√	√	√	√

TABLE III: COMPARISON OF REAL AND VIRTUAL GARMENT PROTOTYPE

Category	Measurement methods	Speed	Cycle	Try-on mode	Modify sample	Cost	Mass customization
Traditional clothes	Manual measurement	slow	long	offline	slow	low	no
Virtual Garment	Smart Measurement	fast	short	online	fast	high	yes

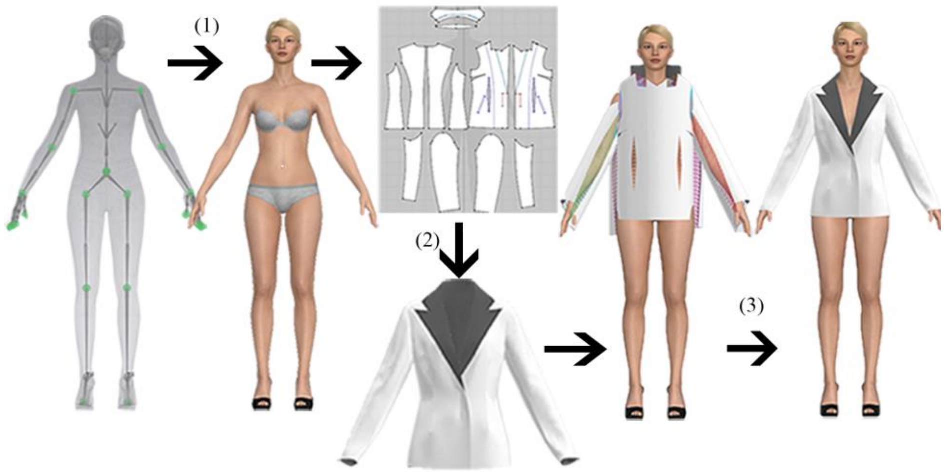
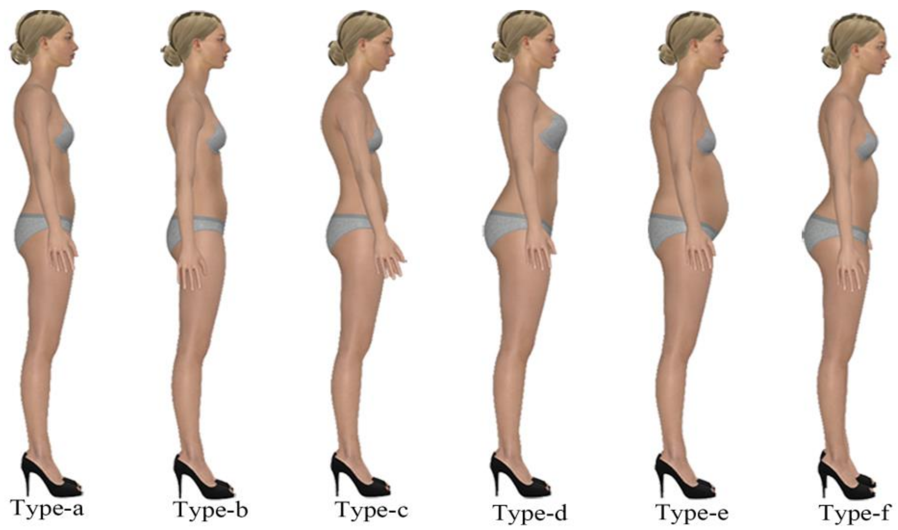


Fig. 3. The process of generate virtual garment prototype.



