Doctoral Dissertation (Shinshu University)

Study on 3D modeling and pattern-making for upper garment

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Abstract

In this study, a new garment modeling method has been proposed to construct proper upper garment model and to make patterns for various sizes bodies using multiplication factors. The method concerns not only horizontal body dimensions, but also vertical body proportions. It is capable of making a proper upper garment model for 3D pattern-making taking into account ease allowance, shape, silhouette and body sizes. It can be used to make individual tailored garments or ready-to-wear garments for different targets. The ability to size these models up or down using multiplication factors could be a substitute for the grading method.

Chapter 1 gives a background to this work. In this section, the overall approaches and techniques for garment modelling are introduced. It also addressed problems related to 3D garment molding and 3D pattern-making.

Chapter 2 is the literature review, the previous studies and published works concerning 3D modeling and pattern-making were summarized, and current research gaps has been stated.

In Chapter 3, research methodologies were introduced, consisting of 3D body scanning, 3D pattern-making theory, 3D garment modeling method, and size-change method. The methodology of 3D pattern-making process is described, from 3D data scanning to garment model, and then how to flatten 3D surface to 2D patterns. A 3D scanner was employed to acquire 3D body and garment data for construct garment models. In 3D modeling, surface of model is formed by triangular polygon mesh. 3D surface fitting method is employed to cover it for generating a surface for cutting. 3D surface fitting refers covering 3D surface with mesh virtually or with pieces of fabric

shapes on object, and fitting the covered shape, for example draping. For 3D pattern-making, a polygon garment model is constructed for fitting. In the process the shearing and bending behavior should be under consideration, fabric's shearability is an important factor affecting covering and flattening operation. The shear limit angle was considered in fitting to making garment models. Sweep method was used to repair convex hull to make smooth surface of a polygon model. Then, grainlines are set on virtual fabric mesh. Then, the mesh is cut by cutting lines to flatten to generate patterns. To make garment models fit for body and suitable for use with different sizes, multiplication factors are referred as the magnification between two distances related to the cross-sections of body and garment, which was applied to expand body model to form a garment model for pattern-making. Vertical body proportion is regarded as three segments: front neck point (NP) to bust line (BL), the bust line to waist line (WL) and the waist line to hip line (HL). Garment model for various sizes could be made under the consideration of body proportions working with multiplication factors.

In Chapter 4, based on the theory and method described in Chapter 3, upper garment models were constructed for making patterns; garments were also made to verify the validity of the modeling method. Two real garment bodices were used to develop patterns. The garments were fitted to a designated dummy body and scanned. Using the scanned data, suitable upper garment basic models were made for 3D pattern-making. To construct garment models that were different in size from the basic model, the multiplication factors of horizontal dimensions (in the front, back, and lateral directions) were calculated between the basic garment and the actual garment shape worn on a body for each basic model. Using the multiplication factors, we made two different size garment models from two different size dummies for each basic model. These models were used to make patterns and garments. Cross-sections of the made garments were extracted from 3D scanned data to evaluate the validity of the modeling method and garment fit.

In Chapter 5, body vertical proportions were taken into consideration to make appropriate patterns for bodies of different besides horizontal dimensions. The vertical body proportions of target bodies were calculated for making proper garment models working with the multiplication factor method. A target dress form was deformed using multiplication factors and vertical body proportions to construct a garment model that fitted the dress form. The method was verified using three different dress forms. The bodices of the jackets were compared with those obtained without adjusting vertical proportions. Employing the proposed method, jacket bodices were made and fitted on target bodies while preserving the original shape. Jackets bodices made without considering vertical proportions had many wrinkles and deformed shape and poor fit around the bust line owing to the different vertical proportions. The vertical proportion is thus an important factor in the three-dimensional garment modeling of garments of different size fitted on a body. Cross-sections of body and made upper garment were extracted from 3D scanned data to evaluate garment fit. The result showed that, the proposed modeling method is applicable to proper garment models for various body sizes.

In Chapter 6, the conclusions of this study were summarized. The recommendations of future work were given.

Table of Contents

Abstract i
Table of Contents iv
List of Figures vii
List of Tables xii

Chapter 1 Introduction 1

1.1 Background 1
1.2 Purpose of This Study 4
1.3 Research Methodology 5
1.4 Thesis Outline 6

Chapter 2 Literature Review 10

2.1 Introduction 10
2.2 Pattern-making Technology 12
2.2.1 Traditional Pattern-making 12
2.2.2 Computer-Aided Pattern-making 13
2.3 3D Pattern-making 14
2.3.1 Body Measurement 14
2.3.2 3D Body Modeling 16
2.3.3 3D Garment Modeling and Simulation 17
2.3.4 3D Pattern Development 18
2.4 Garment Pattern Sizing 21
2.4.1 Pattern Grading 21
2.4.2 Pattern Ease 23
2.5 Garment Fit and Evaluation 24
2.5.1 Garment Fit 24
2.5.2 Garment Fit Evaluation 25
2.6 Garment Virtual Try-on Technologies. 28

2.7 **3D Pattern-making System** ... 29
2.8 **Summary** ... 31

Chapter 3 Research Methodology ... 44

3.1 **Introduction** ... 44
3.1.1 3D Surface Fitting ... 44
3.1.2 3D Pattern-making System ... 45
3.2 **3D Data Acquisition** ... 47
3.2.1 3D Data Scanning ... 47
3.2.2 3D Data Conversion ... 49
3.3 **Garment Modeling** ... 51
3.3.1 Fabric Modeling ... 51
3.3.2 Garment Modeling ... 52
3.3.3 Multiplication Factors ... 53
3.3.4 Vertical Body Proportions ... 55
3.4 **Pattern Developing Theory** ... 58
3.4.1 Defining the Surface Shape ... 59
3.4.2 Setting Grainlines ... 59
3.4.3 Fitting Method ... 60
3.4.4 Cutting Method ... 61
3.4.5 Pattern Flattening ... 61
3.4.6 Calculating Method ... 63
3.5 **Summary** ... 66

Chapter 4 Upper Garment 3D Modeling and Pattern-making ... 69

4.1 **Introduction** ... 69
4.2 **Modeling Method for Upper Garments** ... 72
4.2.1 Deformation of the Model for Different Sizes ... 72
4.2.2 Covering and Flatting Method for Pattern-making ... 76
4.3 **Experimental** ... 77
4.3.1 Reproduction for Basic Jacket Bodice ... 79
4.3.2 Molding and Pattern-making for Different Sizes ... 81

4.4 Results and Discussion 82
4.4.1 Result for Reproduction Basic Jacket Bodice 82
4.4.2 Modeling and Pattern-making With Multiplication Factors 85
4.4.3 Fit Evaluation 91
4.5 Summary 95

Chapter 5 3D Garment-size Change Modeled Considering Vertical Proportions 101

5.1 Introduction 101
5.2 Modeling Method for Different Model Sizes 104
5.2.1 Construction of the Basic Model and Obtaining Multiplication Factors for a Horizontal Cross-Section 104
5.2.2 Construction of Garment Models Considering the Vertical Proportion 105
5.3 Experimental 108
5.4 Results and Discussion 112
5.4.1 Result for Modeling and Pattern 112
5.4.2 Fit Analytics 115
5.5 Summary 122

Chapter 6 Summary and Future Work 126

6.1 Summary 126
6.1.1 Conclusions 127
6.1.2 Value of this Study 129
6.1.3 Limitations 129
6.2 Future Work 131
6.2.1 Application to Other Garment Types 131
6.2.2 Application to Other Body Shapes 131

Published Papers 132

Acknowledgements 133

List of Figures

Figure 2.1 Japanese standard body: (a) Male; (b) Female 15

Figure 2.2 Body Line Scanner 16

Figure 2.3 3D human body modeling: (a) Gregory patches modelling; (b) Spline curves and surface modeling 17

Figure 2.4 Overview of 3D garment pattern development: (a) Featured human model; (b) Input and result of extracting; (c) Setting seam line; (d) Results of separation; (e) Flattened 2D patterns 19

Figure 2.5 Featured curves and pattern pieces 20

Figure 2.6 3D garment model deformation and pattern grading: (a) The deformation of Center Back and Center Front; (b) Size frames deformed from the feature frame . 22

Figure 2.7 Subjective fit evaluation scale] 26

Figure 2.8 Cross-sectional of body and garment at bust line 26

Figure 2.9 Tight skirt pattern and tight skirt 29

Figure 2.10 Pants pattern and pants 29

Figure 2.11 Upper garment and sleeve pattern and the result 30

Figure 3.1 The interface of 3D pattern-making system 46

Figure 3.2 Top-view of Body Line Scanner 48

Figure 3.3 Procedure of polygon model generation: (a) Point cloud; (b) Line model; (c) Polygon model 49

Figure 3.4 Shear deformation and shear angle of fabric model 52

Figure 3.5 Process of convex hull at bust line: (a) Scanned bust line; (b) Bust line with convex hull 52

Figure 3.6 Process of convex hull at bust part: (a) Scanned bust; (b) Bust reconstructed with convex hull 53

Figure 3.7 Calculation of magnification factors 54

Figure 3.8 Expansion of target body: (a) Target body; (b) Expanded line model; (c) Garment model.. 55

Figure 3.9 Vertical segments of body 56

Figure 3.10 Example of change the vertical length of segment BL-WL: (a) Original; (b) Lengthened; (c) Shortened 57

Figure 3.11 Pattern development for a hemisphere: (a) Triangular patched surface of sphere; (b) Two grainlines; (c) The result of fitting; (d) Cutting of hemisphere; (e) The flattened hemisphere 58

Figure 3.12 Configuration of grainlines for a sphere: (a) Top view; (b) Side view.... 60

Figure 3.13 Fitting for a sphere: Top View: (a) L1–L3, (b) L3–L5, (c) L5– L7, (d) L7–L17; Side View: (e) L1–L3, (f) L3–L5, (g) L5– L7, (h) L7–L17 60

Figure 3.14 Fitting in 3D space and flattening into 2D plane: (a) Fitting; (b) Flattening 62

Figure 3.15 Combination of panels: (a) Flattened panels; (b) Panel combination; (c) Pattern... 62

Figure 3.16 Fitting method of fabric lattice onto the triangular patch 65

Figure 4.1 Anatomical body planes (a: Sagittal plane, b: Coronal plane, c: Transverse plane) 73

Figure 4.2 Measurement of distance (bust line)... 74

Figure 4.3 Calculating multiplication factors: (a) S_s, Multiplication factor for side; (b)

S_f, Multiplication factor for front 75

Figure 4.4 Expanding the target body (9AR) using multiplication factors: (a) Front view; (b) Side view 75

Figure 4.5 Covering and flatting method for pattern-making: (a) Polygon model surface; (b) Grainlines and cutting lines; (c) Covering; (d) Flatting........................... 76

Figure 4.6 Jacket1 and patterns for basic model; (a) Original jacket; (b) Original pattern; (c) Simplified pattern.. 77

Figure 4.7 Jacket2 and patterns for basic model; (a) Original jacket, (b) Original pattern.. 77

Figure 4.8 AR Bodies: (a) 5AR; (b) 9AR; (c) 13AR.. 78

Figure 4.9 Basic jacket bodice of Jacket1: (a) Front; (b) Back; (c) Left side; (d) Right side 80

Figure 4.10 Basic jacket bodice of Jacket2: (a) Front; (b) Back; (c) Left side; (d) Right side.. 80

Figure 4.11 Basic garment model of Jacket1: (a) Front; (b) Back; (c) Left side; (d) Right side.. 82

Figure 4.12 Configurations of the cutting lines: (a) Original cutting lines; (b) Cutting lines that differ from the original 83

Figure 4.13 Segmentation and combination of the front pattern piece: (a) Separated pattern; (b) Combined pattern; (c) Cutting pattern; (d) Final pattern 84

Figure 4.14 Patterns and made jacket with the same cutting lines (seam lines) for Jacket1: (a) Pattern; (b) Jacket1 with the same cutting lines..................................... 84

Figure 4.15 Patterns and made jacket with different cutting lines (seam lines) for Jacket1: (a) Pattern; (b) Jacket1 with the different cutting line 85

Figure 4.16 Multiplication factors in the front, back and lateral directions for Jacket1 85

Figure 4.17 Reconstructed jacket models and patterns of size 9AR for Jacket1: (a) 3D dada; (b) Front; (c) Side; (d) Back; (e) Patterns 86

Figure 4.18 Reproduced jacket of size 9AR for Jacket1: (a) Front; (b) Back; (c) Side 87

Figure 4.19 Constructed jacket models and patterns for Jacket1: (a) 5AR model; (b) 5AR garment model; (c) 13AR model (d) 13AR garment model; (e) 5AR Pattern; (f) 13AR Pattern 88

Figure 4.20 Size 5AR jacket bodice of Jacket1: (a) Front; (b) Back; (c) Side 89

Figure 4.21 Size 13AR jacket bodice of Jacket1: (a) Front; (b) Back; (c) Side 89

Figure 4.22 Constructed jacket models and patterns for Jacket2: (a) 5AR model; (b) 5AR garment model; (c) 13AR model (d) 13AR garment model; (e) 5AR Pattern; (f) 13AR Pattern 90

Figure 4.23 Size 5AR jacket bodice of Jacket2: (a) Front; (b) Back; (c) Side 91

Figure 4.24 Size 13AR jacket bodice of Jacket2: (a) Front; (b) Back; (c) Side 91

Figure 4.25 Comparison of the cross-sections of the constructed garment model and original jackets: (a) Jacket1; (b) Jacket2 92

Figure 4.26 Comparison of the cross-sections of the constructed garment model and reproduced Jacket1: (a) 5AR; (b) 13AR.. 93

Figure 4.27 Comparison of the cross-sections of the constructed garment model and reproduced Jacket2: (a) 5AR; (b) 13AR.. 94

Figure 5.1 JIS women's body sizes. (JIS L4005)... 103

Figure 5.2 Scheme of modeling method for horizontal size change: (a) Line model of a target body; (b) Basic garment model; (c) Calculation of multiplication factors ... 105

Figure 5.3 Process of modeling method for vertical size change: (a) Target body; (b) Setting vertical proportion of target body as that of Standard Body; (c) Appling horizontal multiplication factors; (d) Restoring vertical proportion to original of target body 106

Figure 5.4 Standard Body and Standard Jacket: (a) Standard Body; (b) Standard Jacket bodice 109

Figure 5.5 Photographs of three dress forms: (a) Body 1; (b) Body 2; (c) Body 3 .. 110

Figure 5.6 Jacket models obtained with and without adjusting vertical proportions: (a) Model for JK1; (b) Model for JK1N; (c) Model for JK2; (d) Model for JK2N; (e) Model for JK3; (f) Model for JK3N 113

Figure 5.7 Jacket patterns obtained with and without adjusting vertical proportions: (a) Pattern for JK1; (b) Pattern for JK1N; (c) Pattern for JK2; (d) Pattern for JK2N; (e) Pattern for JK3; (f) Pattern for JK3N 114

Figure 5.8 Jacket bodices for Body 1: (a) JK1; (b) JK1N 115

Figure 5.9 Jacket bodices for Body 2: (a) JK2; (b) JK2N 116

Figure 5.10 Jacket bodices for Body 3: (a) JK3; (b) JK3N 117

Figure 5.11 Comparisons of cross-sections for Body 1, JK1 and JK1N: (a) Under-bust; (b) Upper-bust 120

Figure 5.12 Comparisons of cross-sections for Body 2, JK2 and JK2N: (a) Under-bust; (b) Upper-bust 120

Figure 5.13 Comparisons of cross-sections for Body 3, JK3 and JK3N: (a) Under-bust; (b) Upper-bust 120

List of Tables

Table 3.1 Specifications of Body Line Scanner 48

Table 4.1 Measurements for each body size 81

Table 4.2 Measurements for each garment model and made jacket............................ 94

Table 5.1 Measurements of three different dress forms... 111

Table 5.2 Jacket name and modeling method for target body.................................. 111

Table 5.3 Measurements and ease allowances of the bust line, waist line and hip line for three bodies and jackets with and without adjusting body vertical proportions .. 119

Table 5.4 Measurements and ease allowance of under the bust and the upper bust for three bodies and jackets.. 121

Chapter 1

Introduction

Chapter 1 Introduction

1.1 Background

In the apparel manufacturing industry, pattern-making is an essential procedure, which involves the design and creation of templates for clothing and craft items which can be sewn. Usually, patterns are made of pieces of two-dimensional (2D) shapes that are traced onto the fabric for cutting.

Patterns can be formed by either 2D method or a draping process. The 2D pattern-making method consists of flattening, drafting and reverse engineering. In the 2D method, a pattern is generated from an existing foundation pattern, sizing system and body measurement [1, 2]. The 2D pattern-making method is widely used in mass production for ready-to-wear [3]. In addition to 2D method, in the two-dimensional (3D) pattern-making process, pattern pieces are generated from a 3D form. Draping is one of the oldest methods used to generate patterns.

Computers have been used by apparel companies since 1980's [4, 5]. Early garment computer-aided design (CAD) systems focused on 2D pattern drafting and modification [6]. With the development of computer technology, 3D garment CAD methods with the technologies of human body measurement and 3D modeling are studied and proposed as an alternative solution for computerized simulating, pattern-making and manufacturing in the apparel industry for a high efficiency, high quality and low cost [7].

The 3D pattern-making is a process that transforms 3D shapes and styles into 2D flat patterns [8]. In the 3D pattern-making system, the 3D surface of a garment model or a body model is flattened to 2D flat pieces for pattern development.

Researchers [9-12] adopted the 3D garment surface flattening method to develop patterns. These studies used freeform or parameterized deformation methods to make garment models for pattern developing. Such works are very useful for prototypes [13-16] and tight-fitting garments in sport and medical applications [17-19], but they have inherent difficulties for loose-fitting ones, which involves the complex draping of fabrics and curved body shapes [20].

Less of an appropriate ease allowance, those garment models are only capable of generating tight-fitting garment patterns. For other garments, such as jackets and coats, ease allowances cannot be ignored in 3D garment modeling and pattern-making. Human body figures are different in the horizontal direction (girth) and the vertical direction (proportion). In addition, standard bodies differ depending on races or nationalities. It is therefore necessary to consider the differences in the vertical measurements.

To make garment models be applicable to loose-fitting with complex ease allowances for styling and silhouette, the remaining many challenges should be under consideration in garment modeling, such as creating a complex 3D surface with dents, fitting body shapes, and preserving the original 3D shapes for different bodies[21-23].

In this study, upper garment models were constructed with ease allowances in different sizes for various body types, considering both vertical body proportions and horizontal dimensions. Complex garment models that concern ease allowances and silhouettes can be made by adopting the proposed modeling method. The method is applicable for making individually tailored garments or ready-to-wear garments for different targets.

1.2 Purpose of This Study

As described previously, 3D models for tight-fitting garment were constructed by various methods. However, a 3D garment model that includes an appropriate ease allowance, reflecting the real garment shape and can be easily deformed for different sizes is therefore necessary for 3D pattern-making.

This study is focused on tailored upper garment model for 3D pattern-making that takes into account both ease allowances and silhouettes. Also, it concerns horizontal body dimensions, in addition to vertical proportions and is applicable to various body sizes.

The purposes of this study are:

(1) To develop an upper garment modeling method for 3D pattern-making, that which takes into account ease allowances and silhouettes.

(2) To propose a size-changing method for 3D garment modeling, this is applicable to various body sizes considering vertical body proportions, in addition to horizontal dimensions, while preserving the silhouette and the ease of the original garment.

(3) To improve the understanding of the relationship between 3D garment shapes and 2D flat patterns.

1.3 Research Methodology

Two real garment bodices with a surface suitable were used for pattern development. The garments were fitted to a designated dummy body and scanned. Using the scanned data, suitable upper garment basic models were made for 3D pattern-making. Two bodice patterns were produced using the model, one with the original seam lines and the other with seam lines that differed from the original ones, and then compared them with the original jacket bodice. Cross-sectional dimensions and shapes of bodies and garments were obtained by 3D scanning. To construct garment models those were different in size from the basic model, multiplication factors of cross-sectional dimensions (in the front, back, and lateral directions) were calculated between basic garment and the body shape worn on a body for each basic model.

Using the multiplication factors, two different size garment models were made from two different size dummies for each basic model. These models were used to make patterns and garments.

In addition to horizontal multiplication factors, vertical body proportions were also calculated. A target dress form was deformed using multiplication factors and vertical body proportions to construct a garment model that fitted the dress form. The method was verified using three different dress forms. The bodices of the jackets were compared with those obtained without adjusting vertical proportions.

Garment models were constructed to make various sizes pattern for different bodies. Cross-sections of the body and made upper garment were extracted from 3D scanned data to evaluate the garment fit.

1.4 Thesis Outline

In this study, new methods for 3D garment modeling and size-change were proposed, which can be used for 3D pattern-making for various body sizes considering vertical body proportions in addition to horizontal dimensions.

Chapter 1 gives a background of the work undertaken in the thesis, in this section, the overall approaches and techniques for garment modeling are introduced. It also addressed problems related to 3D garment molding and 3D pattern-making.

Chapter 2 is a literature review, the previous studies and published works concerning 3D modeling and pattern-making were summarized.

In Chapter 3, the research methodologies were introduced, consisting of 3D body scanning, 3D pattern-making theory, 3D garment modeling method, and size-change method.

In Chapter 4, based on the theory and method described in Chapter 3, some upper garment models were constructed for making patterns; garments were also made to verify the validity of the modeling method.

In Chapter 5, new garment models and upper garments were made for various sizes of bodies taking into account both horizontal dimensions and vertical proportions. Moreover, the models and garments were investigated both quantitatively and graphically.

Finally, the conclusion of this study and suggestion for future work were described in Chapter 6.

