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Parametric design of garment flat based on body dimension

Kaixuan Liu [a, b, c, d, *], Xianyi Zeng [c, d], Jianping Wang [b], Xuyuan Tao [c, d], Jun Xu [a], Xiaowen Jiang [a], Jun Ren [a], Edwin Kamalha [c, d], Tarun-Kumar Agrawal [c, d], Pascal Bruniaux [c, d]

[a] Apparel and Art Design College, Xi'an Polytechnic University, Xi'an 710048, China
[b] College of Fashion and Design, Donghua University, Shanghai 200051, China
[c] Ecole Doctorale EDSPI, University of Lille 1, Nord de France, 59000 Lille, France
[d] GEMTEX Laboratory, ENSAIT, 59100 Roubaix, France

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ABSTRACT

Garment flats have a wide application in product development production and designing stages. However, the traditional drawing methods of garment flat are very time-consuming, and need professional drawing skills. In this paper, a parametric design method was proposed based on body dimension to draw garment flats. The relations among human body, flats and garment show that a garment flat has a close relation with human body and real garment. Graphic analysis shows that a garment flat is constrained by two kinds of parameters: geometric and dimensional parameters. Then, the parametric relation model between garment flat and human body dimensions was constructed. According to the parametric relation model, all the dimensions of a garment flat can be represented by several dimensional parameters and style parameters. Finally, an application program (JFRS, 2016) based on the proposed method was developed to generate garment flats. The result shows that the proposed method is more effective than traditional methods. Moreover, the engineering design methods have been successfully applied to improve design efficiency in artistic design in this research. This is a novel research idea in the field of fashion design, and could be further applied in other design domains.

1. Introduction

Body dimension is important for product development and evaluation (Sutalaksana and Widyanti, 2016), such as, firefighters' uniform pants (J. Park and Langseth-Schmidt, 2016), furniture (Carneiro et al., 2017; Castellucci et al., 2016), labor-saving tools (Mugisa et al., 2016; Vyavahare and Kallurkar, 2016), pillow (Cai and Chen, 2016), seat (Guo et al., 2016; Zerehsaz et al., 2016), helicopter cockpit (W. W. Lee et al., 2013). In clothing industry, human body dimension is essential for garment pattern making (Liu et al., 2016b, 2017c; Widyanti et al., 2017; Wu et al., 2015) and relates to garment fit directly (Liu et al., 2017a, 2017b). However, the traditional drawing methods of garment flat are not based on body dimension but designers' experience. At present, there are two methods to draw garment flat: hand drawing and computer-aided drawing. Hand drawing requires sophisticated and artistic skills; while, computer-aided drawing requires analytical thinking and continuous comparison of the prototype to what is being drawn. Both these two drawing methods require designers draw garment flat line by line. This process is very time-consuming. Generally, it requires several hours for a designer to draw a complex garment flat. In this case, it is difficult to draw garment flat by computer automatically. With the rapid development of E-commerce, the demand of garment related products is large and growing (Y. Y. Lee et al., 2013). It is necessary to develop a rapid generation technology for garment flats. In this research, a novel drawing method of garment flat based on body dimension was proposed.

Garment flat drawing is an essential part in the fashion design process. Generally, a garment flat is used in pattern making documentation, tech packs, specifications, cost sheets, line sheets and production-related presentations (Chang-Suk et al., 2010; Robson et al., 2011). Designers use garment flats to efficiently convey their design ideas and garment details to related departments. It is essential that garment flats are drawn accurately to avoid misunderstanding and costly mistakes in sampling and production.

* Corresponding author. Apparel and Art Design College, Xi'an Polytechnic University, Xi'an 710048, China.
E-mail addresses: kaixuan.liu@ensait.fr, liukaixuan819@163.com (K. Liu).

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Garment flats are very different from fashion illustrations needed for a presentation. Garment flats do not need much movement or shading, as it can be distracting. A neatly detailed flat simply implies how well in detail can you illustrate your design requirements to the product development production departments. Black and white sketches can be easier to “read” and provide a clearer representation of designers' ideas. Thus, flats are usually composed of black lines, because it is easier for people to follow visual guidelines. Also, garment flat drawing is completely different from garment pattern making. Garment pattern makers make patterns using 3D or 2D methods according to body dimensions (Liu et al., 2016a, 2016b, 2016c, 2017c). However, flats are drawn based on garment proportions rather than body dimensions. Prototypes are measured by trained persons and tech packs are prepared accordingly, including flats. At present, there are two methods to draw garment flat: hand drawing and computer-aided drawing. Hand drawing requires sophisticated and artistic skills; while, computer-aided drawing requires analytical thinking and continuous comparison of the prototype to what is being drawn. It requires several hours for a designer to draw a complex garment flat.

Parametric product design involves the use of one or several key feature parameters to represent the whole product construction. Using this method, the product development efficiency improves significantly. At present, this technology is widely applied in the development of industrial products; for instance, mechanical products (Myung and Han, 2001), 3D human body models (Baek and Lee, 2012; Kim and Park, 2004; Koo et al., 2015; S. Park et al., 2015; Wang, 2005), garment patterns (Kim, 2012; Xiu et al., 2011), filigree jewelry (Stamati et al., 2011), 3D tire molds (Chu et al., 2006) and dies (Lin et al., 2008). However, there are few reports of studies on parametric design of garment flats. Ji et al. proposed a garment technical drawing system to obtain different flats by changing different parts of a garment flat (Ji et al., 2002). Xu et al. developed a web-based design support system (Xu et al., 2016). This system mainly consists of three parts: a sketch representation and composing method, a graphic user interface and a controller. Users can adjust several parameters through the internet to generate skirt flats rapidly and automatically. However, their research does not integrate human body dimensions into flat drawing. By integrating body dimensions into flat drawing and pattern making, the flat and its corresponding pattern have mutual affinity. Thus, using computer-aided design technology, the garment flat can be generated along with the generation of its corresponding garment pattern. To this end, a parametric method was proposed to draw garment flats rapidly. Parametric design belongs to the category of engineering design; however, garment flat drawing belongs to the category of artistic design. This artistic design knowledge should be translated into specific design rules; thus, this kind of knowledge can be read by computers. After this, computer graph technology can be applied to draw garment flat according to these specific design rules.

The acquisition of design rules requires two steps: knowledge extraction and knowledge expression. Two studies were carried out to obtain design knowledge: a questionnaire was used to collect knowledge of Jean style classifications from 20 fashion designers, and anthropometric measurements were generated from 3D scans for 120 women aged 20–25 years. These measurements were used to extract the knowledge of human body dimensions for drawing jean flats. After this, factor analysis, correlation analysis and regression analysis were applied to analyze the collected data. As linear models are the most common in garment pattern making (Xiu et al., 2011), while, the golden ratio is widely applied in the field of artistic design, data analysis results with these two techniques were integrated to represent the jean design knowledge. Finally, the jean design rules are expressed by parametric formulas. Based on these parametric formulas, a jean flat recommendation system was developed. The input items of the developed system are body dimensions' parameters and the jean style's parameters, for example, human stature and jean silhouette; while, the output item is jean flat. Using the developed system, jean flats can be generated rapidly and automatically.

The first aim of this research was to design garment flats rapidly and automatically to enhance design efficiency and reduce product development costs. The second one is to use engineering design to solve the problem in art design. This paper is organized as follows: the first part introduces our general scheme about parametric design of jean flats; the second part presents how to establish three geometric constraint parameters and three dimensional constraint parameters. The third part states how to use these six parameters to represent the whole jean flat by parametric formulas. The fourth part shows results of application and validation. The last part presents some conclusions and possible further works.

2. General scheme for parametric design of a jean flats

2.1. Novel design concept of jean flats

Garment flats focus on the tangible apparel or the actual garment which is to be produced. It is always about the actual garment, rather than a general idea of a garment. Flat drawing requires designers to have professional knowledge on fashion design, for example, aesthetics, ergonomics, and painting. Currently, there are two methods to draw garment flats. One is drawing by hand, which is called “manually drafted”; the other is the use of specially designed software that is called “computer aided drafting”. Both types of technical drawing require a superior drawing skill. The current drawing methods of garment flat are time-consuming and inefficient. Thus, a novel drawing method was proposed to generate flats rapidly and automatically based on anthropometric measurements.

