Pants design and pattern generation based on body images

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ABSTRACT – REZUMAT

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The personalized pattern generation method based on 2D body-measuring technology has considerable application potential in clothing e-commerce, remote clothing customization, clothing production, and other aspects. By inputting the front and side body images, this study proposed a new method of generating personalized patterns automatically. The silhouettes could be extracted from the body images to estimate body sizes and design style. The basic rules between the patterns and the body sizes were analysed, and the rules of the general pattern generation were established through a knowledge-based combination of the basic pattern and the style parameters. The sizes extracted from images were compared with the manually measured values, and the errors of these sizes were analysed. Sample pants were made and tried on with the automatic pattern generation system, and the experiments showed that the sample pants have a good fit at some key landmarks. As a result, this system can automatically generate personalized patterns and style designs based on 2D human body images, to improve garment fit and accelerate clothing customization.

Keywords: *size extraction learning, silhouette design, prediction model, body-garment relationship*

Designul pantalonilor și generarea tiparelor pe baza imaginilor corpului

Metoda de generare a tiparelor personalizate bazată pe tehnologia de măsurare a corpului 2D are un potențial considerabil de aplicare în comerțul electronic de îmbrăcăminte, personalizarea de la distanță a articolelor de îmbrăcăminte, producția de îmbrăcăminte și alte domenii. Prin introducerea imaginilor corpului frontal și lateral, acest studiu a propus o nouă metodă de generare automată a tiparelor personalizate. Siluetele ar putea fi extrase din imaginile corpului pentru a estima dimensiunile corporale și designul. Au fost analizate regulile de bază dintre tipare și mărimile corpului, iar regulile generale de generare a tiparelor au fost stabilite printr-o combinație bazată pe cunoștințe despre tiparul de bază și despre parametrii stilului de construcție. Dimensiunile extrase din imagini au fost comparate cu valorile măsurate manual, iar erorile acestor dimensiuni au fost analizate. Prototipurile de pantaloni au fost realizate și testate cu sistemul de generare automată a tiparelor, iar experimentele au arătat că produsele se potrivesc corespunzător în unele puncte cheie. În concluzie, acest sistem poate genera automat tipare personalizate și modele bazate pe imagini 2D ale corpului uman, pentru a îmbunătăți corespondența articolelor de îmbrăcăminte și pentru a accelera personalizarea îmbrăcămintei.

Cuvinte-cheie: *învățarea extragerii mărimii, designul siluetei, model de predicție, relație corp-îmbrăcăminte*

INTRODUCTION

With the rapid advancement of IT (Information Technology), the traditional clothing industry has stridden towards automation and digitization that drive the growth of electronic commerce and online retailing [1]. Now, the developing tendency of 3D GCAD technology mainly shows as follows: virtual sample manufacture (i.e., tailor-made), remote clothing fitting (i.e., virtual fitting), virtual clothing design, garment pattern generation with quick response, and so on [2]. Many technologies need to be used to realize the automatic generation of personalized garment patterns, such as 2D/3D body measurement, modelling, and parametric pattern design [3, 4].

Therefore, many researchers have focused on how to combine with the new technologies [5]. Early in 1972, the United States took the lead in developing the earliest GCAD system in the world – the MARCON system. Subsequently, Gerber Company developed a series of products, and many GCAD systems have been launched in the clothing industry [6–9], including, an individualized skin-tight garment pattern generation system based on kinematics 3D body models, 2D-3D virtual CAD design system (PGDSS), Optitex V-Stitcher and DC-Suite 3D CAD system, etc. These systems are widely used, which could be summarized as two methods (including A and B) of garment pattern generation. As for method A, the 3D human body model needs to be established according to the human body characteristics, and fashion design can be done based on the model to generate the patterns through parameterization and pattern combination. This method is very difficult to realize 3D garment modelling, and still lacks effective means so far. As for method B, the surface flattening technology simply depends on the computer simulation technology and inevitably has the problem of curve deformation in the mapping process. Therefore, the two methods cannot be well applied in apparel design and pattern generation.