References

1. Ashdown S.P., An investigation of the structure of sizing systems: A comparison of three multidimensional optimized sizing systems generated from anthropometric data with the ASTM standard D5585-94. *International Journal of Clothing Science and Technology*, 1998. 10(5): 324-341.
2. Workman J.E., Body measurement specifications for fit models as a factor in clothing size variation. *Clothing and Textiles Research Journal*, 1991. 10(1): 31-36.
3. Young C., Jirousek C., and Ashdown S., Undesigned: A study in sustainable design of apparel using post-consumer recycled clothing. *Clothing and Textiles Research Journal*, 2004. 22(1-2): 61-68.
4. Yan H. and Fiorito S.S., Communication: CAD/CAM adoption in US textile and apparel industries. *International Journal of Clothing Science and Technology*, 2002. 14(2): 132-140.
5. Fan J., Yu W., and Hunter L., Clothing appearance and fit: Science and technology. 2004, Cambridge, Woodhead Publishing Limited.
6. Liu Y.-J., Zhang D.-L., and Yuen M.M.-F., A survey on CAD methods in 3D garment design. *Computers in Industry*, 2010. 61(6): 576-593.
7. Apeagyei P.R., Application of 3D body scanning technology to human measurement for clothing Fit. *International Journal of Digital Content Technology and its Applications*, 2010. 4(7): 58-68.
8. Au C.K. and Ma Y.S., Garment pattern definition, development and application with associative feature approach. *Computers in Industry*, 2010. 61(6): 524-531.
9. In H.S. and Tae J.K., Interactive garment pattern design using virtual scissoring

method. *International Journal of Clothing Science and Technology*, 2006. 18(1): 31-42.

10. Wang C.C.L., Tang K., and Yeung B., Freeform surface flattening based on fitting a woven mesh model. *Computer-Aided Design*, 2005. 37(8): 799-814.
11. Saeed Mian A., Bennamoun M., and Owens R., Automated 3D model-based free-form object recognition. *Sensor Review*, 2004. 24(2): 206-215.
12. Imaoka H., Shibuya A., and Aisaka N., Automatic paper pattern making using mechanical development method of a curved surface on a plane surface. *Sen-i Gakka/shi*, 1989. 45.
13. Mahnic M. and Petrak S., Investigation of the fit of computer-based parametric garment prototypes. *Journal of Fiber Bioengineering and Informatics*, 2013. 6(1): 51-61.
14. Hlaing E.C., Krzywinski S., and Roedel H., Garment prototyping based on scalable virtual female bodies. *International Journal of Clothing Science and Technology*, 2013. 25(3): 184-197.
15. Yang Y.C. and Zhang W.Y., Prototype garment pattern flattening based on individual 3D virtual dummy. *International Journal of Clothing Science and Technology*, 2007. 19(5): 334-348.
16. Su J., Liu G., and Xu B., Development of individualized pattern prototype based on classification of body features. *International Journal of Clothing Science and Technology*, 2015. 27(6): 895-907.
17. Troynikov O. and Ashayeri E. 3D body scanning method for close-fitting garments in sport and medical applications. HFESA 47th Annual Conference, Crows Nest, 2011.

18. Jeong Y., Hong K., and Kim S., 3D pattern construction and its application to tight-fitting garments for comfortable pressure sensation. *Fibers and polymers*, 2006. 7(2): 195-202.
19. Kim S., Jeong Y., Lee Y., and Hong K., 3D pattern development of tight-fitting dress for an asymmetrical female manikin. *Fibers and Polymers*, 2010. 11(1): 142-146.
20. Chan A., Fan J., and Yu W., Prediction of men's shirt pattern based on 3D body measurements. *International Journal of Clothing Science and Technology*, 2005. 17(2): 100-108.
21. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part II: Garment Modeling. *Textile Research Journal*, 1990. 60(12): 731-737.
22. Umetani N., Kaufman D.M., Igarashi T., and Grinspun E., Sensitive couture for interactive garment modeling and editing. *ACM Trans. Graph.*, 2011. 30(4): 90.
23. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part I: Projection. *Textile Research Journal*, 1990. 60(11): 690-696.

Chapter 2

Literature Review

Chapter 2   Literature Review

This study concerns with upper garment three-dimensional (3D) modeling and pattern-making take into account ease allowance and silhouette. Multidisciplinary knowledge is involved in the research. In this chapter, an overview of the 3D garment pattern technologies, computer-aided technologies, garment sizing and fit were provided to summarize previous research methods, findings and limitations, including 3D body scanning and modeling, 3D garment modeling, 3D garment pattern-making, pattern sizing, virtual try-on and garment fit technologies.

2.1 Introduction

Nowadays, a variety of garments has become able to be produced in the apparel industry. Consumers usually select their clothing among numerous ready-to-wear [1]. They pursue clothing not only for the designs, materials and comforts, but also for whether it can be satisfactory to their own individual taste and figures [2, 3]. The apparel industry is evolving from the traditional mass production system to the mass customization system, which takes into account individual consumers' needs [4].

Apparel manufacturing systems on the market are mainly divided into two categories, mass production and Made-to-Measure (MTM) [5]. Mass production is often used by garment production enterprises at a low cost. In addition to traditional technologies, computer technologies are involved into mass production to improve production efficiencies, such as Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM).

In mass production, pattern grading brings convenience to develop different pattern sizes for different body shapes. However, it still poses a ‘fit’ problem for individuals.

To solve individual’s ‘fit’ problem, MTM is introduced to make a tailored garment for consumers who have high requirements or who have special figures. 3D body scanning is one of the rapid and efficient ways to obtain human body dimensions [6, 7]. Body scanning technology has great potential that benefits the appeal industry. Human body modeling uses the unstructured data points from scanning to generate 3D body model or garment model. The 3D surface of the model is cut in 3D space, and flattened to two-dimensional (2D) patterns. Moreover, a size-change or grading method can be applied to 3D models to develop patterns in various sizes [8-10]. Furthermore, patterns can be assembled by virtual sewing and loaded in the virtual try-on system for draping simulation [11-13], in which researchers are able to evaluate the garment fit before putting it into production [14-16].

2.2 Pattern-making Technology

Pattern-making is a process that transforms 3D styles into 2D flat patterns. In the apparel industry, the methods of pattern-making are commonly classified as 2D pattern design and 3D pattern design.

2.2.1 Traditional Pattern-making

The 2D pattern design technique includes two methods, drafting and alteration. Since 2D pattern design is usually worked on a flat plane, it is also called "flat pattern-making". The flat pattern-making method is the fastest and most efficient method ever devised for developing patterns that control the consistency of sizes and fit of mass production. Mass production is the main manufacturing method. The system depends upon basic patterns referred as a prototype, sloper or block pattern, that have been previously developed and perfected using flat pattern-making method [17]. Flat pattern-making is carried out with mathematical formulas and numerical values of standard bodies. And it is difficult to know what the final products would like to be.

Draping, a 3D pattern design technique is used to make well-fitted garments for individuals. It directly implements the pattern design on a mannequin or human body. Compared with flat pattern-making, draping requires more precise measurements on human bodies and can reflect individuals' body shapes more accurately. Without regard for the time consuming, draping is a perfect solution to achieve the best silhouette and fit, because it provides the advantage of "what you see is what you get", the final garments can be confirmed during the making process.

In the early garment industry, either flat pattern-making or draping was made entirely manually. With the development of computer technology, computer-aided design is introduced to assist traditional pattern-making. Furthermore, new computer-aided pattern making techniques come into being.

2.2.2 Computer-Aided Pattern-making

Computer-aided pattern-making contains 2D, 2D-to-3D and 3D-to-2D approaches. The 2D approach is an assistance of traditional pattern-making generally.

In the 2D-to-3D CAD approach, digital 2D garment patterns are firstly prepared, and assembled through a virtual sewing procedure to produce realistic draping simulation [18-22]. The 2D-to-3D solutions are useful tools for evaluating the visual effects of garment production, but not useful for clothing products and pattern development.

In the 3D-to-2D approach, a 3D human body model or a 3D garment model is firstly constructed, and then a 3D flattening technique is applied to flatten the 3D surface of a model for 2D pattern development [23-27]. The 3D-to-2D approach is an effective method to make simple styles, for example, tight-fitting garments [28, 29] or sleeveless garments [30], not applicable to complex styles, such as tuck and gather.

2D-to-3D and 3D-to-2D approaches usually involve 3D scanning, 3D body and garment modeling, which attracted much attention of researchers in the field.

2.3 3D Pattern-making

At present, 2D CAD systems are widely used in the garment industry. 3D modeling and 3D simulation have made substantial changes in past decades. 3D pattern-making, 3D CAD systems became possible. By adopting 3D techniques, the human body is able to be acquired and medaled accurately and rapidly. 3D pattern-making turns into reality working in coordination with a 3D simulation of cloth and modeling of the body.

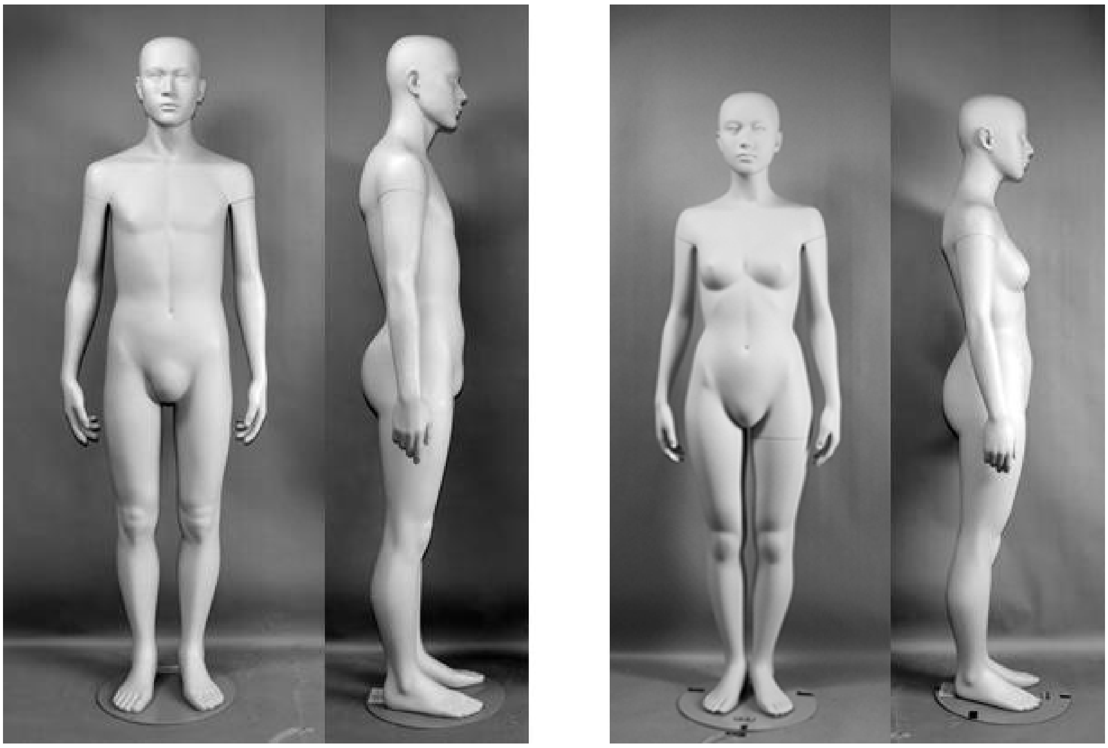
2.3.1 Body Measurement

Body measurement mainly consists of manual measurement, image-based measurement, gypsum mounding, and 3D scanning.

The manual tape measurement is a traditional method of obtaining body dimensions. Image-based measurement uses front/back and side profiles to estimate body dimensions [31] and construct body models [32]. Gypsum mounding is a skin-contact method of modeling human bodies. Compared with mannequins and gypsum, the crucial measuring points and lines on human bodies are difficult to define. To obtain body information entirely, quickly and precisely, researchers have made great contributions to developing 3D systems. Figure 2.1 shows the standard body of Japanese Male and Female in twenties. Figure 2.2 shows a 3D laser scanner, developed by Hamamatsu Photonics, named Body Line Scanner (C9036, Hamamatsu Photonics K.K. Shizuoka, Japan).

Since 1980s, 3D body scanning has received great attention and been widely applied in apparel field. The main applications of body scanning in apparel are as following: (1)non-contact body measurement for size survey, (2) pattern generation for customization, (3) a tailored mannequin for a target market, and (4) garment fit evaluation [33].

For 3D body modeling and pattern-making, 3D digitization of body is essential. 3D scanning is an effective method for an acquisition of precise body measurements. Numberless point data of body surface can be obtained in seconds for a generation of a virtual or physical dress model. The anthropometric data can be used to guide a designing and sizing of the garment.



(a) (b)

Figure 2.1 Japanese standard body: (a) Male; (b) Female

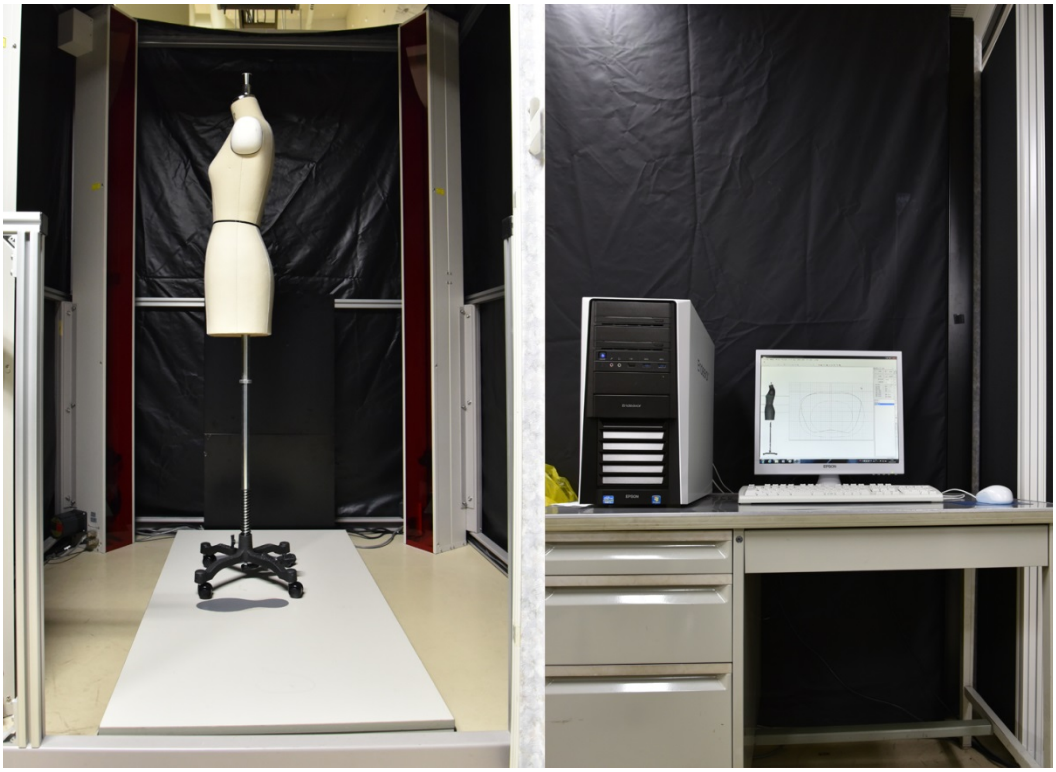


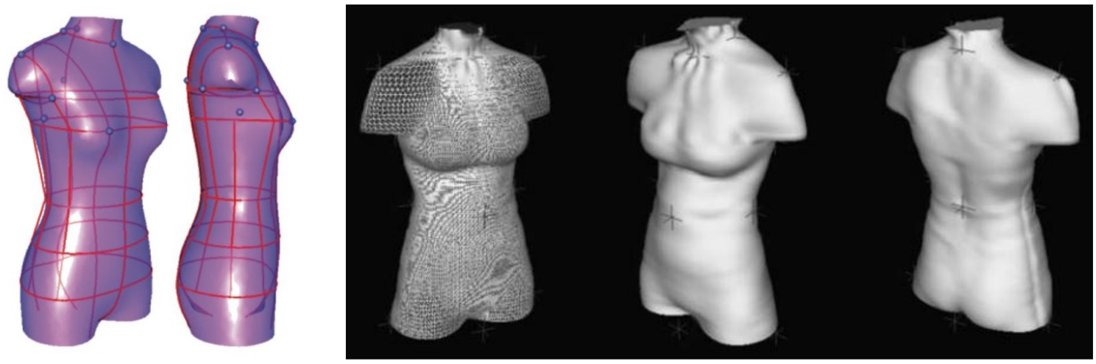
Figure 2.2 Body Line Scanner

2.3.2 3D Body Modeling

3D body scanning technology is being viewed as a significant bridge between craftsmanship and computer-aided design technologies.

As an integral part of computer-aided garment design, 3D body modeling is an active research topic in recent years. 3D body modeling is a significant bridge between 3D scanning and computer-aided design. A properly modeled human body model from unstructured scanned point data cloud has many potential uses for apparel application, such as mannequin development [34], body deformation [30] and mass-customization [23].

Different methods were employed to construct 3D body models to represent the body shapes. Some common methods are: (1) polygonal mashing and patches [30, 34, 35], as shown in Figure 2.3, (2) implicit surface [36, 37], (3) spline curves and surface [38], as shown in Figure 2.3. Polygonal mesh consists of vertices, edges and faces, is the most popular method with flexible applications in geometry processing.



(a) (b)

Figure 2.3 3D human body modeling: (a) Gregory patches modelling [9]; (b) Spline curves and surface modeling [39]

In addition to the 3D method, researcher studied the relationship between human bodies 2D sizes and 3D shapes, and used an image-based measurement and geometry to construct body models [32, 40].

2.3.3 3D Garment Modeling and Simulation

3D Garment modeling based on body model is a simple and effective way to construct a garment model. After creating a body model, a tight-fit garment model is easily constructed by converting the body surface into garment surface [41]. For loose-fit garment pattern generation and simulation, a new garment model should be constructed based on the body surface. Garment simulation and pattern CAD have received much attention from the computer graphics and clothing technology communities [42-47].

The polygonal surface model is mostly used for garment modeling and simulation. Botsch *et al.,* [48] discussed different aspects of polygonal surface applications from the view of geometric modeling. Among these polygonal surfaces, triangle meshes are a valuable alternative to traditional spline, since their conceptual simplicity allows more flexible and efficient processing.

Some commercial 3D systems have been created for modeling the human body and simulating the wearing of garment and patterns in 3D space by utilizing a virtual body model [49-51].

2.3.4 3D Pattern Development

Upon 3D body modeling and garment modeling, garment pattern generation can be achieved by a 3D surface flattening method. 3D pattern developing is a 3D-to-2D approach. 3D model is firstly constructed, and then its surface is cut by line or plane to flatten into 2D patterns. The overview of 3D garment pattern development is shown in Figure 2.4 [52].

Kim and Kang [39] reported a set of algorithms for basic block pattern generation. 2D patterns were made using multi-resolution mesh with optimum planer pattern mapping algorithm based on a body model. Meng [53] conducted trial fitting and pattern alteration to make the well-fitted bodice. Cross parameterization, geometrical and physical integrated deformation and 3D editing methods are employed to map clothing patterns on a model surface for generating patterns as shown in Figure 2.5.

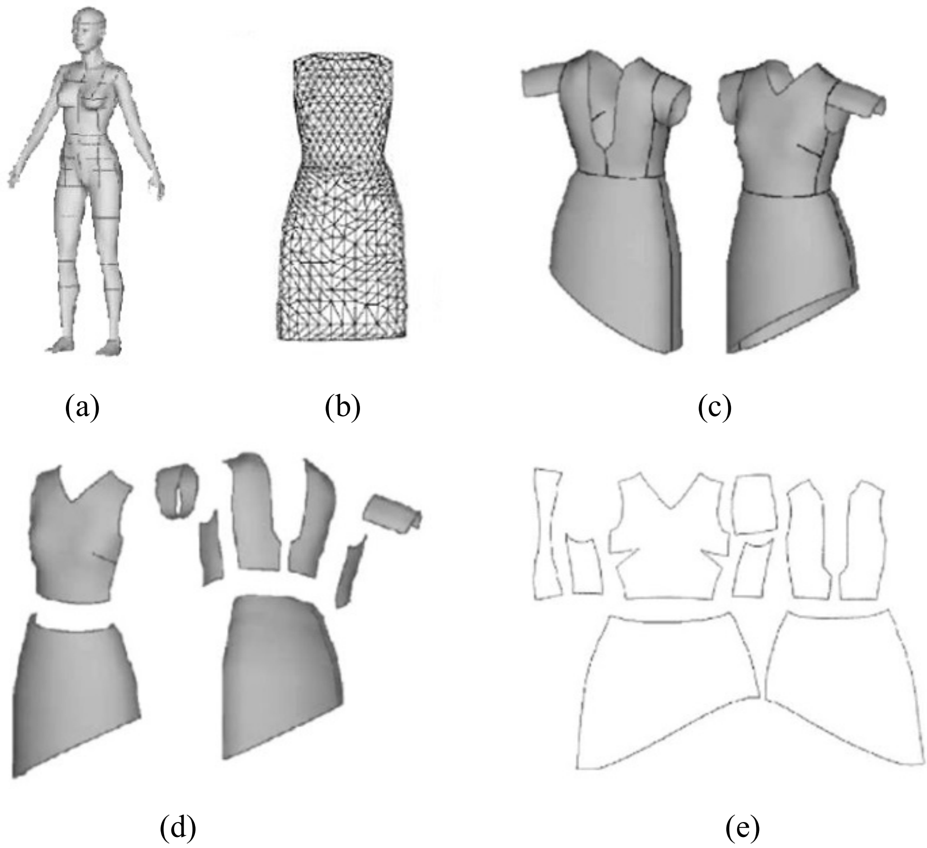


Figure 2.4 Overview of 3D garment pattern development: (a) Featured human model; (b) Input and result of extracting; (c) Setting seam line; (d) Results of separation; (e) Flattened 2D patterns [52]

Kim and Park [54] proposed a basic garment pattern generation method. A fit zone and a fashion zone were defined in their approach to facilitate pattern generation. Zhang *et al.,* [41] presented a sketch based garment modeling method. In the method, they extracted the contour lines of a 3D human body, and then constructed an initial 3D garment surface based on the body, and finally used sketching to deform the garment to obtain a basic garment model, from which 3D surface patches are trimmed and then flattened into 2D patches.

