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Determination of Distance Ease at Crotch Curve for Customized Jeans

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Determination of Distance Ease at Crotch Curve for Customized Jeans

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Abstract

Determination of Distance Ease at Crotch Curve for Customized Jeans

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In the apparel industry, pattern making and alterations are expensive and time consuming, because they require iterative fitting and adjustment to develop garment patterns that fit their target consumers. The goal of this paper is to accelerate the pattern making process for jeans customization, which incorporates proper ease distribution at crotch curve in a 3D jeans design and pattern alteration by developing ease distribution models.

In this research, four female jeans with different crotch ease allowances were developed. The patterns were drafted using flat patterning methods. The fitting process was conducted and evaluated according to standard fitting criteria. Furthermore, the size 8 mannequin, and then the jeans with the mannequin inside were scanned by the Kinect Body Image System. The crotch curves of the mannequin and the jeans were obtained, and were then extracted to the Accumark CAD system where the radial distance eases of the crotch curves were defined and measured. Correlation analysis between the distance ease and crotch ease allowance was conducted, and regression analysis was used to develop ease distribution models. The applications of the regression models in 3D jeans design and jeans pattern alterations were discussed.

This research enhances the understanding of the ease distribution at the jeans crotch area. The results of this research provide essential ease distribution information for the jeans pattern alterations and jeans construction on a 3D model.

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Chapter 1: Introduction

1.1 RESEARCH BACKGROUND

In the apparel industry, the fit of clothing is an integral part of garment quality, and significantly affects consumers' satisfaction (Song & Ashdown, 2012). Yet, according to a report conducted by Kurt Salmon Associates, consumer dissatisfaction rate with ready-to-wear fit has reached 50% in females and 62% in males (Song & Ashdown, 2011; Ashdown & Dunne, 2006; Satam et al., 2011). In terms of fit satisfaction, pants were recognized as the least satisfactory clothing item in ready-to-wear and one of the most difficult clothing to fit because it involves the crotch area (Henson, 1991; McKinney, 2007). The crotch area is the major cause of pants fit problems because it relates to the complicated anatomical structure and body movements (Henson, 1991).

1.1.1 Crotch Curve

Pants crotch curve is defined as the seam line that intersects with the inseam line, connecting the front and the back center lower waist (Henson, 1991). Specifically, the contour line of the crotch shape close to the crotch point is relatively flat (Henson, 1991). It is widely recognized that the design of pants' crotch curves is critical for the pants fit, because it involves the inseam and connects the front to back body (Henson, 1991).

However, it is difficult to take accurate measurement of the crotch area (including crotch shape) manually, because it is obscured between the legs and on the genitals point which would make people feel uncomfortable to have their crotch area measured (Henson, 1991). Henson (1991) used a device called flexible curve (flexicurve), which was usually used in pattern making and architecture, to capture the crotch shape, and she used a plumb line attached to the flexicurve to determine the position of crotch point. However, this method was confronted with the difficulty of determining the orientation of the crotch curve. In addition, the subjects would feel uncomfortable to be measured at their crotch area.

With the 3D body scanner, these problems can be resolved by extracting the crotch curves from the scanning system, and it only takes several seconds to scan a human body without touching it. Current scanners are unable to capture the point clouds of crotch curve between legs; therefore, the curve of that area is estimated by connecting the front and the back center crotch curves. Thus, the accuracy of the crotch shape and measurements has not been clearly defined and therefore it should be carefully evaluated.

1.1.2 Body-to-pattern Relationship at Crotch Curve

Since crotch curve has been the major reason for the misfit of pants, it is essential to develop a scientific relationship between body crotch curve and pattern crotch curves, which will reflect individual body dimension information on the pattern measurements and shape. A few research studies have been done to investigate the body-to-pattern crotch relationship for the best fit of pants. Henson (1991) developed a method to analyze the relationship between body crotch shape and pants crotch shape by comparing the average male crotch seam curve to the pant pattern crotch curves. She built a regression model to determine the best fit shape of the male pants crotch curve. However, due to a lack of integrating ease and style features (darts and pleats) into the crotch seam shape, the comparison was considered to be meaningless. In addition, little body-to-pattern relationship at the crotch area was found.

Moreover, assuming that width and silhouette of the body crotch curve can be directly applied to the pattern crotch width and silhouette, McKinney (2007) copied the body crotch curve to the pattern, and found that the pants generated were too loose at the abdomen and buttock areas. She concluded in her later experiment that the pattern crotch width should be 0.33 inches narrower at abdomen level, and 2.37 inches at hip/buttock level, than the body crotch width. In this study, however, no straight relationship between body crotch shape and pattern crotch shape was found by simply comparing the body crotch measurement/shape and pattern crotch measurement/shape,.

A scientific method is needed to determine the relationship between the silhouettes of the body crotch and pattern crotch curves and lengths, which will help to predict the pattern crotch silhouette for various body shapes. However, the body-to-pattern relationship at the crotch area is complicated, because the single crotch curve involves a variety of body shapes, including the buttock shape, abdomen prominence, the proportion of front and back body and so on.

1.1.3 Traditional Pants Pattern Making and Design

Before exploring the relationship between body crotch curve and pants crotch curve, it is important to understand how to draft the pants pattern in a conventional method based on the body measurements. In the apparel industry, patternmaking is essential in transferring the fashion design to real garments, because proper patternmaking ensures a good fit to the target consumers. In traditional apparel design, there are two major approaches for pattern development: draping and flat patterning technique. Draping, a method to produce patterns by conforming a fabric to the silhouette of a mannequin or human body and then marking, cutting and flattening prototype, ensures the style and the fit of garments. Flat patterning technique, a method of drafting patterns using formulas based on several body measurements (i.e., height, waist girth, hip girth), is widely used in industry due to its efficiency and speed (Huang, 2011).

However, both methods have three major common drawbacks. First, both of them cannot produce consistent patterns. Using the draping method, different people would generate different basic blocks even on the same mannequin (Huang, 2011); and in the flat patterning method, different pattern making experts (Armstrong, 2006; McKinney, 2007; Minott, 1978), according to their own experience, would establish their own formulas and ease allowances in drafting patterns for the same body form. This means that the patterns drafted for the same subject would be different by following different pattern making books. And most of all, those drafting methods cannot guarantee the right fit for all people with various body shapes. It is, therefore, vital to establish a more systematic approach for developing patterns that fit consumers of various sizes and body shapes (Huang, 2011).

Second, both methods are laborious, expensive and time consuming. It takes a long time and many fabrics to drape a design style, especially a complex style, because it goes through styling, marking, cutting the prototype, mock up, cutting the real fabrics and sewing. The flat patterning method requires iterative trial-and-error on paid fit models in order to make sure the patterns fit their target consumers before production (Huang, 2011).

Third, both methods require experienced pattern makers in order to design proper patterns. As pattern makers, they are required to be equipped with sufficient knowledge, skills and experiences of apparel design, garment construction and manufacturing, but usually it would take years of training to obtain those skills and knowledge (Istook, 2002; Huang, 2011).

1.1.4 Computer Aided Pattern Making and Design

All the problems of conventional patternmaking methods can resolved by the new technology--Made-to-Measure (MTM), which automates the apparel pattern making processes based on 3D body scanning measurements (Satam, et al 2011). This technology has been considered as the alternative solution to solve the misfit ready-to-wear situation (Ashdown & Dunne, 2006). Currently, the world-known commercial MTM systems include Gerber MTM Accumark CAD, Lectra FitNet custom patternmaking software, made-to-measure of Assyst Bullmer and Optitex Modulate Made-to-Measure software (Istook, 2002). Based on their principles, they are sorted into two groups.

In the first method, the size of a basic pattern (also called block or sloper) is automatically chosen, according to the individual’s body measurements, by the system from a graded pattern set; and then based on the differences between the standard pattern dimensions and the individual body dimension, multiple alterations are made on the standard pattern pieces; Finally, by merging all the alterations, the customized-fit pattern pieces are generated (Song & Ashdown, 2012). However, the current commercial MTM systems not only require operators to be equipped with professional practical pattern design knowledge and experiences, but also need to manually create various charts, including size chart, alteration chart by manually inputting data (Istook 2002, Song & Ashdown 2012).

The second method, which is applied in Optitex Modulate Made-to-Measure software, is an interactive 3D garment and 2D pattern system. It uses a set of dimensions or modules (e.g., bust, shoulder, hip, etc.) to parametrically define each pattern. As the dimension or arc is modified on the pattern, the garment on the 3D virtual model can be immediately changed and visualized. Compared to the first method, this method does not need to create rule table sets or sizing definitions (Istook, 2002; Song & Ashdown, 2012; Optitex Modulate MTM, 2014).

Although current commercial MTM systems have these alteration and grading functions, it remains challenging to produce custom-fitted clothes that fit well, because their drafting methods are almost based on passed down experience, rather than scientific knowledge of body-pattern relationship (McKinney, 2007). Therefore, fitting process seems to be needed for made-to-measure in order to make sure the garment produced is perfectly fit for the target customers. Moreover, even the most experienced pattern making experts can barely produce pants that are fit for any individual, let alone the fact that many experienced patternmakers are not good at using computer software to draft patterns.

That’s why the MTM has not been widely applied in apparel industry--the current commercial automated patternmaking systems are unable to develop customized garments with perfect fit for all customers. In 2004, Land's End, QVC, JCPenney, and indiDenim were reported to be successful in online MTM program (Song & Ashdown, 2012). They adopted a MTM system established by Archetype Technology. In this system, consumers typed in their key body measurements (e.g., weight and height, the proportions of thighs and hips), according to which apparel patterns were swiftly drafted by using Gerber's7 PDF 20008 and made-to-measure programs, and the patterns were laid out by Nester9 software and cut by Gerber's automatic single-ply DCS 3500 cutters 10. However, for unknown reason, those companies all discontinued their online mass customization programs (Song & Ashdown, 2012; Ives & Piccoli, 2003). It was guessed that the main cause was due to the relatively high rate of returning products resulting from fit issues (Song & Ashdown, 2012). In short, although CAD patternmaking systems can design and alter patterns easily, faster, and in low cost, the quality of CAD patternmaking still highly relies on the expertise of the patternmaker and the expensive fitting process (McKinsey 2012).

Based on the above situation, more and more researchers have been involved in developing better approaches to improve the fit of garments. So far, in academia, there are two major approaches for automatic pattern development: (1) automatic pattern development based on 2D CAD systems; (2) automatic pattern development based on flattening methods on a 3D model (Yang et al., 2007; Satam et al., 2011).

In the first approach, there are three methods in achieving automatic pattern generation in 2D CAD systems: (1) pattern alteration by grading rules; (2) automatic pattern development based on parametric design; and (3) pattern automation using artificial intelligence (Yang et al., 2007). The second approach, also called 3D-to-2D technique, is the process of designing the 3D garment on the 3D individual virtual model, and then generating the patterns by flattening the 3D garment surface (Yang, et al., 2007; Huang, 2011). In this approach, the ease distribution is important to ensure excellent fit of the garment (Huang, 2011). There have been several studies using distance eases, defined as the distances between the garment and the body surfaces, to describe the ease distributions of breast, waist, hip, knee and so on (Xu et al., 2008; Xu & Zhang, 2009; Wang et al., 2006; Zhang et al., 2012; Su et al., 2014). However, it remains unclear about how the ease is distributed at the crotch area, which is an integral part of customized-fit pants design.