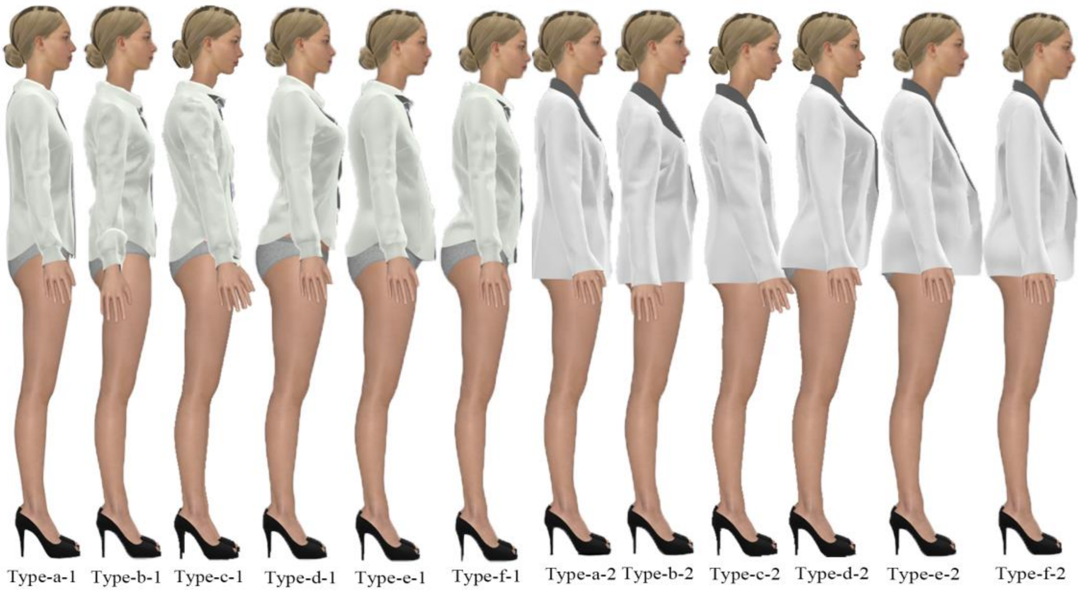
(a): Normal (b): Sloping shoulders (c): Humpback (d): Chest-up (e): Protruding belly (f): Convex hip

Fig. 4. The 6 different body types.

prototype costs lower and with much less time consuming. It can be tried on online and quickly modified. It can also evaluate the fit of virtual garment. The general process of the virtual garment prototype (1. establish a virtual model 2. patterns design 3. virtual try-on), as show in Fig. 3.

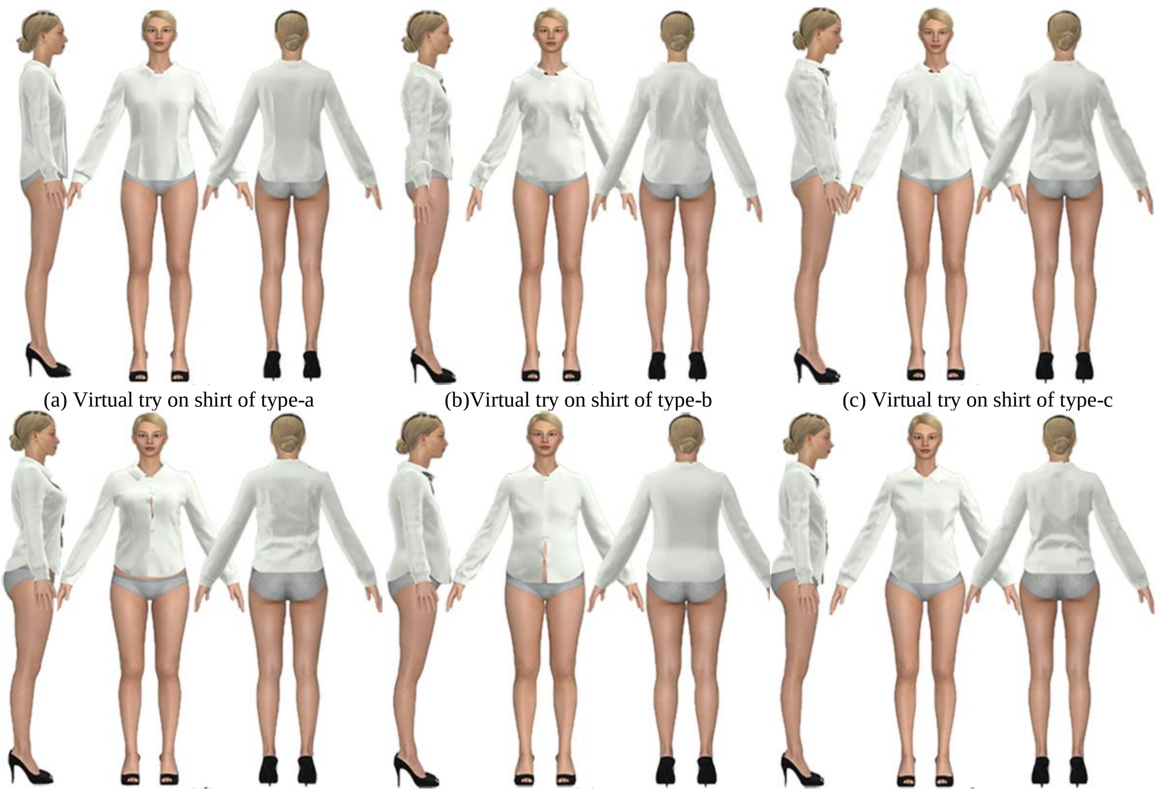
However, there are still many challenges of virtual garment prototype. The composition of the human body is very complex, making it difficult to build a virtual model that is the same as the real human body. Chen, Yin [20] used mathematical models to establish parametric human bodies. Yao, Li [21] used the point cloud reconstruction methods to realize the fully automatic modeling of the human body. Zhu Shuaiyin [22] obtained virtual human bodies from 2D images, which can be used in clothing customization. These research methods can only be applied to normal body types. There are still a lot of limitations in the study of different body types. In order to show the show different body types this paper modified the avatar of CLO 3D system[23]. Fig. 4 shows the six different body types commonly of human body. There are no strict standards for the establishment of different body types. Therefore, the research of virtual human body is still a technical difficulty of virtual prototyping.