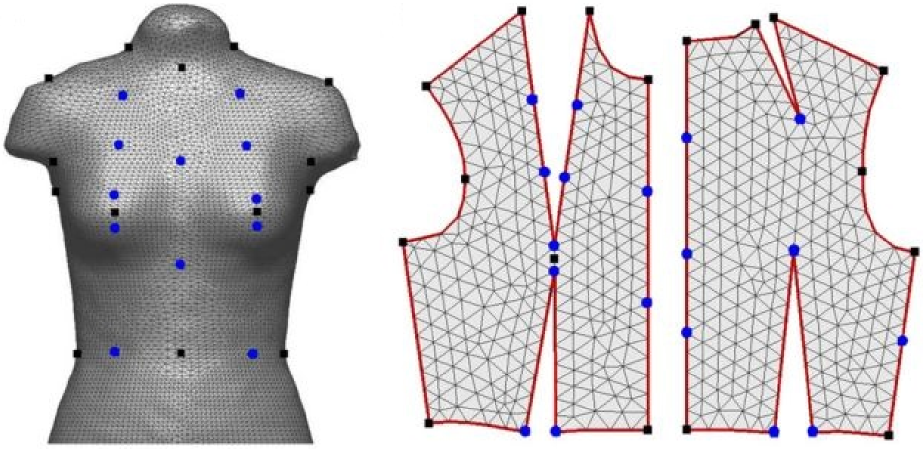


Figure 2.5 Featured curves and pattern pieces [53]

Many studies of computer-aided 3D pattern-making methods have been carried out; however, these systems can create only a limited number of patterns for clothing, while their practical abilities for making clothing have never actually been confirmed. Therefore, a detailed examination and a verification of each pattern are necessary for a practical use.

2.4 Garment Pattern Sizing

The garment sizing system is based on body measurements that date back to the 1940s [3]. Generally, the most notable differences in body sizes and shapes relate to ethnic diversity, age and gender [55]. For sizing garment, girth and longitudinal or length measurements designate the size and are critical in achieving a garment fit. The girth measurements are vital when sizing garments for adults because in most cases, adults grow laterally as opposed to vertically [56].

For ready-to-wear, the objective of garment sizing is to divide standardized dimensions for the body and garments into categories, with the aim to fit the maximum number of people with the minimum number of sizes.

Garment size concerns human body size and garment ease. In mass production and flat pattern-making, grading is the most popular method for making various size garments with a designated size chart. In 3D pattern-making, garment size is usually considered in modeling. The differences in size and ease are modeled within garment models. Grading is also practicable for 3D pattern-making while molding, as well flattened 2D patterns.

For customers, size fit and comfort of the garment are the two most important evaluation criteria when purchasing ready-to-wear [57, 58]. Proper size is very important to consumers, as it increases the chance of finding his or her clothing in a properly proportioned size and style that will involve only a minimum of alterations [59].

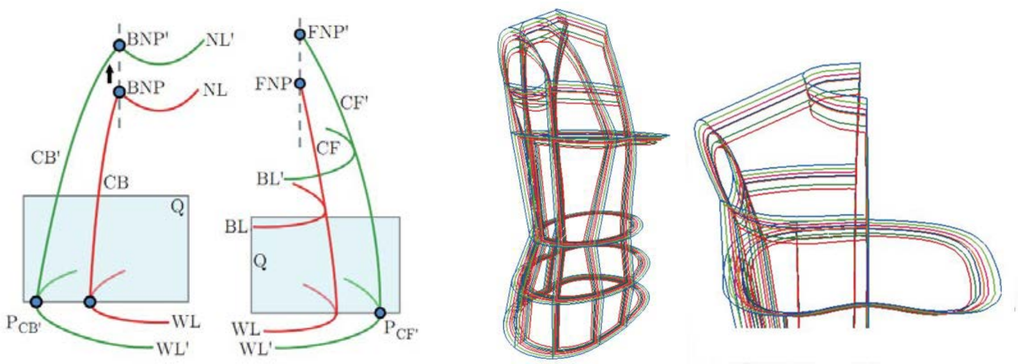
2.4.1 Pattern Grading

To make products in several sizes for different body shapes, pattern grading is a process of proportionally increasing or decreasing the size of a master pattern according to a prescribed set of body measurements (bust, waist, hip, shoulder), based on the average difference between the sizes [59, 60]. A finished master pattern is required for grading, on which carts, drill holes, grainlines, and seam lines all are noted accurately.

The grade varies according to the type of measurement: circumference, length or width, refers to circumference grade, length grade, width grade and uneven grade [59].

In today's apparel industry, many designs, pattern-making, and grading processes are being done on computers, resulting in faster production, improvement of fabric utilization, higher quality, and consistency of graded patterns. Additionally, 3D computerized grading is introduced to pattern making on 3D garment models [61].

Wang and Huang [9] proposed a new automatic featured frame for generating full sizes of garment patterns by flattening 3D garments created from parameterized mannequin models in filling the requirements of body structures, sizing chart and garment fit in 3D system, as shown in Figure 2.6.



(a) (b)

Figure 2.6 3D garment model deformation and pattern grading: (a) The deformation of Center Back and Center Front; (b) Size frames deformed from the feature frame [9]

2.4.2 Pattern Ease

Pattern ease is another factor affecting garment size and comfort. Ease allowance is a measurable difference between the measurement of body and garment. It is generated by adding additional length and girth in design, grading or modeling.

Every garment should have a certain amount of ease for wearing, movement and comfort. Upon garment style, other additional ease may be necessary. Ease allowance for wearing and movement is known as wearing ease, while the ease allowance for style is regarded as design ease [62, 63].

Researchers investigated the basic ease amount for various garment types [64] and use fuzzy logic and sensory evaluation to estimate ease of a garment [65]. Wang [63] and Xu [66] studied the ease distribution on cross-sections of upper garment and body to calculate the ease amount and ease-space for fit evaluation. Some researchers also discussed the ease distribution at the bust section [67] and pants [68] and put forward a proposal to optimize pattern-making.

The required ease amount depends on the design, fabric, body type, the function of garments, and personal preference [36]. Optimum garment eases are important to garment appearance and fit. Ease amount and distribution should be seriously deal with in pattern-making, grading, 3D garment modeling and flattening.

2.5 Garment Fit and Evaluation

Consumer satisfaction with a product is a complex concept that is difficult to quantify. According to Swan and Combs [69], it entails instrumental and expressive performance outcomes. Garment satisfaction is associated with expressive outcomes, while dissatisfaction is associated with instrumental outcomes [69-72]. Garment fit mainly refers to garment size (instrumental outcomes) and comfort (expressive outcomes).

Garment fit has long been regarded as the most important element to customers for purchase decision [33]. To improve the satisfaction of garment, garment fit should be meticulously evaluated.

2.5.1 Garment Fit

The fit is the most important factor leading to the final acceptance or rejection of garment [73]. It is also a crucial element of clothing quality and customer satisfaction [74]. Due to the different characteristics of garments, garment fit has been defined in multiple dimensions, LaBat broadly defined clothing fit as the relationship of clothing to the body, combining the visual analysis of fit and the physical evaluation of comfort [75]. Brown and Rice defined fit as "how well the garment conforms to the three-dimensional human body" [76].

Garment fit is a complex relationship between the human body and clothing assessed to judge how well the clothing conforms to a set of requirements. These requirements or elements of fit are commonly categorized as ease, line, grain, and balance and set [77]. In addition to these elements, "good fit" also depends on fashion trends, standardized sizes and individuals' perception of fit.

In the market, garments made by mass production based on standardized sizes reluctantly supply "good fit" for some consumers, because this method does not reflect individual body shapes, so the garments will not be a perfect fit to an individual [8]. As the purchasing power increases and lifestyle changes, consumers demand more diversified and individualized productions, Made-to-Measure (MTM) and mass customization are some solutions that fulfill the consumers' needs for differentiation and product personalization [78]. Rather than just niche markets, mass customization may become a broad trend for the apparel industry production and retail.

2.5.2 Garment Fit Evaluation

Garment fit is a complex set of requirements. Most consumers just have a sensory evaluation in purchasing through fitting trials. Moreover, evaluation results are often affected by respondents' experience, culture, and education etc. To understand garment fit intensively, the researchers used photographs [79] and videotapes [80, 81] for body shape and garment fit analysis. 3D computer-aided technologies have made considerable progress in the past few decades, such as 3D body and garment scanning, 3D modeling and simulation. Some studies were carried out to investigate the reliability and usability of 3D technology for garment fit evaluation.

Yu *et al.,* [82] and Ng *et al.,* [83] have applied moiré topography for evaluating the fit of various clothing types, such as bra cup and jacket. Moiré system was used to scan the garment surface; the depth of the cloud point indicates unevenness on the surface. Based on moiré topography experimental results, Yu *et al.,* [84] proposed a subjective fit evaluation scale to collect customers' opinions in the form of a questionnaire survey. An example is given in Figure 2.7.

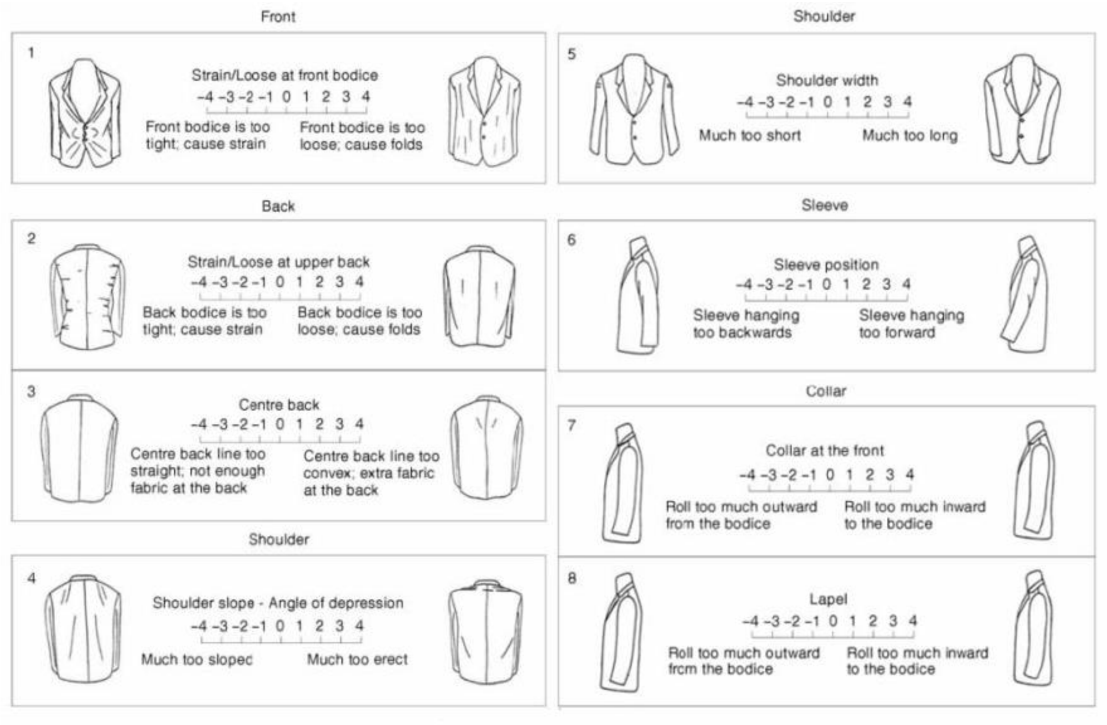


Figure 2.7 Subjective fit evaluation scale [84]

Taya [85] and Zhang [8] extracted body and garment cross-sectional (as shown in Figure 2.8) with 3D body and garment scanning data to evaluate garment fit. The waveform method is capable of applying to most garment types and is easily carried out [33].

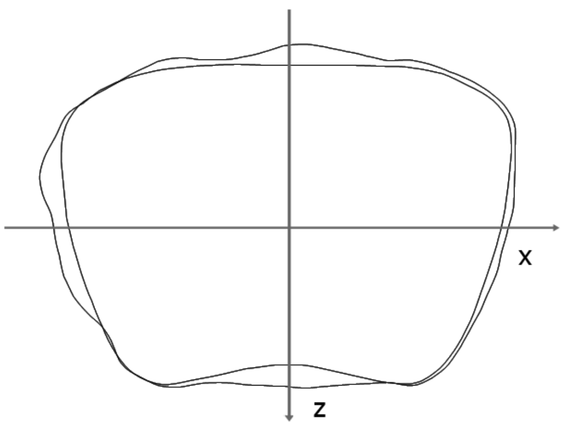


Figure 2.8 Cross-sectional of body and garment at bust line

Other methods, such as pressure evolution and 3D modeling of pressure fit [86] are applied to measure the distribution of pressure actually [29] or virtually [16, 86, 87] for fit evaluation.

Objective evaluation of garment fit is necessary but difficult to achieve. The discussed may lead to 3D garment fit evaluation, based on garment images or 3D data, which will be an efficient and effective decision making in the process of product development and quality control.

2.6 Garment Virtual Try-on Technologies.

With the application of 3D garment modeling and pattern-making, Virtual garment try-on technology arose out for garment simulation, virtual fitting online.

Virtual fitting and try-on refer virtually sewing up garment patterns on human models to visualizing design effects through physical-based real-time simulation. The technique consists of modeling the physical behaviors of textiles based on real data of garment patterns which have to be placed around an avatar [11].

In 3D pattern-making system, patterns are generated from 3D surface. Furthermore, the patterns are capable of doing virtual sewing and trying on a virtual avatar. The process enables pattern maker not only views the garment in 3D instead of trial produce, but also make an adjustment to patterns. Alteration of patterns can be carried out rapidly to provide optimum patterns.

The virtual try-on technique allows consumers to design their own garment by selecting the viewed style, fabric, color online [33]. Consumers make a choice of the garment up to the final visualization and the individual evaluation of fit. Virtual fitting aims to provide optimal fit and revolutionize the online shopping experience. The main feature of this technology is the capability of virtually testing fit on individuals or retail-specified size models. It will also help consumers to know their right sizes of body and garment.

2.7 3D Pattern-making System

A 3D pattern making system was developed in previous study [23], Cho *et al.,* [26, 88] used computerized draping method to fit the 3D model to make a tight skirt by employing this system, an example is shown in Figure 2.9. 3D pattern-making and pattern modification can be conducted in this 3D system. By adopting the system, garments for individuals can be achieved [89-91].

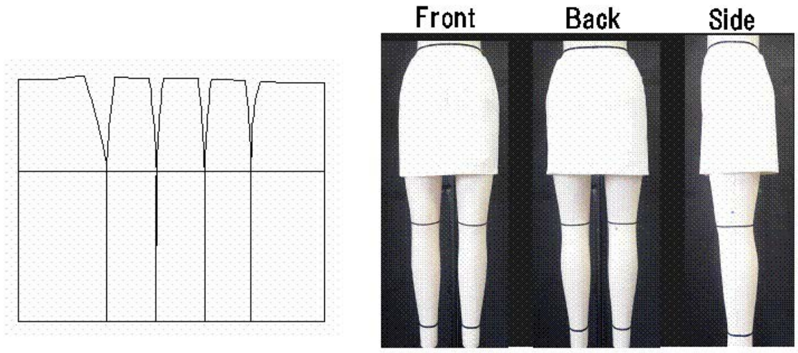


Figure 2.9 Tight skirt pattern and tight skirt [26]

Tsuchiya Cho *et al.,* [92] and Takatera *et al.,* [25, 93] used 3D scanning data of legs to construct a model and make pants patterns. In these studies, crotch line modification method was introduced, which is the key point for making 3D pants model and well-fit pants. The example is shown in Figure 2.10.

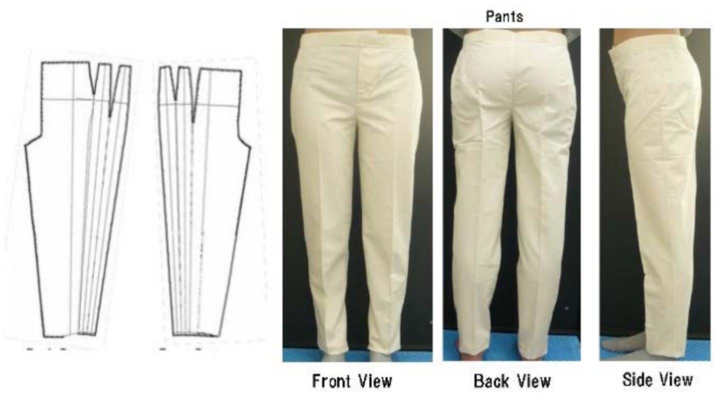


Figure 2.10 Pants pattern and pants [92]

Takahashi and Sofue [24] used sweep method to deal with convex hulls in 3D upper garment modeling and pattern-making. Elbow shape and shearing behavior were considered in the study, an example is shown in Figure 2.11.

Figure 2.11 Upper garment and sleeve pattern and the result [24]

The works are continued in this study for making upper garment model and pattern for different body size and proportions.

2.8 Summary

With the development of computer technology 3D body models and 3D garment models can be easily constructed on a computer. Many researchers and developments concerned 3D garment molding and pattern-making. However, many issues have not stated yet.

1. The traditional flat pattern-making methods are made based on a linear measurement of body or mannequin. In the flat pattern-making process, it is difficult to reflect the 3D shape of the body and garment directly.

2. Researchers attempted to propose 3D modeling method to make patterns. Because of the complexity of 3D body surface shape, 3D shapes of the model was simplified to regular shape to some extent, most of the models are only applicable for making block pattern, sloper, and tight-fitting garment.

3. Some studies concerned ease allowance of the garment in flat pattern-making, ease distribution in 3D garment modeling is still a challenge; it is an essential element in 3D garment modeling and pattern-making for making a better fit garment and has to be under consideration.

4. Mechanical property of the fabric is one of the important elements related to garment modeling and pattern-making. Many studies noted the mechanical properties related to draping behavior to improve simulation reality. However, how to incorporate mechanical properties into garment modeling and pattern-making is still a challenge.

In brief, to make garment model and pattern having good fitness, body shape and proportions, ease allowance, mechanical properties of the fabric are basic factors that should be in overall consideration in 3D garment modeling and pattern-making. There are many challenges remained in this field for researchers.

References

1. Alexander M., Jo Connell L., and Beth Presley A., Clothing fit preferences of young female adult consumers. *International Journal of Clothing Science and Technology*, 2005. 17(1): 52-64.
2. Bye E., Labat K.L., and Delong M.R., Analysis of body measurement systems for apparel. *Clothing and Textiles Research Journal*, 2006. 24(2): 66-79.
3. Zwane P.E. and Magagula N.A., Pattern design for women with disproportionate figures: a case study for Swaziland. *International Journal of Consumer Studies*, 2007. 31(3): 283-287.
4. Yang Y.C. and Zhang W.Y., Prototype garment pattern flattening based on individual 3D virtual dummy. *International Journal of Clothing Science and Technology*, 2007. 19(5): 334-348.
5. Lim H. and Istook C.L., Automatic Pattern Generation Process for Made-to-Measure. *Journal of Textile and Apparel, Technology and Management*, 2012. 7(4): 1-11.
6. Daanen H. and Hong S., Made-to-measure pattern development based on 3D whole body scans. *International Journal of Clothing Science and Technology*, 2008. 20(1): 15-25.
7. Patrick T. and Bond T., Made-to-measure garments for ladies-catering for wide ranging stature and length measurements for standard and outsize ladies. *International Journal of Clothing Science and Technology*, 1999. 11(4): 216-225.
8. Zhang J., Kim K., and Takatera M., Three-dimensional garment-size change modeled considering vertical proportions. *International Journal of Clothing*

Science and Technology, 2016. 28(5): In printing.

9. Wang Y. and Huang H., Three Dimensional Pattern Grading Based on Deformable Body Features and 3D Developable Surface. *Journal of Fiber Bioengineering and Informatics*, 2011. 4(2): 115-128.

10. Workman J.E., Body measurement specifications for fit models as a factor in clothing size variation. *Clothing and Textiles Research Journal*, 1991. 10(1): 31-36.

11. Wacker M., Keckeisen M., Kimmerle S., Straßer W., Luckas V., Groß C., Fuhrmann A., Sattler M., Sarlette R., and Klein R., Simulation and visualisation of virtual textiles for virtual try-on. *Special Issue of Research Journal of Textile and Apparel: Virtual Clothing Technology and Applications*, 2005. 9(1): 37-47.

12. Protopsaltou D., Luible C., Arevalo M., and Magnenat-Thalmann N., Advances in Modelling, Animation and Rendering. A body and garment creation method for an Internet based virtual fitting room. 2002, London, Springer.

13. Meng Y., Mok P.Y., and Jin X., Interactive virtual try-on clothing design systems. *Computer-Aided Design*, 2010. 42(4): 310-321.

14. Lim H.S. (2009). Three dimensional virtual try-on technologies in the achievement and testing of fit for mass customization. Ph.D. Thesis, North Carolina State University.

15. Wu Y., Mok P., Kwok Y., Fan J., and Xin J. An investigation on the validity of 3D clothing simulation for garment fit evaluation.Proceeding of *Proceedings of the IMProVe 2011, International conference on Innovative Methods in Product Design*, 2011. Venice, Italy.

16. Lee J., Nam Y., Cui M.H., Choi K.M., and Choi Y.L. Fit Evaluation of 3D

Virtual Garment. Proceedings of the 2nd international conference on Usability and internationalization, 2007. Berlin, Springer.