Although 3D body scanning systems have been widely studied and used in institutional research, high price and other practical issues have slowed down their widespread applications [10–16]. There has been a need to explore more economical approaches for pattern generation [17–19]. The methods that simply use digital images taken from off-the-shelf cameras to extract human dimensions have been developed to meet this need and may be characterized as a 2D body-measured method [20]. This method can be mainly divided into four steps, including image acquisition, silhouette extraction, landmark recognition, and girth fitting [21–24]. According to the topic "Body size measurement based on body image", 448 papers were found in the database "Web of Science" from 2006 to 2019. Therefore, studies in this direction are attracting more and more attention, and the research results can be applied to the clothing manufacturing industry for garment customization. This study will focus on the rules between the human body sizes and garment pattern lines, and then develop a new approach to apply the 2D body measuring technology to pant apparel design and pattern generation [25, 26]. The research can realize the personalized generation of the Pant pattern, which is of great significance for promoting the development of the clothing industry.

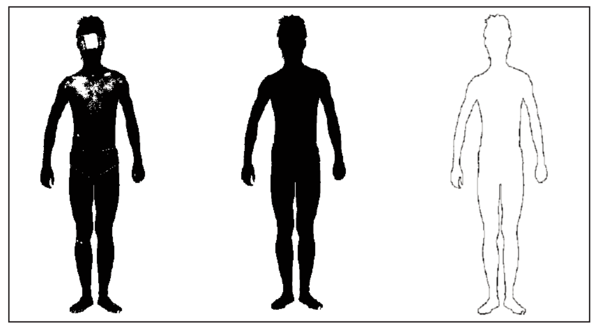
METHODS

Research framework

Figure 1 shows the core scheme of the pattern generation system. First, the front and side silhouettes can be output by inputting the front and side images of the human body, and then some main landmarks of the silhouettes can be identified to estimate the body sizes and design the apparel styles. Size extraction can be realized by calculating the distance between the feature points of the landmarks and the girth prediction model in this process. Second, the rules between human body sizes and basic patterns were researched through experiments, and the mathematical models of style design were established between the feature points moving distances and the values of the pattern lines. Finally, the generation rules of personalized patterns can be obtained by combining the basic pattern rules and design parameters (ΔXi, ΔYi, and ΔGi). In this system, the personalized pattern can be output by inputting images and moving the feature points of the landmarks.

Body size extraction

An imaging system was designed to get the front and side images of the human body in previous research, and the body sizes needed for basic pattern generation could be estimated [27]. The body images were processed through thresholding, filling, and opening functions, and then the smooth silhouettes could be obtained, as shown in figure 2.



a *b* *c*

Fig. 2. Body silhouette extraction: *a* – segmentation; *b* – filling and opening; *c* – body silhouette

According to the body characteristics, the feature landmarks, namely waist, hip, thigh, knee, and ankle, could be determined, and then the feature sizes, such as the heights, lengths, widths, and depths could be obtained. The typical height range (i.e., Ri means the ratio between the landmark's height and the body height) was used to limit the general location of the landmarks by analysing the height measurements from 318 young men, and then the shape feature was analysed to locate the actual position, as shown in table 1 and figure 3, *a*.

Take the hip landmark as an example. According to the statistical analysis of basic body proportion using the manually measured data, the hip height fell into a range between 45% and 52% of the body height, which is denoted as RH-max for the upper limit and RH-min for the lower limit. The hip is defined as the horizontal line at the widest point of the hip, and the hip feature normally is more obvious from the side view. When the landmarks were determined, the feature points could be determined to calculate the body sizes,

