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1 Parametric design of garment pattern based on body 2 dimensions

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8 **Abstract**

9 Garment pattern-making is one of the most important parts in fashion design and production. However,
10 the traditional pattern-making is an experience based work and very time-consuming. In this paper, we proposed
11 a parametric design method of garment pattern based on body dimensions. Based on this method, we constructed
12 a jeans' pattern recommendation system. The input items of the proposed system are three geometric constraint
13 parameters (jean silhouette type, length and waist height) and three-dimensional constraint parameters (human
14 body stature, waist girth and hip girth); the output of the proposed system are jeans' patterns. Also, four
15 adjustable parameters (jeans' length, waist height, knee and leg opening) are designed to adjust patterns
16 generated by the proposed system. If the jeans' pattern is not satisfying after virtual or real try-on, the adjustable
17 input parameters of the proposed system can be applied for adjustment until the patterns are acceptable. Our
18 proposed system can combine traditional pattern-making methods to generate jeans' patterns automatically and
19 rapidly, hence improving pattern-making efficiency significantly.

20 **Keywords**

21 Body dimensions; Pattern-making; Parametric design; CAD; Knowledge modeling, Anthropometric
22 measurement

23 **Highlight**

- 24 1. Human body dimensions and jean style are both integrated into jean pattern-making.
 - 25 2. Jeans' patterns are constrained and adjustable by different parameters.
 - 26 3. Our system can generate garment patterns rapidly and automatically.
- 27

28 **1. Introduction**

29 In the clothing industry, customers' individual needs have become increasingly emphasized and changing
30 over time. This is partly due to the development of economies, and societies, and the advance from cottage
31 industry type, to Mass production and Made to Measure (MTM), to mass customization (Kamalha, Zeng,
32 Mwasiagi, and Kyatuheire, 2013; Satam, Liu, and Lee, 2011; Zhang, Luximon, Pattanayak, and Zhang, 2012).
33 However, the sophistication in consumers' demands and fast fashion result in increased difficulty in clothing
34 making. Mass customization, a hybrid of Mass production and Made to Measure (Yang, Zhang, and Shan,
35 2007), has become a trend in clothing industry; integrating the efficiency and personalized service excellence
36 of the two production modes (Cho et al., 2006; Li, Lu, Liu, Liu, and Wang, 2013; Yang et al., 2007). The
37 emergence of mass customization raises new demands for pattern-making; faster and more fitting. However,
38 faster and more fitting are contradictory targets to be achieved by traditional pattern-making methods.

1 Pattern-making is one of the most critical and technical elements in clothing design and manufacturing
2 (Liu, Wang, Zhu, and Hong, 2016; Liu, Zeng, Bruniaux, et al., 2018). The speed of pattern-making is crucial
3 for efficiency gains. At present, there are two methods to make garment pattern: hand making and computer-
4 aided making. Both the two methods require sophisticated skills. Moreover, the traditional pattern-making
5 method has two shortcomings: one is that the pattern-making process is quite time-consuming and limits the
6 improvement of production efficiency; the other is that this technique is difficult to spread. For a beginner, it
7 takes a long time to study, three to five years just to get in the door as a pattern maker, and at least ten years of
8 mastery. In order to enhance the pattern-making speed, pattern makers develop patterns for a standard body
9 type size and use grading technology to obtain other body type sizes (Cho et al., 2006). Due to the differences
10 in the body measurements, this technology doesn't fit the body well. This is why consumers usually complain
11 that they can't find firm-fitting garments (Liu, Wang, and Hong, 2017; Liu, Zeng, et al., 2017). Currently, MTM
12 can solve the fitting issues; nevertheless, this method results in high manpower cost.

13 In order to solve fitting issues, many scholars used 3D-to-2D flatten technology to develop garment
14 patterns (Liu, Kamalha, Wang, and Agrawal, 2016; Liu, Wang, Zhu, et al., 2016; Liu, Zeng, Bruniaux, et al.,
15 2018). However, this method has four shortages: the first is that this method is only suitable for simple styles,
16 and not suitable for complicated styles; secondly, the ease allowances between the human body and clothing
17 are not determined accurately; the third is that the fabric properties are rarely considered in the flattening
18 process; the fourth is that this method is quite time-consuming and not suitable for industrial production. As
19 such, there's been less progress on this approach and rarely implemented into practical production.

20 Some scholars proposed parametric pattern design methods to develop garment patterns and fashion
21 sketches rapidly (Kim, 2012; Liu, Zeng, Tao, and Bruniaux, 2019; Liu, Zeng, Wang, et al., 2018). However,
22 there has been less progress on this aspect and rarely implemented into practical production. The two main
23 reasons are: firstly, these studies are only for a fixed clothing style, rather than a series of clothing styles.
24 However, one style cannot meet the market demand. The second is that they lack a feedback in the parametric
25 process. For example, if a client is not satisfied with the garment, there is no approach to adjust the result to
26 meet the client's different requirements.

27 In order to solve the issues in parametric pattern design, we proposed a novel parametric pattern-making
28 model. The proposed method can generate patterns rapidly and automatically according to different jean styles.
29 If a user is dissatisfied by the result, it has a feedback to modify the pattern until the pattern fits the body well.
30 The construction of this model mainly involves three steps. Firstly, we carried out a program of anthropometric
31 measurements. We randomly selected 116 young women aged 20-30 years from the Northeast area of China.
32 Secondly, we applied factor analysis, regression analysis and design knowledge to acquire the linear relations
33 between human body stature, hip girth, waist girth and other body dimensions. Finally, a series of parametric
34 models was built according to these linear equations. Finally, some parameters were set in the models to modify
35 patterns to fit body according to client's feedback information.