17. Helen J.A., Patternmaking for fashion design. Third Edition. 1999, New Jersey, Prentice Hall.
18. Pascal V., Frederic C., and Nadia M., From early virtual garment simulation to interactive fashion design. *Computer-Aided Design*, 2005. 37(6): 593-608.
19. Okabe H., Imaoka H., Tomiha T., and Niwaya H. Three dimensional apparel CAD system.Proceeding of *ACM SIGGRAPH Computer Graphics*, 1992. ACM.
20. Kang T. and Kim S., Development of three-dimensional apparel CAD system: Part 1: flat garment pattern drafting system. *International journal of clothing science and technology*, 2000. 12(1): 26-38.
21. Luo Z.G. and Yuen M.M.F., Reactive 2D/3D garment pattern design modification. *Computer-Aided Design*, 2005. 37(6): 623-630.
22. Durupinar F. and Güdükbay U. A virtual garment design and simulation system.Proceeding of *11th International Conference of Information Visualization. IV'07*, 2007. Zürich, Switzerland.
23. Cho Y.S., Okada N., Park H., Takatera M., Inui S., and Shimizu Y., An interactive body model for individual pattern making. *International Journal of Clothing Science and Technology*, 2005. 17(1-2): 91-99.
24. Takahashi Y., Sofue A., Kim K., and Takatera M., Automatic 3D Pattern Making of Fitted Upper Garments Considering Individuals' Figures and Shear Limit of Fabrics. *International Journal of Affective Engineering*, 2013. 12(2): 169-175.
25. Takatera M., Tsuchiya K., Kim K., and Cho Y., Computer Aided Design of Individualized Best Fitting Pants. *Proc. KEER*, 2010.

26. Cho Y.S., Komatsu T., Inui S., Takatera M., Shimizu Y., and Park H., Individual pattern making using computerized draping method for clothing. *Textile Research Journal*, 2006. 76(8): 646-654.

27. Wang J., Lu G., Li J., Chen L., and Zhang D., Pattern design on 3D triangular garment surfaces. *Journal of Zhejiang University SCIENCE A*, 2007. 8(10): 1642-1649.

28. Kim S., Jeong Y., Lee Y., and Hong K., 3D pattern development of tight-fitting dress for an asymmetrical female manikin. *Fibers and Polymers*, 2010. 11(1): 142-146.

29. Jeong Y., Hong K., and Kim S., 3D pattern construction and its application to tight-fitting garments for comfortable pressure sensation. *Fibers and polymers*, 2006. 7(2): 195-202.

30. Zhang J., Innami N., Kim K., and Takatera M., Upper garment 3D modeling for pattern making. *International Journal of Clothing Science and Technology*, 2015. 27(6): 852-869.

31. Meunier P. and Yin S., Performance of a 2D image-based anthropometric measurement and clothing sizing system. *Applied Ergonomics*, 2000. 31(5): 445-451.

32. Lin Y. and Wang M., Constructing 3D human model from front and side images. *Expert Systems with Applications*, 2012. 39(5): 5012-5018.

33. Fan J., Yu W., and Hunter L., Clothing appearance and fit: Science and technology. 2004, Cambridge, Woodhead Publishing Limited.

34. Wang C.C.L., Parameterization and parametric design of mannequins. *Computer-Aided Design*, 2005. 37(1): 83-98.

35. Huang H. (2011). Development of 2D block patterns from fit feature-aligned flattenable 3D garments. Ph.D. Thesis, The Hong Kong Polytechnic University.

36. Masuda T. and Imaoka H., An estimation of gap lengths on the back bodice tight-fitting pattern by draping for understanding the back trunk from clothing design. *Journal of the Japan Research Association for Textile End-Uses*, 1999. 40(9): 592-604.

37. Shen J. and Thalmann D. Interactive shape design using metaballs and splines. Proc. Implicit Surfaces95, 1995.

38. Douros I., Dekker L., and Buxton B.F. Reconstruction of the surface of the human body from 3D scanner data using B-splines. Electronic Imaging'99, 1999. International Society for Optics and Photonics.

39. Kim S.M. and Kang T.J., Garment pattern generation from body scan data. *Computer-Aided Design*, 2003. 35(7): 611-618.

40. Zhu S., Mok P.Y., and Kwok Y.L., An efficient human model customization method based on orthogonal-view monocular photos. *Computer-Aided Design*, 2013. 45(11): 1314-1332.

41. Zhang D., Wang J., and Yang Y., Design 3D garments for scanned human bodies. *Journal of Mechanical Science and Technology*, 2014. 28(7): 2479-2487.

42. Choi K. and Ko H., Research problems in clothing simulation. *Computer-Aided Design*, 2005. 37(6): 585-592.

43. Lin G., Luo X., Li C., Shi X., Li Y., and Wang R., The skim of balance theory of 3D garment simulation. *Applied Mathematics and Computation*, 2011. 218(2): 492-501.

44. Cugini U. and Rizzi C. 3D design and simulation of men garments.Proceeding

of *The 10-th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision*, 2002. Plzeň.

45. Durupınar F. (2004). A 3D garment design and simulation system. Ph.D. Thesis, Bilkent University.
46. Kim S. and Park C.K., Parametric body model generation for garment drape simulation. *Fibers and Polymers*, 2004. 5(1): 12-18.
47. Chittaro L. and Corvaglia D. 3D virtual clothing: from garment design to web3d visualization and simulation. Proceedings of the eighth international conference on 3D Web technology, 2003. ACM.
48. Botsch M., Pauly M., Kobbelt L., Alliez P., Lévy B., Bischoff S., and Röossl C., Geometric modeling based on polygonal meshes. In SIGGRAPH 07: ACM SIGGRAPH 2007 courses. 2007, New York, ACM Press.
49. Digital Fashion Ltd. DressingSim LSX; Available from: http://www.dressingsim.com/, [Accsessed: March 20, 2016].
50. Apparel CAD | Toray ACS Ltd. Available from: http://www.toray-acs.co.jp/, [Accsessed: March 20, 2016].
51. Fontana M., Rizzi C., and Cugini U., 3D virtual apparel design for industrial applications. *Computer-Aided Design*, 2005. 37(6): 609-622.
52. Wang C.C.L., Wang Y., and Yuen M., Feature based 3D garment design through 2D sketches. *Computer-Aided Design*, 2003. 35(7): 659-672.
53. Meng Y., Mok P.Y., and Jin X., Computer aided clothing pattern design with 3D editing and pattern alteration. *Computer-Aided Design*, 2012. 44(8): 721-734.
54. Kim S. and Kyu Park C., Basic garment pattern generation using geometric modeling method. *International Journal of Clothing Science and Technology*,

2007. 19(1): 7-17.

55. Apeagyei P.R., Application of 3D body scanning technology to human measurement for clothing Fit. *International Journal of Digital Content Technology and its Applications*, 2010. 4(7): 58-68.

56. Tamburrino N., Apparel sizing issues, Part 1. *Bobbin*, 1992. 33(8): 44-46.

57. Eckman M., Damhorst M.L., and Kadolph S.J., Toward a model of the in-store purchase decision process: Consumer use of criteria for evaluating women's apparel. *Clothing and Textiles Research Journal*, 1990. 8(2): 13-22.

58. Hsu H.-J. and Burns L.D., Clothing evaluative criteria: A cross-national comparison of Taiwanese and United States consumers. *Clothing and Textiles Research Journal*, 2002. 20(4): 246-252.

59. Price J. and Zamkoff B., Grading techniques for fashion design. Second Edition. 1996, New York, Fairchild Publications.

60. Cooklin G., Pattern Grading for Women's Clothes. 1991, Oxford, England, Wiley-Blackwell.

61. Ng R., Three-dimensional grading of virtual garment with design signature curves, in *Digital Human Modeling*. 2011, Springer. p. 328-336.

62. Xu J.H., Zhang W.B., and Xiao P. A study on impact factors of the distance eases between body and garment.Proceeding of *9th International Conference on Computer-Aided Industrial Design and Conceptual Design, 2008. CAID/CD 2008* 2008. Kunming.

63. Wang Z.H. (2008). A study of ease distribution in relation to jacket pattern alteration. Ph.D. Thesis, The Hong Kong Polytechnic University.

64. Wang X., Analysis study of the ease allowance needed for garment. *Journal of*

Textile Research, 2005. 4: 043.

65. Chen Y., Happiette M., Bruniaux P., Ng R., and Yu W., Estimation of ease allowance of a garment using fuzzy logic, in *Fuzzy Applications in Industrial Engineering*. 2006, Springer. p. 367-379.

66. Xu J.H., Chen X.F., and Zhang W.B., A Study on Area Ease Distribution between Body and Garment. *Journal of Fiber Bioengineering and Informatics*, 2009. 2(2): 101-107.

67. Zhang A., Wang Y., and Yao Y., Study on relationships between garment's distance ease distributions at bust section. *Journal of Textile Research*, 2012. 33(6): 76-80.

68. Su J.Q., Gu B.F., Liu G.L., and Xu B.G., Determination of distance ease of pants using 3D scanning data. *International Journal of Clothing Science and Technology*, 2015. 27(1): 47-59.

69. Swan J.E. and Combs L.J., Product performance and consumer satisfaction: A new concept. *Journal of marketing*, 1976. 40(2): 25-33.

70. Maddox R.N., Two-factor theory and consumer satisfaction: Replication and extension. *Journal of consumer research*, 1981: 97-102.

71. Francis S.K. and Dickey L.E., Dimensions of satisfaction with purchases of women's dresses: Before and after garment care. *Journal of Consumer Studies & Home Economics*, 1984. 8(2): 153-168.

72. Campbell L.D. and Horne L., Trousers developed from the ASTM D5586 and the Canada Standard Sizing for women's apparel. *Clothing and Textiles Research Journal*, 2001. 19(4): 185-193.

73. Obinnim E. and AfiPongo N., The Significance of Flat Pattern Making In

Fashion Designing: A Case Study of Dressmakers in the Ho Municipality Of Ghana. *International Journal of Innovative Research in Science, Engineering and Technology*, 2015. 4(4): 1850-1857.

74. Song H.K. and Ashdown S.P., An exploratory study of the validity of visual fit assessment from three-dimensional scans. *Clothing and Textiles Research Journal*, 2010.

75. LaBat K.L. and DeLong M.R., Body cathexis and satisfaction with fit of apparel. *Clothing and Textiles Research Journal*, 1990. 8(2): 43-48.

76. Brown P. and Rice J., Ready-to-wear apparel analysis. 2013, New Jersey, Prentice Hall.

77. Erwin M.D., Kinchen L.A., and Peters K.A., Clothing for moderns. 1979, New Jersey, Prentice Hall.

78. Zipkin P., The limits of mass customization. *MIT Sloan management review*, 2001. 42(3): 81.

79. Douty H.I., Visual somatometry in health related research. *Journal of Alabama Academy of Science*, 1968. 39(1): 21-24.

80. Kohn I.L. and Ashdown S.P., Using video capture and image analysis to quantify apparel fit. *Textile research journal*, 1998. 68(1): 17-26.

81. Schofield N.A., Ashdown S.P., Hethorn J., LaBat K., and Salusso C.J., Improving pant fit for women 55 and older through an exploration of two pant shapes. *Clothing and Textiles Research Journal*, 2006. 24(2): 147-160.

82. Yu W., Harlock S., Leaf G., and Yeung K., Instrumental design for capturing three-dimensional moiré images. *International Journal of Clothing Science and Technology*, 1997. 9(4): 301-310.

83. Ng R., Chan C., Pong T., and Au R. Objective measurement of the "fit" of an apparel.Proceeding of *77th textile institute world conference*, 1995. Tampere, Finland.

84. Yu W.M., Yeung K.W., and Lam Y.L. Assessment of garement fit.Proceeding of *the HKITA & CTES Conference on Hand-in-Hand Marching into 21st Century*, 1998.

85. Taya Y., Shibuya A., and Nakajima T., Evaluation method of clothing fitness with body—Part 1: Evaluation index of clothing fitness. *J Text Mach Soc Japan*, 1995. 48(2): 48-55.

86. Zhang X., Yeung K., and Li Y., Numerical simulation of 3D dynamic garment pressure. *Textile Research Journal*, 2002. 72(3): 245-252.

87. Ashdown S.P., Loker S., Schoenfelder K., and Lyman-Clarke L., Using 3D scans for fit analysis. *Journal of Textile and Apparel, Technology and Management*, 2004. 4(1): 1-12.

88. Cho Y.S., Komatsu T., Park H., Inui S., Takatera M., and Shimizu Y., Computerized Pattern Making System Allowing Fabric Shear. *Textile Research Journal*, 2006. 76(8): 646-665.

89. Cho Y.S., Komatsu T., Takatera M., Inui S., Shimizu Y., and Park H., Posture and depth adjustable 3D body model for individual pattern making. *International journal of clothing science and technology*, 2006. 18(2): 96-107.

90. Cho Y.S., Tsuchiya K., Takatera M., Inui S., Park H., and Shimizu Y., Computerized pattern making focus on fitting to 3D human body shapes. *International Journal of Clothing Science and Technology*, 2010. 22(1): 16-24.

91. Cho Y.S., Relationship between Hip Shape and Pattern Using 3D Body Model.

Journal of the Korean Society of Clothing and Textiles, 2009. 33(2): 266-275.

92. Tsuchiya K., Cho Y.S., and Takatera M., Individual Pattern making of skirts and pants using computerized draping method. *Proc. KEER*, 2007.

93. Takatera M. and Kim K., Improvement of individualized pattern making using surface flattening technique. *Journal of Fiber Bioengineering and Informatics*, 2013. 6(4): 467-480.

Chapter 3

Research Methodology

Chapter 3 Research Methodology

Three-dimensional (3D) pattern-making is a process of constructing a 3D model and flattening the 3D surface to two-dimensional (2D) patterns. 3D model is covered by a mesh in 3D virtual space and the covered 3D surface is cut by cutting lines to generate patterns [1].

In this chapter, the methodology of 3D pattern-making is described, from 3D data scanning to garment model, and then how to flatten 3D surface to 2D patterns.

3.1 Introduction

In 3D modeling, surface of model is formed by triangular polygon mesh. 3D surface fitting method is employed to cover it for generating a surface for cutting. As for fabric, the shearing and bending behavior should be under consideration.

3.1.1 3D Surface Fitting

3D surface fitting refers covering 3D surface with virtual fabric mesh or pieces of fabric shapes on object, and fitting the covered shape, for example draping.

Researchers have studied how to form a curved surface of the fabric and how to flat a curved surface. Mack and Taylor [2] have noted the differential equation for analyzing fitting based on the shearing and bending behavior of woven fabric, Shinohara and Uchida [3] have presented the approximate solution of fitting for a sphere. West *et al.*, [4] reported computational simulation for fitting on a curved surface with a virtual cloth, and Heisey and Haller studied the functional relationship for projecting a known 3D fabric surface onto a 2D surface [5, 6]. However, these equations are only useful for spherical or simple surfaces, not applicable to the complex surface like the human body. Imaoka *et al.* [7] introduced the mechanical calculation approach for the development of a 3D surface into a 2D pattern using a finite element method. This method is difficult to reflect the irregular surface defined in the cylindrical coordinate system onto a flat pattern defined in the Cartesian coordinate system [8]. It is also difficult to fit the each polygon together to produce a continuous pattern.

3.1.2 3D Pattern-making System

For 3D pattern-making, a polygon garment model is constructed for fitting. Grainlines are set as warp and weft lines on fabric for covering with virtual fabric mesh. Then, the mesh is cut by cutting lines to flatten to patterns.

Cho *et al.*, [9-11] developed a 3D pattern-making system. Computerized draping method was applied to fit the surface for a making tight-fit skirt with consideration of the shear limit of fabrics. By adopting this system, Tsuchiya *et al.*, [8] improved system to modify the crotch line and made pants for individuals' fit. Takatera *et al.*, [12, 13] and Takahashi *et al.*, [1] made individualized upper garment bodice and sleeves considering elbow shape.

In this study, I improved this system and made upper garment for various body sizes using this 3D pattern-making system. The interface of 3D pattern-making system is shown in Figure 3.1 [14, 15].

With continual development, this 3D pattern-making used is capable of making individualize upper garment, pants, skirt and sleeves. Also, it is useful for size-changing to make different size garments for different bodies. Silhouette, ease allowance and shearing properties are taken into account to make a well-fit garment.

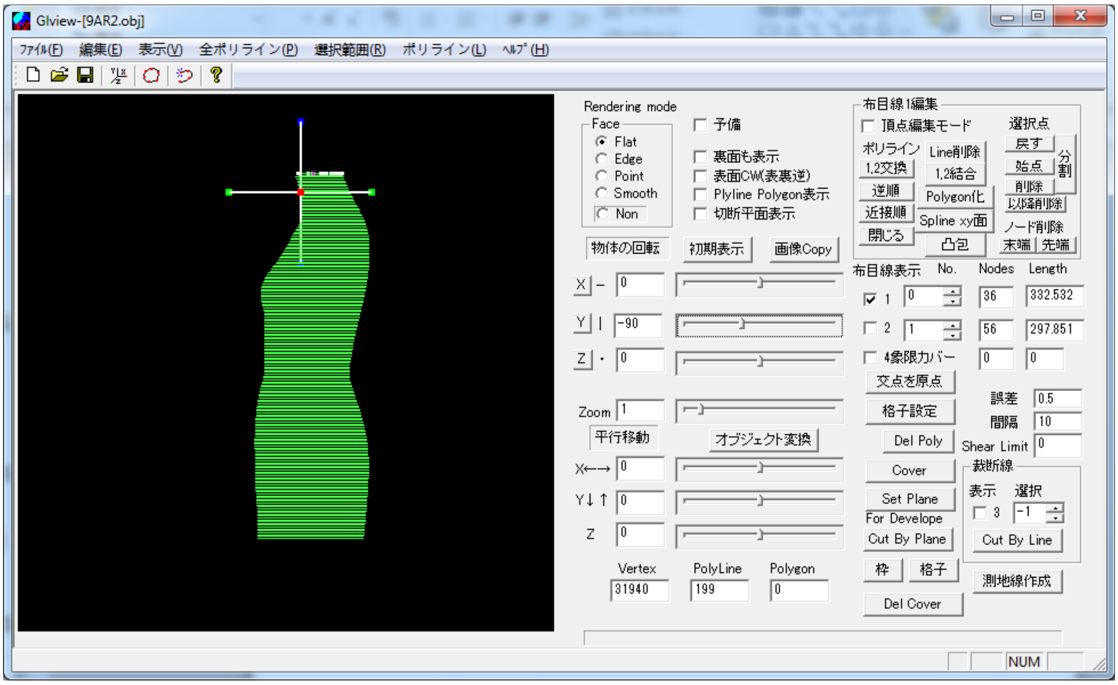


Figure 3.1 The interface of 3D pattern-making system

3.2 3D Data Acquisition

Manual measurement, image-based measurement, gypsum mounding, and 3D scanning is the commonly used as body data acquisition methods. 3D scanning is an accurate method for obtaining 3D body data rapidly, which is capable of converting and 3D modeling. In this study, a 3D scanner is employed to scan the body and garment for modeling.

3.2.1 3D Data Scanning

A non-contact 3D scanner (Hamamatsu Photonics K.K., Body Line Scanner) shown in Figure 2.2 is used for acquiring 3D data in this study. The specifications of the scanner are listed as Table 3.1. There are four pillars in the four corners of the equipment installed with sensor unit, which moves up and down to collecting 3D data as shown in Figure 3.2. The measurement results are converted into visualized 3D shape through dedicated software named Body Line Manager. This device is capable of detecting the landmarks to extract the feature point according to the International Organization for Standardization (ISO) standard for gathering body dimensions automatically.

Body or garment is set into the darkroom for scanning. To obtain 3D data with high precision, the low-speed mode is used to scan the object. The point cloud of a 3D surface is the original form, and is saved as the Wavefront .obj format for further use.

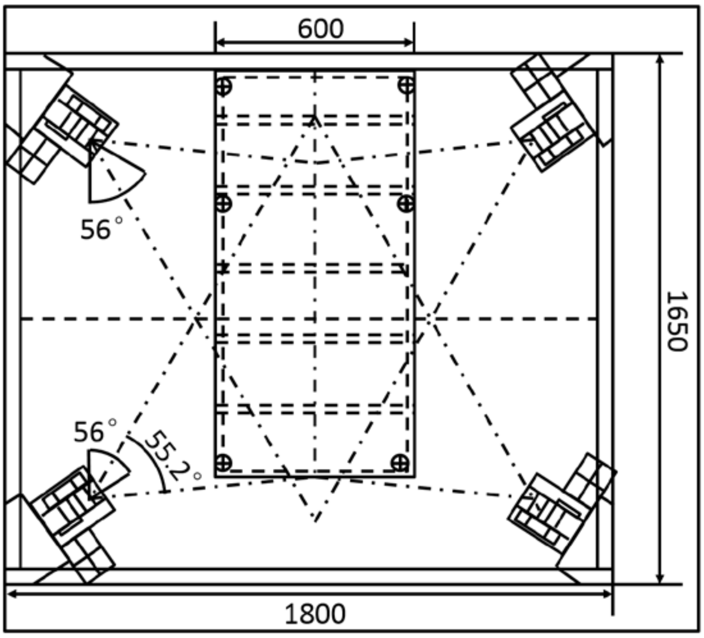


Figure 3.2 Top-view of Body Line Scanner

Table 3.1 Specifications of Body Line Scanner

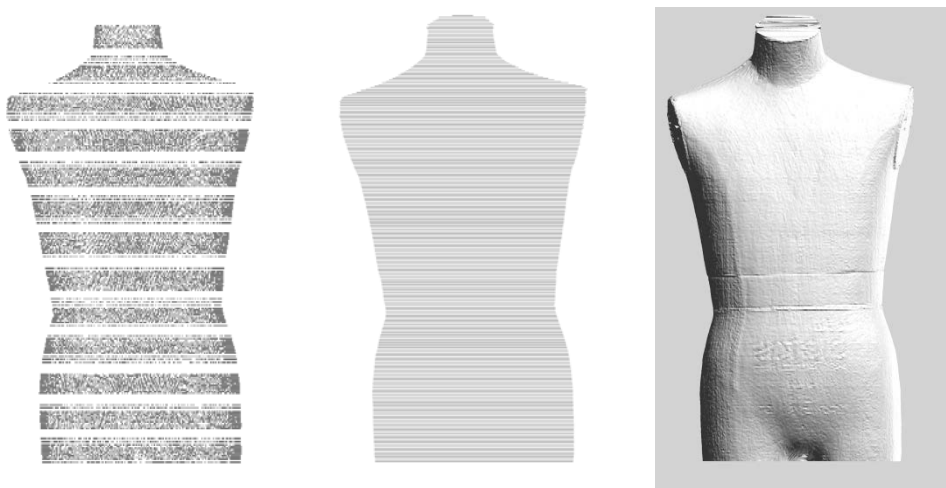
Item	Spec
Measurement principle	Optical blocking
Measurement range	H2000*W1000*D600mm
Number of cameras	4
Measurement method	Sensor-based direct mode of operation
Measuring time	6 seconds (high-speed) 11 seconds (low-speed)
Point pitch	5mm (horizontal)
Measurement accuracy	± 0.5%
Number of points	1,024,000 points (high-speed) 2,048,000 points (low-speed)
Environment	Darkroom

3.2.2 3D Data Conversion

3D shape data is composed of coordinates of each point on the curved surface after scanning. Unnecessary data are deleted. Due to the accuracy of 3D scanner, the scanned 3D data usually have redundant data point or ambiguous geometric structures. Reparation for noise and redundant points is first conducted to clear point cloud and pitch up data imperfection.