A garment flat's size has a close relationship with human body dimensions. As shown in Fig. 1, a jean flat's size (Jean waist height type is high and jean length is long) have one-to-one relationships with human body dimensions in the height direction. Meanwhile, the widest parts of jean cross sections are equal to the widths of the corresponding positions of the jean flats. And the real jean dimensions are equal to human body dimensions, plus ease allowances. Thus, the relationships between the dimensions of a jean flat and human body can be represented by mathematical formulas. In other words, a jean flat's size can be deduced from human body dimensions. By adjusting body dimensions, various jean flats can be generated. This is the basic idea of this research. The proposed method is completely different from the traditional method of manually drawing garment flats.

2.2. General schemes

The general scheme of the mentioned parametric design for jean flats is described in Fig. 2. Its basic steps are given below.

Firstly, constraint factors which influence the shape of a garment flat were analyzed. Results showed geometric constraint and dimensional constraint.

Secondly, two studies were carried out to establish which parameters impact the geometric constraint and dimensional constraint respectively. In the first study, a questionnaire was used to survey 20 fashion designers for obtaining knowledge of jean style classification. In the second study, 120 young females were measured to collect anthropometric data. The collected data were analyzed by factor and correlation analysis for acquiring key dimensional constraint parameters of the jean flats.

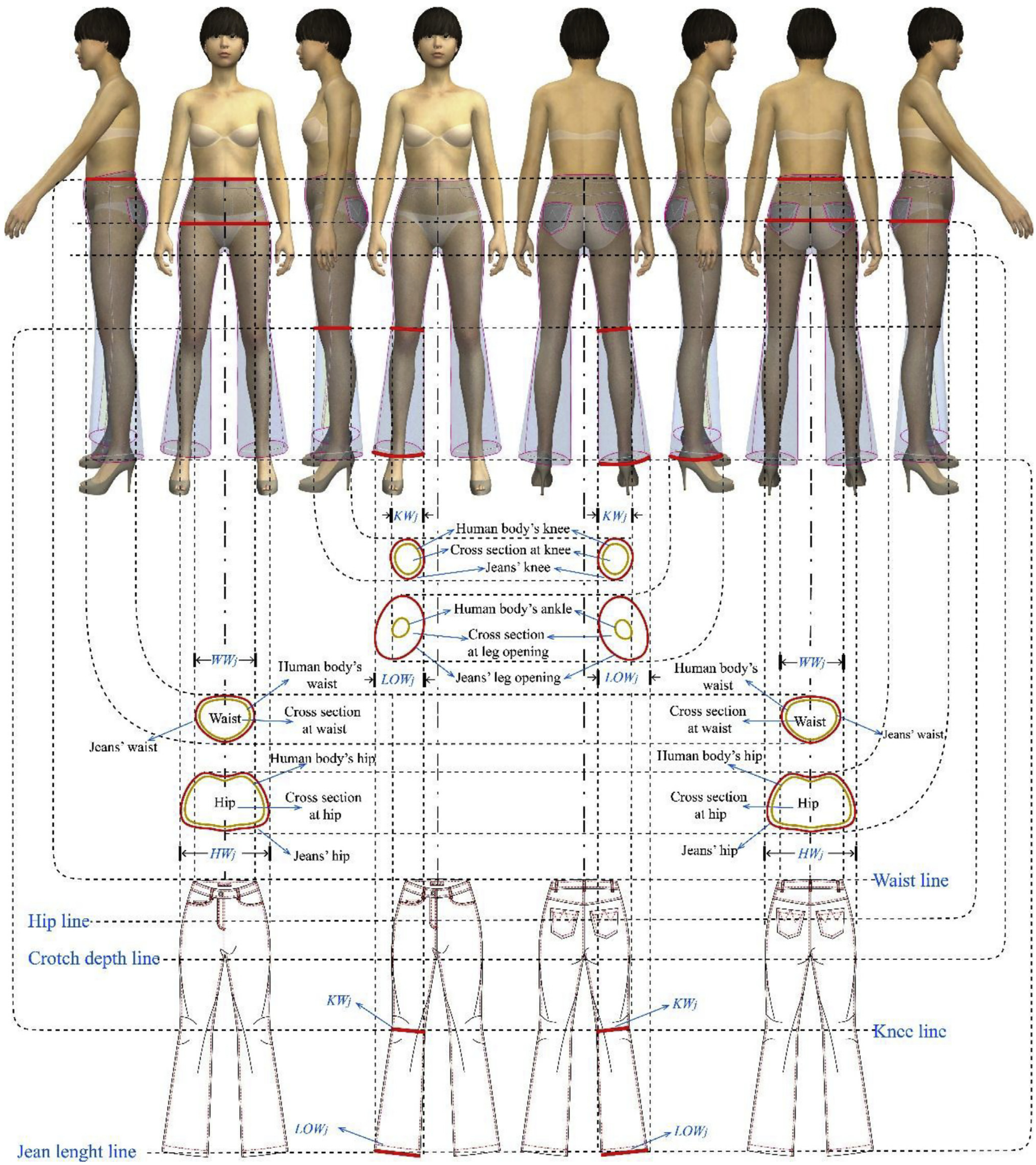


Fig. 1. Relationships among lower body, jean flats and real jeans.

Thirdly, linear regression analysis was applied to establish formulas between stature parameters and other dimensions in height direction. The golden ratio was applied to establish the formulas between hip parameter, waist parameter and other dimensions in width direction.

Finally, a computer program was developed to realize the parametric design of the jean flats. Using this system, six input parameters (stature, waist, hip, silhouette type, length type, waist height type) can generate jean flats rapidly and automatically.

3. Establishing constraint parameters of the jean flats

3.1. Graphic constraints of the jean flats

From the perspective of graphics, constraints can be divided into two categories: dimensional and geometric constraints (Xiu et al., 2011). As shown in Fig. 3 (a), the rectangle and circle are geometrically constrained, as they are different from geometric shapes. The two rectangles in Fig. 3 (b) being different from dimension;