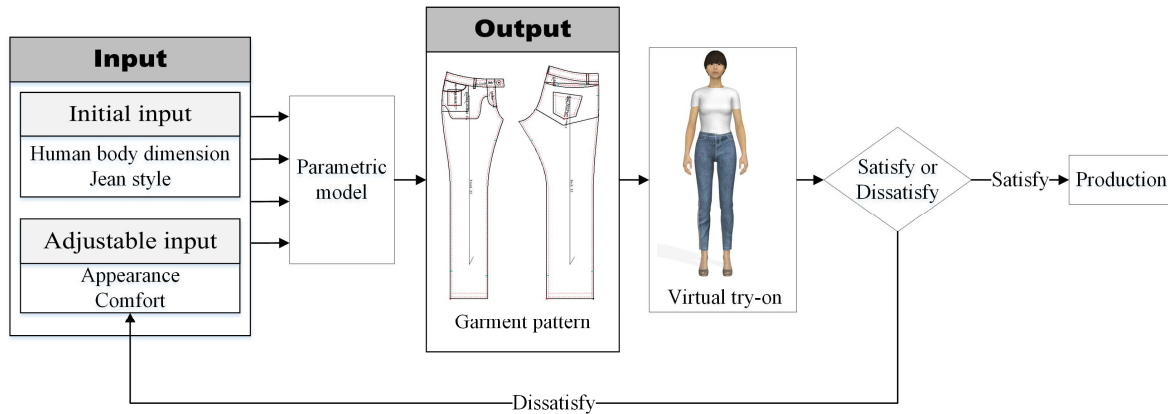
36 We selected jeans as the research focus mainly due to the universal prevalence of jeans use all over the
37 world. Sure, our method is not limited to jeans, it can be applied in other fashion styles. This article was
38 organized as follows: section 2 presented the general scheme of jeans' pattern recommendation system; section
39 3 discussed how to construct the proposed system using the parametric design method; section 4 introduced the
40 application and validation of the proposed system; finally, some conclusions and possible further works were
41 presented in section 5.

42 **2. General scheme of jeans' pattern recommendation system**

1 2.1. Construction of jeans' pattern recommendation system

2 The construction of jeans' pattern recommendation system is described in Fig. 1. It consists of four parts:
3 initial input part, adjustable input part, parametric model part and output part. Its basic steps are as follows:

- 4 ◇ Designing the initial input parameters of the proposed system.
- 5 ◇ Designing the adjustable input parameters of the proposed system.
- 6 ◇ Modeling the relations between jeans' patterns and initial input parameters.
- 7 ◇ Modeling the relations between jeans' patterns and adjustable input parameters.
- 8 ◇ Developing an application according to the above models to generate garment patterns automatically.



9
10 **Fig. 1.** General scheme of jeans' pattern recommendation system.

11 2.2 Basic function of jeans' pattern recommendation system

12 The basic functions of jeans' pattern recommendation system are described in Fig. 1. Its basic functions
13 are given below. A user inputs his body dimensions and selects jean style. Using our parametric model, the
14 proposed system can generate garment patterns automatically. Next is to adjust the 3D human body model
15 according to the user's body dimensions. Then, the patterns are assembled on the adjusted virtual avatar using
16 virtual try-on technology. The user then evaluates the virtual garment. If the result is satisfactory, then the
17 garment is produced; otherwise, the patterns are adjusted using adjustable parameters until it meets
18 requirements.

19 **3. Methodology**

20 3.1 Acquisition of initial input parameters and adjustable input parameters

21 3.1.1. Graphics constraints of the jeans' patterns

22 From the perspective of graphics, graphics constraints are divided into two categories: dimensional and
23 geometric constraint (Xiu, Wan, and Cao, 2011). As shown in Fig. 2 (a), the patterns of bell-bottom jeans and
24 pencil jeans have different geometric shapes, so are geometrically constrained. The two pairs of bell-bottom
25 jeans in Fig. 2 (b) being different in form of dimensions; therefore, are dimensionally constrained. These two
26 types of constraints can finally fix the shape of jeans' patterns. It is necessary to establish geometric constraint
27 parameters and dimensional constraint parameters for jeans' patterns. For jeans' patterns, the geometric
28 constraint is style, and dimensional constraints are pattern dimensions.

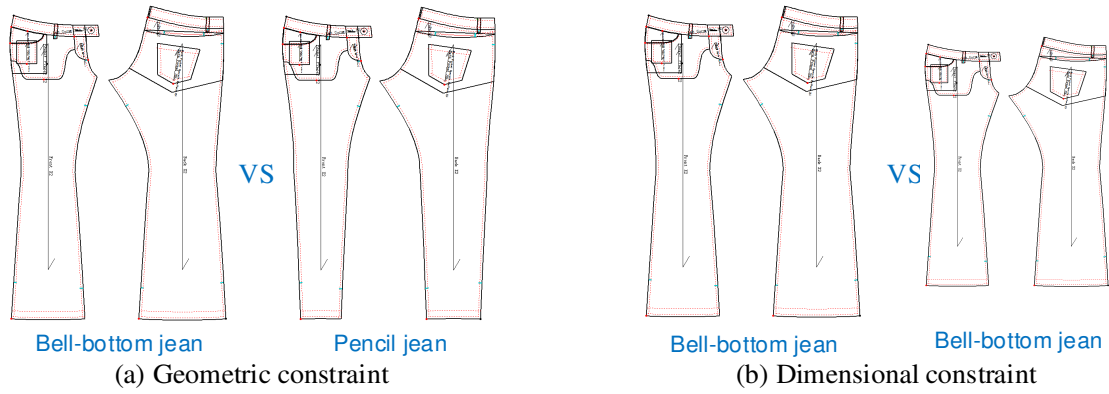


Fig. 2. Geometric constraint and dimensional constraint.

3.1.2 Definition of geometric constraint parameters

Two steps of questionnaire surveys were carried out to extract jean classification criteria (geometric constraint parameters). In the first stage, 20 fashion designers were surveyed to collect influencing factors for jeans styles. The 20 fashion designers are familiar with the design of women's jeans in the 20-30 age group. The first-stage survey results showed that jeans style mainly depends on three factors, i.e., silhouette, length and waist height type (Fig. 3). We defined the three factors as three parameters. Thereafter, based on the results, the three parameters were further subdivided through a second survey of 20 fashion designers. The subdivision results in Fig. 3 were selected as the initial input items of the proposed recommendation system in Fig. 1.