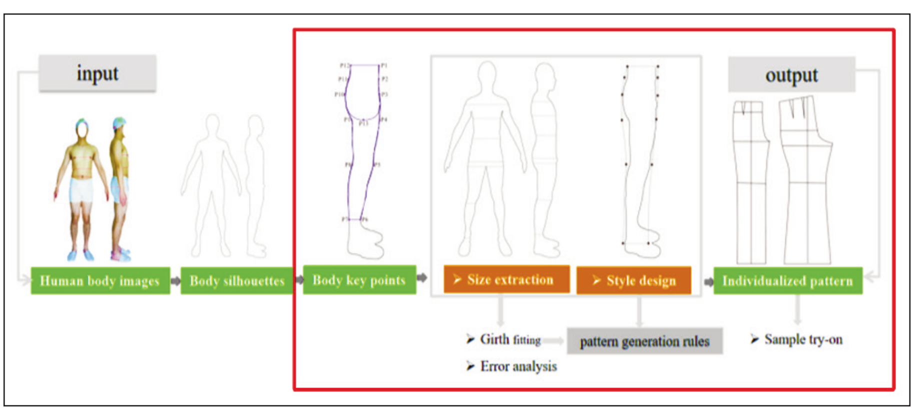


Fig. 1. Pattern generation system based on body images

Table 1

DEFINITION AND TYPICAL HEIGHT RANGE OF THE LANDMARKS			
Landmark	**Definition**	**Ri-min**	**Ri-max**
Waist	The horizontal line at the natural waist, is the narrowest point around the torso, below the bottom rib and above the hip bones.	0.58	0.65
Hip	The horizontal line at the widest point of the hip, typically across the fullest part of the hip and over the upper end of the thigh bone.	0.45	0.52
Thigh	The fullest part of the thigh, high up on the leg, just below the crotch.	0.41	0.49
Knee	The horizontal line goes over the protruding bone at the inside of the knee and across the kneecap.	0.18	0.29

Note: Ri-min and Ri-max represent the minimum and the maximum value of the ratio between the landmark's height and the body height; i mean the waist (W), hip (H), thigh (T), and knee (K).

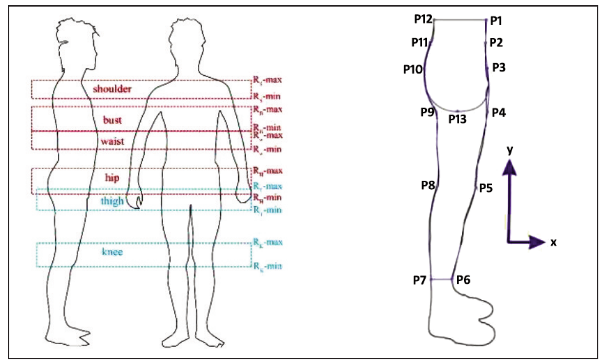
including the heights, widths, depths, and lengths, however, the girths of the landmarks could not be directly obtained. Considering that the width and depth at a landmark are the major parameters that reveal the shape information of the cross-section, the width-depth ratio (R = width/depth) can be used to classify human body shape. Therefore, the girth values of the characteristic parts were predicted based on the widths and depths.

Apparel design based on body silhouettes

To realize the interactive apparel design online, we choose the side body silhouette for the pant design, as shown in figure 3, *b*. According to the relationship between human body characteristics and pattern structure, thirteen feature points at the side silhouette were defined, including waist, abdomen, hip, crotch, thigh, knee, and ankle. The front crotch is the base of the torso at its centre point between the legs. The ankle is the horizontal line that goes across the inside ankle's most prominent point. The definitions of the other landmarks were already shown in table 1.

Table 2 shows the feature points of the corresponding landmarks. For example, P1 is the front waist point, P12 is the back waist point, and the distance between P1 and P2 is the waist depth. According to the rules, these points can be identified in human body silhouettes. For other points which cannot be directly determined, such as P13, the relationship between the coordinate of the P13 and crotch depth is analysed.