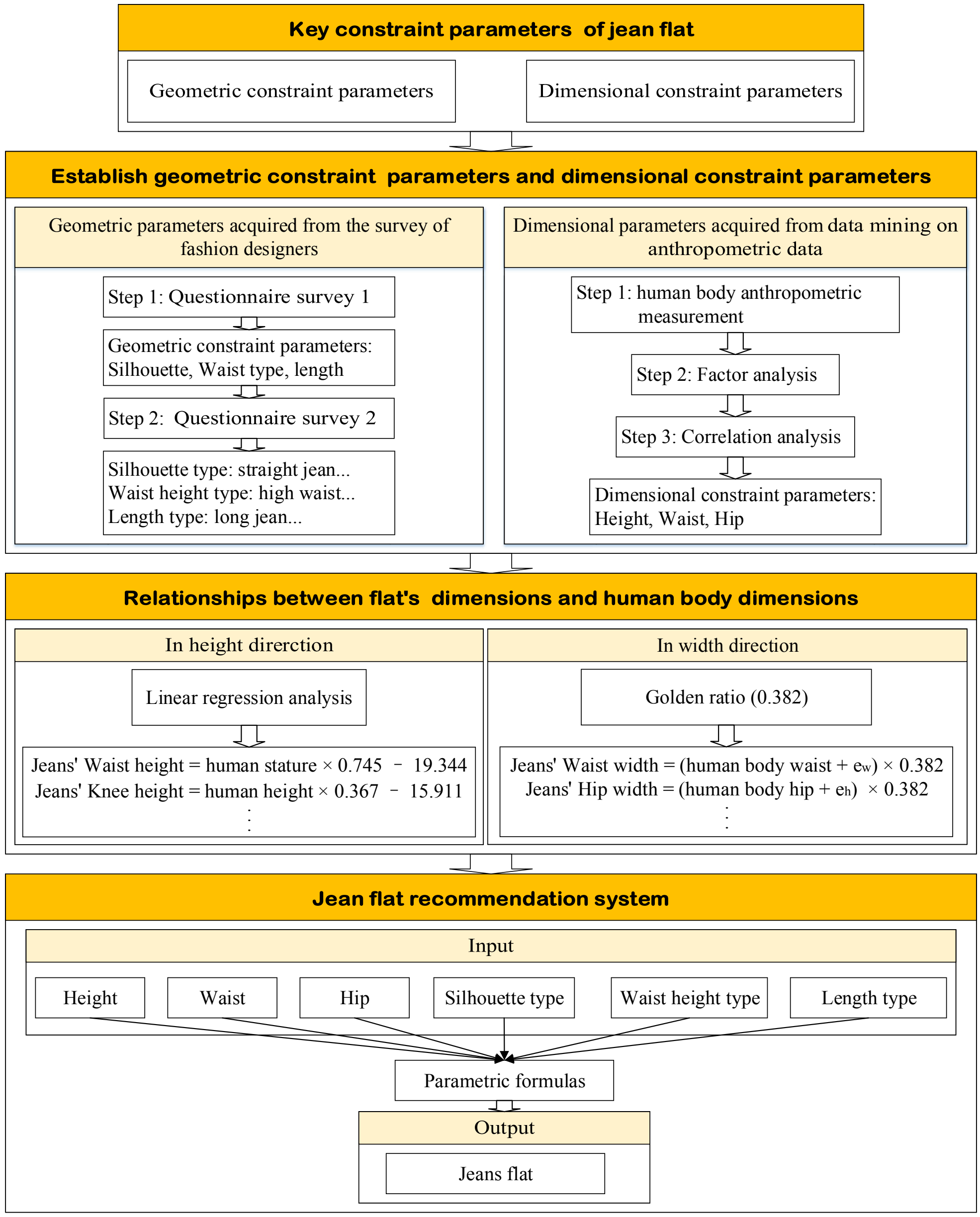


Fig. 2. General scheme of parametric jean flat design.

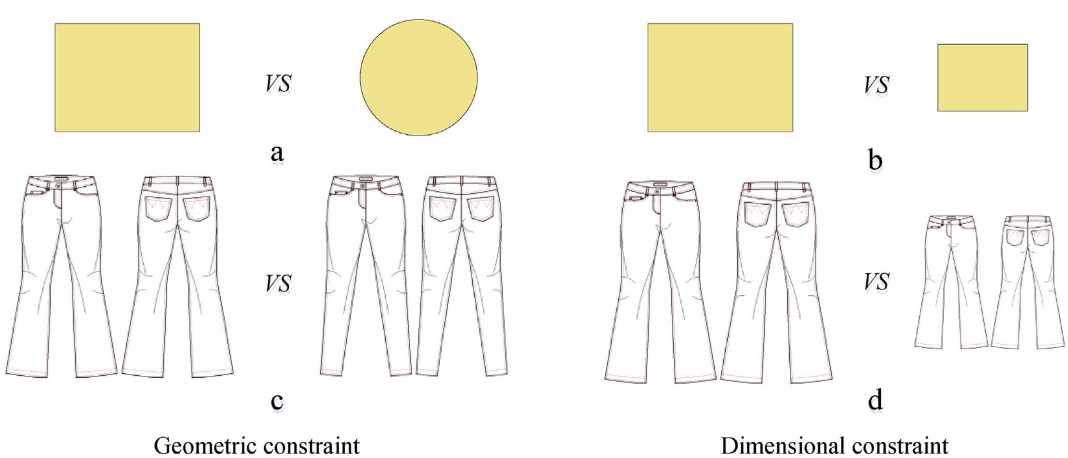


Fig. 3. Geometric constraint and dimensional constraint.

therefore, so are dimensionally constrained. If drawing a rectangle, the first step is to know the shape of the graph is (geometric constraint) (Fig. 3 (a)); the second step is to know the length and width of the rectangle (dimensional constraint) (Fig. 3 (b)). The same principle is applied to draw the jean flats. Firstly, the jean style and its all parts' dimensions are established for the flat (Fig. 3 (c) and (b)). However, a jean flat consists of many curves. Each curve's dimension is a kind of dimensional constraint. So many dimensional constraints complicate flat drawing. In order to simplify this process, a few key constraint parameters are used to represent other secondary constraints parameters. Thus, all the curves of a jean flat can finally be represented by the key constraints parameters.

3.2. *Definition of geometric constraint parameters (jean style classification)*

As already indicated, the shape of a jean flat depends on two types of constraint parameters: geometric constraint parameters and dimensional constraint parameters. This section presents how to establish the geometric constraint parameters.

Two steps of questionnaire surveys were carried out to extract jeans' classification criteria. In the first stage, 20 fashion designers were surveyed to collect influencing factors for a jean style. The first-stage survey results show that a jean's style mainly depends on three factors (parameters), i.e., silhouette, length and waist height type (Fig. 4). Waist height type, length type and silhouette type were finally selected as three geometric constraint parameters according to the above questionnaire surveys. Thereafter, based on the results, the three factors (parameters) were further subdivided through the second survey of 20 fashion designers. The subdivision results are shown in Fig. 4.

3.3. *Definition of dimensional constraint parameters (jean dimensions)*

In this section, how to establish the dimensional constraint parameters of the jean flats was expounded.

3.3.1. *Collection of human anthropometric data*

120 women aged 20–30 years were randomly selected from the Northeast area of China. A 3D body scanner (Vitus Smart), which has the advantages of accuracy and speed (Daanen and Ter Haar, 2013; Daanen and Van de Water, 1998), was used to measure and extract body dimensions. The measurement software automatically extracted dozens of body dimensions from each subject. For the subsequence factor, correlation and regression analysis, 13 body dimensions were retained (Fig. 5), which are closely related to the dimensions of the jean flats.

3.3.2. *Factor analysis*

According to the factor loading coefficients of the rotated component matrix in Table 1, the first two components were began by extracting. If their accumulative contribution rate was found low, next was to add the next component until the result is was satisfactory. The accumulative contribution of the first two factors accounts for 85.86% (Table 2) of variability. It indicates that the two factors represent the vast of the information of human body dimensions.

The first factor mainly includes stature, inside length, waist height, hip height, abdomen height and knee height. These measuring items reflect the height of corresponding parts of the body; therefore, it was denoted as “height factor”.

The second factor mainly includes crotch width, waist, abdomen, thigh, and knee. These measuring items reflect the thickness and circumference of corresponding parts of the lower body. Actually, the width has a strong correlation with the circumference; therefore, it was denoted as “girth factor”.

3.3.3. *Correlation analysis*

Factor analysis found that two factors influence human body dimensions significantly. However, these two factors contain several measuring items. In order to reduce measuring items, correlation analysis was applied to find key measuring items from the two factors. As shown in Table 3, all the measuring items of the height and girth factors have obvious correlations. As the stature is the easiest measuring item, it was selected as a key measuring item (the first of three dimensional constraint parameters); and can be used for representing other dimensions in the height direction. Because the waist and hip girth can easily be measured; and for their importance in the design of bottoms, they were selected as other two parameters (the second and third of three dimensional constraint parameters). Other dimensions in girth and width directions can be represented by hip or waist.

Finally, stature, hip and waist were selected as three dimensional constraint parameters following the same above factor analysis and correlation analysis.

4. Parametrization of the jean flats

4.1. *Parametric design of the jean flat: the application of geometric constraints*

4.1.1. *Silhouette design*

From our questionnaires, the silhouettes of jeans are usually

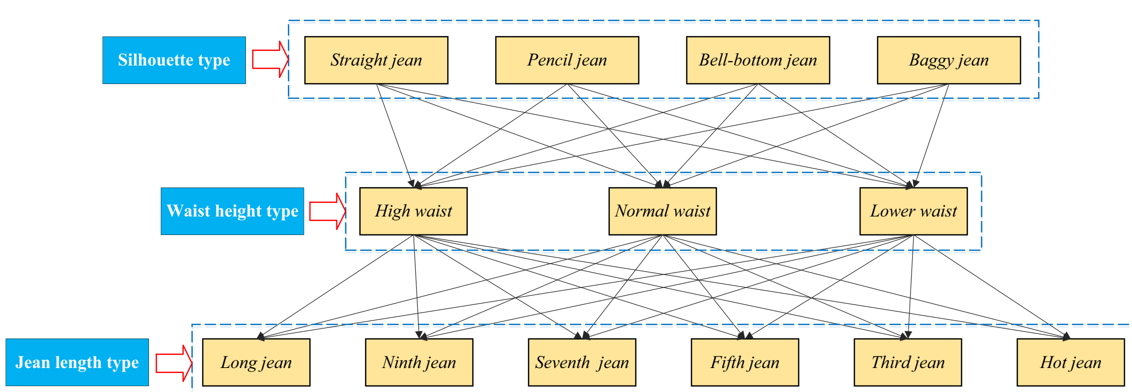


Fig. 4. Jean style classification.