Therefore, it is attractive to use 3D body scanner to study the distance ease distribution at crotch area, and to find out the relationship between distance ease and ease allowance at crotch length, so that once given the ease allowance of crotch length, the distribution of distance ease at this area can be predicted automatically. The results of this study can be applied in the 3D customized-fit jeans design to improve the fit of jeans, as well as in jeans pattern alterations.

1.2 THESIS OVERVIEW

Hence, the scopes of this study are to 1) systematically review and analyze the state-of-art methods of automatic customized pattern development, and to 2) determine the relationship between the crotch length ease allowance and the distance ease distribution.

This thesis consists of four major parts. The first part systematically reviews and analyzes the existing automatic pattern generation methods. In this part, two general methods were discussed: automatic pattern generation methods in the 2D CAD system as well as automatic pattern making based on a 3D apparel model (Chapter 2).

The second part of the thesis describes the methodology of the experiments. The body crotch curve and the jeans crotch curves of four various ease allowances were compared, and the distance eases at various angles were measured. Correlation analysis and regression analysis were used to find out the relationship between the distance ease and the ease allowance at crotch curve (Chapter 3).

In the third part, the experimental results were demonstrated. (Chapter 4).

The final part draws the conclusion, highlights the key results, discusses the limitations of this study, and provides recommendations for future work in this area (Chapter 5).

Chapter 2: Systematic Analysis of Existing Automatic Pattern Making Methods and Distance Ease Distribution

The fit of clothes is a fundamental element to earn consumers' trust of the brand. In order to bring their consumers back, JCPenny's 2014 spring slogan was "When it fits, you feel it", which showed that JCP's main focus was to fit their target consumers (JCP "when it fits, you feel it" commercial). The nature of fit is the relationship between body variations and pattern shapes for specific size (Gazzuolo, 1985). As the conventional pattern making process requires iterative fitting and adjusting, which is expensive and laborious, the automatic patternmaking systems have attracted a lot of researchers' interests to achieve the automation of customized fit garments pattern making (Huang, 2011).

In general, there are two main paths to automatic garment development process for mass customization. One path is based on the 2D flat pattern design using commercial CAD system, which involves the relationships between garment topography, body scan data, and apparel pattern design; and the second path produces pattern directly from 3D individual models by flattening technology (Satam et al., 2011; Yang et al., 2007; Carrere, et al, 2000).

2.1 AUTOMATIC PATTERNMAKING METHODS FOR GARMENT CUSTOMIZATION IN 2D CAD SYSTEM

2D pattern drafting methods are still widely used in computer aided pattern design systems. In this path, there are three methods under development: (1) pattern alteration by grading rules; (2) automatic pattern development based on parametric design; and (3) pattern automation using artificial intelligence (Yang et al., 2007).

2.1.1 Pattern Alterations by Grading Rules

In the apparel industry, standard blocks of different sizes are usually drafted by hand, and digitized and stored in the CAD systems. Customized garment patterns are generally created directly based on individual body measurements or are from the alterations of the standard blocks for specific size (Lim & Istook, 2012; Istook, 2002; Turner and Bond, 1999). There are two approaches to conduct pattern alterations in CAD systems. The first approach uses algebraic formula to modify the basic patterns based on the standard size charts and the proportions of the body dimensions; and the second approach grades the patterns using sizing, grading and alteration tables based on individual body measurements (Turner & Bond, 1999; Istook, 2002; Yang et al., 2007).

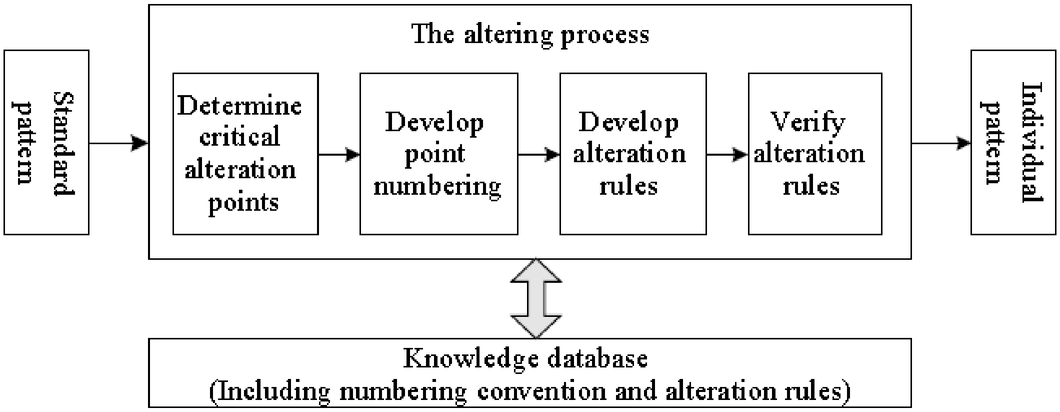


Figure 2.1 The patter n alteration process in MTM CAD system (Yang et al., 2007)

Although current MTM CAD systems use different approaches, the preparatory activities are of the same pattern alteration process, as demonstrated in figure 2.1. In this process, a standard pattern was the input of the alteration system. The pattern alteration process in the CAD system requires designers to possess a strong background of apparel design, grading, garment construction as well as excellent skills of CAD operations. Designers should always be clear about which points should be altered and how many changes needs to be made according to different individual measurement data, so that they can set the alteration rules for developing individual customized patterns (Yang, et al., 2007; Istook, 2002).

In conclusion, the principle of automatic pattern generation based on alteration is very straightforward and easy to understand for experienced experts. It not only allows customization of any size by inserting the individual size into normal manufacturing line, but also of any desired style by creating huge libraries of garment styles. Also, since it is faster and better fit for individual's body shape, customer loyalty will improve. On the other hand, this method has several drawbacks. First, since it involves establishing large libraries of garment styles and iterative testing of alteration rules, the work to build the system library is laborious; second, this method requires designers to have a strong knowledge of garment pattern design and production as well as excellent performance of CAD system which are not easily obtained. For beginners who have no clear clue about where and how to alter the pattern, this method is too difficult for them (Istook, 2002).

2.1.2 Automatic Pattern Development Based on Parametric Design

In this approach, apparel pattern can be considered a combination of a set of geometric elements (point, arc, line, and curve, etc.). Each pattern is defined and designed according to the constraint condition and topology structure. The pattern dimension is automatically modified as the input of individual measurement data updates. The nature of the parametric pattern design is that the pattern making production process is stored into the computer program by using a set of parameters that control the structure and size of a specific individual pattern. When the parameters are assigned by different values, the existing pattern pieces are transformed into new patterns (Yang et al., 2007).

Since garment pattern design involves a lot of experience values, the introduction of an expert knowledge database, which “absorbs” skilled pattern makers’ experiences and learns the way in which they analyze and alter patterns, is the key to guarantee the fit of garments. In order to tell the computer how to design the patterns, the patterns are graphically described by topology structure, geometric parameters and structure parameters. The topology structure means the pattern rules; the geometric parameters are used to indicate the geometric information (i.e., coordinate location) of the pattern; and the structure parameters involves the relationship between topology structure and geometric parameters (Yang et al., 2007).

Among three of them, the structure parameters of garment pattern can be classified into four categories: measurement parameters, design parameters, graphical parameters, and compound parameters. Measurement parameters are related to the critical measurements of body and clothes; design parameters, such as the ease amount and pleat value, often depends on the design style and consumers fit preference; graphical parameters, such as back hip width, are geometric variables (length of a curve or line) that decide other geometric values (i.e., crotch extension); Compound parameters, the combination of the above three parameters by a formula, are usually defined by experienced pattern makers (Yang et al., 2007).

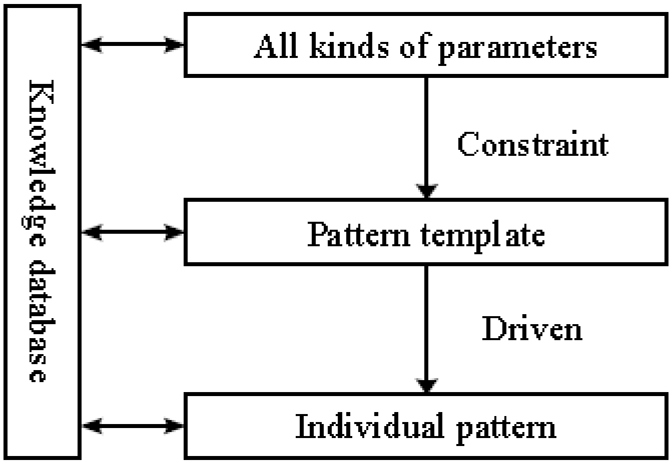


Figure 2.2 The principle of the parametric design for pattern making (Yang et al., 2007)

As indicated in figure 2.2, there are three main steps in the process of automatic pattern making in applying parametric design. First, the pattern development process is documented and the pattern template is defined by graphical structure. Second, the pattern template is constrained by all the parameters mentioned above. Last, with the input of individual measurement data, the parameter values are updated and new patterns are created automatically (Yang et al., 2007).

By recording the patternmaking process into computer, it becomes faster to develop patterns by using parametric design method. However, apparel design relies on pattern makers' experience and involves a lot of factors, including fabric properties, body shape analysis, manufacturing capability, it is critical to establish knowledge database to guide the drafting and alterations of pattern making, which is a laborious process. But once the database is established, the CAD system is ready to produce customized garments. Currently, pattern development systems based on parametric design are normally applied in the customization of garments with certain styles, such as suit, shirt, jeans and jacket (Yang et al., 2007).

2.1.3 Pattern Automation Using Artificial Intelligence

Another approach to automatically generating customized patterns is based on artificial intelligence (AI). The advantage of AI over the two approaches above is that it does not rely on a pattern maker's experiences to build the expert knowledge database. Two techniques of AI have been applied in apparel pattern design: one is Artificial Neural Network (ANN), the other one is Fuzzy Logic (Yang et al., 2007). For example, Chen et al. (2003) applied AI to predict shirt patterns by body measurement, fabric properties and fitting preferences. Zhu (2004) designed a men's wear MTM system by using fuzzy clustering pattern recognition theory through AutoCAD and VB programming. Although the method of AI reduces reliance on experienced pattern makers, it requires a number of experiments to evaluate whether the patterns are fit or not. Also, in order to apply AI in MTM, more work needs to be done for generating garments with different styles by applying more AI technique (Yang et al., 2007).

Although these methods provide a better fit of pants as well as accelerate pattern making process, still, the fit satisfaction rate remains relatively low. McKinney (2007) pointed out that it remained a challenge to develop custom-fitted clothes that fit well because the scientific knowledge of a body-pattern relationship, including ease values, remained unclear. Therefore, in order to design and produce customized jeans, it is necessary to study the relationship between body and pattern crotch curves with ease distribution incorporated, so that the front/back pattern crotch shape and lengths can be directly predicted from the corresponding body crotch shape and lengths.