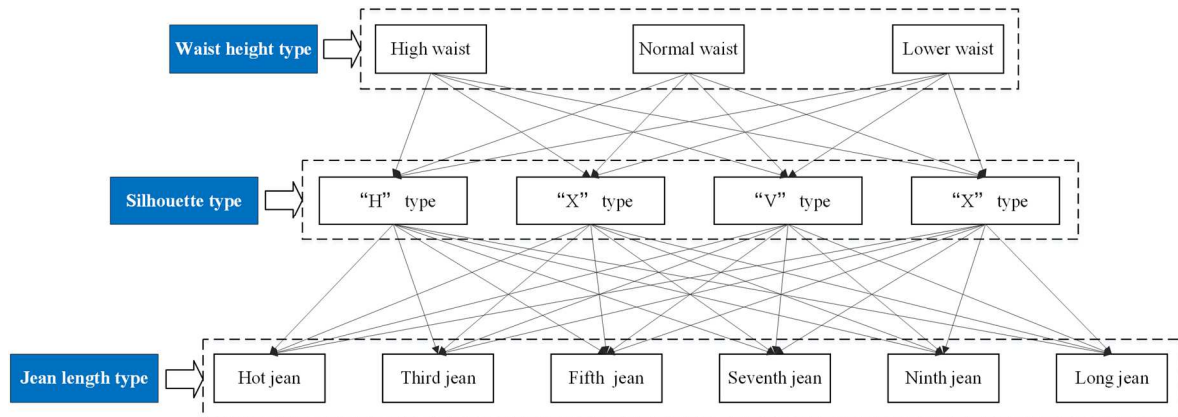


Fig. 3. Jean style classification.

3.1.3 Definition of dimensional constraint parameters

If we want to make patterns for jeans, every jean's part dimension should be established. However, jeans' patterns consist of many curves. Each curve's dimension is a kind of dimensional constraint. Too many dimensional constraints complicate pattern-making. In order to simplify pattern-making, we should use a few key dimensional constraint parameters to represent other secondary dimensional constraints parameters. Research has showed that all dimensions of pants in the height direction can be represented by stature and in the girth direction, can be represented by hip girth and waist girth (Liu, Wang, Kamalha, Li, and Zeng, 2017; Liu, Wang, Zeng, et al., 2016). Thus, the stature, hip girth and waist girth were selected as the initial input items of the proposed recommendation system in Fig. 1.

3.1.4 Acquisition of adjustable input parameters of jeans' pattern recommendation system

1 Currently, the parametric design of garment patterns only focus on how to make patterns rapidly (Xiu et
 2 al., 2011). However, there is no means to modify the pattern if the consumer is not satisfied with the jeans. For
 3 example, if the jean is too long or the leg opening is too wide, how to modify? In this research, adjustable input
 4 parameters are designed to adjust patterns, which do not meet satisfaction after try-on, by the wearer. Through
 5 questionnaire survey, we established that consumers' dissatisfaction usually focuses on two aspects: appearance
 6 dissatisfaction and comfort dissatisfaction. The appearance dissatisfaction contains four factors: jeans' length,
 7 waist height type, leg opening girth and knee girth; and the comfort dissatisfaction contains four factors: waist
 8 girth, hip girth and crotch width. Thus, these seven factors were selected as seven adjustable input parameters
 9 for pattern adjustment in case of need.

10 Finally, through the above analysis, three geometric constraint parameters (jean waist height type,
 11 silhouette and length type) and three-dimensional constraint parameters (human stature, hip girth and waist
 12 girth) were selected as the initial input parameters to construct the proposed system. Jeans' length, waist height,
 13 leg opening girth, knee girth, waist girth, hip girth and crotch width were selected as the adjustable parameters
 14 to construct the proposed system.

15 3.2 Modeling the relations between geometric constraint parameters and jeans dimensions

16 In the previous section, we designed the input parameters for jeans' pattern recommendation system. In
 17 this section, we model the relations between input parameters and jeans' pattern dimensions.

18 3.2.1 Modeling the relations between jean waist parameter and jeans' pattern dimensions

19 As shown in Fig. 4, the high waist, normal waist and low waist jeans' waist lines correspond with the
 20 human body waist line, lower waist line and abdomen line respectively. The lower waist line is about at the
 21 middle of the human body waist line and abdomen line. Different jeans' waist types mainly influence the parts
 22 above crotch depth line and do not influence the parts below it (Fig. 4). Thus, drop of waist-to-hip and crotch
 23 depth are involved in waist design; and they are two key dimensions for pattern-making of bottoms. According
 24 to the relations between jeans and the human body in Fig. 4, jeans' drop of waist-to-hip and crotch depth are
 25 defined as follows:

$$DWH_j = DWH_h + f_{DWA}(p_{waist}) \quad (1)$$

$$CD_j = CD_h + f_{DWA}(p_{waist}) \quad (2)$$

$$f_{DWA}(p_{waist}) = \begin{cases} 0 & p_{waist} = \text{high waist} \\ -DWA_h/2 & p_{waist} = \text{normal waist} \\ -DWA_h & p_{waist} = \text{low waist} \end{cases} \quad (3)$$

26 Where,

27 DWH_j is jeans' drop of waist-to-hip;

28 DWH_h is human body's drop of waist-to-hip;

29 CD_j is jeans' crotch depth;

30 CD_h is human body's crotch depth;

31 DWA_h is human body's drop of waist-to-abdomen;

32 p_{waist} is the parameter of waist height; it includes three values: high, normal and low waist (refer to Fig. 4).

33 Definitions (1), (2) and (3) are used for the parametric design of jean waist types.



1

2 **Fig. 4.** Jean waist design. (WH_h is human body waist height; CD_h is human body crotch depth; DWH_h is
3 human body drop of waist-to-hip; DWA_h is human body drop of waist-to-abdomen.)

4 3.2.2 Modeling the relations between jeans' silhouette parameter and jeans' pattern dimensions



5

6 **Fig. 5.** Jeans' silhouette design.

7 As shown in Fig. 5, the area between waist line and crotch depth line is the fit-zone; and the area below
8 the crotch depth line is the design-zone. Jeans should fit the body well in the fit-zone; meanwhile, designers can
9 design various jeans in this zone. Thus, jean styles' characteristics mainly depend on the part below crotch depth
10 line. Different jeans' silhouettes mainly influence the parts below crotch depth line and do not influence the
11 parts above it (Fig. 5). Thus, knee girth and leg opening girth are involved in silhouette design; and they are
12 two key dimensions for pattern-making of bottoms. According to the relations among the four silhouette types
13 in Fig. 5, jeans' knee girth and leg opening girth are defined as follows:

$$K_j = a(H_h + e_h) + f_k(p_{silhouette}) \quad (4)$$

$$LO_j = a(H_h + e_h) + f_{LO}(p_{silhouette}) \quad (5)$$

$$f_k(p_{silhouette}) = \begin{cases} 0 & p_{silhouette} = "V" \\ 0 & p_{silhouette} = "H" \\ \text{depend on the value of } LO_j & p_{silhouette} = "X" \\ \text{depend on the value of } LO_j & p_{silhouette} = "A" \end{cases} \quad (6)$$

$$f_{LO}(p_{silhouette}) = \begin{cases} -\alpha & p_{silhouette} = "V" \\ 0 & p_{silhouette} = "H" \\ \beta & p_{silhouette} = "X" \\ \gamma & p_{silhouette} = "A" \end{cases} \quad (7)$$

1 Where,

2 K_j is jeans' knee girth;

3 LO_j is jeans' leg opening girth;

4 H_h is human body hip girth;

5 e_h is Ease allowance at hip; its value depends on the design requirement.