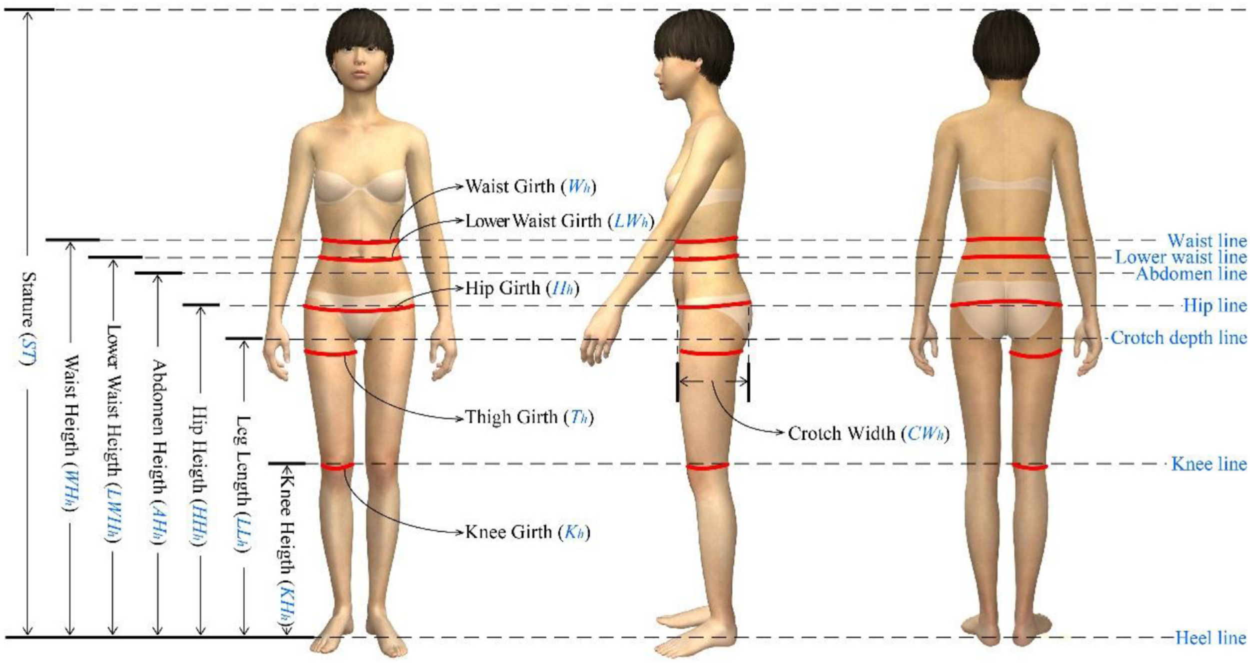


Fig. 5. Legend of measurement dimensions.

Table 1
Rotated component matrix of anthropometric measurement.

NO.	Measuring items	Abbr.	Component	
			1	2
1	Stature	ST	0.960	0.205
2	Human body Waist Height	WH_h	0.956	0.193
3	Human body Lower Waist Height	LWH_h	0.943	0.155
4	Human body Abdomen Height	AH_h	0.930	0.152
5	Human body Hip Height	HH_h	0.941	0.166
6	Human body Leg Length	LL_h	0.894	0.006
7	Human body Knee Height	KH_h	0.903	0.228
8	Human body Waist girth	W_h	0.002	0.915
9	Human body Lower Waist girth	LW_h	0.202	0.919
10	Human body Hip girth	H_h	0.279	0.902
11	Human body Thigh girth	T_h	0.178	0.916
12	Human body Knee girth	K_h	0.227	0.775
13	Human body Crotch Width	CW_h	0.040	0.854

Note: Extraction method is principal component analysis; Rotation method is varimax with Kaiser Normalization.

Table 2
Total variance explained.

Component	Factor	Initial Eigenvalues		
		Total	% of Variance	Cumulative %
1	Height factor	6.29	48.40	48.40
2	Girth factor	4.87	37.47	85.86

Note: Extraction method is principal component analysis.

classified into four categories: pencil jean, straight jean, bell-bottom jean and baggy jean (Fig. 4). As shown in Fig. 6, the area between waist line and crotch depth line is the fit-zone; and the area below the crotch depth line is the design-zone. Jeans should fit well in the fit-zone; meanwhile, designers can design various jeans in this zone. Thus, jean styles' characteristics mainly depend on the part below crotch depth line. Further, the main differences in jean silhouette are values of the knee width and leg opening width (Fig. 6). Especially, the main difference in pencil jean, straight jean and bell-bottom jean are the values of leg opening girth.

Based on the above analysis, jean silhouette was defined as follows (the first of three geometrical constraint parameters):

$$Silhouette = \begin{cases} "V", & (LOW_j = KW_j - \alpha) \\ "H", & (LOW_j = KW_j) \\ "X", & (LOW_j = KW_j + \beta) \\ "A", & \left(\begin{array}{c} LOW_j = \dfrac{HW_j}{2} + \gamma \\ KW_j = \dfrac{2LOW_j \times (LL_h - KH_h) + HW_j \times LL_h}{2(2LL_h - KH_h)} \end{array} \right) \end{cases} \quad (1)$$

Where, "V", "H", "X" and "A" are pencil jean, straight jean, bell-bottom jean and baggy jean respectively; LOW_j, KW_j, HW_j, KH_h and LL_h are jean Leg Opening Width, jean Knee Width, jean Hip Width, human body Knee Height and human body Leg Width (see Fig. 6); α, β and γ are positive constants, and their values depend on design requirements.

Definition (1) shows that if jean Leg Opening Width is greater than jean Knee Width, then the jean is bell-bottom jean; if jean Leg Opening Width equals to jean Knee Width, then the jean is straight jean; if jean Leg Opening Width is smaller than jean Knee Width, then the jean is pencil jean; if jean Knee Width approximately equals to half of the sum of jean Leg Opening Width and jean Hip Width, the jean is baggy jean. Finally, the definition (1) is used for the parametric design of jean silhouette.

4.1.2. Waist design

Through our questionnaire survey, jean waist type is generally classified into three categories: high waist, normal waist and lower waist (Fig. 4). As shown in Fig. 7, the high waist jean's waist line corresponds to human body waist line; the normal waist jean's waist line corresponds to human body lower waist line; and the

Table 3
Pearson correlation coefficients between 13 measuring items.

	ST	WH_h	LWH_h	AH_h	HH_h	LL_h	KH_h	W_h	LW_h	H_h	T_h	K_h	CW_h
ST	1.00	–	–	–	–	–	–	–	–	–	–	–	–
WH_h	0.95	1.00	–	–	–	–	–	–	–	–	–	–	–
LWH_h	0.95	0.92	1.00	–	–	–	–	–	–	–	–	–	–
AH_h	0.89	0.95	0.87	1.00	–	–	–	–	–	–	–	–	–
HH_h	0.92	0.94	0.90	0.91	1.00	–	–	–	–	–	–	–	–
LL_h	0.85	0.81	0.82	0.78	0.81	1.00	–	–	–	–	–	–	–
KH_h	0.92	0.88	0.87	0.83	0.85	0.81	1.00	–	–	–	–	–	–
W_h	0.19	0.19	0.14	0.14	0.14	0.07	0.21	1.00	–	–	–	–	–
LW_h	0.39	0.37	0.33	0.33	0.32	0.20	0.39	0.88	1.00	–	–	–	–
H_h	0.47	0.45	0.41	0.41	0.41	0.20	0.44	0.75	0.88	1.00	–	–	–
T_h	0.36	0.34	0.31	0.29	0.33	0.15	0.37	0.78	0.84	0.90	1.00	–	–
K_h	0.36	0.36	0.33	0.34	0.32	0.18	0.40	0.65	0.70	0.71	0.74	1.00	–
CW_h	0.20	0.19	0.17	0.17	0.21	0.09	0.22	0.76	0.73	0.77	0.74	0.56	1.00

Note: ST is Stature; WH_h is human body Waist Height; LWH_h is human body Lower Waist Height; AH_h is human body Abdomen Height; HH_h is human body Hip Height; LL_h is human body Leg Length; KH_h is human body Knee Height; W_h is human body Waist girth; LW_h is human body Lower Waist girth; H_h is human body Hip girth; T_h is human body Thigh girth; K_h is human body Knee girth; and CW_h is human body Crotch Width.