2.2 AUTOMATIC PATTERN FLATTENING METHODS BASED ON 3D MODELS

Different from flat patterning and alterations in 2D CAD system, automatic pattern making method based on a 3D apparel model (also called 3D to 2D technique) is a method in which a 3D customized garment is constructed and draped on the individual virtual model and then the 3D garment surfaces are flattened into a 2D flat surface (Huang, 2011).

The process of using this approach is stated as follows: first of all, the individual is scanned by a 3D body scanner, point cloud data is obtained, a triangular human mesh model is created, and a torso model is established and represented by B-spline. Second, the key feature points and structure lines are identified, and the feature-aligned and ease-incorporated garment wireframe is represented by a set of B-spline curves. Third, ease allowances at various body positions were distributed around the human body to create an ease incorporated wireframe. Fourth, a 3D garment model is generated based on the ease incorporated wireframe; multi-resolution mesh generation. Finally, surface flattening technique is used to flatten three-dimensional garment surface into a 2D flat surface. (Huang, 2011; Kim & Kang, 2003).

In the past decades, there has been considerable interest in using 3D-to-2D flattening method to produce 2D blocks from 3D virtual clothes (Huang, 2011). There are generally four methods to flatten the garment surface: (1) physical flattening methods; (2) geometric flattening methods; (3) mathematical flattening methods; (4) pattern flattening using developable surface.

2.2.1 Physical Flattening Methods

The physical flattening technique uses triangles to represent each model with defined energy equilibrium (Liu et al., 2010; Huang, 2011; Yang, et al., 2007). Each triangular grid is simulated as an elastic spring-mass model with predefined energy model of system forces, masses, and elastic distortion (Huang, 2011; Yang et al., 2007). During the surface flattening process, the 2D pattern is mapped from all the 3D triangular grids with well-defined constraints, and the final pattern silhouette is determined when the system distortion energy diffusion reaches the minimum (Yang et al., 2007). The overlapping error might happen frequently, and it can be avoided by applying the penalty function which allows the vertices to move to the reverse direction (Wang et al., 2002).

In the study by Kim & Park (2007), the 3D garments were represented by triangular meshes. The patterns were modelled by inducing strain models. For every two vertices on each edge, the total strain can be calculated by the scheme in figure 2.3:

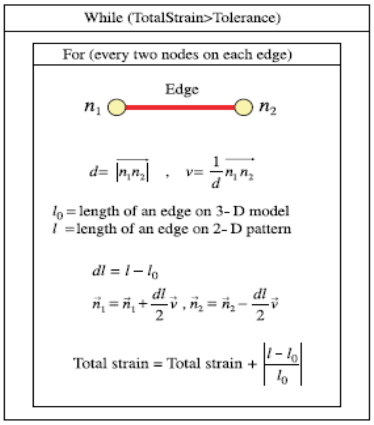
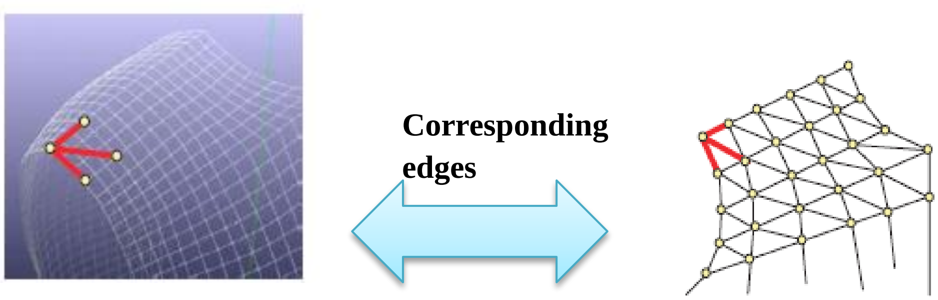


Figure 2.3 Scheme in physical flattening methods used by Kim & Park (2007)

By iterative correction and equalization of each corresponding edge (figure 2.4), the flat patterns were roughly determined. Pattern outlines for different fabrics were obtained by incorporating fabrics' physical properties, including "maximum elastic allowance and maximum shear angle allowance during the strain reduction, even the optimum shapes of patterns for different fabric material" (Kim & Park, 2007, p14). When the total strain deformation rate reached a predefined threshold rate, the final flats were acquired.



(a) 3D pattern

(b) 2D patter

Figure 2.4 Illustration of physical flattening method by Kim & Park (2007)

However, the physical flattening methods were considered inappropriate to be applied in pattern generation for the following reasons: first, even with the adoption of more constraints to define the model, distortions during the flattening process are inevitable, which results in considerable inaccuracy (Yang et al., 2007); second, as the definitions of the preliminary constraints and boundary conditions are significantly influential, and reliability of the system is not guaranteed (Huang, 2011).

2.2.2 Geometric flattening method

Surface parameterization, referring to "a one-to-one mapping from the surface to a suitable parameter domain" (Floater & Hormann, 2005, p157), is widely applied in geometric modelling (Sheffer et al., 2005; Shimada & Tada, 1991). The surfaces are characterized by triangular meshes and the mappings are achieved by piecewise linear functions, as shown in figure 2.6 (Floater & Hormann, 2005, p167). The model is segmented into several parts, and the surface is parameterized, and then combined on one surface, as indicated in figure 2.7 (Lévy et al., 2002). However, distortions in angle or areas usually occur from parameterizations, and the flattened surface silhouettes are usually irregular (Floater & Hormann, 2005). The major issue for geometric modelling is to preserve the shape when mapping (Huang, 2011). Several researches (Floater & Hormann, 2005; Sheffer et al., 2005; Shimada & Tada, 1991) proposed approaches, such as fixed (convex) boundary technique and Angle Based Flattening (ABF), to maintain the least distortion during mapping, however, the distortion remained unavoidable. In addition, without incorporating fabrics' properties and manufacturing limitations, geometric flattening techniques were considered not appropriate to be applied in apparel pattern flattening (Huang, 2011; Yang et al., 2007).

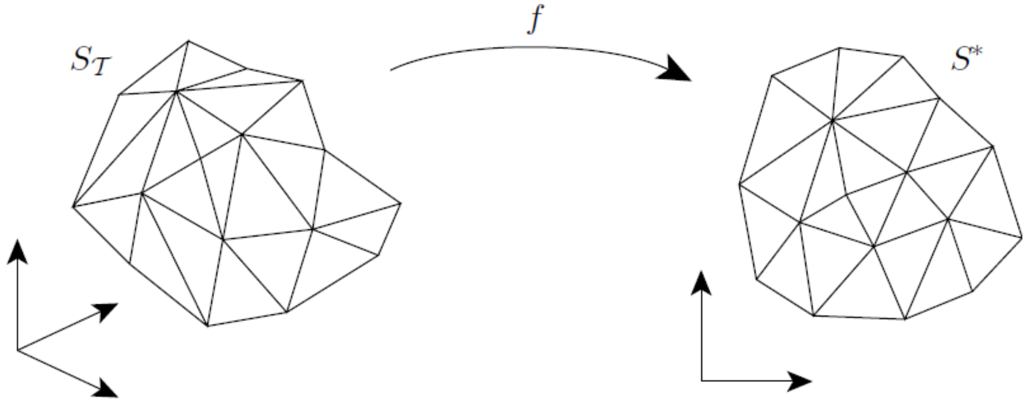


Figure 2.6 Transformation from 3D surface to 2D surface using piecewise linear functions (Floater & Hormann, 2005)

Figure 2.7 Surface parameterization: (a) Segmentation of the surface; and (b) the results of the surface flattening (Lévy et al., 2002)

2.2.3 Mathematical Flattening Methods

The mapping of the 3D garment curves to the predefined plane can also be achieved by using mathematical flattening methods (Petrak et al., 2006). Three methods were proposed by Petrak et al. (2006) to transform 3D curves into 2D patches:

1) Projecting a 3D curve to the surface defined by three points;
2) Projecting a 3D curve to the surface defined by Gaussian method of least squares;
3) Projecting a 3D curve to the surface defined by Gaussian method of least squares and related “function extreme”.

Before using these methods, the 3D pattern silhouette should be defined by conducting the first two steps:

1) Three 3D curve k is partitioned into m parts: k1, k2,…kj, …km, and each segment can be considered approximately as a straight line.
2) Each segment is then defined by n points.

The second approach, the Gaussian method of least squares, was introduced specifically by Petrak et al. (2006). This method involves finding, from planes parallel to plane j, a plane where the sum of the squares of the distances between the spatial points T_k and the projected points $T_{k`}$ reaches the minimum (figure 2.10 and figure 2.11). The equation for calculating the sum of the squares is shown below:

$$\sum_{k=1}^{n} d_k^2 = \sum_{k=1}^{n} (x_k \cos\alpha + y_k \cos\beta + z_k \cos\gamma - p)^2$$

where, p is the distance between the plane p and the plane r_j, the cosines of the angles α, β, is to express the coordinate axes x, y and z (Petrak et al., 2006).

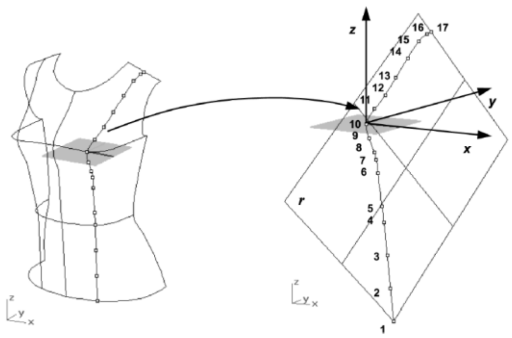


Figure 2.8 The transformation of a 3D garment curve on to a surface r (Petrak et al., 2006).

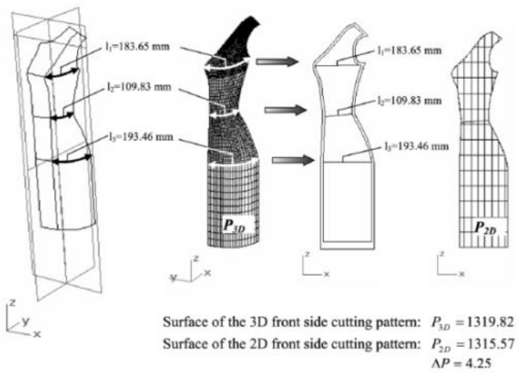


Figure 2.9 3D-to-2D transformation and lengths comparisons (Petrak et al., 2006)

Before using this method to flatten the 3D garment dummy, ease distribution might need to be defined in advance for a comfortable fit for an individual body. This mathematical method, however, hardly can be widely applied in fashion industry for at least two reasons. First of all, simply by projecting the edge curve of each panel, it seems to be impossible to create darts or gussets which are the important shaping devices of patterns. Secondly, regardless of the fabric's physical and mechanical traits, the accuracy of flattened pattern silhouette is hard to guarantee.