6 a is a coefficient; its value depends on the ratio of knee -to-hip girth;

7 α , β and γ are positive constants, whose values are given by the designer.

8 $p_{silhouette}$ is a silhouette parameter, which includes four values: "A" type, "V" type, "X" type and "A" type
9 (refer to Fig. 5);

10 Definitions (4), (5), (6) and (7) are used for jeans' silhouette parametric design.

11 3.2.3 Modeling the relations between jeans' length parameters and jeans' dimensions

12 As shown in Fig. 6, for the hot length style, the length line in the style figure is usually d cm below crotch
13 depth line. The fifth jean's length line overlaps with the human body's knee line. The long jean's length line
14 overlaps with the human body heel line. The third jean's length line is in the middle of hot jean's length line
15 and the fifth jean's length. The seventh and ninth jean's lines are the trisections between human body knee line
16 and heel line. According to the relations between jeans and human body in Fig. 6, jeans' lengths are defined as
17 follows:

$$JL = CD_j + f_{JL}(p_{length}) \quad (8)$$

18 Where,

19 JL is jeans' length;

20 CD_j is jeans' crotch depth;

21 p_{length} is the parameter of jeans' length design; it includes six values: hot, third, fifth, seventh, ninth and long
22 (refer to Fig. 6).

23 Then, substituting Eq. (3) into Eq. (9), we obtain Eq. (3) as follows:

$$JL = DWH_h + f_{DWA}(p_{waist}) + f_{JL}(p_{length}) \quad (9)$$

$$f_{JL}(p_{length}) = \begin{cases} d & p_{length} = hot \\ d + (LL_h - d - KH_h)/2 & p_{length} = third \\ LL_h - KH_h & p_{length} = fifth \\ LL_h - 2/3 \times KH_h & p_{length} = seventh \\ LL_h - 1/3 \times KH_h & p_{length} = ninth \\ LL_h & p_{length} = long \end{cases} \quad (10)$$

24 Where,

25 JL is jeans' length;

26 DWH_h is human body's drop of waist-to-hip;

27 p_{waist} is the parameter of waist design; it includes three values: high, normal and low waist (refer to Fig. 3);

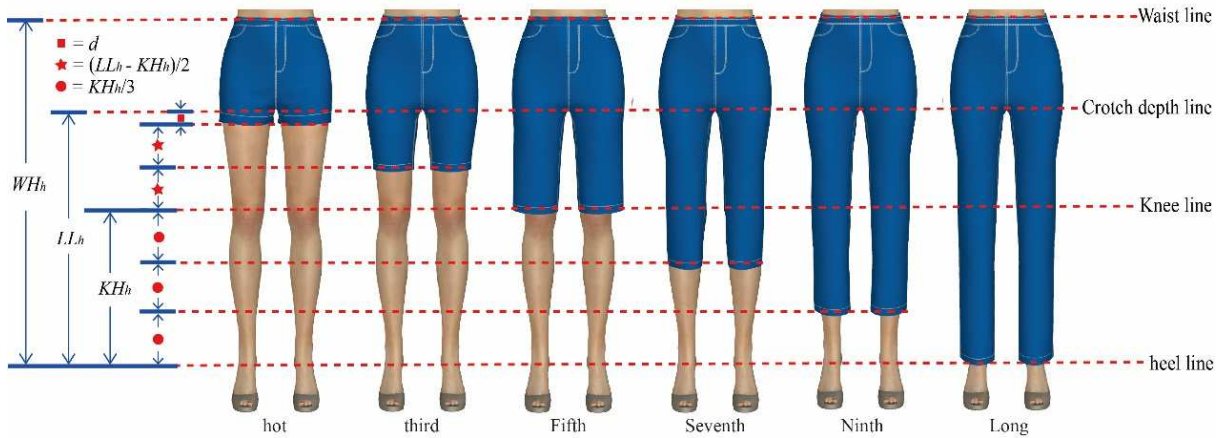
28 p_{length} is the parameter of jeans' length design; it includes six values: hot, third, fifth, seventh, ninth and long
29 (refer to Fig. 6);

30 LL_h is human body leg length;

31 KH_h is human body knee height;

32 d is a positive constant given by the designer.