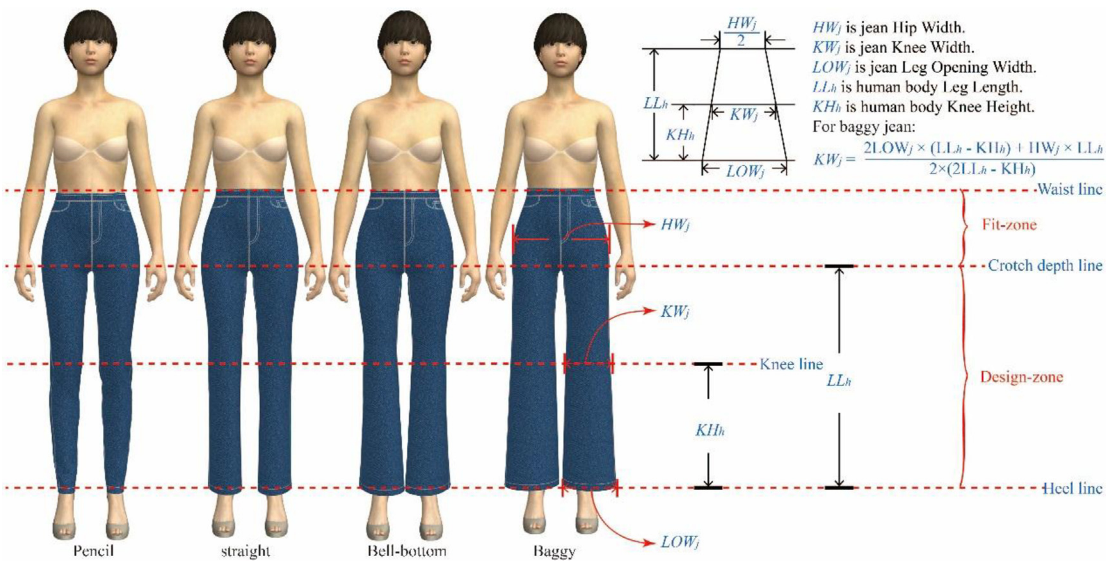


Fig. 6. Jean silhouette design.

lower waist jean's waist line corresponds to human body abdomen line. The lower waist line is at about the middle of human body waist line and abdomen line. Therefore, the grade difference of jean waist type is as follows:

$$GD_1 = DWA_h / 2 \tag{2}$$

Where, DWA_h is human body Drop of Waist-to-Abdomen; GD_1 is the Grade Difference of jean waist height.

With further analysis, the main differences in waist types are values of the crotch depth and drop of waist-to-hip (Fig. 7). Combined with the grade difference of jean waist (Eq. (2)), jean waist parameters were defined as follows (the second of three geometrical constraint parameters):

$$Waist\ type = \begin{cases} Height\ waist, & \begin{pmatrix} CD_j = CD_h \\ DWH_j = DWH_h \end{pmatrix} \\ Normal\ waist, & \begin{pmatrix} CD_j = CD_h - GD_1 \\ DWH_j = DWH_h - GD_1 \end{pmatrix} \\ Lower\ waist, & \begin{pmatrix} CD_j = CD_h - 2GD_1 \\ DWH_j = DWH_h - 2GD_1 \end{pmatrix} \end{cases} \tag{3}$$

Where, GD_1 is the Grade Difference of jean waist height; CD_j is jean Crotch Depth; DWH_j is jean Drop of Waist-to-Hip; CD_h is human body Crotch Depth; DWH_h is human body Drop of Waist-to-Hip.

Definition (3) shows that if jean's waist height is greater than human body waist height, then the jean is height waist; if jean's waist height equals to human body waist height, then the jean is normal waist; if jean's waist height is smaller than human body waist height, then the jean is low waist. Definition (3) was applied to design jean waist type.

4.1.3. Length design

From our questionnaires, jean length can be divided into six categories: hot jean, third jean, fifth jean, seventh jean, ninth jean and long jean (Fig. 4). As shown in Fig. 8, the hot jean's length line is d cm below crotch depth line (This value depends on design requirements); the fifth jean's length line corresponds to human body knee line; the long jean's length line corresponds to human body leg length line. The third jean's length line is at the middle of hot jean's length line and fifth jean's length line. The seventh and ninth jeans' length lines are in upper the third and lower third of the distance between knee line and leg length line. Therefore, the grade differences of jean length are as follows:

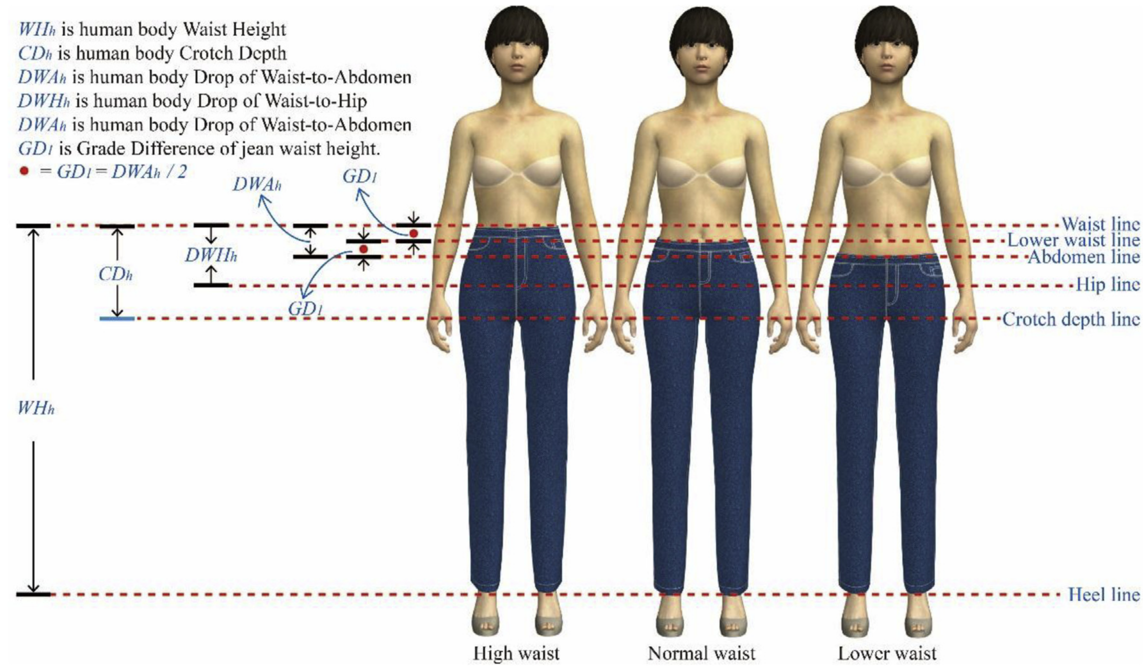


Fig. 7. Jean waist design.

$$GD_2 = KH_h/3 \tag{4}$$

$$GD_3 = (LL_h - d - KH_h)/2 \tag{5}$$

Where, GD_2 is the Grade Difference of long, ninth, seventh, and fifth jean; GD_3 is the Grade Difference of hot, third and fifth jean; KH_h is human body Knee Height; LL_h is human body Leg Length; d is a positive constant, whose value depends on design requirements.

Further, the main differences of jean length type are values of the waist height and drop of waist-to-abdomen, knee height and length (Fig. 8). Combining the grade differences of jean length (Eq. (2), (4) and (5)), jean length was defined as follows (the third of three geometrical constraint parameters):

$$JL = \begin{cases} long, \begin{pmatrix} JL = WH_h, height\ waist \\ JL = WH_h - GD_1,\ normal\ waist \\ JL = WH_h - 2GD_1,\ lower\ waist \end{pmatrix} \\ ninth, \begin{pmatrix} JL = WH_h - GD_2, height\ waist \\ JL = WH_h - GD_2 - GD_1,\ normal\ waist \\ JL = WH_h - GD_2 - 2GD_1,\ lower\ waist \end{pmatrix} \\ seventh, \begin{pmatrix} JL = WH_h - 2GD_2, height\ waist \\ JL = WH_h - 2GD_2 - GD_1,\ normal\ waist \\ JL = WH_h - 2GD_2 - 2GD_1,\ lower\ waist \end{pmatrix} \\ fifth, \begin{pmatrix} JL = WH_h - 3GD_2, height\ waist \\ JL = WH_h - 3GD_2 - GD_1,\ normal\ waist \\ JL = WH_h - 3GD_2 - 2GD_1,\ lower\ waist \end{pmatrix} \\ third, \begin{pmatrix} JL = WH_h - 3GD_2 - GD_3, height\ waist \\ JL = WH_h - 3GD_2 - GD_3 - GD_1,\ normal\ waist \\ JL = WH_h - 3GD_2 - GD_3 - 2GD_1,\ lower\ waist \end{pmatrix} \\ hot, \begin{pmatrix} JL = WH_h - 3GD_2 - 2GD_3, height\ waist \\ JL = WH_h - 3GD_2 - 2GD_3 - GD_1,\ normal\ waist \\ JL = WH_h - 3GD_2 - 2GD_3 - 2GD_1,\ lower\ waist \end{pmatrix} \end{cases} \tag{6}$$

Where, JL is Jean Length; WH_h is human body Waist Height; GD_1 is the Grade Difference of jean waist height; GD_2 is the Grade Difference of long, ninth, seventh, and fifth jean; GD_3 is the Grade Difference of hot, third and fifth jean. Definition (6) was applied to design jean length type.