2.2.4 Pattern Flattening from Developable Surface

Developable surface is a surface which can be unfolded into a plane without distortion (Huang, 2011; Liu et al., 2007). A lot of research has been done on the approximation of developable surfaces (Pottmann & Wallner, 1999; Wang et al., 2004;

Decaudin et al., 2006; Huang 2011). Wang et al (2004) developed a method to improve the developability of non-uniform rational B-spline (NURBS) surface patches by minimizing Gaussian curvature. Decaudin et al. (2006) proposed a novel technique for approximation of developable surfaces. First, each piece is represented by a triangle developable surface which is approximated best locally. Second, each triangle is adjusted/rotated onto a plane with the minimum deformation of vertex position. The application of developable surface has been very popular in virtual garment construction and pattern flattening technologies (Huang, 2011; Decaudin et al., 2006).

Another flattening technique using developable surface is proposed by Huang (2011). First, the garment surface is segmented into 3D developable surface patches by applying a boundary triangulation method based on definition of closed region. Second, each developable patch is represented by successive triangles. It is assume that the shared angle between two triangles is θ. By rotating one triangular surface by angle θ, the two triangles become coplanar. This process repeats until all the triangles in the patch are on the same surface (figure 2.12). Third, after all the patches are flattened, they are not on one plane, and instead, they are positioned randomly in the air. A co-planarization algorithm is applied to position the patches onto a flat surface. Fourth, each patch is viewed as a vertice and the adjacent patches are linked by a curve (figure 2.13); based on the angle between the related edges and the Euclidean distance between the midpoints of two neighboring edges, the linking relationship between the patches is decided to be kept or removed. Those remaining linked patches are glued together as one group. Finally, the resulting patterns are created with the darts without fabric tearing or stretching (figure 2.14).

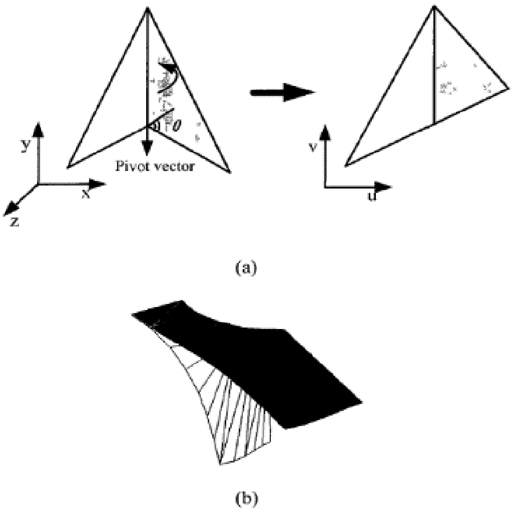


Figure 2.10 The principle of developable surface flattening through rotating triangles: (a) rotating the two triangles into co-planar by angle θ; (b) all the triangles of the developable pieces were unfolded (Huang, 2011)

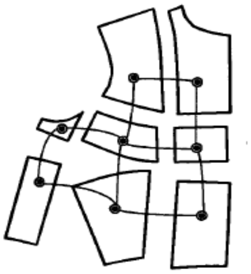


Figure 2.11 Linking developable patches using curves (Huang, 2011)

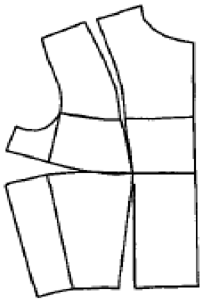


Figure 2.12 The resulting pattern (Huang, 2011)

Different from physical flattening method which uses spring-mass model to represent different fabric properties, this method puts textile properties into consideration by adjusting the ease distribution of the garment. When the ease amount reaches 20% of the original measurements, a fabric's physical and mechanical constraints need to be considered in pattern construction (Huang, 2011). In the apparel industry, various factors, such as fabric properties and garment construction, should be considered cautiously when designing the ease distribution (Huang, 2011). For example, when using stretchy fabrics, such as knits, ease amount tends to be zero or even be negative, while the ease distributions for non-stretchy woven fabrics are usually positive. Another example is pants. Depending on fashion trends, jeans tend to fit body tightly, while trousers are much looser (Armstrong, 2006).

This method (Huang, 2011) has advantages. First, since developable surface is utilized, the patterns generated from 3D garments are not distorted, which guarantees the accuracy of the pattern fit. Second, the textile constraints are incorporated into the ease distributions. However, the ease distributions are complicated and inconclusive because it is related to multiple factors, including the textiles constraints, wearers' fit preference, and body structure and so on. Therefore, it is important to conduct large scale experiments to summarize the ease amount on different fabrics.

2.3 EASE ALLOWANCE AND DISTANCE EASE DISTRIBUTION

Ease, "the dimensional difference between body and garment surfaces", is crucial for allowing wearers to move and breathe comfortably (Huang, 2011, P37). The ease amount needed for comfort, movement and desirable appearance is affected by various factors, such as design style, fabric physical and mechanical attributes, body shape, wearing occasion and personal preference (Rasband & Liechty, 2006).

Virtually, there are three types of ease: standard ease, dynamic ease, and fabric ease (Chen et al., 2006). As humans breathe, the body dimensions regularly expand and shrink in a slight range. Standard ease allowance, needed for standing and sitting, refers to the dimensional difference between the maximum and minimum body circumference at various body locations. The determination of dynamic ease allowance relies on body shape (i.e., big hip, prominent abdomen) and movements (i.e., walking and jumping). Fabric ease allowance is determined by the mechanical properties of textiles used in garment making (Chen et al., 2006). So far, the determinations of proper ease allowance and distance ease remain a challenge for current automatic pattern making systems or garment CAD systems because only standard ease allowance is generally considered (Chen et al., 2006). Chen et al. (2006) used fuzzy logic and sensory evaluation method to take both standard ease and dynamic ease into consideration to improve the pattern generation system.

Traditionally, ease allowance refers to the girth difference between body and garment (Wang et al., 2006), the distribution of distance ease means “the gap or vacant space between the body and the garment which includes distance, area and volume” (Xu et al., 2008, p201). Based on the current literatures, three types of distance eases have been proposed: radial distance ease, normal distance ease and longitudinal distance ease (Zhang et al., 2012; Xu & Zhang, 2009; Su et al., 2014). The radial distance ease refers to the radial distance between garment and body, as shown figure 2.15 (Zhang, et al., 2012). The normal distance ease, given in figure 2.16, is the length of the normal lines between body and garment surfaces (Xu & Zhang, 2009). It is reported that normal lines are more reasonable than radial distance ease in defining the vacant space between body and garment, because they are shorter and perpendicular to both garment and body surfaces (Xu, et al., 2009). The third type of distance ease is defined by a different way. Rather than a distance on a radial line, the longitudinal distance is the vertical distance between the garment and the body, as shown in figure 2.17 (Su et al., 2014).

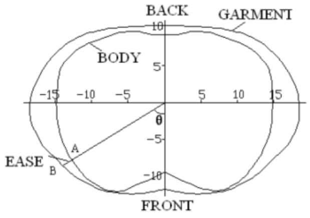


Figure 2.13 The radial distance at bust line (Zhang, et al., 2012)

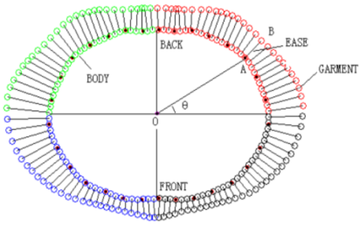


Figure 2.14 The normal distance at waistline (Xu & Zhang, 2009)

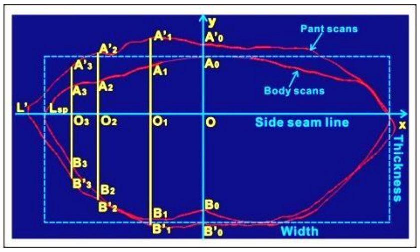


Figure 2.15 The longitudinal distance at hip line (Su et al., 2014)

The study of ease distribution using 3D body scanning data has attracted a lot of attention for the past decade. Xu et al. (2008) found that fabric material attributes have a significant effect on the distance ease amount. Xu & Zhang (2009) estimated the distribution of normal distance ease. Wang et al. (2006) developed a mathematical model of ease distribution using surface fitting method. Zhang et al., (2012) investigated the correlation between the distance ease and the average ease allowance, and developed mathematical models of ease distribution using regression analysis. These methods could be applied in the construction of 3D customized-fit virtual garment.

In addition, the determination of ease allowance also has the potential to improve the pattern alterations systems. In order to generate customized pants of desired fit, Su et al., (2014) selected cross sections of four key lower body positions—abdomen, hip, thigh and knee. First of all, the distance ease distribution was represented by the regression relationship between the distance ease and the ease allowances at the four body locations. Second, in their study, the cross sections of the body and the pants were conceptualized as two circles and the distance ease was approximately equal to the radius, as shown in figure 2.18. Then the segmental ease allowance $\Delta L = L_c - L_b$, can be equal to DE * α. From the figure 2.19, as we can see, the cross sections are divided into several segments. Each segmental ease allowance, also called pant increments at each part of the circle, were calculated and recorded. Last, for the balance of the pants, the segmental ease allowances were evenly diffused in the pants alterations (figure 2.20).

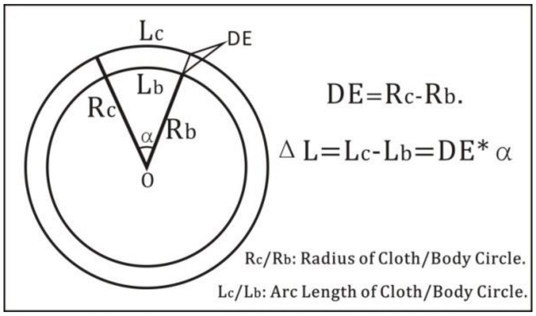
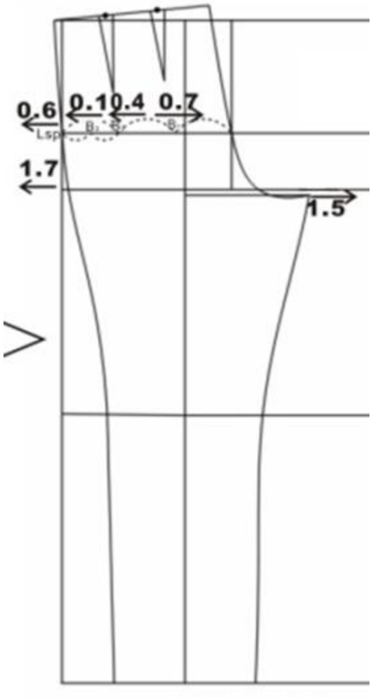


Figure 2.16 Conceptualized model for distance ease calculation (Su et al., 2014)



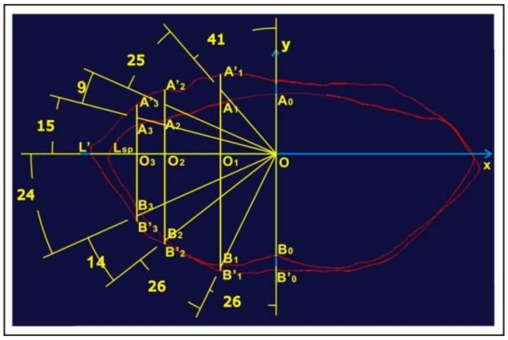


Figure 2.17 Distance eases at sampling points (Su et al., 2014)

Figure 2.18 The alteration of pants pattern using distance ease (Su et al., 2014)

The ease distribution has been studied on jackets (Xu et al., 2008; Xu & Zhang, 2009; Wang et al., 2006), shirts (Zhang et al., 2012), and pants (Su et al., 2014). The studies mostly focused on the ease distribution of the cross-sections of bust line, waistline, hipline, abdomen, thigh and knee. However, to the best of our knowledge, there is little study conducting research on the ease distribution of crotch curve.