1 Definitions (8), (9) and (10) are used for the parametric design of jeans' length.

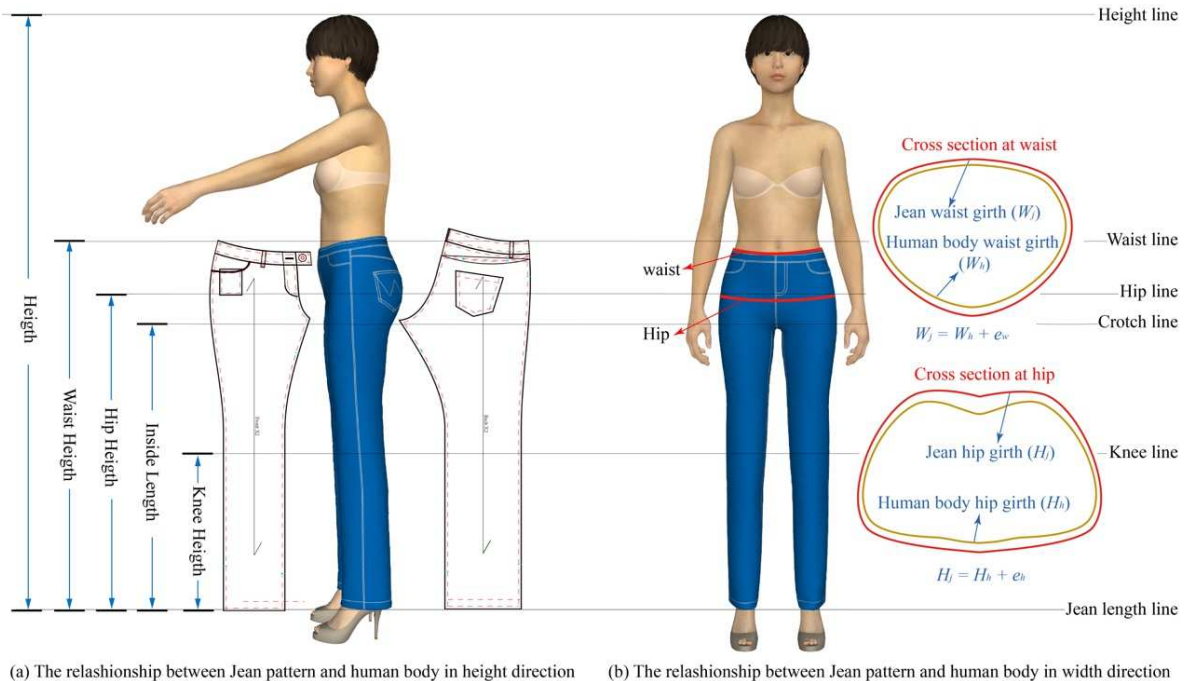


2
3 **Fig. 6.** Jeans' length design. (Note: The jeans refer to height waist type's jeans. WH_h is human body Waist
4 Height. LL_h is human body Leg Length. KH_h is human body Knee Height.).

5 **3.3 Modeling the relations between dimensional constraint parameters and human body dimensions**

6 In our previous analysis, jeans' shape is constrained by geometric constraints and dimensions constraints;
7 and we modeled the relations between geometric constraint parameters and jeans' pattern dimensions. In the
8 following sections, we model the relations between dimensional constraint parameters and human body
9 dimensions. Thus, all dimensions of jeans' patterns can be represented using several key human body
10 dimensional parameters (hip, waist and stature).

11 **3.3.1 Relations between human body and jeans' pattern**



12 (a) The relationship between Jean pattern and human body in height direction (b) The relationship between Jean pattern and human body in width direction
13 **Fig. 7.** Relations between jean pattern's dimensions and human anthropometric measurements in width
14 direction. (Note: W_j is jean Waist Girth; W_h is human body Waist Girth. H_j is jean Hip Girth; H_h is human
15 body Hip Girth. e_w is ease allowance at waist; e_h is ease allowance at hip; e_k is ease allowance at knee.).

16 As shown in Fig. 7, jeans' patterns' dimensions have a one-to-one relation with human body dimensions
17 in the height direction; jeans' pattern dimensions are equal to corresponding human body girths plus ease

1 allowance in girth direction. For example, human knee height corresponds to jean knee height (Fig. 7 (a)); jean
 2 hip girth is equal to human body hip girth plus ease allowance (Fig. 7 (b)). Thus, we can measure human body
 3 dimensions, and use these dimensions to make patterns. However, it is very time-consuming to measure all the
 4 related-pattern-making dimensions. In order to simplify pattern-making process, it is necessary to use several
 5 key dimensions to represent other secondary dimensions. In our previous analysis, we selected stature and hip
 6 as the key parameters to represent other height direction dimensions and girth direction dimensions respectively.
 7 As linear models are widely applied in the garment pattern-making (Xiu et al., 2011), we selected a linear model
 8 to construct the relations between stature, hip girth and other human body dimensions in the following sections.

9 3.3.2 Modeling the relations between human stature parameter and other dimensions in height direction.

$$WH_h = a_1 * ST + b_1 \quad (11)$$

$$HH_h = a_2 * ST + b_2 \quad (12)$$

$$LL_h = a_3 * ST + b_3 \quad (13)$$

$$KH_h = a_4 * ST + b_4 \quad (14)$$

10 Where,

11 ST is human body stature;

12 WH_h is human body waist height;

13 HH_h is human body hip height;

14 LL_h is human body leg length;

15 KH_h is human body Knee height;

16 a_1 is regression coefficient between stature and human body waist height;

17 a_2 is regression coefficient between stature and human body hip height;

18 a_3 is regression coefficient between stature and human body leg length;

19 a_4 is regression coefficient between stature and human body knee height;

20 b_1 is constant term of regression equation the between stature and human body waist height;

21 b_2 is constant term of regression equation the between stature and human body hip height;

22 b_3 is constant term of regression equation the between stature and human body leg length;

23 b_4 is constant term of regression equation the between stature and human body knee height;

24 Equations (11),(12),(13) and (14) construct the linear regression relations between stature and waist height,
 25 hip height, leg length, and knee height. Other dimensions related to jeans' pattern-making in height direction
 26 can also be represented by stature. For example, the drop of waist-to-hip is equal to waist height minus hip
 27 height; crotch depth is equal to waist height minus leg length, etc. Finally, all dimensions of jeans' pattern in
 28 height direction can be represented by stature parameter through these regression equations like Equations
 29 (11),(12),(13) and (14).

30 3.3.3 Modeling the relations between human hip parameter and other dimensions in girth direction.

31 According to the analysis in Fig. 7 (b), the relations between human body and jeans are as follows:

$$W_j = W_h + e_w \quad (15)$$

$$H_j = H_h + e_h \quad (16)$$

32 Where,

33 W_j is jeans' Waist girth;

34 W_h is human body Waist girth;

35 H_j is jeans' Hip girth;

1 W_h is human body Waist girth;
 2 e_w is Ease allowance at waist; its value depends on the design requirement;
 3 e_h is Ease allowance at hip; its value depends on the design requirement.

4 Human body hip girths are highly correlated to other girth direction dimensions (Liu, Wang, Kamalha, et
 5 al., 2017; Liu, Wang, Zeng, et al., 2016). Thus, the girth direction dimensions can be represented by hip girth
 6 using linear regression.

$$K_j = aH_j \Rightarrow K_j = a(H_h + e_h) \quad (17)$$

7 Where,
 8 K_j is jeans' Knee girth;
 9 H_j is jeans' Hip girth;
 10 H_h is human body Hip girth;
 11 e_h is Ease allowance at hip; its value depends on the design requirement.

12 Finally, all dimensions of jeans' patterns in girth direction are represented by hip girth using unary linear
 13 regression equation like Equation (17).