These feature points can be moved up and down to change the height of the landmarks, or left and right to change the ease allowance of the pants. The change values which were defined as "ΔYp" of P in the vertical direction will affect the height of the landmarks, such as high-waist and low-waist. The changes at the knee and ankle lines mainly are in heights and widths, to generate the flared pants or tapered pants, and long or short pants, therefore, the change values which were defined as "ΔXp" of P in the horizontal direction will affect the girth of the landmarks, such as the flared pants or tapered pants. For the style design of pants, the change values of the width relevant with "ΔXp" for the pattern had been defined as "ΔGp", and then the rules between "ΔXp" and "ΔGp" was researched.



a *b*

Fig. 3. The landmarks and Style design: *a* – the height range of the landmarks; *b* – pants' feature points

Table 2

THE CORRESPONDING LANDMARKS OF THESE FEATURE POINTS	
Pant points	**Landmark**
P1(XP1,YP1)/P12(XP12,YP12)	Front/back waist point
P2(XP2,YP2)/P11(XP11,YP11)	Front/back abdomen point
P3(XP3,YP3)/P10(XP10,YP10)	Front/back hip point
P4(XP4,YP4)/P9(XP9,YP9)	Front/back crotch point
P5(XP5,YP5)/P8(XP8,YP8)	Front/back knee point
P6(XP6,YP6)/P7(XP7,YP7)	Front/back ankle point
P13(XP13,YP13)	Crotch point

Note: Xi and Yi (i= P1-P13) mean the X-direction and Y-direction values of the key points. For the points of the pants, YP1=YP12, YP2=YP11, YP3= YP10, YP4=YP9, YP5=YP8, YP6=YP7.

Pattern generation rules

Fifty young men were selected as subjects to research the rules, the real sizes of the human body were calculated by the image measurements and prediction formulas, and their basic pants' patterns were obtained by draping experiments and mannequin modification, to analyse the rules between the basic pattern and human body size. Figure 4 shows the basic pants' rules, and the front and back patterns of the pant were placed against the body to connect the lines and curves with the sizes of the human body based on six main characteristic landmarks, including

Table 3

THE GENERAL PATTERN RULES			
Lines	**Body measurements**	**Lines**	**Body measurements**
A1A2	ankle height+ΔYp6	B1B2	ankle height+ΔYp6
A1A3	knee height+ΔYp8	B1B3	knee height+ΔYp8
A1A4	thigh height+ΔYp4	B1B4	thigh height+ΔYp4
A1A5	hip height+ΔYp3	B1B5	hip height+ΔYp3
A1A6	waist height+ΔYp1	B1B6	waist height+ΔYp1
A7A8	Front waist girth/2+Front dart width	B7B8	Back waist girth/2+Back dart width
A8A9	Front centre length+ΔYp1+ΔYp3	B8B9	Back centre length+ΔYp10+ΔYp12
A9A10	(Front hip girth+ΔGFH)/2	B9B10	Back hip girth/2+ΔXp3+ΔXp10
A11A12	Front thigh girth+ΔGFT	B11A12	Back thigh girth+ΔGBT
A13A14	Front knee girth+ΔGFK	B12B13	Back knee girth+ΔGBK
A15A16	Front ankle girth+ΔGFAN	B14B15	Back ankle girth+ΔGBAN
A16A17	Inside leg length–ΔYp8–A12A16 curve length	B14B17	Inside leg length–ΔYp8–A12B14 curve length
A15A18	Outside leg length–ΔYp8–A11A15 curve length	B15B16	Outside leg length–ΔYp8–B11B15 curve length
A19-A21	Front dart design	B18-B23	Back dart design

Note: ΔYpi, i = 1-16, means the height change at the key landmarks, ΔGi, i = FH (front hip), BH (back hip), FT (front thigh), BT (back thigh), FK (front knee), BK (back knee), FAN (front ankle) and BAN (back ankle) mean the girth change at the landmarks.

the waist, abdomen, hip, thigh, knee, and ankle. There are twenty-one key points (A1 to A21) for the front pant pattern and twenty-three key points (B1 to B23) for the back pant pattern. Thirty-two structural lines were selected for the pants' patterns, for example, A1A2 represents the position of the height at the pant hemline, which is related to the ankle position of the human body, A7A8 means the front waist girth of the pants' pant (including the front waist dart and girth ease). Since the darts of the pattern were designed based on experiences in practice, points A19-A21, and B18-B23 were determined according to the design requirements.