4.2. Parametric design of the jean flat: the application of dimensional constraints

Drawing a flat by our proposed method needs some primary dimensions and secondary dimensions. The secondary dimensions for drawing flat are derived from the primary dimensions. For a jean flat, the primary dimensions in height direction are waist height, hip height, leg length, knee height; and the primary dimensions in width direction are waist width, hip width, knee width, and leg opening width. These primary dimensions were deduced in the subsequence sections.

4.2.1. The relationship between stature parameter and other dimensions in height direction

The previous correlation analysis shows that human stature is highly correlated to other body dimensions in height direction. Thus, dimensions in height direction can be represented by stature. Currently linear models are widely applied in garment pattern making (Xiu et al., 2011). These applications indicate that errors of linear models are acceptable in garment pattern making. Garment flats are entirely different from garment patterns. Garment patterns demand very accurate dimensions; whereas flats do not. The main function of flats is to show details of all parts of a real garment for product development downstream production departments. The accuracy requirement of a garment flat is lower than normally expected in pattern making. As a linear model is suitable for pattern making, this model is also suitable for fashion drawing. As shown in Table 4, R square and adjusted R square of the proposed models are both more than 0.7, indicating that the goodness-of-fit of the linear models is higher. The probabilities of the significance test of the four regression formulas are 0 in Table 4. The test results indicate a significant linear

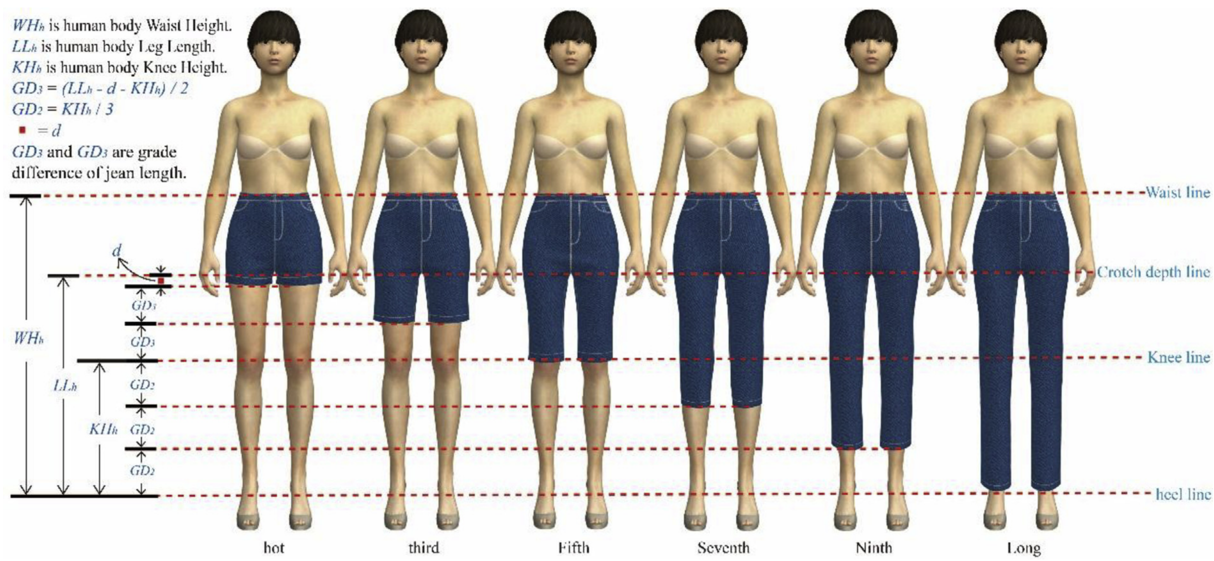


Fig. 8. Jean length design.

relationship between stature and other dimensions in height direction.

$$\textit{Height direction} = \begin{cases} WH_h = 0.745ST - 19.344 \\ HH_h = 0.686ST - 28.210 \\ LL_h = 0.532ST - 14.478 \\ KH_h = 0.367ST - 15.911 \\ DWH_h = WH_h - HH_h = 0.059ST + 8.866 \\ CD_h = WH_h - LL_h = 0.213ST - 4.866 \end{cases} \tag{7}$$

Where, WH_h is human body Waist Height; HH_h is human body Hip Height; LL_h is human body Leg Length; KH_h is human body Knee Height; DWH_h is human body Drop of Waist-to-Hip; CD_h is human body Crotch Depth; ST is human body human Stature.

Based on the above analysis, linear regression models were adopted to construct the relationships between stature and waist height, hip height, leg length, and knee height. Moreover, other dimensions related to a jean flat in height direction can also be represented by stature. For example, drop of waist-to-hip is equal to waist height less hip height; crotch depth is equal to waist height minus leg length (Fig. 5). Finally, all dimensions of the jean flat in height direction were represented by stature parameter through these regression equations.

4.2.2. The relationship between hip parameter and other dimensions in width direction

The correlation analysis in the previous sections showed that human body hip girth and waist girth are highly correlated to other body dimensions in girth direction. Thus, dimensions in girth direction can be represented by hip and waist girth.

The ease allowances at hip and waist are as follows:

$$W_j = W_h + e_w \tag{8}$$

$$H_j = H_h + e_h \tag{9}$$

Where, W_j is jean Waist girth; W_h is human body Waist girth; H_j is jean Hip girth; W_h is human body Waist girth; e_w is Ease allowance at waist, whose value depends on the design requirement; e_h is Ease allowance at hip, whose value depends on the design requirement.

As shown in Fig. 9 (a), the jean waist width is the diameter of circle C_w. In order to calculate its value (this value is used for drawing the flat), its circumference needs to be known. Fig. 9 (a) shows that the value of circle C_w's circumference is slightly larger than human body waist girth. Therefore, according to formula (8) and (9), the relationship between jean waist width and human body waist was deduced as follows:

$$WW_j = 0.382\,(W_h + e_w) \tag{10}$$

$$HW_j = 0.382\,(H_h + e_h) \tag{11}$$

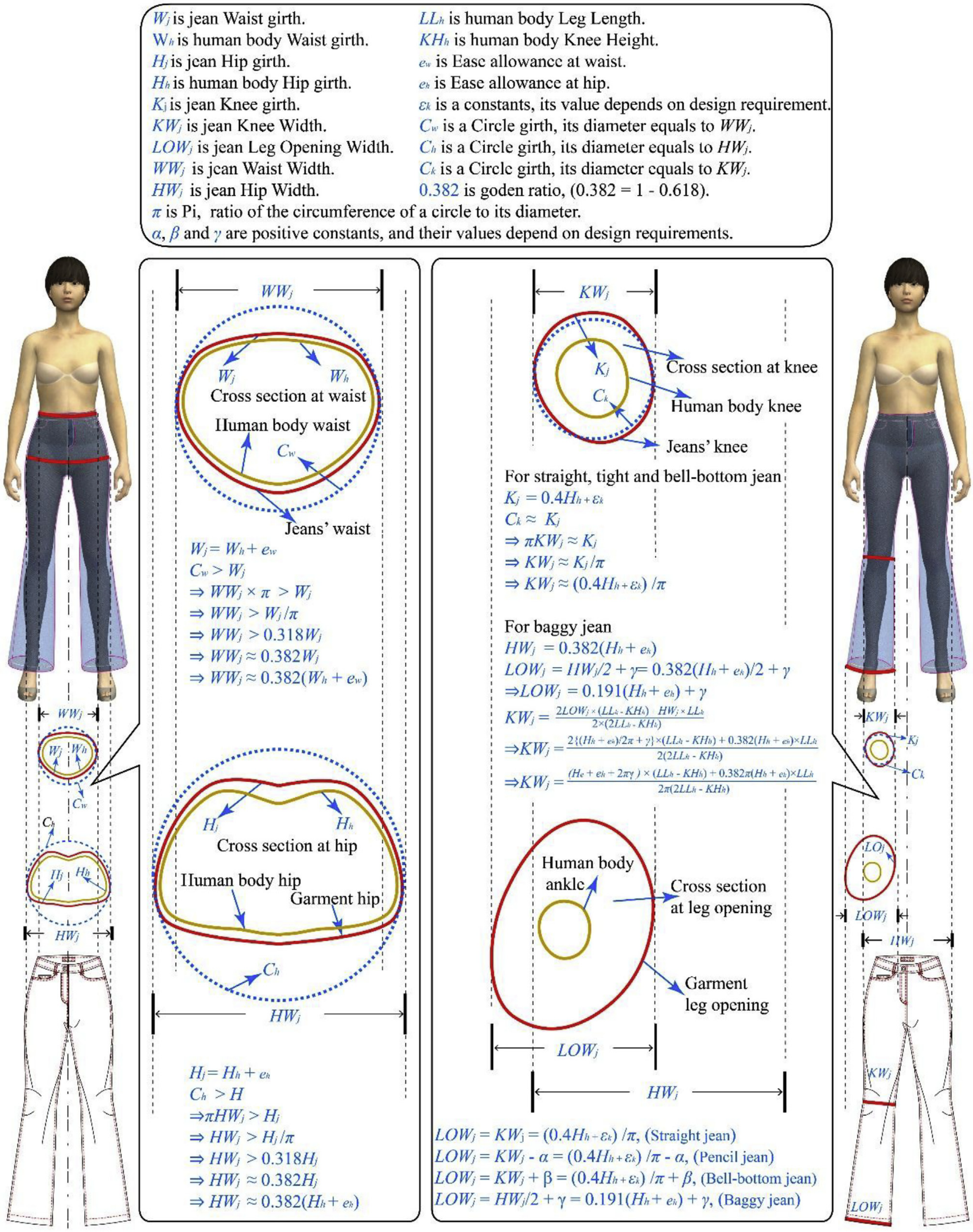
Where, WW_j is jean Waist width; HW_j is jean Hip width; W_h is human body Waist girth; H_h is human body Hip girth; e_w is Ease allowance at waist, whose value depends on the design requirement; e_h is Ease allowance at hip, whose value depends on the design requirement. The deduction of jean waist width (WW_j) and jean Hip width (HW_j) are shown in Fig. 9 (a).

The jean Knee width (KW_j) and Leg opening width (LOW_j) were given as follows:

Table 4
Linear regression analysis and modeling.

No.	Model	R2	Adjusted R2	F	Sig.
1	WHh = 0.745ST - 19.344	0.90	0.90	942.44	0.00
2	HHh = 0.686ST - 28.210	0.85	0.85	1402.51	0.00
3	LLh = 0.532ST - 14.478	0.72	0.72	276.16	0.00
4	KHh = 0.367ST - 15.911	0.85	0.84	579.89	0.00

Note: St is human body stature; WHh is human body waist height; WHh is human body waist height; WHh is human body waist height. Sig. is significance. Confidence level is 95%. R2 is R square.



(a) The relationship between human body waist girth and jean waist width, and the relationship between human body hip girth and jean hip width

(b) The relationship between human body girth and jean knee width, and the relationship between human body hip girth and jean knee width.

Fig. 9. Relationships between jean flat's dimensions and human anthropometric measurements in width direction.

$$KW_j = \begin{cases} (0.4H_h + \varepsilon_k)/\pi, & "V" \\ (0.4H_h + \varepsilon_k)/\pi, & "H" \\ (0.4H_h + \varepsilon_k)/\pi, & "X" \\ \dfrac{(H_h + e_h + 2\pi\gamma) \times (LL_h - KH_h) + 0.382\pi(H_h + e_h) \times LL_h}{2\pi(2LL_h - KH_h)}, & "A" \end{cases} \quad (12)$$

$$LOW_j = \begin{cases} (0.4H_h + \varepsilon_k)/\pi - \alpha, & "V" \\ (0.4H_h + \varepsilon_k), & "H" \\ (0.4H_h + \varepsilon_k) + \beta, & "X" \\ 0.191(H_h + e_h) + \gamma, & "A" \end{cases} \quad (13)$$

Where, "V", "H", "X" and "A" are pencil jean, straight jean, bell-bottom jean and baggy jean respectively; KW_j is jean Knee Width; LOW_j is jean Leg Opening Width; H_h is human body Hip girth; LL_h is human body Leg Length; KH_h is human body Knee Height; ε_k is a constant, whose value depends on design requirement; e_h is Ease allowance at hip, its value depends on the design requirement; α, β and γ are positive constants, and their values depend on design requirements; π is pi, the ratio of the circumference of a circle to its diameter. The deducing process of jean Knee width (KW_j) and Leg opening width (LOW_j) are shown in Fig. 9 (b).

Finally, all dimensions of the jean flat in width direction were represented by hip parameter and waist parameter.

5. Application and validation

5.1. Application

In order to apply our proposed method, Visual Basic computer language was used to develop an application named jean flat recommendation system 2016 (JFRS, 2016) following Eq. (1) through (13). In the recommendation system, the value of α, β, γ, π, e_h, e_w and ε_k were set to 6, 4, 6, 3.14, 2, 15, and 0 respectively. If fashion designers are not satisfied with the flat generated by defaults, they can adjust them until a satisfying result is obtained. As shown in Fig. 10, six parameters; jean silhouette type, length and waist height type (geometric constraint parameters), and human body stature, waist and hip (dimensional constraint parameters) can be input and selected, and the output of this system is a jean flat.

For a designer, the garment flat is used to transform their abstract design concepts into concrete drawing. With the help of JFRS 2016, a series of jean flats are generated by adjusting different parameters. In Fig. 11(a–c), only one of design parameter is