Left handed coordinate system with y-axis being vertical upper direction was used. Point cloud data with same y coordinate values are connected in horizontal to form a line model consisting of cross-section. By converting the line model, the deformation of the cross-sectional shape of the 3D object is facilitated.

After conversion into the line model, polygon model is constructed by connecting the point cloud in triangular planes. The surface of polygon model is applied to develop pattern using a 3D flattening method. Figure 3.3 is a process for making a polygon model of a scanned dress form.



(a) (b) (c)

Figure 3.3 Procedure of polygon model generation: (a) Point cloud; (b) Line model; (c) Polygon model

In this Study, dress forms and garments are scanned using the 3D scanner, about two millions coordinate points are collected for 3D deformation and modeling. For efficient deformation of object shape, 3D coordinate axes should be set and combined with the scanned data.

Points with same y coordinate values are linked horizontally and deformed to a closed polyline. The polylines correspond to cross-sections of body. And the feature lines of body, such as bust line, waist line and hip line are easily extracted for further use. All the polylines are gathered to generate a line model as Figure 3.3 (b).

All the deformations are carried out by changing the shape of each polyline in the line model. Finally, a 3D polygon model is produced by constructing a triangular polygon meshes with constituent of adjacent vertices in the polylines, as referred in Figure 3.3 (c).

3.3 Garment Modeling

In 3D pattern-making, a garment model is essential for generating patterns. When fitting the fabric mesh on a 3D garment model, fabric's shear ability is an essential factor affecting covering and flattening operation. Therefore, shear limit should be considered in 3D pattern-making.

3.3.1 Fabric Modeling

In the process of practical operation, fabric is the basic materials used to make a garment. Formability of the curved surface of the fabric varies with different mechanical properties of fabrics. The stretching, compressing, bending and shearing behavior significantly influences fabric forming a curved surface without wrinkles. The shearing behavior of woven fabric is generally considered to be the most important factor governing whether fabric can conform to a 3D object. The elongation in the yarn direction and the bending limit do not need to consider when a woven fabric covers on a garment surface [11].

As for woven fabric, the warp and weft yarns are crossed at right angles in initial plane state. It is easily sheared without changing the lengths in the yarn direction. A simplified fabric model is shown in Figure 3.4. When making a garment, fabric should be deformed to cover a 3D shape for fitting an undevelopable surface of a body or a garment. Therefore, in the covering process of woven fabrics, only the shear deformation should be considered. However, every fabric has a shear limit angle [10, 16]. The shear limit angle of the fabric refers to maximum angle for shearing without causing wrinkle. If the shearing behavior exceeds its shear limit angle, wrinkle will appear. Accordingly the shear limit angle of a fabric was considered in the system.

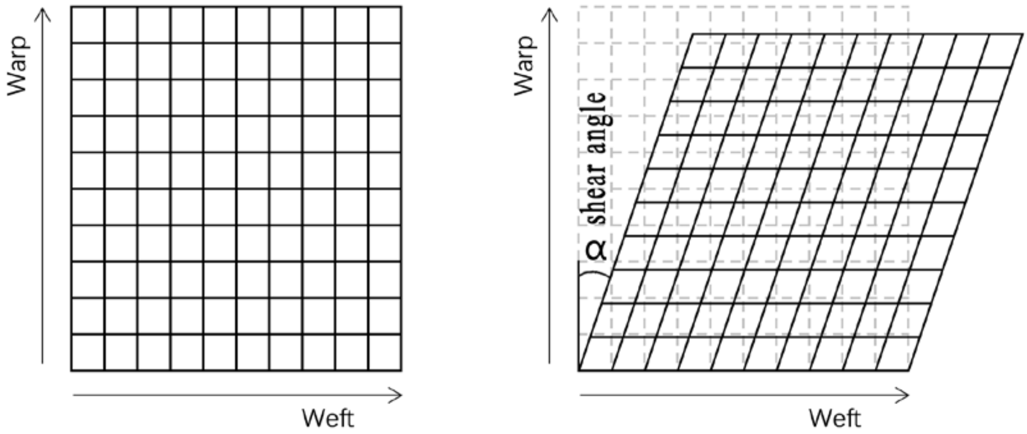
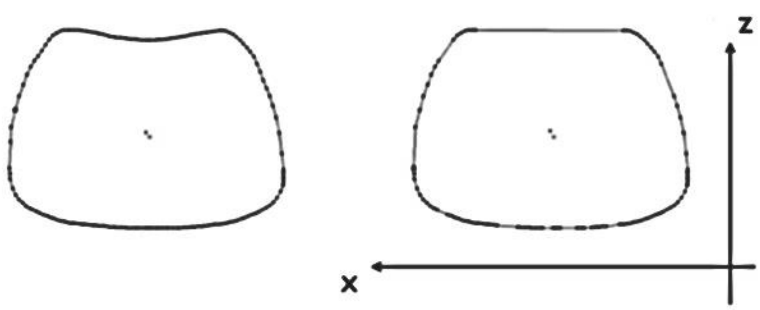


Figure 3.4 Shear deformation and shear angle of fabric model

3.3.2 Garment Modeling

As for the general garment, a fabric does not have to fit on a locally dented part of a body. Accordingly when making a garment model from a body model, it is necessary to make those parts flat. Converting a dented curve into a convex hull is a method for repairing to make a convex polyline model. A new smooth polygons is created by connecting the vertexes of the convex polylines to remove the concave portion of a surface. Figure 3.5 and Figure 3.6 are examples of applying convex hull method to remove dented part of a bust line and reconstruction of a bust surface using the convex polylines.



(a) (b)

Figure 3.5 Process of convex hull at bust line: (a) Scanned bust line; (b) Bust line with convex hull

(a) (b)

Figure 3.6 Process of convex hull at bust part: (a) Scanned bust; (b) Bust reconstructed with convex hull

3.3.3 Multiplication Factors

To make garment models fit for body and suitable for use with different sizes, ease allowance and size-change is necessary to be incorporated into garment modeling. A new method that creates a garment model is proposed.

In this approach, a model of a body and a model of a garment fitting it are used. The relations of the horizontal sections of two models are checked. In this study, three horizontal magnification factors were used about each section.

The multiplication factor is referred as the magnification between two distances related to the cross-sections of body and garment. The magnification factors were calculated about the front, the back, and lateral directions of each cross section of the body and garment since the right and left symmetricalness of them.

Figure 3.7 shows the horizontal distances for the garment and body surfaces from the original point on *x-z* plane. The distance of a body surface referred as Z_{jf} in front and Z_{jb} in back direction, another is the horizontal distance of garment surface from original point, referred as Z_{bf} in front and Z_{bb} in back. The multiplication factor at center back is Z_{jb}/Z_{bb}, and Z_{jf}/Z_{bf} is the multiplication factor for center front, as shown in Figure 3.7. The multiplication factor for side direction is X_j/X_b. The lateral and the front magnification factors are obtained in the same way. The multiplication factor contains ease allowance and body shape.

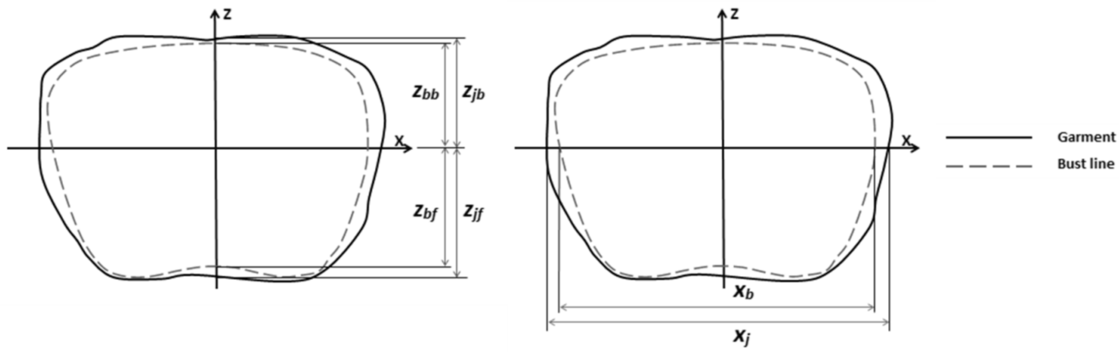


Figure 3.7 Calculation of magnification factors

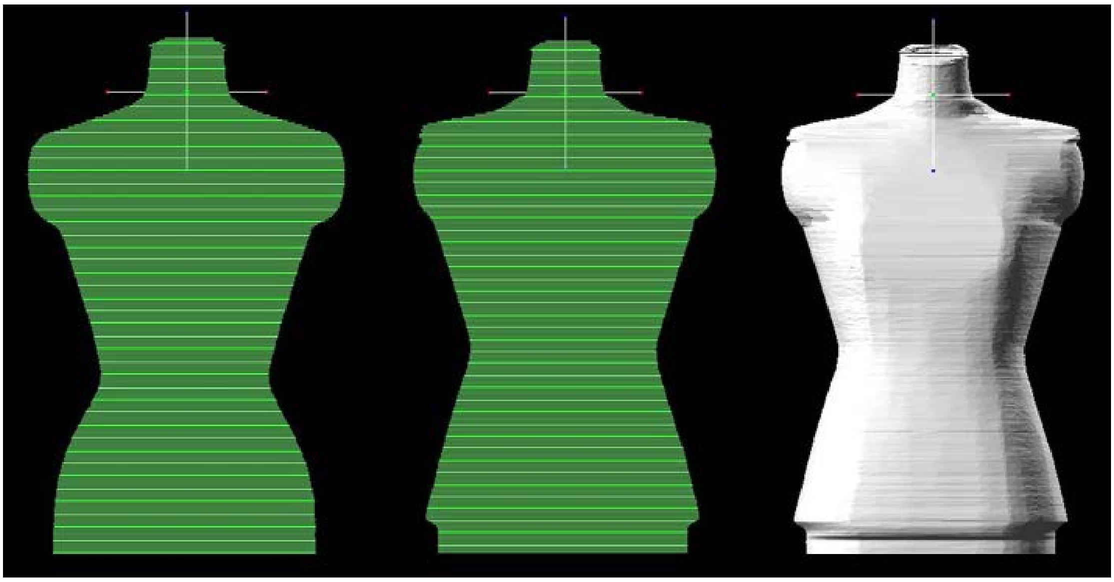
It consists of 4 steps to obtain the multiplication factor and expand the target body for constructing garment model.

Step 1: Setting the coordinate axes;

Step 2: Measuring the distances from the origin to the body and jacket contour in the front, back and side directions (shown in Figure 3.7);

Step 3: Calculating the multiplications (shown in Figure 3.7);

Step 4: Expanding the target body to construct garment model (shown in Figure 3.8).



(a) (b) (c)

Figure 3.8 Expansion of target body: (a) Target body; (b) Expanded line model; (c) Garment model

When a different body model is given, the model of a garment fitting the body is provided by deforming each section of the body model using the magnification factors. However, it is supposed that the proportion in the height direction of the original and the new body agrees. The embodiments and the discussion of the usefulness of this method are described in Chapter 4.

3.3.4 Vertical Body Proportions

Human bodies are different not only horizontal dimensions, but also vertical proportions. In this study, the vertical body proportion is regarded as three important segments: front neck point (NP) to bust line (BL), the bust line to waist line (WL) and the waist line to hip line (HL) as shown in Figure 3.9 Vertical segments of body Figure 3.9. The three vertical distances of NP–BL, BL–WL and WL–HL were measured to calculate body vertical proportions.

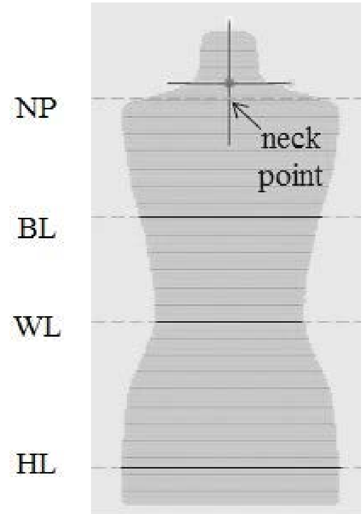


Figure 3.9 Vertical segments of body

The change of a length between y coordinates *y1* and *y2* of a vertical section into a new length *L* is carried out as follows:

$\Delta y' = |L|$

$\Delta y = |y_2 - y_1|$

$m = \Delta y' / \Delta y$; $d = \Delta y' - \Delta y$

(1) when $y_2 > y_1$

$y = y_1 + (y - y_1)*m$ if $y_1 \leqq y \leqq y_2$

$y = y + d$ if $y_2 < y$.

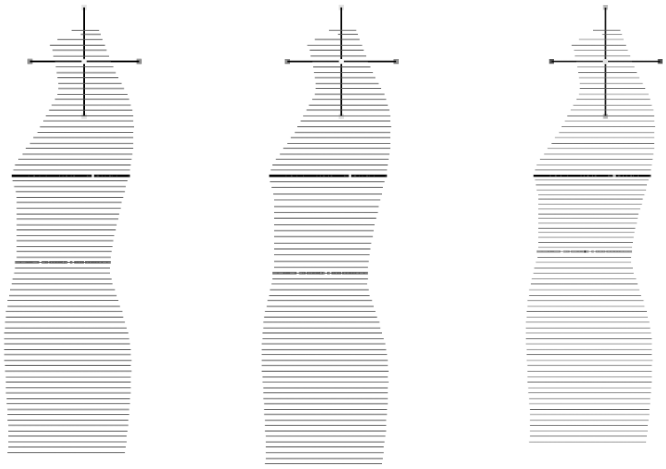
(2) when $y_2 < y_1$

For y coordinates of each cross section,

$y = y_1 + (y - y_1)*m$ if $y_1 \geqq y \geqq y_2$

$y = y - d$ if $y_2 > y$.

Figure 3.10 shows an example of change the vertical length of segment BL-WL of a body model.



(a) (b) (c)

Figure 3.10 Example of change the vertical length of segment BL-WL: (a) Original; (b) Lengthened; (c) Shortened

For making garment model for various sizes, in addition to the horizontal multiplication factors, vertical proportions are also taken into consideration. After each segment length is adjusted to that of the original body, a given body is deformed with the magnification factors, and then the proportion of the given body is restored. Its usage and effectiveness will be described experimentally in Chapter 5.

3.4 Pattern Developing Theory

To introduce the pattern developing theory, a polygon sphere model is employed as the object for fitting and flattening to generate 2D patterns. The procedure of the pattern-making for a hemisphere using this system is shown in Figure 3.11 [11].

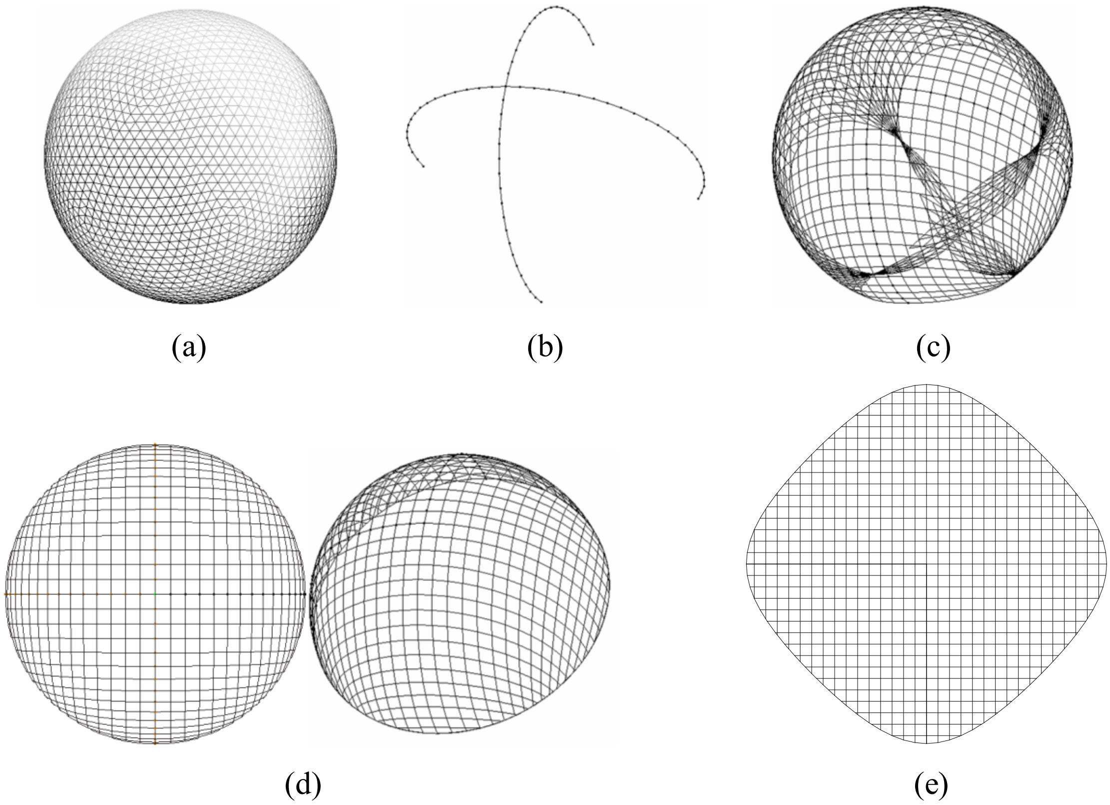


Figure 3.11 Pattern development for a hemisphere: (a) Triangular patched surface of sphere; (b) Two grainlines; (c) The result of fitting; (d) Cutting of hemisphere; (e) The flattened hemisphere [11]

It consists of 5 steps to achieve the goals.

Step 1: Defining the surface shape (Figure 3.11 (a));

Step 2: Setting grainlines (Figure 3.11 (b));

Step 3: Fitting fabric to the surface (Figure 3.11 (c));

Step 4: Cutting the 3D surfaces (Figure 3.11 (d));

Step 5: Flattening the 3D fitted fabric into a 2D pattern (Figure 3.11 (e)).

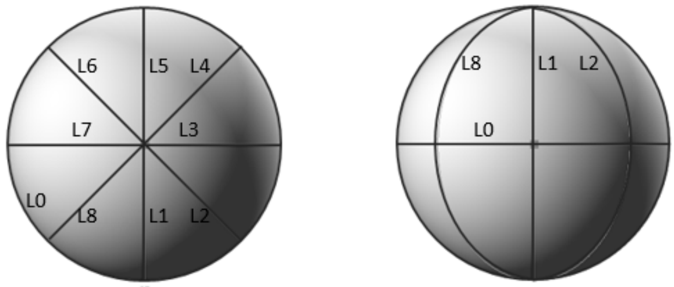
3.4.1 Defining the Surface Shape

In the case of tight-fitting clothes, the curved surface of a 3D body model could be considered as "clothes contour surface". For other types of garment, the surface of a 3D garment modeling is the "clothes contour surface" containing ease and style. In this study, triangular patches are used to construct the contoured surface of the clothes.

3.4.2 Setting Grainlines

In the draping process, correct grainline alignment is essential for determine the fitting (covering) path. Incorrect alignment will cause shear leading to poor fit. The grainlines should be accurately set for weft and warp direction of a woven fabric. The intersection of the primary weft and warp grainline is the basic reference point used in the fitting process. The grainlines can also acts as cutting lines.

For instance, in the case of making an 8-panels sphere, longitude lines and equator line are usually set as grainlines, which refer to warp and weft of fabric as Figure 3.11 (b). The grainlines L0, L1–L8 are set on the sphere as shown in Figure 3.12.