Virtual garment with normal size rules is not suitable for special body types. The results of normal-size shirts and suits on 5 special body types are shown in Fig. 5. Type-a-1 represents virtual try-on shirt on Type-a. Sloping shoulders type (b-1, b-2): The shoulders lean forward and causing a gap in the shoulders. Increased chest folds lead to deformation of chest garments and longer sleeves. Humpback body type (c-1, c-2): The protruding back leads to looser chest. The length of the back garment becomes shorter and the length of the front garment increases. Chest-up body type (d-1, d-2): The protruding body of the human body causes the front chest of the garment to become tight and the front hem becomes shorter. Protruding belly type (e-1, e-2): The protruding belly leads to the protrusion of the front belly of the garment. The front hem of the virtual garment is shortened, and the back waist is wrinkled. Convex hip body type (f-1, f-2): The protruding buttocks of the human body cause the back piece to become shorter and the front piece to become longer. There are wrinkles at the back waist. The abdomen sticks out causing tightness at the front waist. Fig. 6 and Fig. 7 show the effect of fitting shirts of the same type on different body types. Existing clothing models are only suitable for Type-a body types, and are not suitable for the other 5 body types. According to the comparison of Fig. 6 and Fig. 7, the different body types cause the virtual garment prototype to be incompatible. Not only the virtual prototype needs to be revised on the model, but also different body types need to be studied. In addition, different fabrics have different effects on the fit of virtual garment prototype[24]. The authenticity of the fabric directly affects the authenticity of the virtual prototype. The performance of the fabric and the dynamic effect of the fabric must be considered.



(a) Shirt prototype on different body types (b) Suit prototype on different body types