2.4 SUMMARY

After reviewing the studies on the automatic pattern making methods, it can be concluded:

(1) Although 2D pattern making methods are widely applied due to its being straightforward and efficient, however, most of the methods rely on pattern making experts' experience and knowledge; and for pattern automation using artificial intelligent, it requires a large scale experiments to create libraries for different sizes and styles.

(2) In terms of the 3D-to-2D techniques, the procedures were described and the four surface flattening techniques were reviewed. It was found that physical, geometrical and mathematical methods were not appropriate for apparel pattern making. In contrast, the pattern flattening using developable surfaces seemed to be the best technique so far because no distortion occurred.

(3) Distance ease distribution models have been widely studied, but little research so far has investigated the distance ease distribution at the crotch curve using 3D body scanning body measurement data. Therefore, it is critical to study the ease distribution of the crotch curve for the application of the 2D pants pattern automatic alterations as well as for the 3D jeans pattern design.

Chapter 3: Methodology

The aim of this study is to determine the distance ease at crotch curve, and to develop regression models between distance ease of the crotch curve. The experimental results will be useful in building up the 3D female pants for jeans model in the 3D-to-2D automatic pattern generation system, and in shaping the crotch silhouette of pants patterns.

In the study of ease distribution, a mannequin is often used in order to prevent the impact of respiration and unconscious movements of the human body (Xu & Zhang, 2009; Zhang et al., 2012; Xu et al., 2008). In this study, a size 8 mannequin was selected as the model for our customized fit jeans.

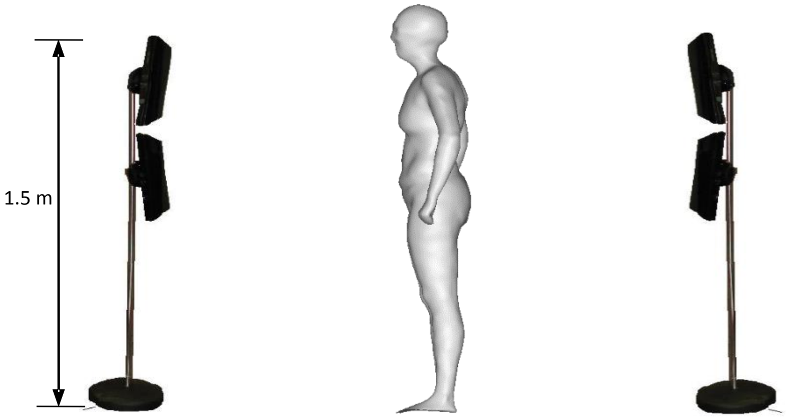


Figure 3.1: Schematic illustration of the Kinect body image system setup (Human Dimension Research Laboratory, School of Human Ecology at the University of Texas at Austin)

The mannequin was scanned by the Kinect Body Image system (KBI) at Gearing Hall (GEA) 207, the Human Dimension Research Laboratory at the University of Texas at Austin. The Kinect body imaging system is made of four Microsoft Kinect sensors, two are placed in the front and two in the back, as shown in Figure 3.1. Each sensor covers one quarter of subject's body surface. The Kinect sensor uses inferred light pattern for depth sensing, and captures the depth map of the imaged 3D space in VGA resolution (640×480). When the 3D body model was captured by KBI, the landmarks and dimensions of the body were extracted automatically. The method of extracting the landmarks and measurements of the body was the same as that in Xu et al. (2009), as shown in figure 3.2. Since the cameras could not capture the point clouds of the body between the legs, the crotch curve between the legs was estimated by smoothing the curve from the front and back portions of crotch curves.

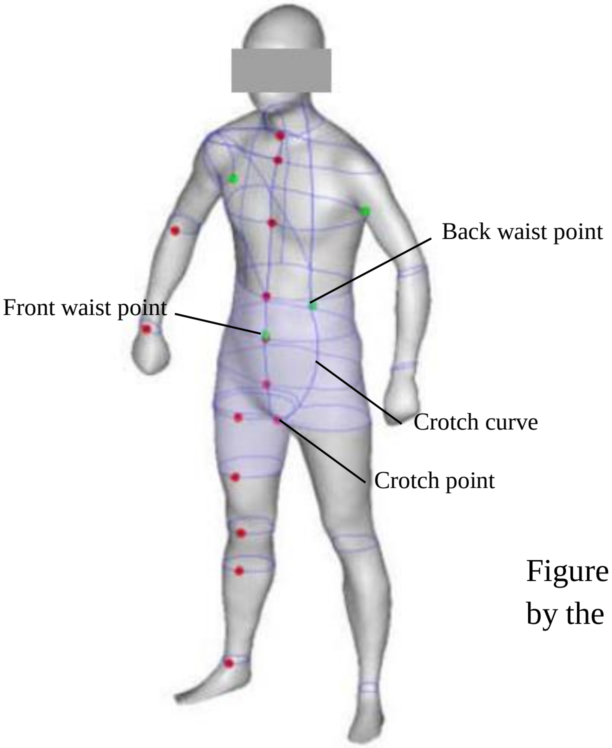


Figure 3.2: The landmarks and dimensions extracted by the 3D body image system (Xu et al., 2009).

Based on the measurements obtained from the scanning system, patterns of the four pants blocks for jeans with different crotch length ease allowances were drafted using Accumark CAD by following the jeans drafting method by Armstrong (2006). Since the focus of this study is crotch curve, only the foundations, the portion above the thigh line, of the pants block were developed. The ease allowances at the crotch curve lengths for four jeans are displayed in table 3.1.

Jeans subjects	**Measured Ease Allowance (mm)**	**Designed Ease Allowance (mm)**
Jeans #1	12.77	12.7
Jeans #2	26.07	25.4
Jeans #3	52.01	50.8
Jeans #4	78.14	76.2

Table 3.1: Jeans number and the corresponding ease allowance

Muslin was chosen because its fiber contents and weave structure were similar to denim. After the jeans samples were made, they were placed on the mannequin for fitting. In the fitting process, the fitting problems were analyzed, and pattern alterations were made accordingly. According to Erwin (1954) and Song & Ashdown (2012), there are five most important fitting elements to be considered: ease, line, grain, set and balance. The principles for pants fit judging taken by Song & Ashdown (2012) and Henson (1991) are as follows: a sufficient ease allowance for body movement, lines of pants conforming to the body form, and the grain line being parallel to the front and back center of the pants; pants that fit well should follow the silhouette of the front and back crotch curves, waist, and buttocks without wrinkles or looseness, and no fabrics are pulled or folded in these areas.

Four new jeans shorts were made after the patterns were adjusted for proper fit. The jeans were placed on the mannequin again to re-evaluate the fit. The unclothed mannequin and mannequins wearing the four jeans were scanned. The virtual models were generated, and the body measurements were obtained. The crotch curves coordinate points of all the unclothed mannequins and dressed mannequins were extracted from the image system. By inputting the coordinate point data and then connecting the related coordinate points, the crotch curves were regenerated in the Accumark CAD system, as shown in figure 3.3. The red line stands for the unclothed mannequin crotch curve, and the blue line represents the crotch curve of the mannequin in jeans #4.

In this coordinate system, the hipline is set as the x-axis, while the y-axis, perpendicular to the x-axis, is a line passing through the crotch point. From the origin of the coordinates, point O, radials were drawn every 15°. The distance eases (DEs) were defined as the space distance between the jeans and the body, as described by the following equation:

$$DE = d_j - d_b$$

where, d_j stands for the distance from point O to any location of the jeans crotch curve, and d_b stands for the distance from point O to any location of the body crotch curve.

Since the front and back waist points are the start and end points of the crotch curve, we added additional distance eases of these two points into the system. The distance eases at the front and back waist points were obtained by connecting the points of mannequin waist and jeans waist, and the lines were horizontal.

With all the distance eases at the various angles obtained, correlation analysis was used to determine the relationship significance between the distance ease and ease allowance at different locations. Based on the correlation analysis results, only those points with high correlation were selected and analyzed using the regression analysis to build the regression models between the crotch length ease allowance and the distance eases.

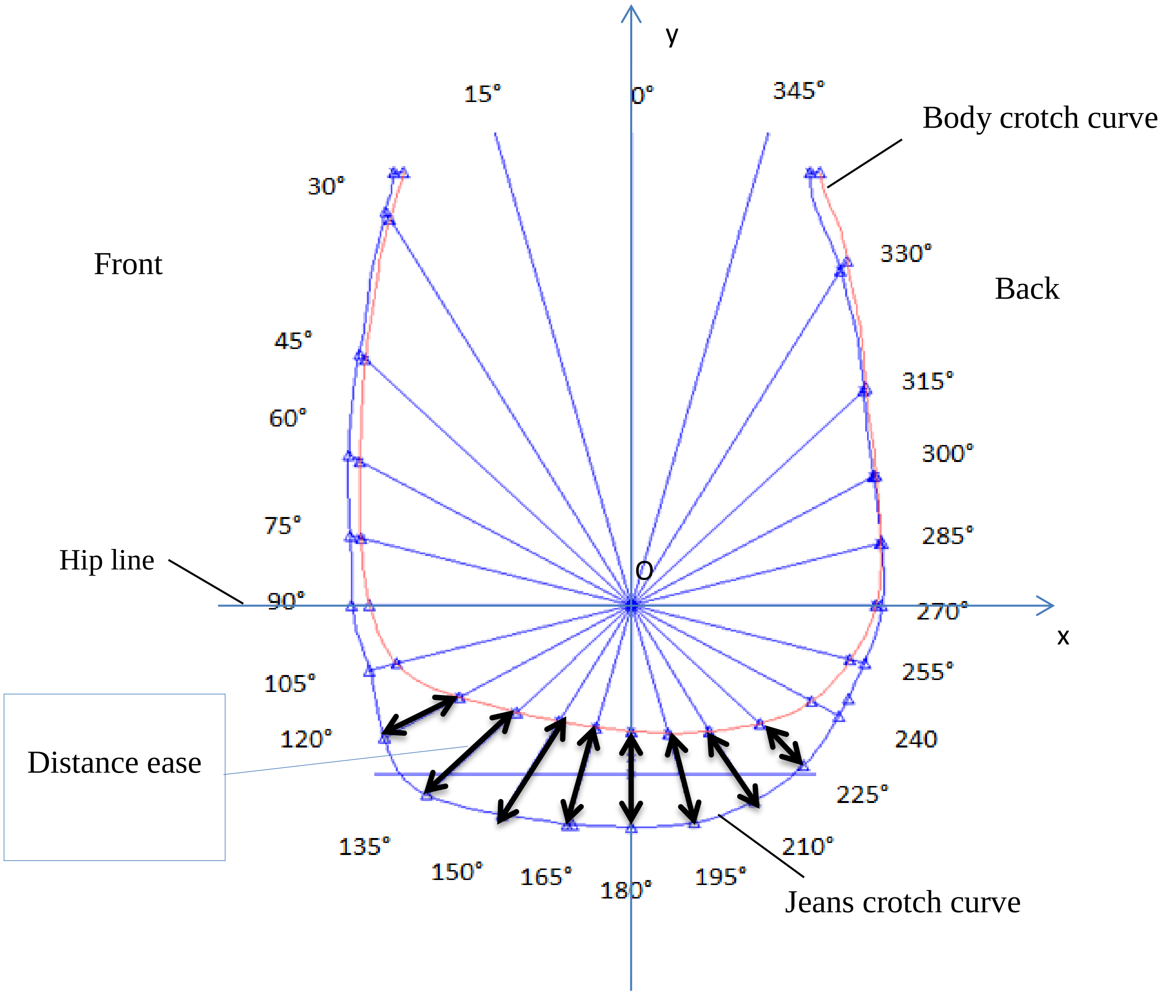


Figure 3.3: Distance ease of the crotch curves at different angles on the coordinates

Chapter 4: Experimental Results

4.1 FITTING ISSUES

For the size 8 mannequin, we found that the patterns made from instructions from the book (Armstrong, 2006) do not properly fit under the buttock, as shown in figure 4.1. Although the parts above the hipline fitted perfectly, the fabric under the buttock was pulled while extra fabric were folded at the hipline; furthermore, the jeans waistline was ½ inch (12.7 mm) lower than the mannequin waistline.