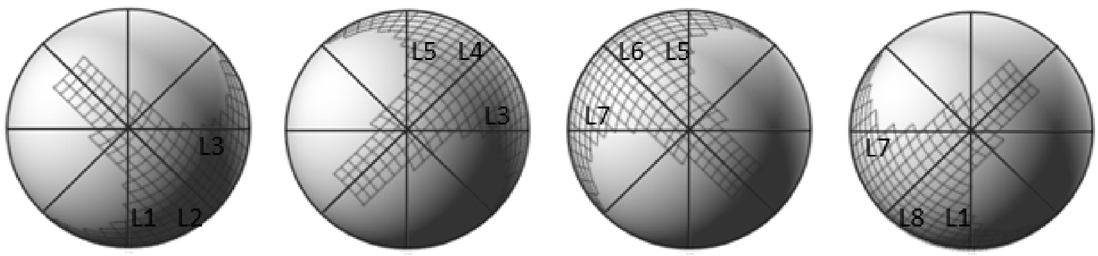


(a) (b)

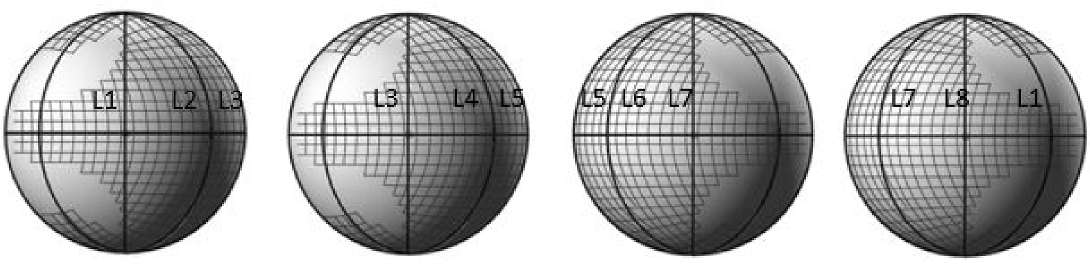
Figure 3.12 Configuration of grainlines for a sphere: (a) Top view; (b) Side view

3.4.3 Fitting Method

After setting grainlines, virtual fabric lattice is set to cover the object 3D surface. Fabric lattice is referred as a mesh structure in weft and warp direction. In fitting, perpendicular two grainlines work in pairs for warp and weft. Different grainlines could be set in different areas for covering. To construct the fabric lattice, two grainlines were assigned perpendicularly at their intersection on the curved surface.



Top View: (a) L1–L3 (b) L3–L5 (c) L5– L7 (d) L7–L1



Side View: (e) L1–L3 (f) L3–L5 (g) L5– L7 (h) L7–L1

Figure 3.13 Fitting for a sphere: Top View: (a) L1–L3, (b) L3–L5, (c) L5– L7, (d) L7–L17; Side View: (e) L1–L3, (f) L3–L5, (g) L5– L7, (h) L7–L17

Fabric lattice is only capable of covering certain area within its shear limit angle; therefore, the curved surface should be converted area by area as Figure 3.13, and then flattened to panels.

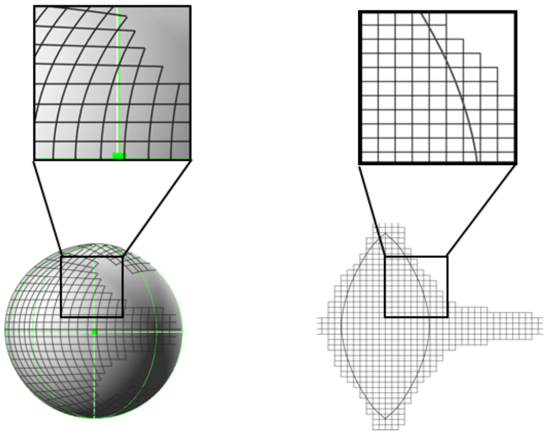
3.4.4 Cutting Method

After fitting the fabric lattice to the contour surface, the surface is cut into pieces for flattening. There are two methods for cutting 3D surfaces. One is cutting by a plane and another is cutting by a curved line. In this study, 3D surfaces were cut by both plane and line on the curved surface. As for the sphere, a regular figure, cutting by a plane is an efficient method for making patterns. The intersection points of plane and fabric lattice are used to define polylines, which are used as the cutting lines. Polylines shown in Figure 3.12 is used as cutting lines to flatten the sphere surface.

3.4.5 Pattern Flattening

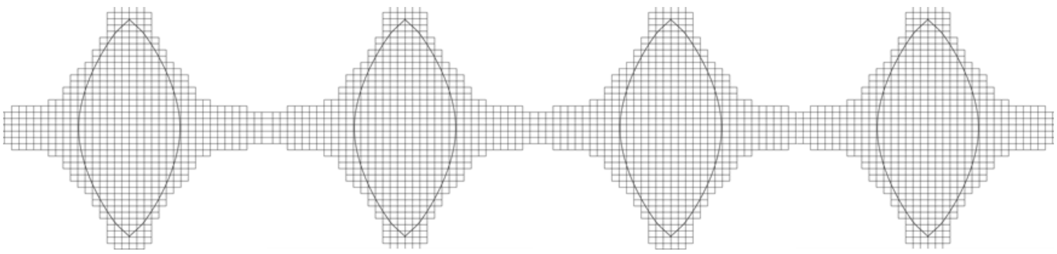
The 3D surface is cut into pieces in 3D space by line or plane, flattening method is applied to make a flat panel. In fitting process, fabric lattices are sheared as a parallelogram with a limit angle to generate a 3D surface, and then the sheared fabric lattices restored as square to platen as shown in Figure 3.14.

In this process, 3D cutting lines are also flattened into the 2D pattern and become seam lines. Finally, the pattern generation is archived. Unnecessary seam lines are combined together to reduce cutting and sewing as Figure 3.15.

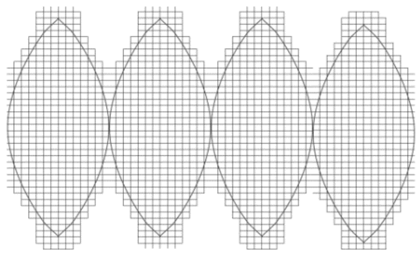


(a) (b)

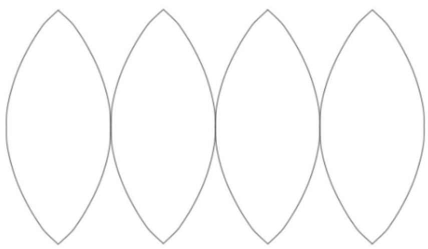
Figure 3.14 Fitting in 3D space and flattening into 2D plane: (a) Fitting; (b) Flattening



(a)



(b)



(c)

Figure 3.15 Combination of panels: (a) Flattened panels; (b) Panel combination; (c) Pattern

3.4.6 Calculating Method

The calculating method for fitting fabric lattice onto the triangular patches is introduced in this section [11].

As shown in Figure 3.16, there are position vectors P_0, P_1, P_2 on the grainline and $\mathbf{A}, \mathbf{B}, \mathbf{C}$ of vertexes A, B, C for ΔABC of a triangular patch. If there is a position $\mathbf{P}_3$ in the ΔABC, which is locates the same distance *r* from P_1, P_2 and gives a satisfactory condition for fitting. To establish whether $\mathbf{P}_3$ is in ΔABC or not, two spheres were superimposed which have radius *r*and center point of P_1, P_2. Therefore the intersection face of the two spheres includes a circle that has radius *R* and position vector $\mathbf{Q}$ as its center point.

$$\mathbf{Q} = (Q_x, Q_y, Q_z) = (2\mathbf{P}_1 + \mathbf{P}_{12})/2; \qquad \mathbf{P}_{12} = \mathbf{P}_2 - \mathbf{P}_1 \qquad (1)$$

The intersection of the two spheres creates a plane, called Π. Plane Π passes the point $\mathbf{Q}$ and has a normal vector $\mathbf{P}_{12}$. The edge of ΔABC which crosses plane Π is determined by investigating sign of scalar product. Therefore these are needed vectors $\mathbf{V}_{QA}, \mathbf{V}_{QB}, \mathbf{V}_{QC}$ which connect to vertex $\mathbf{A}, \mathbf{B}, \mathbf{C}$ and point $\mathbf{Q}$, and normal vector $\mathbf{P}_{12}$.

Vectors $\mathbf{V}_{QA}, \mathbf{V}_{QB}, \mathbf{V}_{QC}$ are given by

$$\mathbf{V}_{QA} = \mathbf{Q} - \mathbf{A}, \ \mathbf{V}_{QB} = \mathbf{Q} - \mathbf{B}, \ \mathbf{V}_{QC} = \mathbf{Q} - \mathbf{C} \qquad (2)$$

Here are conditions.

I : $\mathbf{V}_{QA} \cdot \mathbf{P}_{12} \geq 0$

Ⅱ: $\mathbf{V}_{QB} \cdot \mathbf{P}_{12} \geq 0$

Ⅲ: $\mathbf{V}_{QC} \cdot \mathbf{P}_{12} \geq 0$

1) Whether or not the conditions are satisfied, that is to say all vertexes $\mathbf{A},\mathbf{B},\mathbf{C}$ locate same direction on plane Π.

2) If only Ⅰ is satisfied, or Ⅱ and Ⅲ together are satisfied, vertex A will be opposite to vertex B and C. Then, edge AB and AC intersect plane Π.

3) If only Ⅱ is satisfied, or Ⅰ and Ⅲ together are satisfied, vertex B will be opposite to vertex A and C. Then, edge AB and BC intersect plane Π.

4) If only Ⅲ is satisfied, or Ⅰ and Ⅱ together are satisfied, vertex C will be opposite status to vertex A and B. Then, edge AC and BC intersect plane Π.

E and F (the points at which plane Π intersects Δ ABC) is based on the above conditions [1]. After defining the position of E and F, then whether $\mathbf{P}_3$ is located distance R from point $\mathbf{Q}$ on the line EF or not, it has to be established. This describes line EF using parameter t, direction vector $\mathbf{L} = (L_x, L_y, L_z)$ and $\mathbf{E} = (E_x, E_y, E_z)$.

$$\overrightarrow{EF} = \mathbf{E} + \mathbf{L}t \tag{3}$$

t is located at a distance of R from point $\mathbf{Q}$. When distance R is between $\mathbf{E} + \mathbf{L}t$ and $\mathbf{Q}$ point, t is a root of following equation.

$$|\mathbf{E}\text{-}\mathbf{L}t\text{-}\mathbf{Q}|^2 = (\mathbf{E}\text{-}\mathbf{L}t - \mathbf{Q}) \cdot (\mathbf{E}\text{-}\mathbf{L}t - \mathbf{Q}) = R^2 \tag{4}$$

When the roots are given by t_1 and t_2, if $t = t_1$ or $t = t_2$ is on the line EF , and vector $\mathbf{P}_3$-$\mathbf{Q}$ and $\mathbf{P}_{0Q}$=$\mathbf{Q}$-$\mathbf{P}_0$ both have same status, then $\mathbf{P}_3$ can be defined.

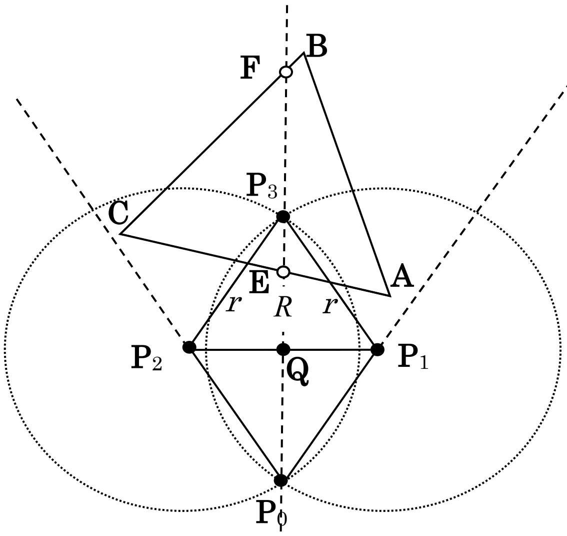


Figure 3.16 Fitting method of fabric lattice onto the triangular patch [11]

For fitting the fabric lattice to curved surface, it is necessary to define three point positions on grainlines and another point on the triangular patch. The intersection point of the grainline is the basic reference point used in the fitting process. When the limit angle of the fabric's shear ability on given lattice size is exceeded, the process is interrupted.

3.5 Summary

In this Chapter, 3D pattern-making theory and garment modeling method have been proposed to establish a proper model for making garment patterns.

3D data are firstly acquired by a 3D scanner, data reparation is carried out to generate a polyline model. And then, polyline model is adopted to make a deformation for constructing the desired 3D shape. 3D polygon model is finally established for fabric lattice fitting.

Mechanical properties of fabric should be taken into account in 3D fitting process in order to make plat patterns. Shearing limit angle, one of the most important factor affecting 3D fitting and flattening, is regarded in fitting and flattening.

Moreover, to make 3D garment patterns for different size bodies, multiplication factors between garment and body are calculated and used to deform polygon model for making garment model and patterns in various sizes.

Vertical body proportion is another element that affects garment fit. It was also taken into consideration in constructing garment model for a better fit.

References

1. Takahashi Y., Sofue A., Kim K., and Takatera M., Automatic 3D Pattern Making of Fitted Upper Garments Considering Individuals' Figures and Shear Limit of Fabrics. *International Journal of Affective Engineering*, 2013. 12(2): 169-175.
2. Mack C. and Taylor H., The Fitting of Woven Cloth to Surfaces. *Journal of the Textile Institute Transactions*, 1956. 47(9): 477-488.
3. A S. and S U., The surface fitting of textile fabric. *SEN-IKIKAI GAKKAISHI*, 1966. 19: 17-23.
4. Van West B., Pipes R.B., Keefe M., and Advani S., The draping and consolidation of commingled fabrics. *Composites Manufacturing*, 1991. 2(1): 10-22.
5. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part I: Projection. *Textile Research Journal*, 1990. 60(11): 690-696.
6. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part II: Garment Modeling. *Textile Research Journal*, 1990. 60(12): 731-737.
7. Imaoka H., Shibuya A., and Aisaka N., Automatic paper pattern making using mechanical development method of a curved surface on a plane surface. *Sen-i Gakka/shi*, 1989. 45.
8. Tsuchiya K., Cho Y., and Takatera M., Individual Pattern making of skirts and pants using computerized draping method. *Proc. KEER*, 2007.
9. Cho Y., Okada N., Park H., Takatera M., Inui S., and Shimizu Y., An interactive body model for individual pattern making. *International Journal of Clothing Science and Technology*, 2005. 17(1-2): 91-99.
10. Cho Y., Komatsu T., Park H., Inui S., Takatera M., and Shimizu Y.,

Computerized Pattern Making System Allowing Fabric Shear. *Textile Research Journal*, 2006. 76(8): 646-665.

11. Cho Y.S., Komatsu T., Inui S., Takatera M., Shimizu Y., and Park H., Individual pattern making using computerized draping method for clothing. *Textile Research Journal*, 2006. 76(8): 646-654.
12. Takatera M., Tsuchiya K., Kim K., and Cho Y., Computer Aided Design of Individualized Best Fitting Pants. *Proc. KEER*, 2010.
13. Takatera M. and Kim K., Improvement of individualized pattern making using surface flattening technique. *Journal of Fiber Bioengineering and Informatics*, 2013. 6(4): 467-480.
14. Zhang J., Innami N., Kim K., and Takatera M., Upper garment 3D modeling for pattern making. *International Journal of Clothing Science and Technology*, 2015. 27(6): 852-869.
15. Zhang J., Kim K., and Takatera M., Three-dimensional garment-size change modeled considering vertical proportions. *International Journal of Clothing Science and Technology*, 2016. 28(5): In printing.
16. Takatera M., Kumoda N., Bao L., Shimizu Y., Kamijo M., Hosoya S., and Iida H., Large Deformation of Woven Fabrics under Free Shearing Uniaxial Load. *Sen'i Gakkaishi*, 1999. 55(7): 306-314.

Chapter 4

Upper Garment 3D Modeling and Pattern-making

Chapter 4 Upper Garment 3D Modeling and Pattern-making

Nowadays, consumers usually select their clothing from numerous ready-to-wear garments, each produced in several sizes. To meet the ease allowance requirements of these garments, grading is used to increase or decrease the pattern sizes, based on the average difference between sizes. Although this is a convenient way to develop different pattern sizes, it still poses a "fit" problem for individuals. The method does not reflect individual body shapes, so the garments will not be a perfect fit to an individual. It is possible to solve this problem using the draping method, with a dummy model that corresponds to a specific customer. However, this technique is not used for mass production because it is expensive and time-consuming.

4.1 Introduction

With the development of computer technology, to solve "fit" problem for individuals, three-dimensional (3D) pattern-making methods have been investigated by many researchers, both geometrically [1-3] and mechanically [4]. 3D body data have been used to make garment models and patterns by various 3D pattern-making systems [5-7].

In previous studies, researchers used body modelers to make an individual model [8-11]. By transforming a body model with measurement parameters, they developed a computerized pattern-making system for individual body shapes as shown in Figure 3.1. A skirt and upper garment with a minimum allowance were successfully made using this system [12, 13].

In 3D pattern-making systems, patterns are developed from garment models. The garment model is formed from a scanned dummy or made by a geometrical modeler. For tight-fitting garments that tightly follows the contours of the part of the body being covered, these models are constructed by smoothing a scanned body-[14-17] or dummy model [18, 19] and work well for tight-fitting garments in sport and medical applications. There models have no appropriate ease allowance, and as such are only adapted for use in tight-fitting clothing. In addition, they do not work well for clothing with ease allowance, such as jackets.

Body modelers have been included in recent 3D apparel computer-aided design (CAD) systems. Practical applications of computerized 3D pattern-making have been developed and used in education and demonstration [20-22]. Basic garment patterns without ease allowance can be easily obtained by developing the surface of a human body model or dummy model using these CAD systems. However, it should be noted that ease allowance is necessary for garment comfort, movement and design. Even though it is possible for a commercial modeler to make an appropriate garment model with ease allowance, in practical pattern-making process, these are many problems to make an appropriate garment.

Some researchers have measured 3D ease allowance, used it for pattern making and comfort evaluation [23-25]. However, these studies did not actually produce a 3D garment model. Clothing usually has an uneven ease allowance, depending on its silhouette and design. The silhouette and the shape of clothing produced from patterns developed from those models can be changed after sewing.

It is important to take into account ease allowance when considering size development in pattern-making. To obtain different sizes of garment patterns for different size bodies, grading in two dimensions or three dimensions has been used to generate basic upper garment patterns of different sizes [26, 27], but it was still difficult to produce a suitable ease allowance when taking into account the real garment shape and style. A 3D garment model that includes an appropriate ease allowance reflects real garment shape and can be easily deformed for different sizes is therefore necessary for 3D pattern-making.

The aim of this study is to make an upper garment model for 3D pattern-making that takes into account both ease allowance and silhouette. A new modeling method was proposed for upper garments, one that can be developed by computerized pattern-making systems. A magnification method was also proposed using multiplication factors to make different sized models with appropriate ease allowance.

4.2 Modeling Method for Upper Garments

In this study, the 3D surface data of a jacket bodice were used to make an upper garment model and subsequent patterns. It was focused on the jacket, so a jacket bodice was made without a collar and sleeves, then placed the bodice on a female dummy and scanned the shape. The shape measurements were converted to a cross-sectional line model. A convex hull was used for each cross-section to remove dents in the horizontal cross-section. The line model was converted into a polygon model, which was used as the basic garment model. Seam lines were obtained in the 3D scanning process.

4.2.1 Deformation of the Model for Different Sizes

To construct a garment model suitable for use with different sizes, a new method was developed that creates a garment model by expanding a body model with different multiplication factors. The horizontal multiplication factors were obtained between the cross-sections of the basic garment model and the body on which put the jacket. The multiplication factors were obtained in the front, back, and lateral directions. A garment model was made for different body sizes by deforming the body shape using the multiplication factors.

It consists of 4 steps to obtain the multiplication factor and expand the target body for constructing garment model.

Step 1: Setting the coordinate axes (Figure 4.1);

Step 2: Measuring the distances from the origin to the body and jacket contour in the front, back and side directions (Figure 4.2);

Step 3: Calculating the multiplications (Figure 4.3);

Step 4: Expanding the target body to construct garment model (Figure 4.4).

Figure 4.1 shows the anatomical body planes and coordinate axes. The planes were defined as follows:

yz plane: a vertical plane through the center front and center back (Sagittal plane)

xy plane: a vertical plane across the shoulder points (Coronal plane)

xz plane: a horizontal plane across the center neck points

The coordinate origin is the crossover point of the three planes.

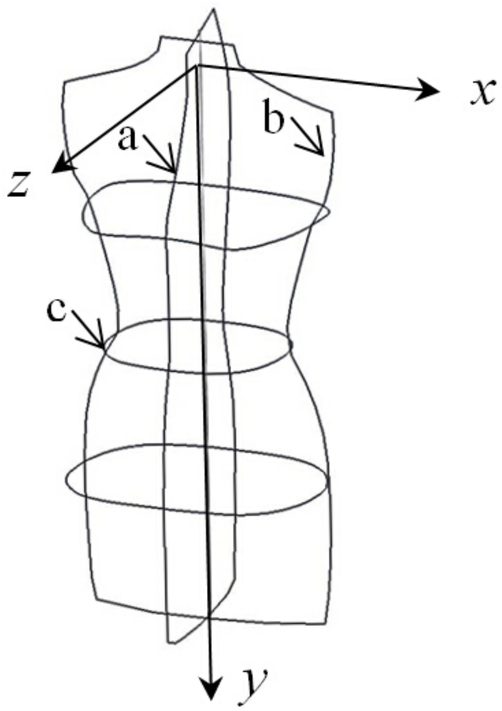


Figure 4.1 Anatomical body planes (a: Sagittal plane, b: Coronal plane, c: Transverse plane)

The distances from the origin to contour in the y, $+z$ and $-z$ directions for each cross-section of the jacket and the body were measured, as shown in Figure 4.2. z_{jf} and z_{jb} represent the distance from the origin to the jacket contour in the front and back directions, respectively. z_{bf} and z_{bb} represent the distance from the origin to the body contour in the front and back directions, respectively. x_j and x_b are the widths of a cross-section along the x-axis of the jacket and the body, respectively.