14 3.4 Modeling the relations between adjustable parameters and jeans' pattern dimensions.

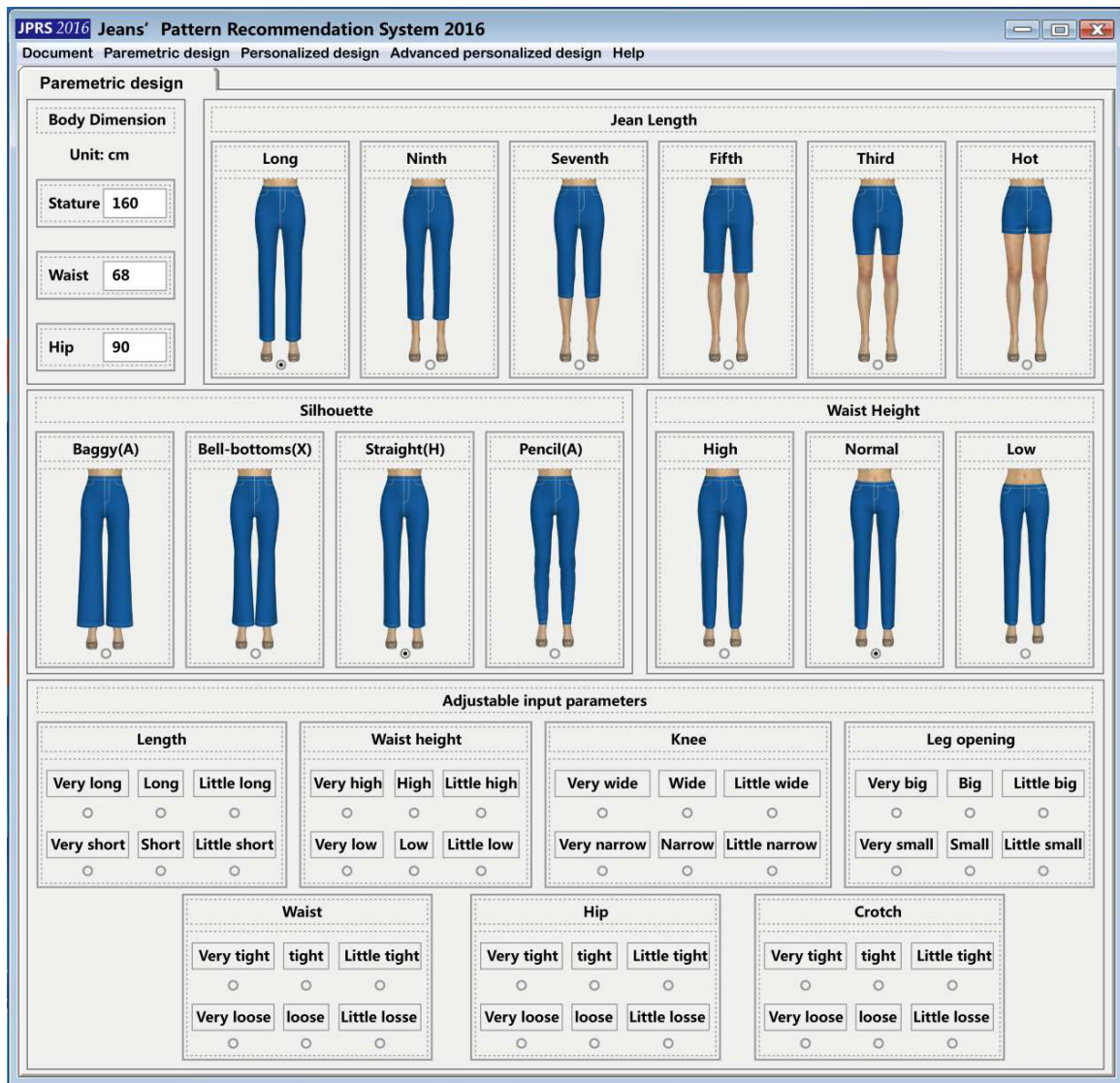
15 The adjustable parameters are used for adjusting jeans' patterns with which are the consumer is dissatisfied
 16 following a virtual or real try-on. For example, if a consumer feels the jean is too long through try-on, we can
 17 adjust the length parameters to shorten the jeans' length. In our previous analysis, jeans' length, waist height
 18 type, leg opening girth and knee girth are selected as the adjustable parameters to construct the proposed system.
 19 Thus, we classified dissatisfaction for each part into six degrees on a scale and pattern modification rules are
 20 shown in Table 1.

21 **Table 1** Pattern modification rules.

Adjustable type	Modification Parts	IF	THEN
Appearance adjustment	Length	Very long	Decreasing 3 ω % in length
		Long	Decreasing 2 ω % in length
		Little long	Decreasing ω % in length
		Little short	Increasing ω % in length
		Short	Increasing 2 ω % in length
		Very short	Increasing 3 ω % in length
	Waist height	Very high	Decreasing 3 ω % in waist height
		High	Decreasing 2 ω % in waist height
		Little high	Decreasing ω % in waist height
		Little low	Increasing ω % in waist height
		Low	Increasing 2 ω % in waist height
		Very low	Increasing 3 ω % in waist height
	Knee	Very wide	Decreasing 3 ω % in knee
		Wide	Decreasing 2 ω % in knee
		Little wide	Decreasing ω % in knee
		Little narrow	Increasing ω % in knee
		Narrow	Increasing 2 ω % in knee
		Very narrow	Increasing 3 ω % in knee
	Leg opening	Very big	Decreasing 3 ω % in leg opening
		Big	Decreasing 2 ω % in leg opening
Little big		Decreasing ω % in leg opening	
Little small		Increasing ω % in leg opening	
Small		Increasing 2 ω % in leg opening	
Very small		Increasing 3 ω % in leg opening	
Comfort adjustment	Waist	Very tight	Decreasing 3 ω % in waist girth
		Tight	Decreasing 2 ω % in waist girth
		Little tight	Decreasing ω % in waist girth

	Little loose	Increasing $\omega\%$ in waist girth
	Loose	Increasing $2\omega\%$ in waist girth
	Very loose	Increasing $3\omega\%$ in waist girth
Hip	Very tight	Decreasing $3\omega\%$ in hip girth
	Tight	Decreasing $2\omega\%$ in hip girth
	Little tight	Decreasing $\omega\%$ in hip girth
	Little loose	Increasing $\omega\%$ in hip girth
	Loose	Increasing $2\omega\%$ in hip girth
	Very loose	Increasing $3\omega\%$ in hip girth
Crotch	Very tight	Decreasing $3\omega\%$ in crotch width
	Tight	Decreasing $2\omega\%$ in crotch width
	Little tight	Decreasing $\omega\%$ in crotch width
	Little loose	Increasing $\omega\%$ in crotch width
	Loose	Increasing $2\omega\%$ in crotch width
	Very loose	Increasing $3\omega\%$ in crotch width

1 Note: ω is an adjustable parameter. It can be adjusted according to the customer's perception of the length
 2 and tightness of the garment. Its value defaults to 10 in our software.