With the help of a pattern making expert, the problems were analyzed: First, the fabric was pulled at the area under the buttocks because the crotch extension was too short. Second, there was extra fabric folded at the hipline, because the book (Armstrong, 2006) suggested opening a wedge on the back piece to supplement the total crotch length, which turned out to be inappropriate for the mannequin body shape—low and flat hip. Third, the jeans waistline was ½ inch (12.7 mm) lower, which means the ease of crotch depth was not sufficient.

Based on the problems we found, the patterns were properly altered: (1) the wedge on the back piece was closed; (2) the crotch points were extended horizontally by ¾ inch (19.05 mm) for the back piece, and ½ inch (12.7 mm) for the front piece for crotch length augmentation; (3) the waistline was ½ inch (12.7 mm) evenly offset from the original place, which indicates the crotch depth is ½ inch (12.7 mm) higher; (4) the triangle value for the back piece is lengthened by ¼ inch (6.35 mm); (5) the crotch curve was finally blended. The resulting jeans placing on the mannequin are shown in figure 4.2.

(a) (b)

Figure 4.1: Jeans #1 before fitting, (a) Front; (b) Back.

(a) (b)

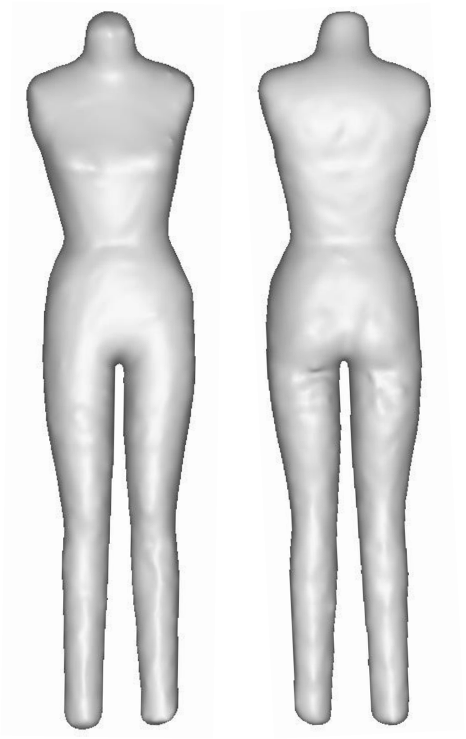
Figure 4.2: Jeans #1 after fitting, (a) Front; (b) Back.

4.2 DATA PROCESSING

The waistlines for the five scanned mannequins were supposed to be at the same horizontal level; however, the resulting data showed that the waistlines of the four dressed mannequins were generally higher than that of the unclothed mannequin. After analysis, it was found that the waistline of the unclothed mannequin was ½ inch wide, and during the scanning experiments, the jeans waistlines could be between the lower edge and the upper edge of waistline, while the image system considered the lower edge of the waistline was the waistline, which would cause the waistlines to be unmatched. Therefore, we deleted those extra points beyond the natural waistline to ensure the waist points of all the crotch curves were at the same horizontal level as the waistline of the unclothed mannequin.

4.3 MANNEQUIN MODELS GENERATION

The front and back view of the unclothed mannequin and the dressed mannequin wearing jeans #1 are illustrated in figure 4.3 and figure 4.4.



(a) (b)

Figure 4.3: Unclothed mannequin
(a) Front; (b) Back.

(a) (b)

Figure 4.4: Dressed mannequin
Wearing jeans #1 (a) Front; (b) Back.

4.4 DISTANCE EASE DISTRIBUTION OF THE CROTCH CURVES

The crotch curves of the unclothed mannequin and the dressed mannequins were regenerated in Accumark CAD system, as shown in figure 9. From figure 9 (a) (b) (d), we can see that, above the back high hip area, the body crotch curves were wider than the jeans crotch curves. Since the angle of the mannequin affect the capture of the crotch curve, even though we tried our best to keep the mannequin from moving, it was sometimes unavoidable and possibly undetectable to slightly change the angle of the mannequin when the jeans were taken on and off the mannequin, because the scanned mannequin was hanging in the air and was not fixed. Therefore, it would be possible that angles of the mannequins were slightly different when they were scanned.

The distance eases of the four jeans with different ease allowances were measured at various angles, as illustrated in figure 4.5 (in the x-axis, the “frt pt” is short for “front waist point”, and the “bk pt” is short for “back waist point”). The DE distributions at different angles are illustrated in figure 4.6. According to the DE distribution in figure 8, four conclusions can be made: 1) the DEs from the front waist point ~ 105° and from 240° ~ back waist point were the smallest. This was because the mannequin’s abdomen and hip shapes were both flat which makes the fabrics following the front and back body silhouettes, resulting in little significant DE variance within these two ranges. 2) As the point at 105° was the turning point of the body crotch curve, it was the turning point of the distance eases distributions as well, because after 105°, the distance ease value increased significantly for the four jeans. 3) The DEs at angles, from 120° ~ 225°, ranged significantly higher than the rest area of the crotch curve; and for jeans #1 and jeans #2, the DEs reached the highest at 135°; and for jeans #3 and jeans #4, the DEs reached the peak at 150°. 4) The DE variance increases as the ease allowance grows. Among the four jeans, the jeans #4 had the largest DE variance, ranging from -5.32 mm ~ 52.61 mm, and the jeans #1 had smallest DE variance, ranging from -3.34 mm ~ 11.97 mm.

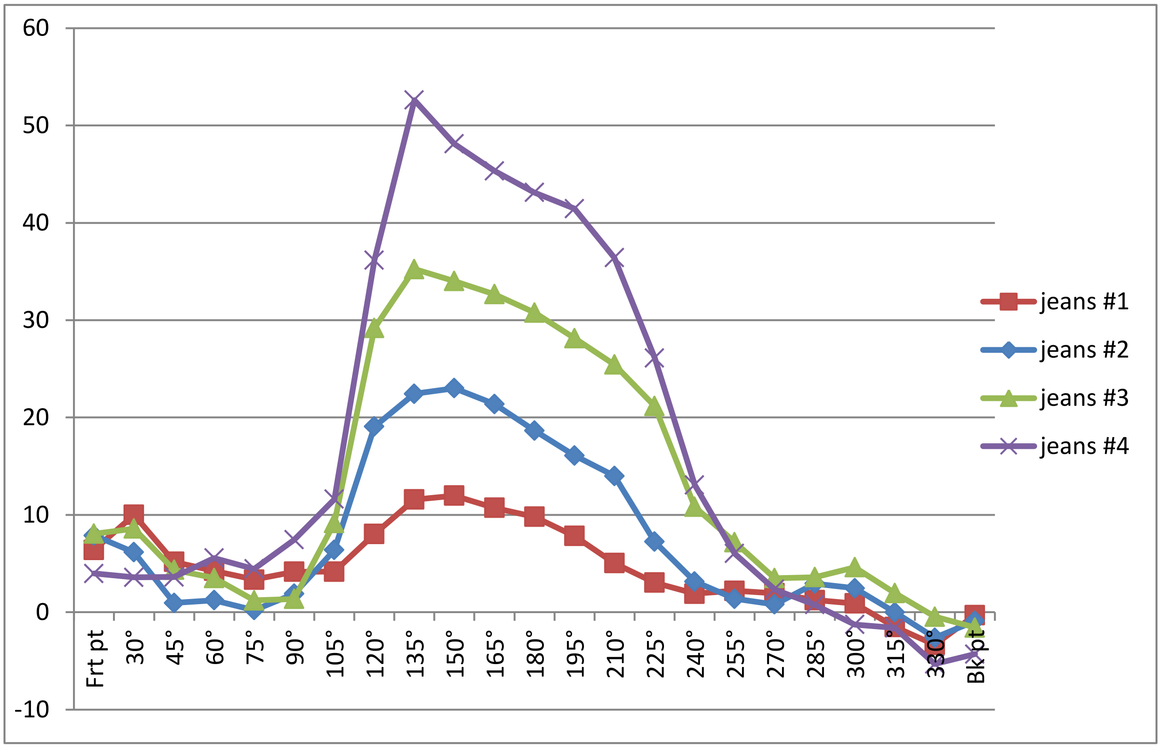
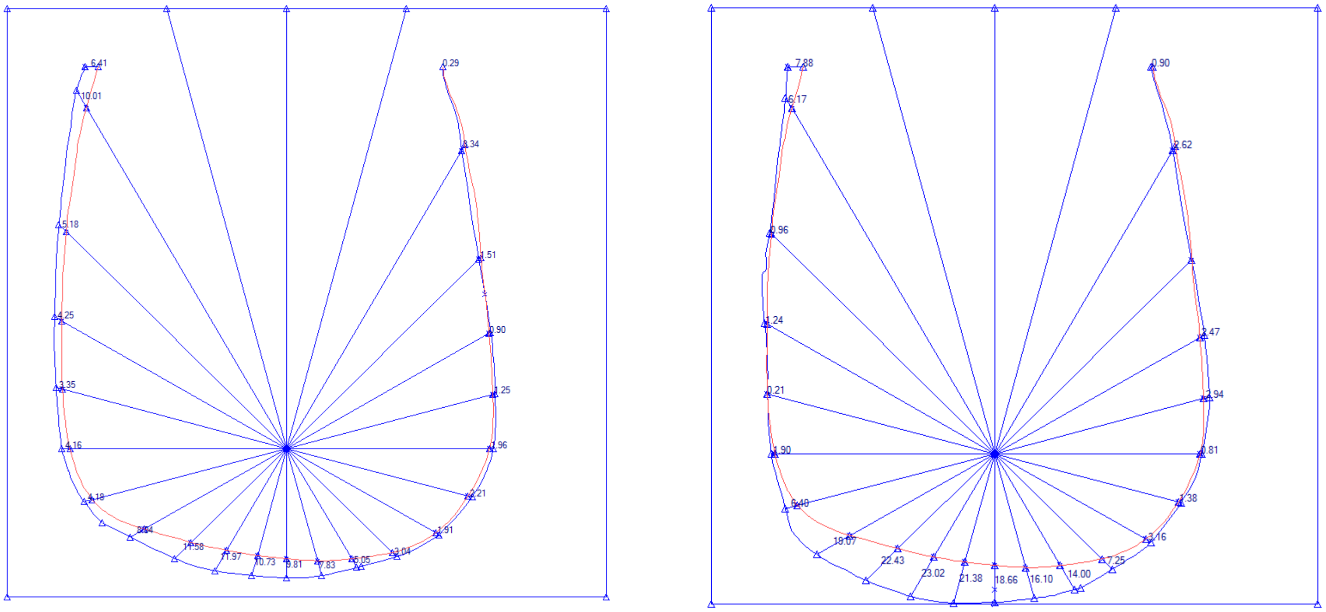
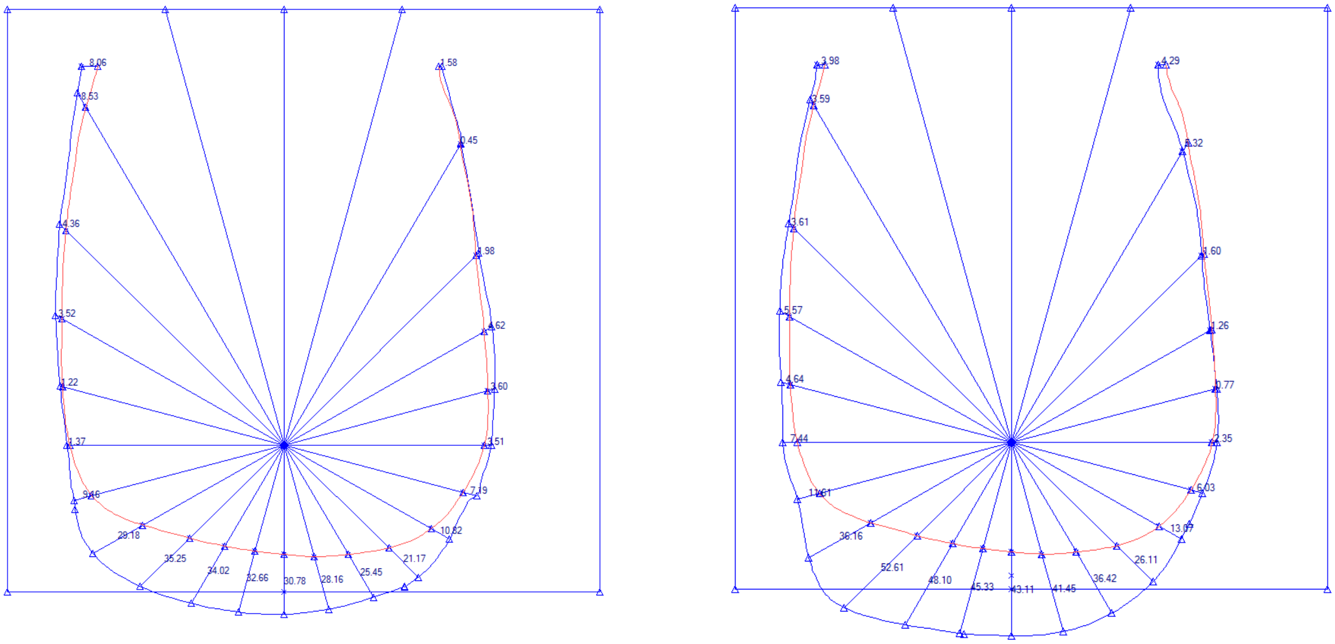