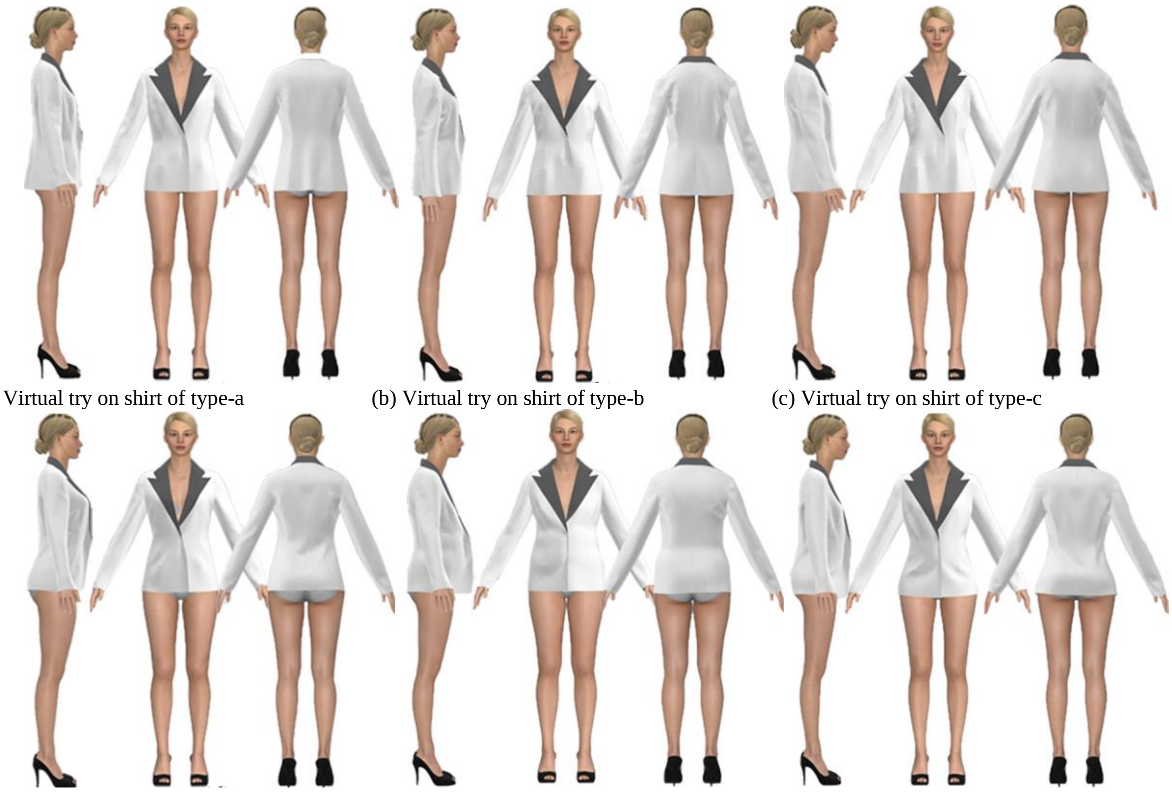
Fig. 5. The side view of virtual try-on shirt and suit of different body types



(a) Virtual try on shirt of type-a (b)Virtual try on shirt of type-b (c) Virtual try on shirt of type-c

(d) Virtual try on shirt of type-d (e) Virtual try on shirt of type-e (f) Virtual try on shirt of type-f

Fig. 6. Front, side and back virtual try-on of shirts on different body types

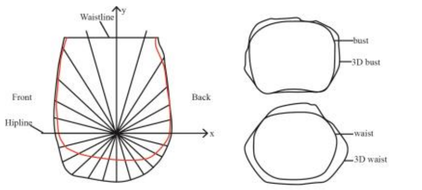
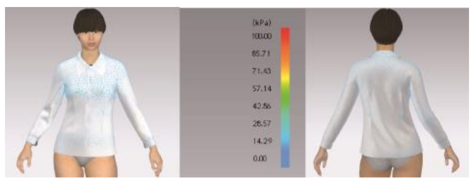


(a) Virtual try on shirt of type-a (b) Virtual try on shirt of type-b (c) Virtual try on shirt of type-c

(d) Virtual try on shirt of type-d (e) Virtual try on shirt of type-e (f) Virtual try on shirt of type-f

Fig. 7. Front, side and back virtual try-on of suits on different body types.

TABLE IV: THE EVALUATION OF VIRTUAL GARMENT PROTOTYPE METHODS

Methods	Category	Evaluation index	Method schematic diagram
loose volume	dress[24] shirt[25]	bust, waist	
	pants[26],[27]	waist, abdomen, hip, leg, knee circumference	
	suit[28]	bust, waist, abdomen, hip, shoulder	
pressure	sports top[29],[30]	chest, shoulder, upper chest, waist, abdomen, hip, collar and side stitches, princess line, intersection of front and back center lines, shoulder blade points	
	pants[31],[32],[33]	intersection of waist hip, high, knee, foot circumference and side stitches, front and back girdle lines, and wide lines	

To sum up, current technologies on virtual garment prototype could not generate intelligently personalized patterns and couldn't be applied to special body types. Therefore, virtual garment prototype should take either the authenticity of virtual models, patterns, and fabrics in consideration. It needs to develop a virtual garment prototype process standard and evaluate the fit of the virtual garment prototype. Virtual garment prototype technology should formulate virtual prototyping standards for special body types and apply to all types of clothing of all body types.