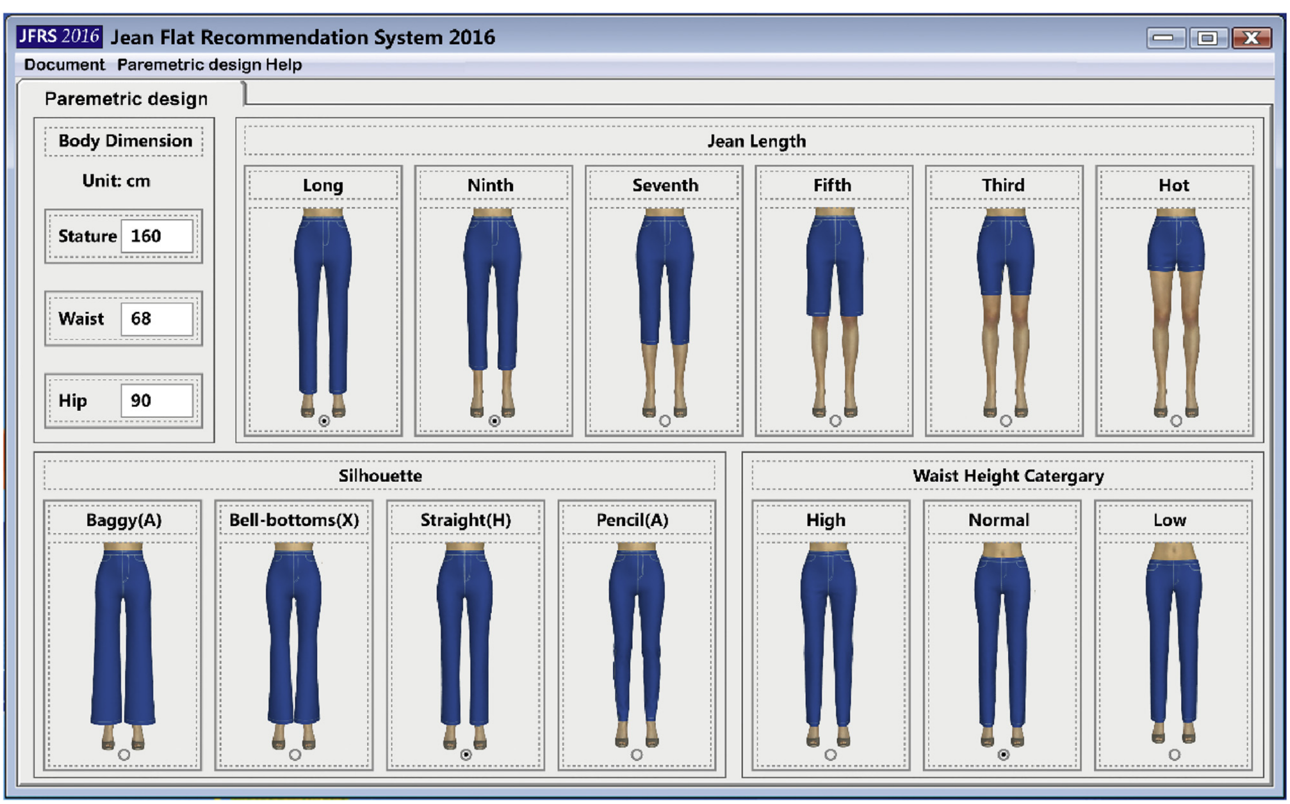


Fig. 10. Interactive interface of jean flats recommendation system 2016 (JFRS, 2016).

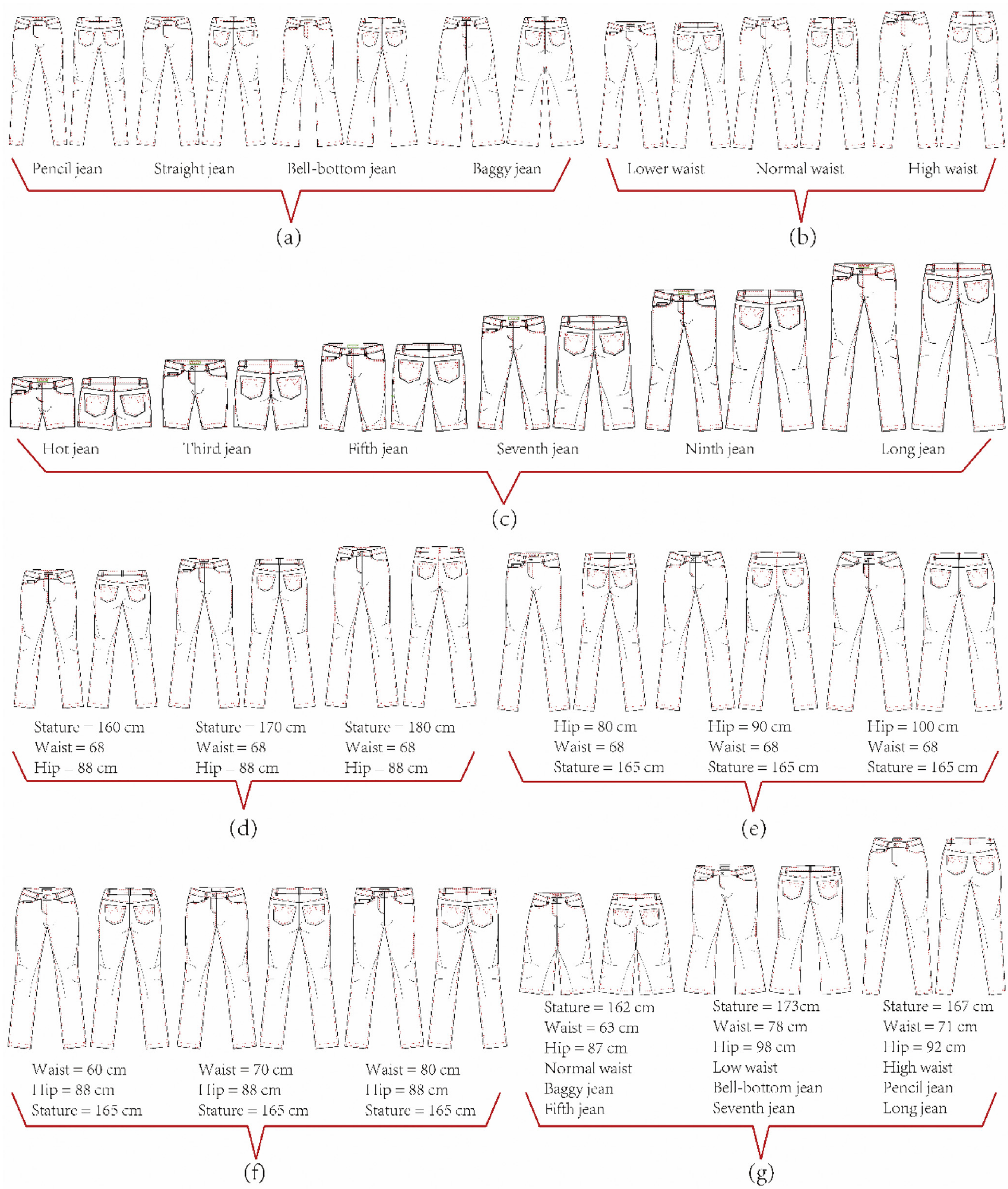


Fig. 11. Jean flats generated by JFRS 2015.

changed, the generated flats correspond to the virtual jeans in Figs. 6–8. In Fig. 11(d), three different values are used for parameter stature, the length of jean flat increases with the stature and the whole structure of jean style is harmony and proportionate. The same effects can be observed in Fig. 11(e) and (f) when the different values are applied for hip girth and waist girth. Fig. 11(g) shows the result of random values of six parameters. Through inputting and adjusting the six parameters, JFRS 2016 can generate various jean flats (Fig. 11).

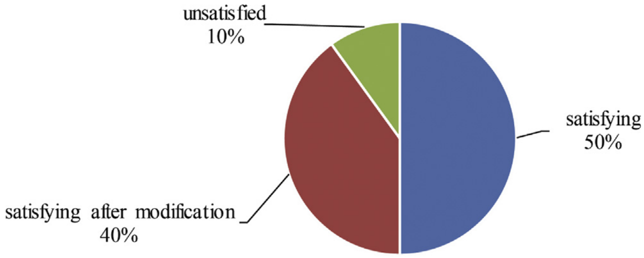


Fig. 12. Designer satisfaction survey.

5.2. Validation

In the actual design process, a fashion designer draws a complex flat requiring several hours; however, only a few seconds are required by using our method. The design efficiency is improved significantly. Our technique also offers the option of easily adjusting inputs, where the generated flats do not completely meet the requirements of fashion designers. For example, if the designer is satisfied with the whole flat generated by JFRS 2016, except the part of pocket; the only part that would need to be modified is the pocket. As a result, the efficacy of this method is also higher than completely redraw a new one by hand.

In order to test whether jean flats generated by our proposed method meet designers' requirements, 20 fashion designers were invited to use JFRS 2016. Every designer used JFRS 2016 to generate a jean flat according to his own idea. After this, each designer contrasted whether the generated flat fits with his idea. The result of designer satisfaction survey is shown in Fig. 12, 40% designers satisfy the jean flats generated by the proposed system at the first time; 40% designers satisfy the jean flats generated by the proposed system after modification. Only 20% designers were dissatisfied with the jean flats that were generated by the proposed system. In general, the jean flats generated by parametric design method can accurately represent jean's characteristics. They can clearly express the fashion designer's intention.

6. Conclusion

In this paper, a parametric method was developed to generate jean flats. Ultimately, the jean flat was parameterized by six parameters: silhouette type, length type, waist height type, human body stature, human body hip and human body waist. Compared to the traditional manual drawing method of jean flats, our parametric design method draws jean flats rapidly and automatically. Further, our proposed method is timesaving for fashion designers, and distinctly reduces jeans' development costs. Users without fashion design knowledge can also develop professional jean flats rapidly using JFRS 2016. Although, this research only focuses on the parametric design of jean flats, this method can also be applied for development of flats for other clothing styles.

Moreover, the design of a garment flat involves not only artistic creation, but also engineering design. The result of garment flat parametric design showed that engineering design and artistic design have a close relationship. Engineering design has been successfully applied to solve the question of artistic design. This is a novel research idea in the field of fashion design, and can be further applied in other design domains.

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