Figure 4.5: Distance Ease Distributions on Different Crotch Length Ease Allowance.



(a) Jeans #1 and the body

(b) Jeans #2 and the body



(c) Jeans #3 and the body

(d) Jeans #4 and the body

Figure 4.6: Jeans and body crotch curves and the corresponding distance eases at angles.

4.5 CORRELATION ANALYSIS

The correlations between distance eases and ease allowances were analyzed using Excel. The results are displayed in table 4.1. As we can see from the table 4.1, the correlations at the back waist point and within 105° ~ 240° were significant at 95% or 99% significance level, and their corresponding R^2 were all larger than 0.9. Additionally, the correlations at front waist point, within 30° ~ 90°, and 255° ~ 330° were poor, because the jeans usually conform to the front and back body silhouettes, where little distance ease variance occurs, no matter how the ease allowance at the crotch curve changes. This explanation is the same as in section 4.4, which indicates the correlation analysis results were reliable.

4.6 REGRESSION ANALYSIS

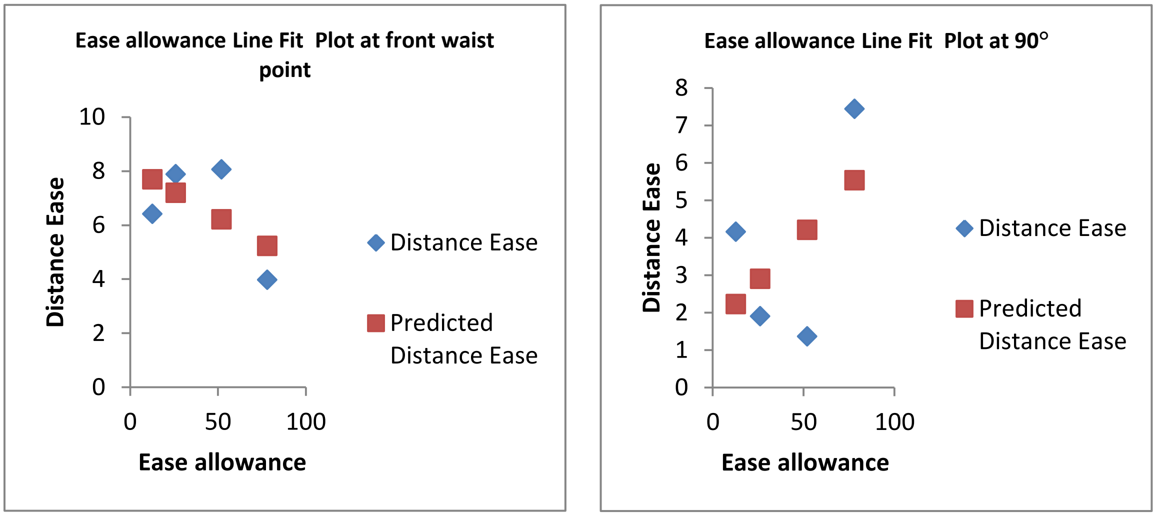
Regression analysis was used in Excel to build regression models between distance eases and ease allowances. The ease allowance line fit plots are important tool to examine the fit of models. In the Excel results, the plots were all displayed, but for illustration, only take some sample points with low correlation (i.e., front waist point, point at 90°) and those with high correlations for illustration, as displayed respectively in figure 4.6 and figure 4.7. From the plots, we can see that the models of points with poor correlations (i.e., at front waist, at 90°) lack significant fit, while higher correlation corresponds to better fit (i.e., at 180° and at 105°). Therefore, it is meaningless to create models for the points with low correlation.

Based on the correlation results and the fit plots, only those points with high correlation were selected for building regression equations. The points were the ones at angles 105°, 120°, 135°, 150°, 165°, 180°, 195°, 210°, 225°, 240°, and back waist center. The dependent variable y is defined as the distance ease at a certain angle, and the independent variable x is defined as the ease allowance of the crotch length. The regression equations are displayed in table 4.2.

Degree	**R^2**	**Significance F**
Front waist point	0.336	0.421
30°	0.553	0.256
45°	0.001	0.975
60°	0.319	0.435
75°	0.172	0.586
90°	0.281	0.47
105°	0.988	0.006**
120°	0.95	0.025*
135°	0.994	0.003**
150°	0.988	0.006**
165°	0.988	0.006**
180°	0.996	0.002**
195°	0.998	0.001**
210°	0.991	0.004**
225°	0.961	0.019*
240°	0.946	0.028*
255°	0.652	0.193
270°	0.244	0.506
285°	0.034	0.815
300°	0.095	0.691
315°	0.002	0.956
330°	0.097	0.688
back waist point	0.912	0.045*

Note: * means the correlation is significant at 95% significance level,
and ** means the correlation is significant at 99% significance level.

Table 4.1: Correlation analysis between distance ease and ease allowance



(a) (b)

Figure 4.7: Ease allowance line fit plot at points with low correlation: (a) at front waist point; (b) at 90°.

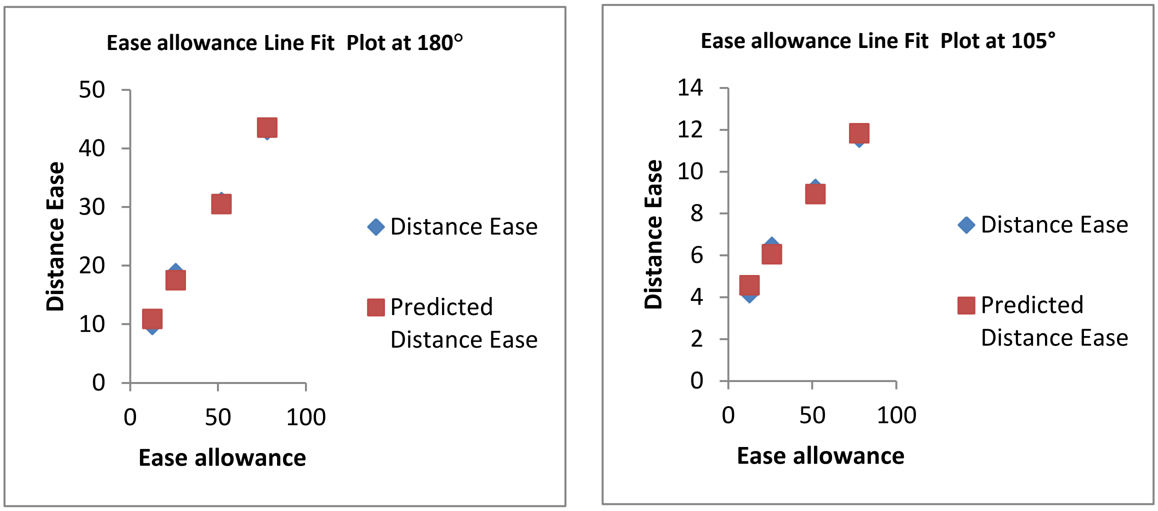


Figure 4.8: Ease allowance line fit plot at points with high correlation: (a) at front waist point; (b) at 90°.