C. Evaluation of Virtual Garment Prototype

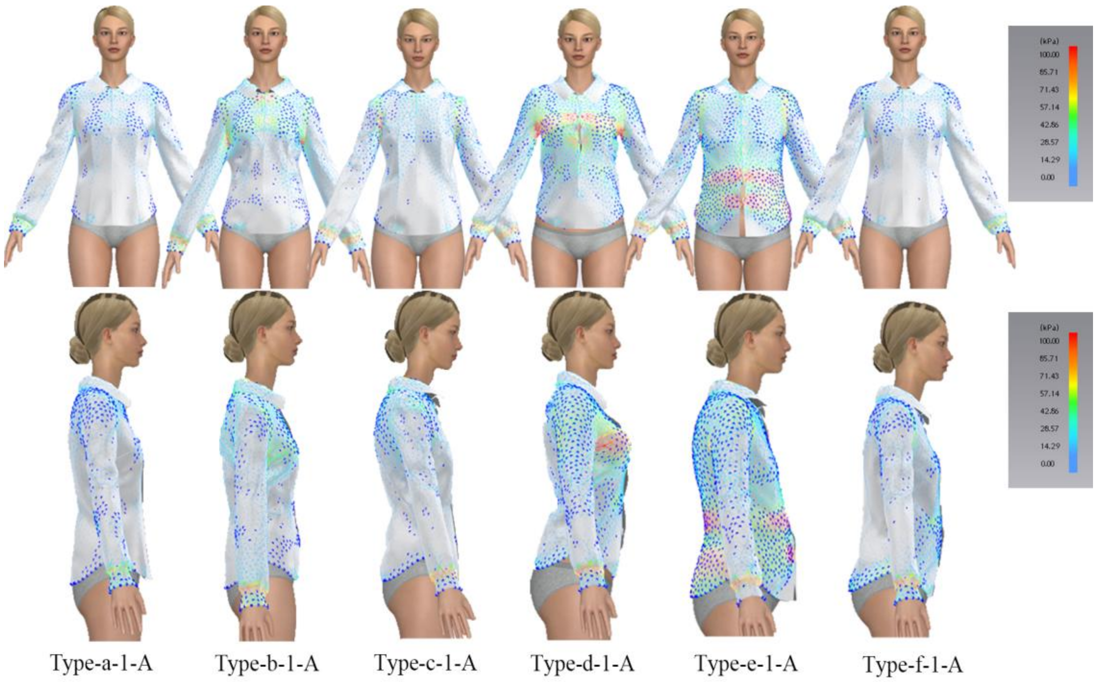
The fit evaluation of the virtual garment prototype can ensure the fit of the real garment. It will reduce the production cycle and cost of the garment. It is very important to conduct research on the fit evaluation of virtual garment prototype. Table IV shows the evaluation of virtual garment prototype methods.

1) Looseness methods

Looseness method is commonly used to assess fitness. A large number of researchers[26],[34] used the cross-section methods to measure ease distance, and used the looseness index to evaluate the fit. Gu, Bingfei[27] used the ease distance to establish a new curve of the crotch, obtaining a new trouser model to make the trousers fit. Zhang, Jun[35] compared the customization of shirts with vertical size and girth size. The shirts considered the vertical ratio are more fit. The fit of different body types was considered[36]. Therefore, the MC not only needs to consider the girth size, but also consider the proportional dimensions in the vertical direction. As an indicator of fit, the looseness method cannot evaluate all clothing, such as tight-fitting clothing. There is no looseness between people and clothing. The looseness methods cannot evaluate the fit.

2) Pressure methods

Fig. 8. Virtual clothing pressure points and pressure distribution



(a) On type-a (b) On type-b (c) On type-c (d) On type-d (e) On type-e (f) On type-f

Fig. 9. Pressure points and pressure distribution diagrams of shirts of different body types.