3
 4 Fig. 8. Interactive interface of jeans pattern recommendation system 2016.

5 **4. Application and validation of jeans' patterns parametric design**

6 *4.1 Application of jeans' pattern parametric design*

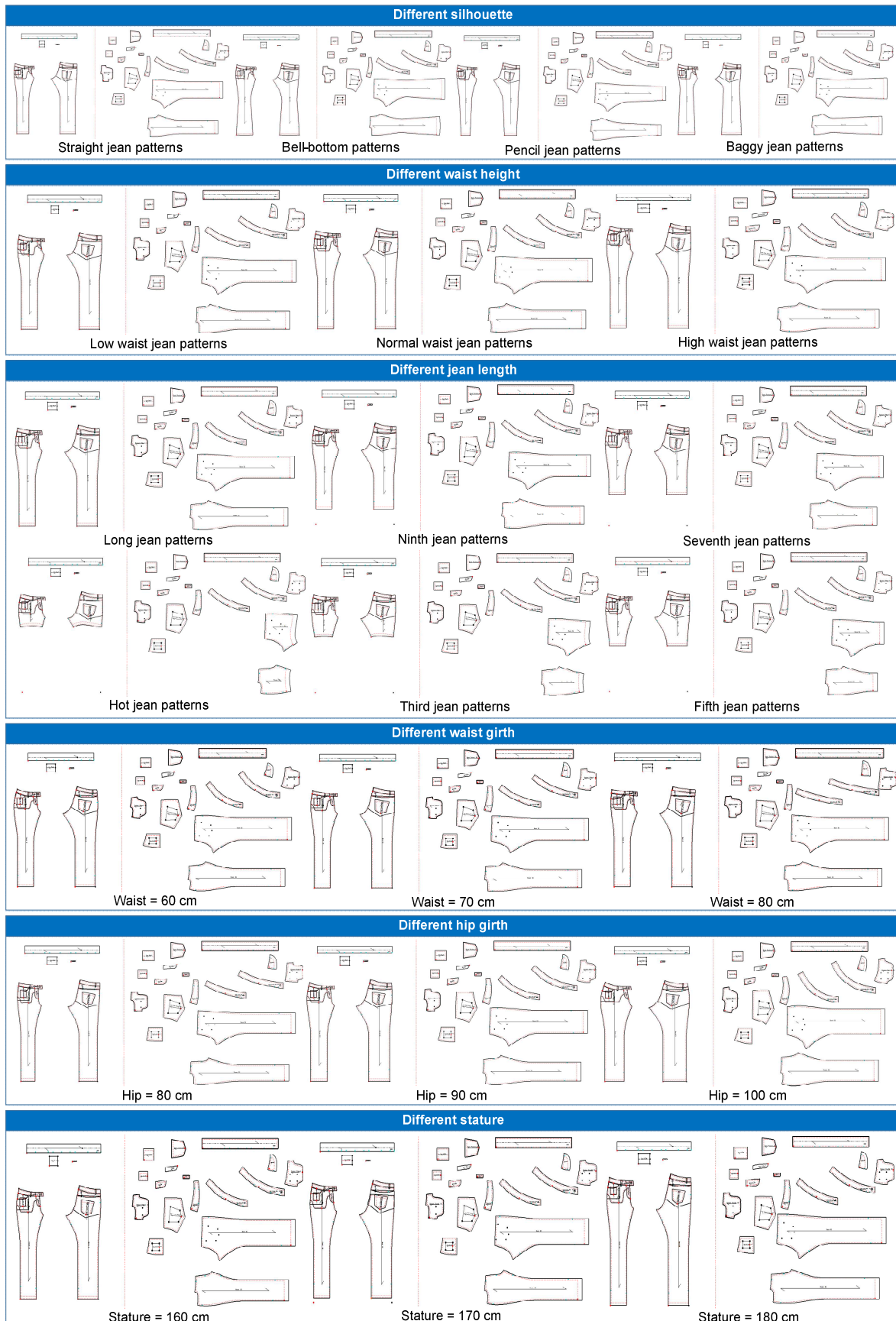


Fig. 9. Examples of different styles and dimensions' patterns are generated by our proposed system.

In order to realize the proposed system, a data collection of anthropometric measurement, which were involved in 120 young women in northeast area of China, was conducted to calculate regression coefficients a_1 , a_2 , a_3 , a_4 and constant terms b_1 , b_2 , b_3 , b_4 in Equations (11),(12),(13) and (14). An application

1 named jeans' pattern recommendation system 2016 (JPRS 2016) was developed according to formula (1), (2),
 2 ..., (17) and modification rules in Table 1 using visual basic computer language (Fig. 8). In the proposed system,
 3 the default values of a , α , β , γ , e_h , e_w , ω , a_1 , a_2 , a_3 , a_4 , b_1 , b_2 , b_3 and b_4 are shown in Table 2.
 4 If fashion designers are not satisfied with the patterns by these defaults, they can adjust them until they are
 5 satisfied. As shown in Fig. 8, three geometric constraint parameters (jeans silhouette type, length and waist
 6 height) and three-dimensional constraint parameters (human body stature, waist girth and hip girth) are designed
 7 as the initial input items; and four adjustable parameters (jeans' length, waist height, knee and leg opening)
 8 are designed as the adjustable parameters. By inputting human body dimensions and a selected style, this system
 9 can generate jeans' patterns automatically. If the jeans' pattern is not satisfying after virtual or real try-on, the
 10 adjustable input parameters can be applied to adjust the patterns'.