By combining the basic pattern rules with the changes in the heights and girths at the landmarks, the personalized pattern rules are expressed in table 3, to show the detailed pattern-making methods for the customized pants.

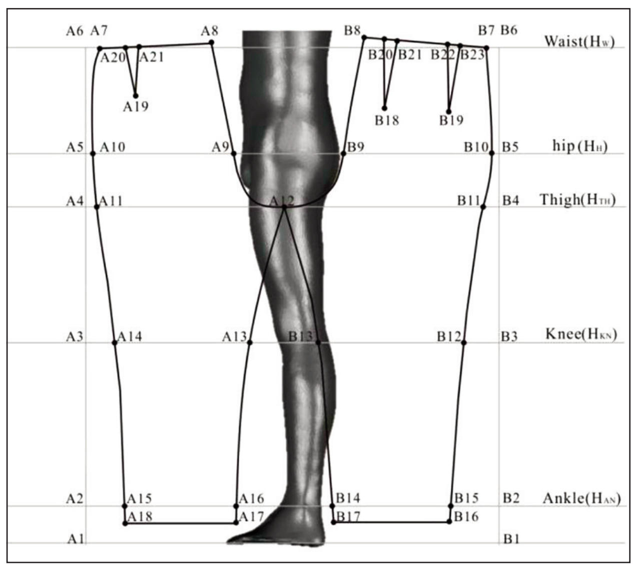


Fig. 4. Front and back patterns of pants based on the human body

RESULTS AND DISCUSSIONS

Girth prediction

The shape of the landmarks was classified according to the ratio between the widths and depths of 318 subjects, and the calculation rules of the girths at the waist and hip were shown in table 4.

Error analysis

The girths extracted from the system were compared with the manually measured sizes for error analysis. The absolute error (EA) and relative error (ER) were both used to verify the accuracy of this system, and the calculative models are in the following equations 1 and 2. Among these equations, G_S means the girths predicted by the system, and G_M means the girths measured manually.

$$E_A = |G_S - G_M| \quad (1)$$

$$E_R = \frac{E_A}{G_M} \% \quad (2)$$

Table 5 shows the relationship between the absolute error (EA) and relative error (ER) at each landmark, and the percentage (P) within the error ranges. When the ER value is less than 2%, the EA values at all landmarks were all less than 2 cm, and the EA values of hip girth are relatively higher. When the ER value is less than 3%, the EA value of the hip girth is 2.09 cm, and the others are still less than 2 cm. As for the percentage, it was found that about 80 percent of the samples can have their EA values within the range of

Table 4

CALCULATION RULES OF GIRTHS AT MAIN LANDMARKS									
Waist					**Hip**				
Width/Depth	**R2**	**a0**	**a1**	**a2**	**Width/Depth**	**R2**	**a0**	**a1**	**a2**
1.10~1.20	0.830	8.969	–8.826	10.070	1.10~1.20	0.972	–25.546	–5.862	8.700
1.21~1.30	0.952	–0.321	–0.393	3.198	1.21~1.30	0.909	1.12	1.87	1.325
1.31~1.40	0.900	–1.853	0.639	2.382	1.31~1.40	0.817	7.832	2.442	0.696
1.40~1.50	0.933	3.482	1.534	1.536	1.41~1.50	0.826	16.623	1.434	1.194
1.51~1.60	0.932	7.150	0.722	1.901	1.51~1.60	0.795	80.518	–5.273	3.442

Note: The form of calculation rules: Girth = a0 + a1 × depth + a2 × width, a0, a1 and a2 mean the coefficients of the regression model.