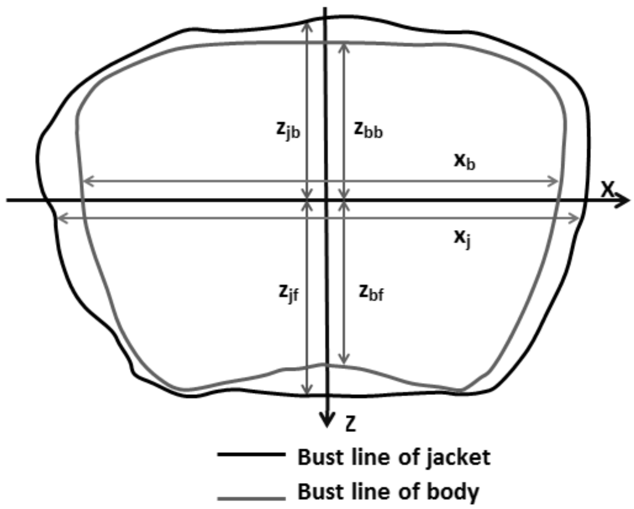
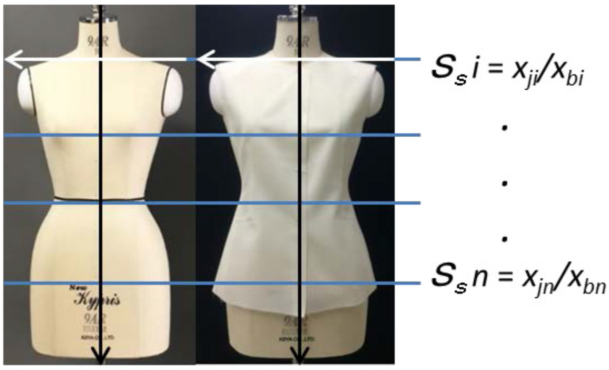


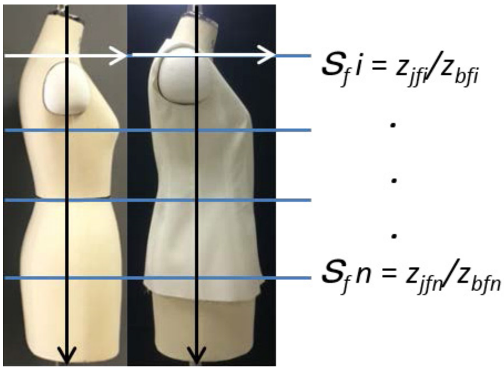
Figure 4.2 Measurement of distance (bust line)

The multiplication factors of the dummy body and jacket were calculated using the distances as shown in Figure 4.2 and Figure 4.3. The multiplication factor in the front direction, S_f, was determined by z_{jf}/z_{bf}; the multiplication factor of the back direction, S_b, was determined by z_{jb}/z_{bb}; and the multiplication factor of the transverse direction, S_s, was determined by x_j/x_b. Multiplication factors were obtained for each horizontal cross-section.

After obtaining the multiplication factors in front, back and side directions, they were applied to expand the target body horizontally for constructing garment model as shown in Figure 4.4.

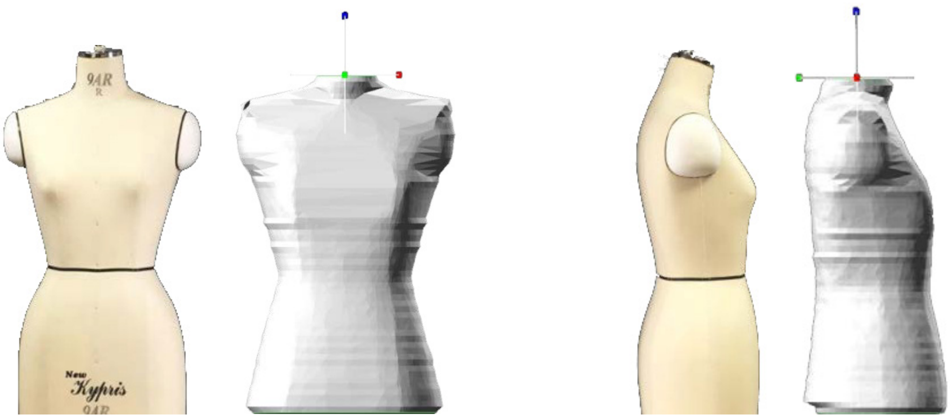


(a)



(b)

Figure 4.3 Calculating multiplication factors: (a) S_s, Multiplication factor for side; (b) S_f, Multiplication factor for front

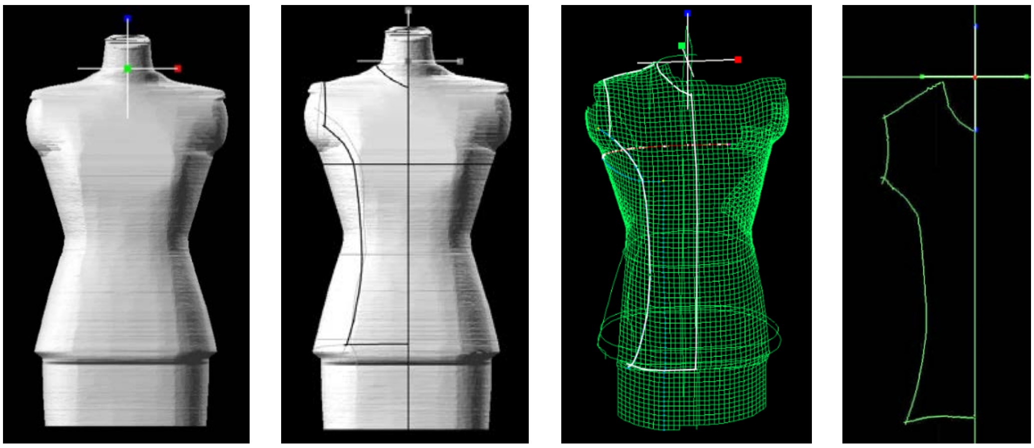


(a) (b)

Figure 4.4 Expanding the target body (9AR) using multiplication factors: (a) Front view; (b) Side view

4.2.2 Covering and Flatting Method for Pattern-making

After constructing a 3D garment model, covering and flatting methods in 3D pattern-making system [9, 12] were used to flat 3D surface to 2D patterns. On a 3D garment model surface, as shown in Figure 4.5 (a), two intersecting lines are determined in advance for covering and flatting path. They are equivalent to warp and weft directions in the fabric lattice and named grainlines as shown in Figure 4.5 (b). The intersection of the primary weft and warp grainlines are the basic reference point used in covering process. A fabric lattice with a mesh structure was formed in weft and warp direction. The fabric lattice covers the garment model geometrically with shear from the intersection point of the grainlines as shown in Figure 4.5 (c). The different grainlines are set in different areas for creating multiple pattern panels.



(a) (b) (c) (d)

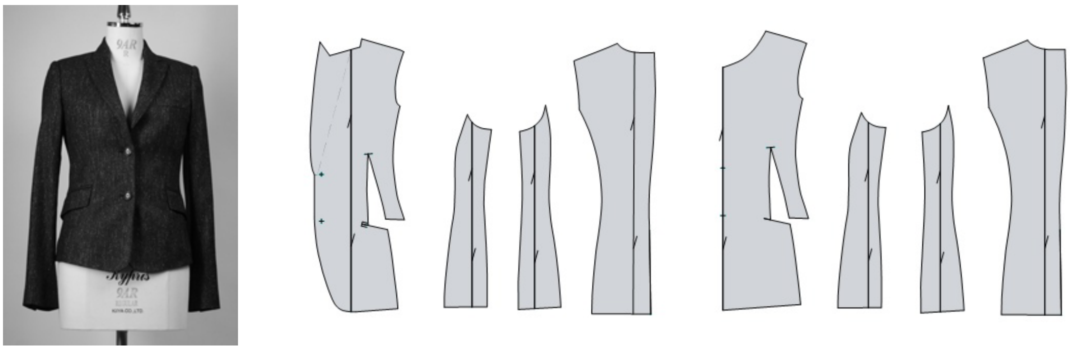
Figure 4.5 Covering and flatting method for pattern-making: (a) Polygon model surface; (b) Grainlines and cutting lines; (c) Covering; (d) Flatting

After the covering, the fabric lattice is cut by arbitrary cutting lines in three dimensions. A 2D pattern is then flattened by returning the shear deformation of the covered lattice. Finally, a 2D pattern can be obtained as shown in Figure 4.5 (d).

4.3 Experimental

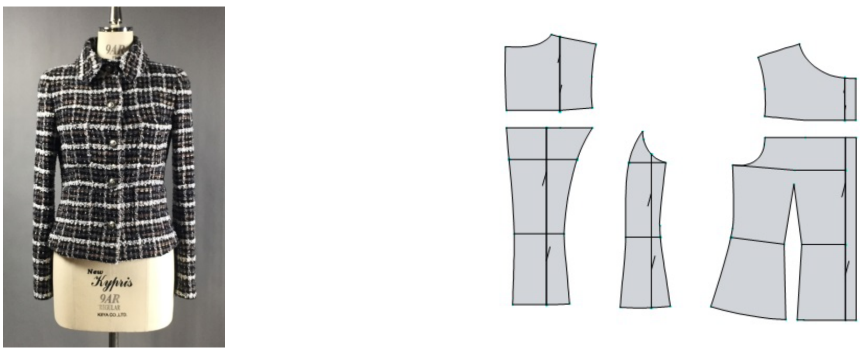
To verify the modeling method, two jacket bodice models were created for reproducing those patterns. The models were also used to make jackets in different sizes, to confirm the proposed deformation method.

For the experiments, two jackets (Jacket1 and Jacket2) with different patterns were selected to make basic garment models as shown in Figure 4.6 and Figure 4.7. They were suitable for a Japanese Industrial Standards (JIS) size 9AR female body Figure 4.8 (b). The sizes of the body are shown in Table 4.1.



(a) (b) (c)

Figure 4.6 Jacket1 and patterns for basic model; (a) Original jacket; (b) Original pattern; (c) Simplified pattern



(a) (b)

Figure 4.7 Jacket2 and patterns for basic model; (a) Original jacket, (b) Original pattern

(a)

(b)

(c)

Figure 4.8 AR Bodies: (a) 5AR; (b) 9AR; (c) 13AR

4.3.1 Reproduction for Basic Jacket Bodice

In this study, it is focused on the bodice part of the jacket. The lapel and the front edge of the original patterns from manufacturer were revised, and the sleeves and collar parts were also removed, as shown in Figure 4.6 (c) and Figure 4.7 (b). The jacket bodices were carefully made to accurately reflect the original shapes. Cream-colored wool fabric (fabric weight: 149.0 g/m^2) was used to reduce scanning errors. To obtain a similar shape to the original, adhesive interlinings (fabric weight: 72.8 g/m^2) were fused to every part. The reproduced jacket bodices of Jacket1 and Jacket2 were shown in Figure 4.9 and Figure 4.10.

The jacket bodices were worn on size 9AR female body (Kypris 9AR, Kiiya Co., Ltd., Tokyo, Japan) and were scanned by a 3D scanner (Body Line Scanner, Hamamatsu Photonics K.K., Shizuoka, Japan) shown in Figure 2.2. Before scanning, small dots of reflective tape were put on the seam lines of the jacket bodice surface so as to detect the original seam lines in 3D. The scanned data were used to construct basic models by the previously discussed method.

Jackets were made from patterns that were created using these model and the seam lines were used as basic verification. To make these patterns, a weft grainline was set on the bust line, and warp grainlines were set orthogonal to the weft grainline. The jacket polygon model was covered by a mesh with shear deformation. The cutting line was set according to the detected seam lines. Then, the model was used to obtain patterns, a process that was performed by the pattern-making system by described in Chapter 3. After making the jackets, the patterns and jackets were compared with the originals. Another patterns and jackets were also created with different cutting lines to confirm the applicability of the 3D model.

(a) (b) (c) (d)

Figure 4.9 Basic jacket bodice of Jacket1: (a) Front; (b) Back; (c) Left side; (d) Right side

(a) (b) (c) (d)

Figure 4.10 Basic jacket bodice of Jacket2: (a) Front; (b) Back; (c) Left side; (d) Right side

Table 4.1 Measurements for each body size

Item \ Body	**5AR**	**9AR**	**13AR**
Assumed height	158 cm	158 cm	158 cm
Bust	81 cm	87 cm	93 cm
Waist	57 cm	63 cm	69 cm
Hip	89 cm	93 cm	97 cm

4.3.2 Molding and Pattern-making for Different Sizes

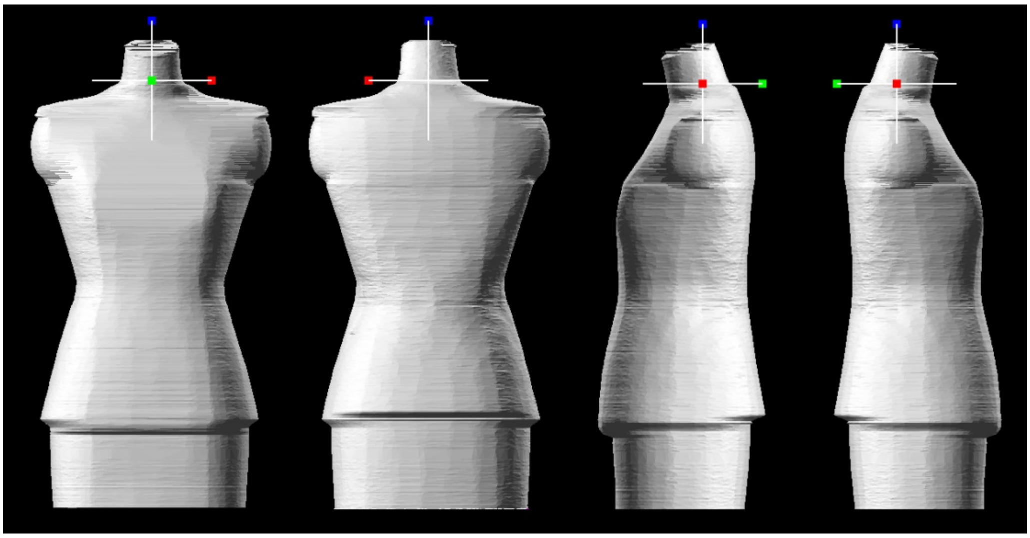
Different size garment models were made to verify the proposed deforming method. Two female bodies (Kypris 5AR and 13AR, Kiiya Co., Ltd., Tokyo, Japan) were selected shown in Figure 4.8 (a) and (c). The measurements of the bodies are shown in Table 4.1.

The horizontal multiplication factors were obtained using the basic garment and the 9AR body data by calculating the magnification between two distances related to the cross-sections of the body and garment as shown in Figure 3.7. Using the multiplication factors, the body model of sizes 5AR and 13AR were expanded to produce two jacket bodice models. Patterns were obtained by applying the garment model to the covering and flatting process. The weft and warp grainlines were set at the same position on the basic model. The cutting lines were set in similar positions to the original jacket.

4.4 Results and Discussion

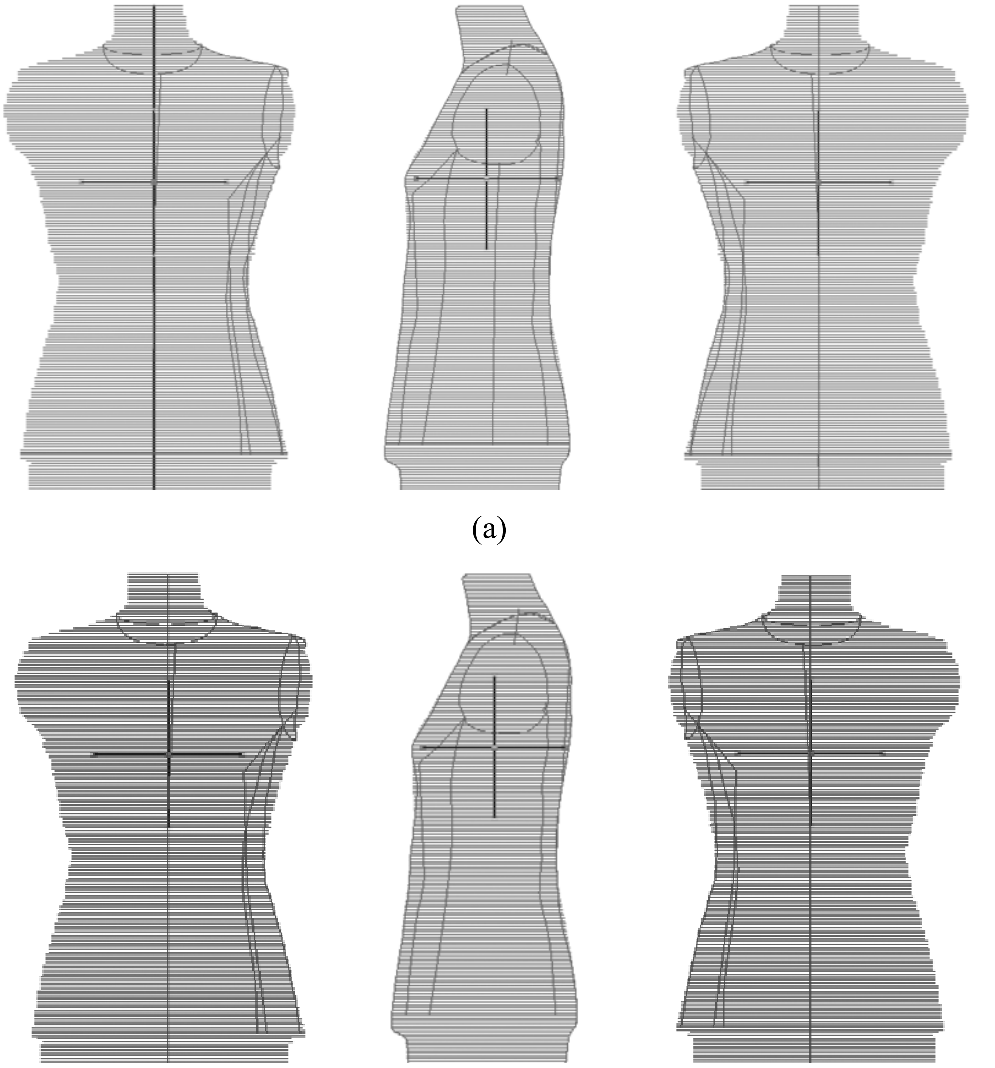
4.4.1 Result for Reproduction Basic Jacket Bodice

The basic garment model of Jacket1 was constructed as demonstrated in Figure 4.11. Figure 4.12 shows the configurations of the original cutting lines and the cutting lines that differed. Different cutting lines were used to construct three panels instead of the four panels in the original garment. By developing the model according to the cutting lines, two sets of patterns were obtained. Because of restrictions of the pattern-making system, Separated bodice parts of four segments were obtained, as shown in Figure 4.13 (a). To make patterns that were similar to the original ones, those segments were combined and cut as shown in Figure 4.13 (b) and (c). The final patterns are shown in Figure 4.13 (d). This process is the same as dart manipulation in pattern-making [28].



(a) (b) (c) (d)

Figure 4.11 Basic garment model of Jacket1: (a) Front; (b) Back; (c) Left side; (d) Right side

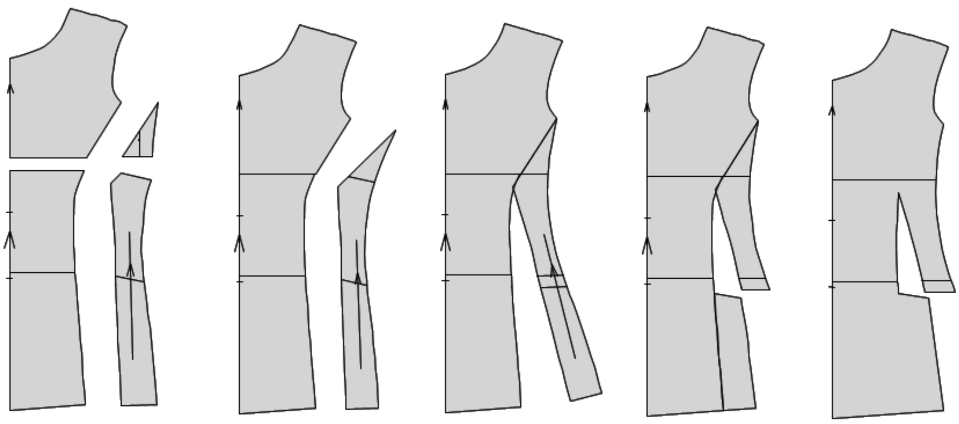


(a)

(b)

Figure 4.12 Configurations of the cutting lines: (a) Original cutting lines; (b) Cutting lines that differ from the original

Two sets of patterns and jackets were made using Jacket1 bodice model. Figure 4.14 (a) shows patterns with the same cutting lines as the original. The pattern shapes of the original cutting line were almost the same as the original in Figure 4.6 (c). Figure 4.14 (b) shows the jacket made with the same seam lines. It shows almost the same shape and silhouette as the original. Thus, the original pattern and jacket were able to be recreated using the basic garment model. Figure 4.15 (a) shows patterns using different cutting lines. The jacket is shown in Figure 4.15 (b) has a similar shape to the original, even though it has fewer panels. It was therefore possible to make a similar garment to the original using the basic garment model with different cutting lines. This indicates that various jacket patterns for the same jacket shape can be made using the 3D garment model of a jacket being worn by a body.



(a) (b) (c) (d)

Figure 4.13 Segmentation and combination of the front pattern piece: (a) Separated pattern; (b) Combined pattern; (c) Cutting pattern; (d) Final pattern

(a) (b)

Figure 4.14 Patterns and made jacket with the same cutting lines (seam lines) for Jacket1: (a) Pattern; (b) Jacket1 with the same cutting lines

(a) (b)

Figure 4.15 Patterns and made jacket with different cutting lines (seam lines) for Jacket1: (a) Pattern; (b) Jacket1 with the different cutting line

4.4.2 Modeling and Pattern-making With Multiplication Factors

Using the proposed method, the cross-sectional sizes of both the body and the original jacket were measured to calculate the multiplication factors in the front, back and lateral directions. The calculated multiplication factors are shown in Figure 4.16.