Degree	R^2	Regression equations
105°	0.988	y = 3.143 + 0.111x
120°	0.95	y = 5.683 + 0.412x
135°	0.994	y = 4.788 + 0.608x
150°	0.988	y= 6.873 + 0.53x
165°	0.988	y=5.955+0.511x
180°	0.996	y=4.472+0.5x
195°	0.998	y=2.021+0.506x
210°	0.991	y=0.397+0.469x
225°	0.961	y=-1.351+0.373x
240°	0.946	y=-0.613+0.186x
back waist point	0.912	y=0.693-0.058x

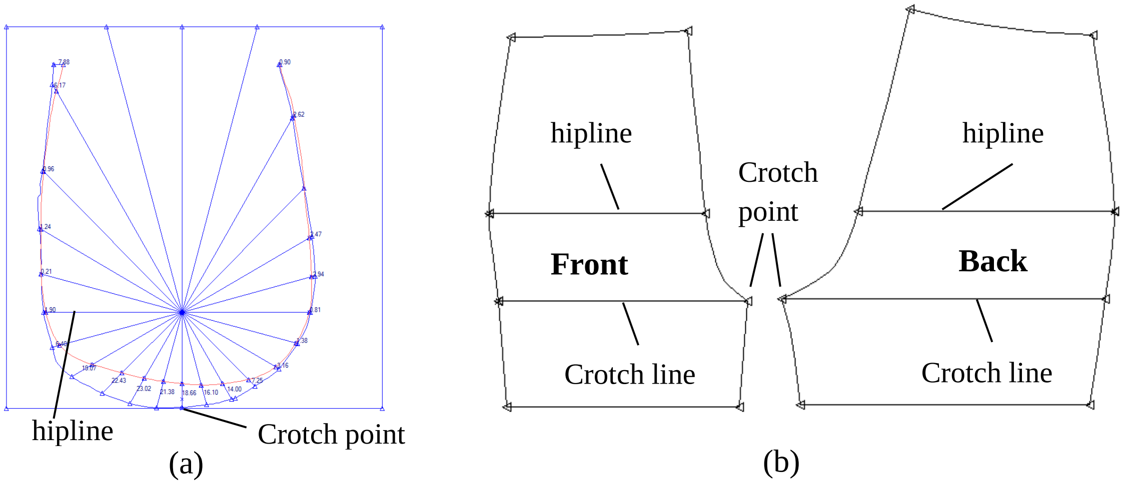
Table 4.2: Regression models between distance ease and ease allowance at angles.

4.7 APPLICATIONS IN 3D FEMALE JEANS CONSTRUCTION AND PATTERN ALTERATIONS

The result of this study can be applied in 3D female jeans construction. Proper ease distributions at key body locations are an integral part of the 3D garment wireframe construction in the automatic pattern customization based on 3D model. To the best of our knowledge, little research has been done on the ease distribution at crotch curve. The ease distribution models established in this study can be used to predict the distance ease of the crotch curve at every 15° when the ease allowance at crotch curve and the body crotch curve shape/measurement are presented. Based on the distance ease at each angle, the estimated jeans crotch curve will be generated by connecting the points using B-spline curves.

In addition, the ease distribution models developed in this study can also be applied in pattern alterations for jeans customization. Conventionally, jeans pattern alteration can be achieved by two methods—the slash and spread method and the seam method (Wang, 2008). The slash and spread method can be used when extra length or fabric is needed. For example, when the back crotch length is not sufficient, the hipline would be slashed and spread to complement the difference. This method is usually employed when an individual's hip is much more prominent than "ideal" hip shape. In seam method, the edge is altered based on the dimensional differences (Wang, 2008).

These two methods can be better implemented with the consideration of ease distribution at key body locations. As the ease distribution model of the crotch curve for customized jeans was established, the distance ease at every 15° angle can be estimated when the body crotch length and its ease allowance are provided, as shown in figure 4.9 (a). Meanwhile, the jeans blocks of specific size, displayed in figure 4.9 (b), are selected based on the individual body measurements. In order to alter the pattern for better fit, the crotch curve is divided into four parts: (1) front waist to front hipline, (2) front hipline to crotch point, (3) crotch point to back hipline, and (4) back hipline to back waist point. The jeans pattern alterations are implemented by adjusting the four parts of curves consecutively. For example, when the estimated distance between the front waist point to front hipline of the jeans crotch curve is 12.7 mm longer than that of the standard block crotch, the hipline would be slashed, and the pattern above the hipline would be rotated in count clock wise direction until the distance reaches certain length (figure 4.10). Moreover, given in figure 4.9 (a), the crotch depth is 18.66 mm lower than the body crotch level, the crotch line of the standard pattern would be moved downward by that amount. Furthermore, when the distance between the front hipline and the crotch point of jeans is 25.4 mm longer than that of the block, the front crotch point is extended by 25.4 mm, and the new curve of this part is generated by extending the original curve to the new front crotch point, as shown in the front piece in figure 4.10. The final crotch curve is determined by blending the two curves. The same concept can be applied on the back jeans pattern (figure 4.10).



(a) (b)

Figure 4.9: (a) Distance ease distribution at crotch curve. (b) Jeans sloper with hipline as a slash line.

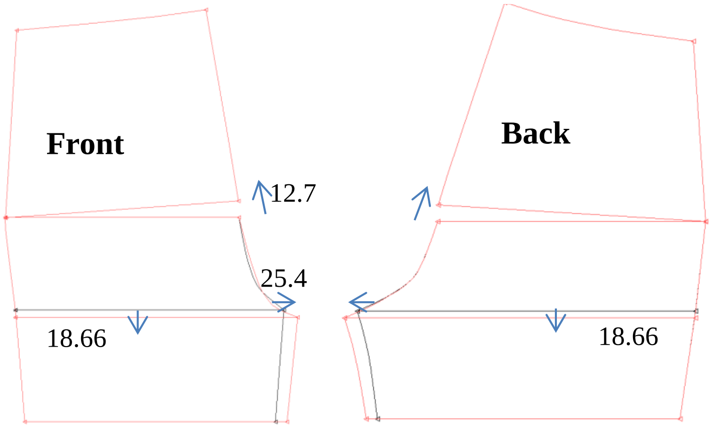


Figure 4.10: Altered jeans pattern with ease

Chapter 5: Conclusion and Recommendations for Future Work

5.1 Introduction

The purpose of this study is to analyze the existing automatic pattern development methods and to examine the distance ease distribution of jeans crotch curves. In this study, a systematic analysis of the existing automatic pattern development methods has been conducted. There are two main approaches for achieving automatic pattern making based on the 3D body scanning data: (1) two-dimensional patternmaking in 2D CAD systems, and (2) 3D-to-2D techniques. In the first approach, experience and expertise in pattern development are the key to ensure excellent fit. In the second approach, the ease distributions at various locations are essential in drafting customized-fit garment patterns; and yet, the distance ease distributions at the crotch curve remained unclear.

In order to fill the gap, in the second part, an experiment was conducted to investigate the relationship between the distance ease and the given crotch length ease allowance. Based on the scanning measurements of a size 8 mannequin, jeans patterns with four different crotch ease allowances were drafted in Accumark CAD, and were printed in full scale using an HP printer. The patterns were cut on muslin fabric, and four jeans were produced. Fitting process was conducted and patterns were adjusted to produce the best fit jeans. Further, the unclothed mannequin and the corresponding dressed mannequins were scanned again by the Kinect Body Image System. Then, the crotch curves were regenerated in Accumark CAD system, and the distance eases were measured every 15°. Correlation analysis and regression analysis were used to analyze the relationship between the distance ease and ease allowance.

The key experimental results of this study are summarized as below:

1) In terms of crotch curve, distance eases are mainly distributed between the legs.
2) There exists big difference of correlations, from different angles, between distance ease and crotch length ease allowance. The distance eases at back waist point and from the angle 105° to 240° were significantly affected by the ease allowance, while no correlation was found at front waist point, 30° ~ 90° and 255° ~ 330°.
3) The regression models between distance ease and ease allowance at key angles were generated, which can be further applied in prediction of distance ease distribution given by any crotch length ease allowance.
4) Better correlation between ease allowance and distance eases contributed to better model fit.

In order to obtain the accurate crotch curve data, it is critical to keep the mannequin facing the front cameras at right angle, and to prevent it from moving, because once the mannequin's angle changes even slightly, the crotch curve captured by the system could be slightly or sometimes quite wider/narrower from the real crotch curve. That's why sometimes the mannequin crotch width was slightly wider than the jeans crotch width. Therefore, it might be a challenge if the subject is human instead of a mannequin, because we cannot guarantee that human body will not to move during scanning.

A similar methodology has been utilized in horizontal cross sections of breast girth (Zhang et al, 2012), hip girth, abdomen girth, and knee girth (Su, 2014). And yet, very few studies have been done to study the distance ease of crotch curve, which is essential in the fit of pants/jeans. Nevertheless, the conclusion that better correlation resulted in better fit of regression model is the same as the conclusion made by Zhang et al. (2012); and the distance ease distributions at the front center and back are similar to the findings of McKinney (2007). On the other hand, the findings of the distance ease distributions under the crotch curve and between the legs were never found before, and the new findings can be applied in 3D jeans design and pattern alterations, which would improve the fit of jeans.

5.2 Limitations of this study

Since the focus of the present study is the ease distribution of the crotch curve, this study is limited to the jeans block foundation for females; the foundation refers to the portion of jeans above the crotch line. Another limitation of this study is that the sample size of jeans ease allowances was too small. In this study, only four jeans with various ease allowances (12.7 mm, 25.4 mm, 50.8 mm, and 76.2 mm) were developed and studied. It would be better if the more detailed classification of ease allowances (i.e., 0 mm, 12.7 mm, 25.4 mm, 38.1 mm, 50.8 mm, 63.5 mm, 76.2 mm … etc.) were studied.

In addition, since a mannequin is usually used in the study of ease distribution to avoid the effect of respiration, breath and unconscious body movements of the human body, and that the concept of ease distribution in 3D garment is a relatively novel concept, this study is limited in using a female mannequin instead of human body. It would be ideal if a larger scale of experiments can be conducted to analyze the ease distribution of female/male human bodies of various sizes and body shapes using 3D body scanners and reverse engineering technology.

Moreover, since the focus of this study is the DE at crotch curve, other variables, such as the DEs of hip girth, waist girth, thigh girth, and knee girth were not considered in the research. Further research is needed to integrate the all the DEs into consideration to design jeans that fit the best.

Furthermore, muslin is commonly used in the sample making of garments, and it is widely used in the studies of pants making. However, it is still necessary to use denim to test the ease distributions.

Notwithstanding the limitation of this study, the results provide strong support for 3D female jeans constructions and for female jeans pattern alterations, which would improve the fit of jeans.

5.3 Recommendations on future study

The ease distribution of crotch curves for female jeans has been studied on the female mannequin of size 8 in this research. The recommendations on future study are stated below:

(1) Male or children's jeans block patterns should be studied using the proposed method.

(2) A software which incorporates all the processes of this study should be developed to speed up the 3D jeans design and patternmaking.

(3) A large scale and comprehensive investigation which covers different age groups, body shapes and sizes should be conducted for establishing more robust models between crotch ease allowances and distance eases.

(4) Subjective and objective fitting evaluations should be conducted on human bodies to test the comfort of the crotch curves on real humans.

(5) The ease distribution in the cross sections of hipline, high hip line, waistline, knee line, and crotch curve should be fully considered in designing customized jeans.

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