Table 5

ERROR ANALYSIS BETWEEN PREDICTED GIRTHS AND MEASURED MANUALLY										
ER (%)	**Waist girth**		**Abdomen girth**		**Hip girth**		**Thigh girth**		**Knee girth**	
	EA (cm)	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**	**EA (cm)**	**P (%)**
≤2	1.74	56.2	1.81	49.0	1.93	60.6	1.21	44.9	0.81	52.8
≤3	1.65	72.2	1.87	63.5	2.09	76.5	1.56	63.3	1.06	72.8

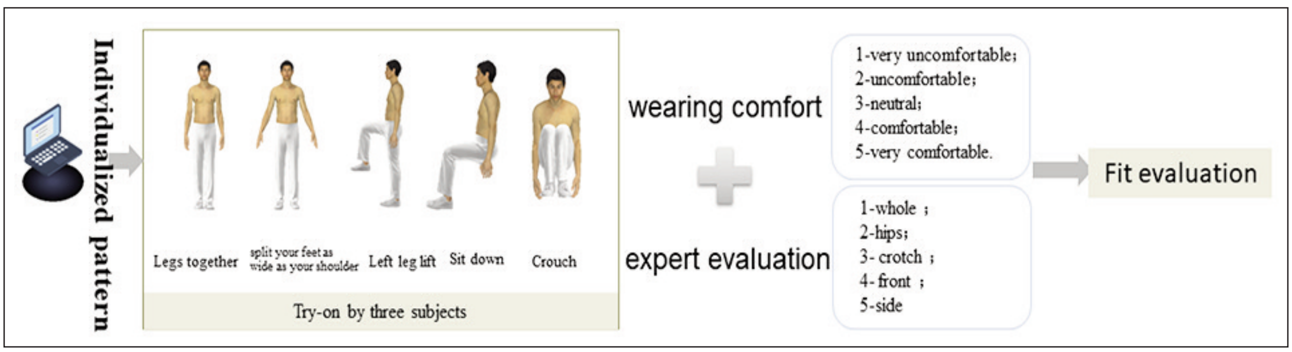


Fig. 5. Pants' pattern evaluation process

2 cm. Because the cross-sectional shape of the bust and hip is more complicated due to body characteristics, the prediction models may not be suitable for all people.

Garment evaluation

20 subjects with different body shapes were selected to evaluate the customized pants produced by the system effectively [28], by considering from two perspectives, including the expert evaluation and subjects' wearing comfort, and the evaluation framework was shown in figure 5.

For the expert evaluation, ten experts with at least five-year experience in the clothing industry were invited to evaluate the try-on effect at the feature landmarks, including waist, hip, crotch, outer and inner, and the experts gave a score with the range of 1–10 for each landmark, which means the higher the score, the better the effect. According to the final results, the mean of the score at the waist, outer, and inner is concentrated between 8 and 9, indicating that the fitting effect of pants at the waist, outer and inner is suitable. However, the mean of the score at the hip and crotch in under 8, which shows the pattern structure at the crotch and hip needs to be improved in further study.

For the subjects' wearing comfort, the pant fit was evaluated by the subjects to evaluate the comfort with five postures. In the questionnaire provided to the subjects, none of them chose "feel uncomfortable" during body movements. All the subjects reported "very comfortable" or "comfortable" during wearing the pants under the two postures, including 1-legs together and 2-legs apart as wide as your shoulder. When the posture changed to 3-sit down, 4-crouch, and 5-left leg lift, all the subjects reported "neutral" and "comfortable". Overall, the patterns generated with this method showed satisfactory fitting effects for the subjects with different body dimensions.

CONCLUSIONS

This study proposed a method for personalized pattern generation of pants by extracting body sizes and designing styles from body images automatically. For pants, 13 feature points were identified on the body silhouettes which were obtained by side image and then sizes extract and style design can be realized by moving these points. The models were built to predict girths from the 2D body sizes, and the rules between body sizes and patterns were researched. From the test results on 20 subjects, it was found that the body sizes predicted by the system were in good correlation with the manual measurements. The try-on test demonstrated the customized pants using this method could fit the subject's body well at important characteristic landmarks. All in all, this method can realize rapid and effective pattern-making, and meet the customers' demands for individuation and garment fit.

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