Fig. 8 shows the pressure point and pressure distribution of the virtual garment prototype. Researchers used pressure as a measure of fit. L,Silina [37] used the pressure sensor to measure the pressure value of the actual clothing fitting part to evaluate the fit. Abtew, Mulat Alubel[38] took 33 pressure points on the virtual pants, and judged whether they fit here by the fluctuation of the pressure value of the corresponding parts of the pressure points. Liu, Kaixuan[32] determined the 20 pressure point data of virtual pants to input the learning model, outputting the fit data evaluation. The pressure as an index for fit evaluation is more accurate than the looseness index. Fig. 9 shows the evaluation of the fit of the garment by pressure color and pressure point size. Type-a-1-A represents the pressure and pressure point distribution of virtual try-on shirt on type-a. In Fig. 9 (d) and (e), there is significant pressure on the chest and waist. In a special part, the pressure point is significantly increased, and it can be judged that it is not suitable, such as the back of Fig. 9 (c) and the buttocks of Fig. 9 (f). However, the selection and distribution of pressure points for different body types are different. The pressure method is not suitable for loose clothing. Therefore, the method of combining pressure and looseness can be used to objectively evaluate virtual garment prototype. It is necessary to objectively evaluate the fit of virtual garment prototype of special body types. The fit evaluation of the virtual garment prototype needs to be objectively quantified to apply more clothing styles. It can formulate evaluation standards and correction standards for all body types.

III. Discussion

According to the analysis of the key technology of MC, the existing customization system can customize standard body. The complex styles of garment cannot be customized. In addition, there is no personality for sportswear. The pattern-making could only generate patterns for type-A body, which is not suitable for all type of bodies and the generated pattern only for few categories of garment. The intelligent pattern-making for sportswear still have great gaps.

The curial step is to establish the digital garment prototype. In reality, the real garment prototype has been made and for evaluation the fitness and then modified and re-made the garment prototype until it achieves perfect fitting which has a long production cycle. Therefore, it is necessary to establish digital prototypes to achieve online try-on quickly. In experiments results as show in Fig. 5, the comparison of shirts and suits on the different body types for virtual try-on: the rules for making virtual garment prototype are also related to the clothing category and fabric. As show in Fig. 6 (a) and (b)-(f), virtual try on shirts of the same category for different body types. The key parts of virtual garment prototype production: chest, back, waist, abdomen, buttocks. Fig. 7 conducts online suit fitting analysis. Only Type-a can meet the digital garment prototype standard, and the other 5 body types are not. Therefore, digital garment prototype also needs to establish rules of different body types. Since there is no evaluation method for digital garment prototype. In this paper adopted virtual pressure analysis as one of the methods to evaluate the fitness. The experiment results Fig. 9 shows that higher pressure could be the potential unfitness part of garment. Fig. 9 shows the pressure distribution of special parts affects the fit of the virtual garment prototype. The virtual pressure distribution of clothing and the looseness methods combination on different body types can establish digital evaluation rules for mass customization. Table IV discusses that the loose volume and pressure method is the evaluation index of the virtual garment prototype. Therefore, it is necessary to establish a virtual evaluation criterion combining pressure and looseness. Through the experiment of virtual garment prototype, the production and evaluation rules of virtual garment prototype are established.

IV. Conclusions

The paper analyzes the key technologies of mass customization: intelligent pattern-making, virtual garment prototype and the evaluation of apparel fitness. Applied comparison of difference between traditional and virtual garment prototypes provided rules for intelligent pattern making. By the virtual garment prototype experiment, the rules of the virtual garment prototype are obtained: i) By establishing different types of digital human models to ensure the authenticity of virtual garment prototype. ii) Compare shirts and suits of different body types for virtual try-on. By analyzing the virtual effects of key parts: chest, back, waist, abdomen, buttocks, the authenticity of the virtual garment prototype clothes can be ensured from the fabrics and patterns. iii) Through virtual pressure experiments on shirts and suits of different body types, the pressure indicators are used to evaluate the fit of the virtual garment prototype. At the same time, the looseness and pressure are combined to establish the evaluation rules of the digital clothing prototype. The work of this paper on standard of generate digital garment prototype and establish evaluation rules on fitness of virtual garment prototype which have improve the intelligent customization and benefit the digital process of garment industry.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Qianqian Sun conducted experiments and data analysis. Xiaodong Sun had the initial idea of this paper and guided Qianqian Sun. Qianqian Sun wrote this paper; all authors approved the final version.

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