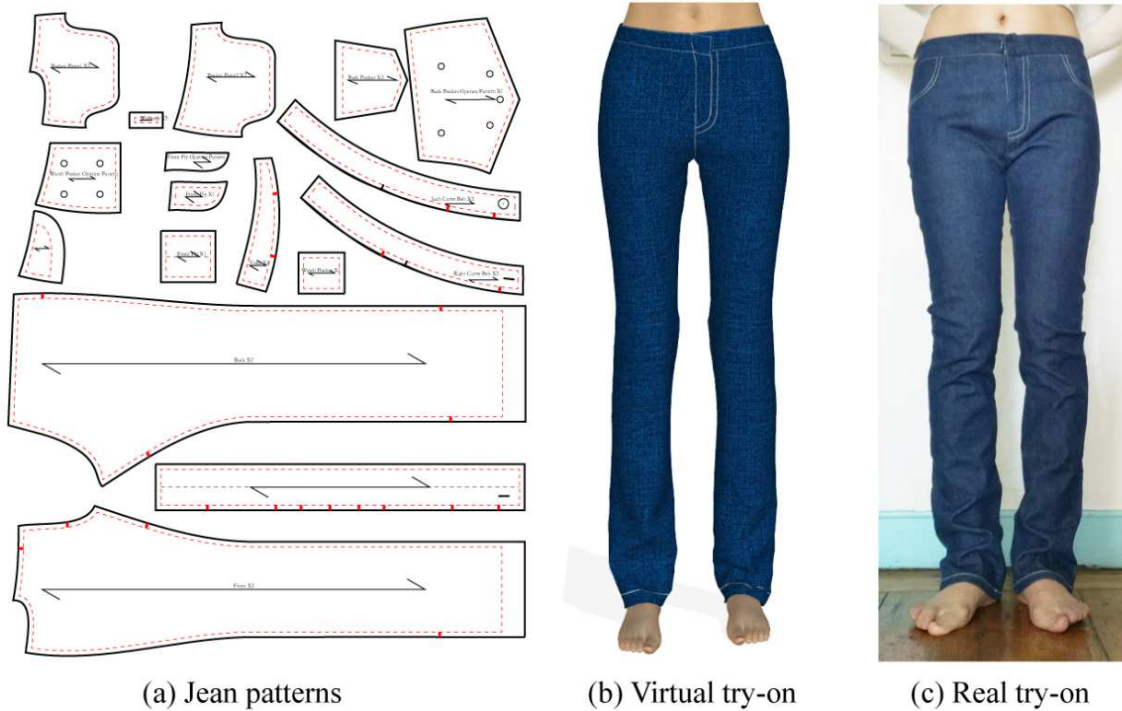
11 Using the proposed system, various jeans' patterns can be generated at the conditions of different
 12 silhouettes, waist heights, jean lengths, human body waist girths, human body hip girths, statures, as shown in
 13 Fig. 9. The results indicate that our proposed system can generate jeans' patterns according to different body
 14 dimensions and styles.

15 **Table 2**
 16 Constants' default values in this paper's formulas.

Item	a	α	β	γ	e_h	e_w	ω	a_1
Default value	0.4	4	6	6	15	2	5	0.75
Item	a_2	a_3	a_4	b_1	b_2	b_3	b_4	
Default value	0.69	0.53	0.37	-19.34	-28.21	-14.48	-15.91	

17 Note: the unit of α , β , γ , e_h , e_w , b_1 , b_2 , b_3 and b_4 is centimeter, and ω , a_1 , a_2 , a_3 and a_4 are dimensionless.

18 *4.2 Validation of jeans' pattern parametric design*



19 (a) Jean patterns (b) Virtual try-on (c) Real try-on

20 **Fig. 10.** Jeans pattern and try-on.

21 The aim of this research was to develop garment patterns rapidly; therefore, it was necessary to test the
 22 patterns generated by the proposed system for fit. In order to validate the proposed method, we measured and
 23 recorded a person's stature, hip girth and waist girth; 165 cm, 68 cm and 88 cm respectively. Then we input
 24 these dimensions into the developed system in Fig. 8 and selected jeans' length as long, silhouette as straight,
 25 and waist height as normal. The final patterns were generated as shown in Fig. 10 (a). Using the virtual and real
 26 try-on, the jean was tested by a designer and the person. We used virtual try-on to check whether jean style
 27 meets design requirements. The jean fit is tested by real try-on. If virtual try-on shows that the jean style meets

1 design requirements, we will carry out real try-on to evaluate garment fit. If virtual try-on shows that the fashion
2 style doesn't meet design requirements, we will regenerate patterns until the fashion style meets design
3 requirements. Results show that the patterns meet the subject's and design requirements. The time of pattern
4 generation took only several seconds. Through combing the traditional pattern-making method, our method can
5 improve the efficiency significantly.

6 In the actual design process, a pattern maker makes patterns for a complex style in at least one day;
7 however, using our method, only a few seconds are required. The pattern-making efficiency improves
8 significantly. Even when the garment patterns generated by our proposed method, do not completely meet
9 pattern makers' requirements, they can adjust it easily. For example, if a pattern maker is satisfied with the
10 whole pattern generated by our method, except the part of the pocket, the only part to be modified is the pocket.
11 As a result, the materials and time are saved by not requiring to completely make a new one.

12 **5. Conclusion**

13 In this paper, we proposed a parametric design method of garment pattern based on body dimensions.
14 Based on this method, we developed a recommendation system of jeans' pattern. The jeans' patterns are
15 parameterized by three geometric constraint parameters (jeans silhouette type, length and waist height type) and
16 three-dimensional constraint parameters (human body stature, waist girth and hip girth). Through combing the
17 traditional manual pattern-making method, the parametric design method can generate jeans' patterns rapidly
18 and automatically. Our proposed method saves plenty of time for pattern makers, and the jeans' development
19 cost reduces distinctly. Even persons with limited or no pattern-making knowledge can also develop
20 professional garment patterns using our proposed system.

21 Although our research can generate garment patterns automatically with parametric design method without
22 expert knowledge, it still has some limitations. For a complex fashion style, it will take a lot of work to
23 parameterize its patterns. How to parameterize complex styles base on body dimensions will be a research
24 direction. Moreover, we only used linear models to construct relations between body dimensions and garment
25 patterns in this study. The relations between body dimensions and garment patterns are not entirely linear. In
26 the future, non-linear models, such as neural networks, can be used to construct the mathematical relations
27 between them.

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