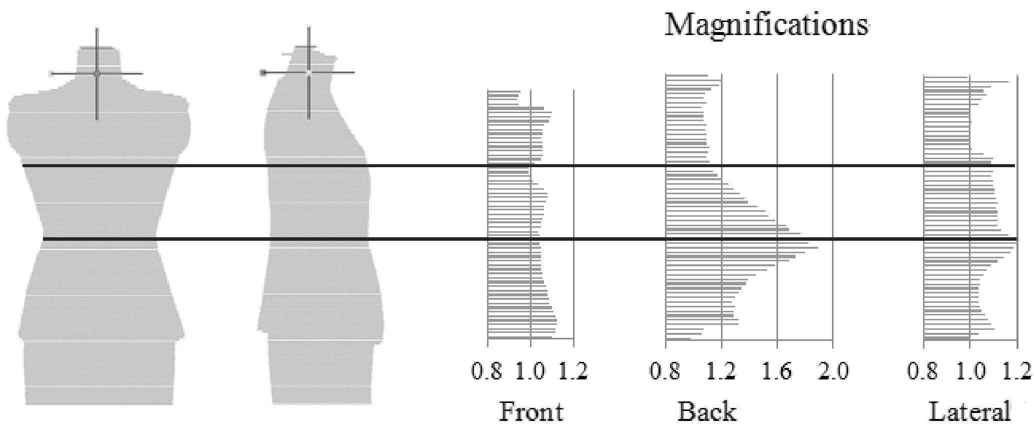


Figure 4.16 Multiplication factors in the front, back and lateral directions for Jacket1

To confirm the magnification method, a 9AR size model and patterns were made using the multiplication factors for 9AR body. Figure 4.17 shows the reconstructed 9AR garment model and patterns. Figure 4.18 shows the reproduced jacket for 9AR.

The silhouettes of the reconstructed jacket model in the front and side views in Figure 4.17 are similar to the basic garment model presented in Figure 4.11. Figure 4.25 (a) shows the cross-sections of the original and the jacket models of Jacket1. The contour shapes of bust and hip of both models are similar; however the waist shapes are slightly different. The back of the original jacket was angular, whereas the back of the reconstructed model is round. This was due to an uneven allowance. The waist has a larger and more uneven allowance than the other parts, depending on direction.

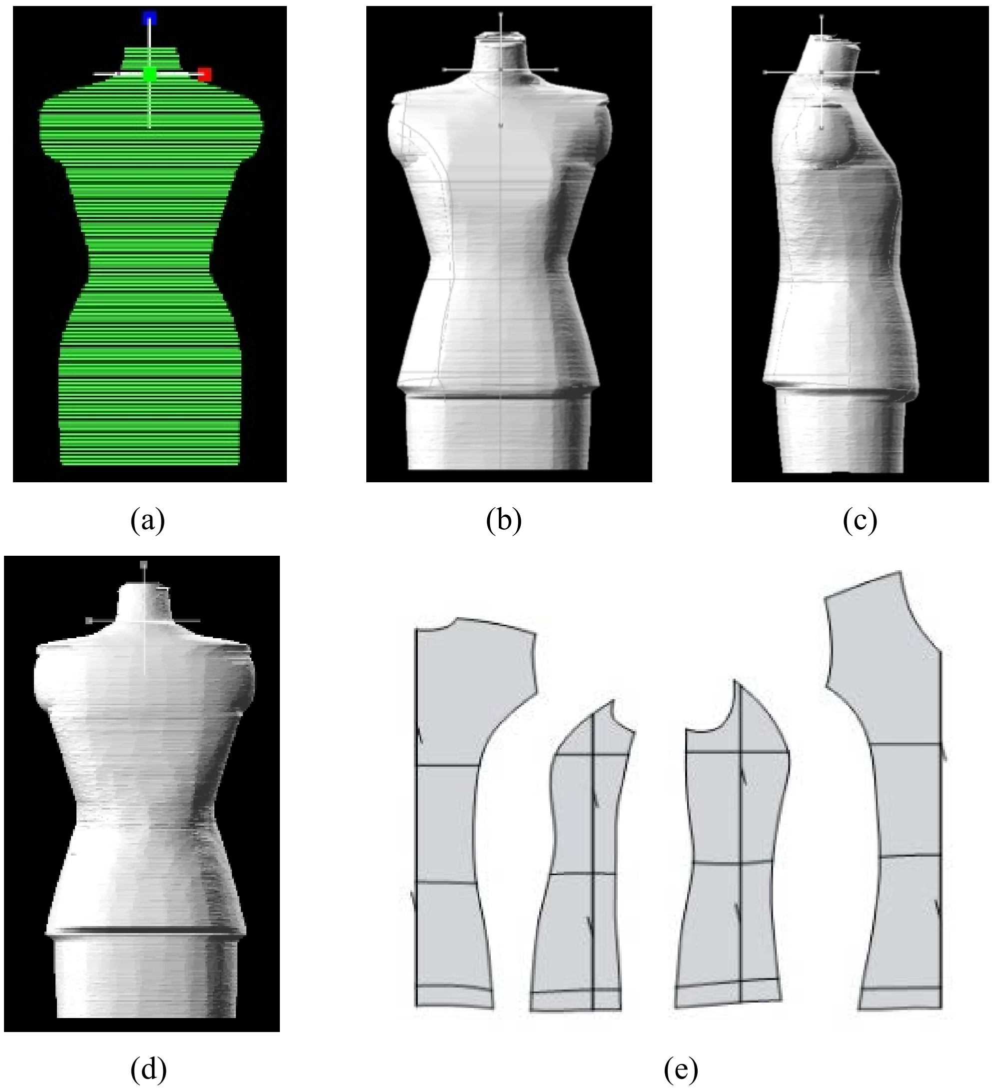


Figure 4.17 Reconstructed jacket models and patterns of size 9AR for Jacket1: (a) 3D dada; (b) Front; (c) Side; (d) Back; (e) Patterns

In the method, three directions were taken into account and so the waist circumference became rounded. Despite this small difference in waist size, the overall shapes of the two models were similar. Two different garment models and pattern sizes were also created for 5AR and 13AR size bodies, using the multiplication factors. Figure 4.19 shows the garment model and patterns. Figure 4.20 and Figure 4.21 show the jacket bodices for Jacket1. The jackets fitted on the bodies very well, indicating that the proposed method can be applied to make patterns for different size bodies.

Models and patterns of two different sizes of 5AR and 13AR bodies for Jacket2 were also obtained. The patterns are shown in Figure 4.22. Figure 4.23 and Figure 4.24 show the made jacket bodices. Those jacket bodices also were fitted well on the body.

(a) (b) (c)

Figure 4.18 Reproduced jacket of size 9AR for Jacket1: (a) Front; (b) Back; (c) Side

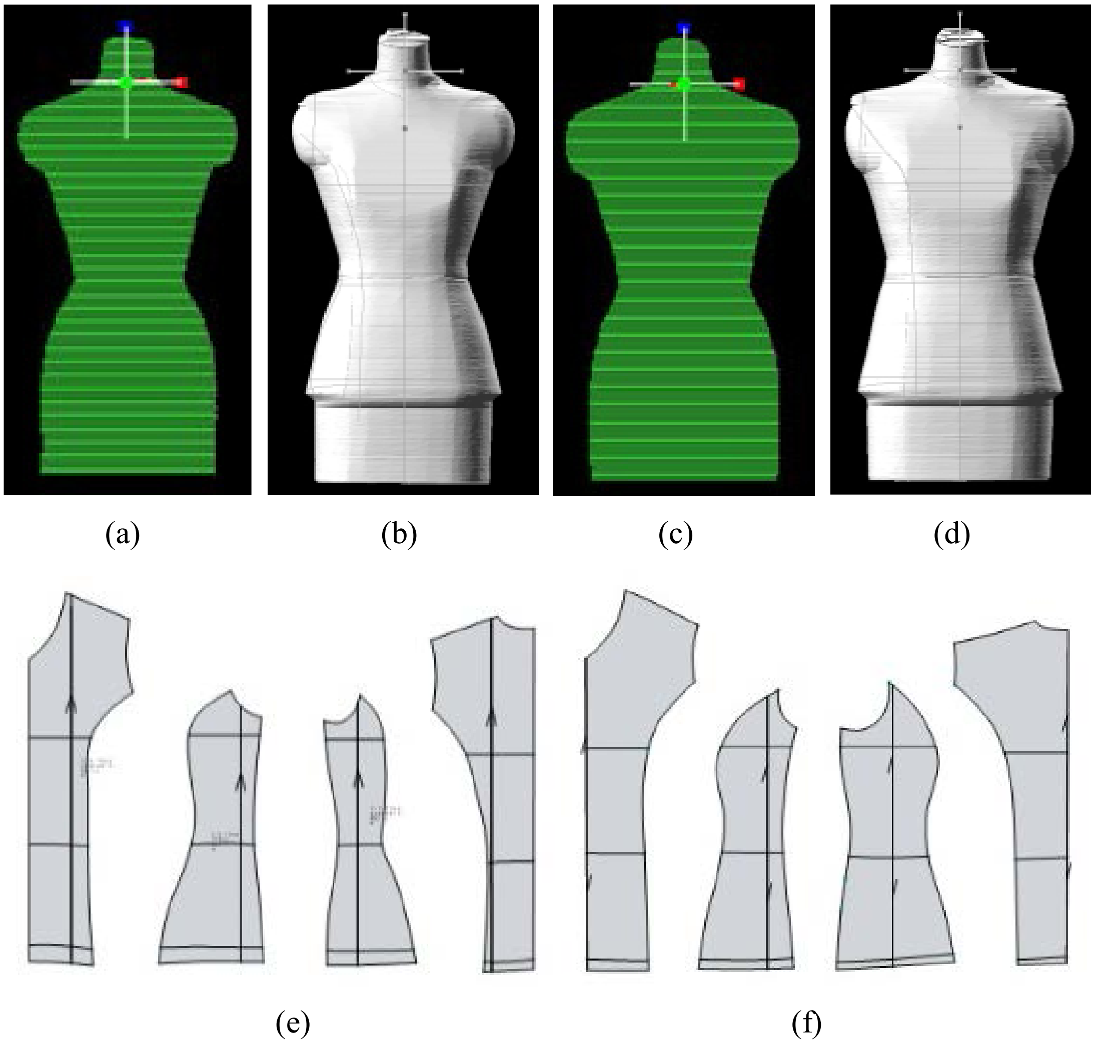


Figure 4.19 Constructed jacket models and patterns for Jacket1: (a) 5AR model; (b) 5AR garment model; (c) 13AR model (d) 13AR garment model; (e) 5AR Pattern; (f) 13AR Pattern

(a) (b) (c)

Figure 4.20 Size 5AR jacket bodice of Jacket1: (a) Front; (b) Back; (c) Side

(a) (b) (c)

Figure 4.21 Size 13AR jacket bodice of Jacket1: (a) Front; (b) Back; (c) Side

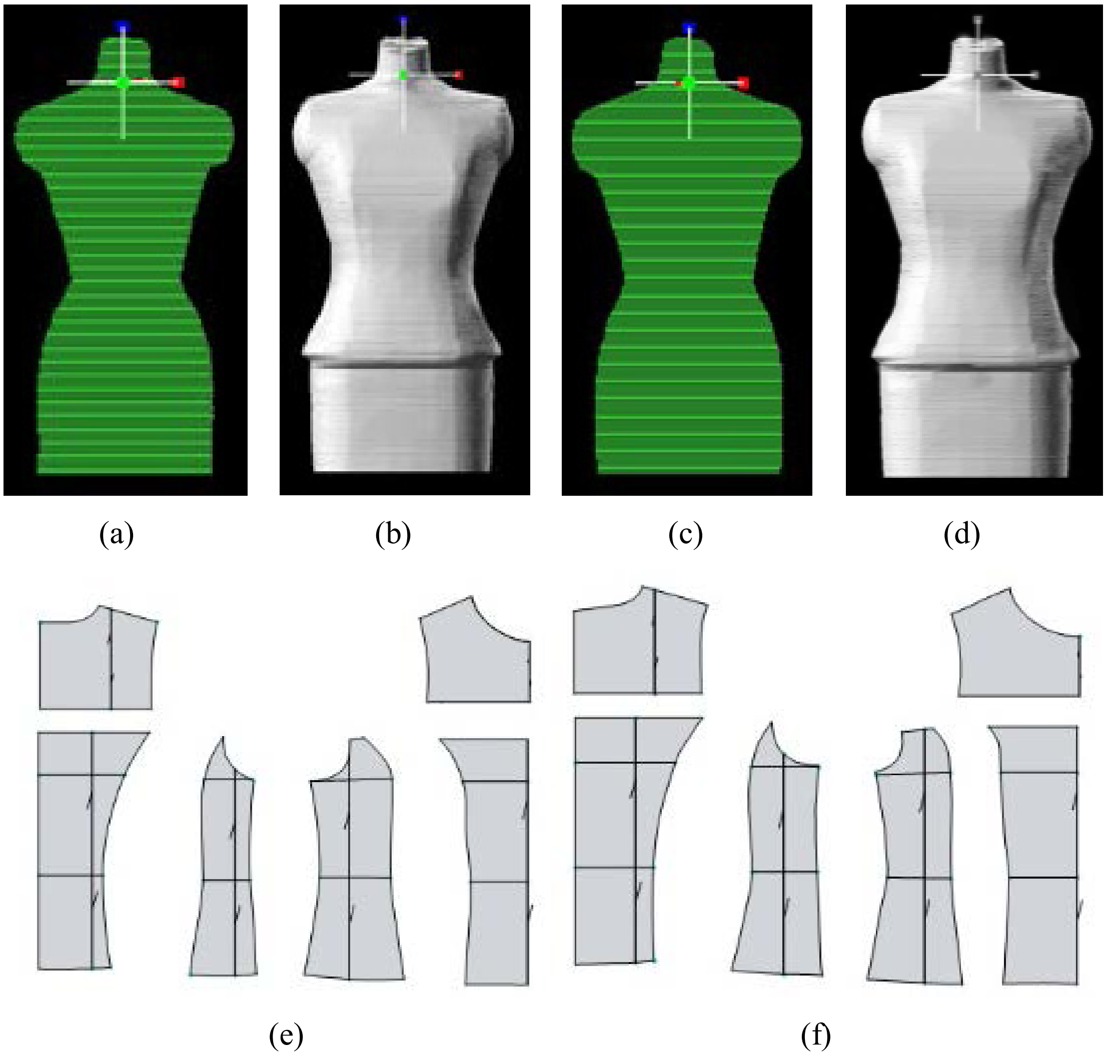


Figure 4.22 Constructed jacket models and patterns for Jacket2: (a) 5AR model; (b) 5AR garment model; (c) 13AR model (d) 13AR garment model; (e) 5AR Pattern; (f) 13AR Pattern

(a) (b) (c)

Figure 4.23 Size 5AR jacket bodice of Jacket2: (a) Front; (b) Back; (c) Side

(a) (b) (c)

Figure 4.24 Size 13AR jacket bodice of Jacket2: (a) Front; (b) Back; (c) Side

4.4.3 Fit Evaluation

The cross-sections of jackets were extracted from 3D data scanning to compare and analyze the fit for bodies.

Figure 4.25 (b) shows the cross-sections of original jacket and the reconstructed jacket model of Jacket2. They also show a similar shape with each other. Moreover, the shapes of waist line were closer than ones of Jacket1. It was due to less allowance in the waist area of Jacket2 than Jacket1. The waist allowances of Jacket1 and Jacket2 are 17.9cm and 15.4cm, respectively (see Table 4.1 and Table 4.2). Thus, if the cross-section has less ease allowance, the constructed model is closer in shape to the original, but it is difficult to recapture the original shape if the ease allowance is large.

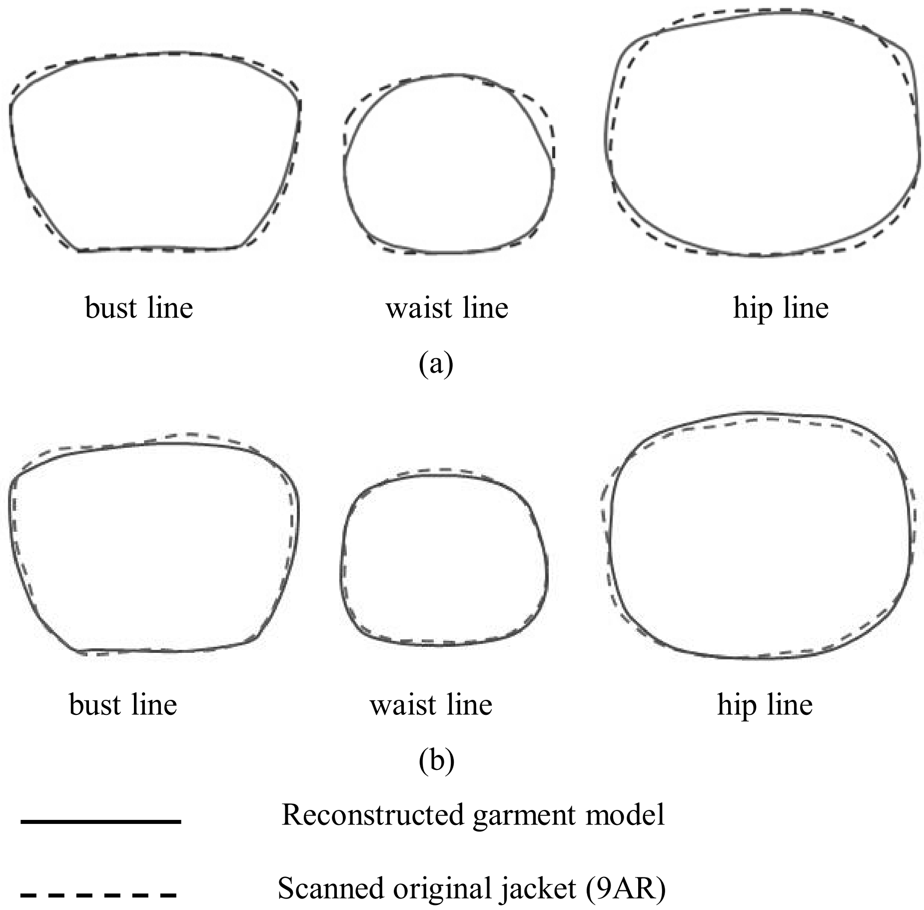


Figure 4.25 Comparison of the cross-sections of the constructed garment model and original jackets: (a) Jacket1; (b) Jacket2

Figure 4.26 and Figure 4.27 show the cross-sections of reconstructed garment model of Jacket1 and Jacket2 for 5AR and 13AR size bodies. All the cross-section curves of the models and jackets are almost the same respectively. The sizes of all the models and jackets were measured, and the measurements are shown in Table 4.2. Those sizes of made jackets agree with ones of the constructed garment models.

Consequently, we were able to make patterns in different sizes using the proposed method. Therefore, this method can be used as a size changing method, especially for creating individualized garments.

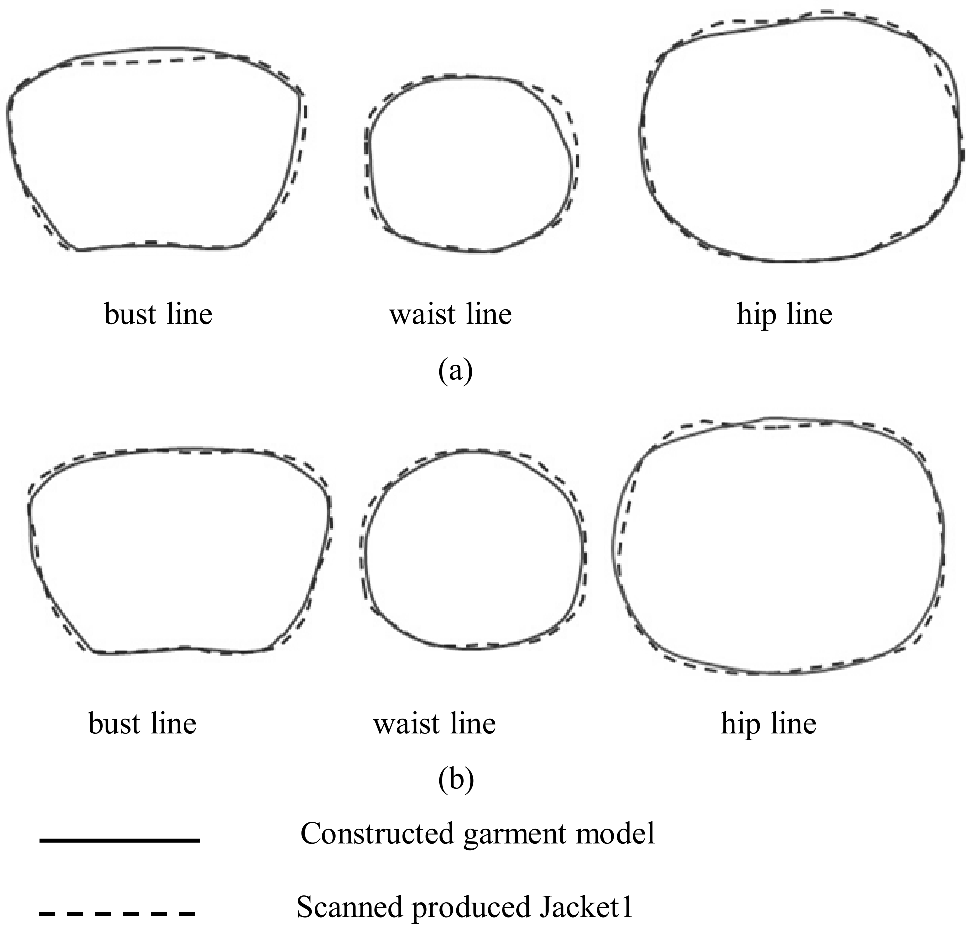


Figure 4.26 Comparison of the cross-sections of the constructed garment model and reproduced Jacket1: (a) 5AR; (b) 13AR

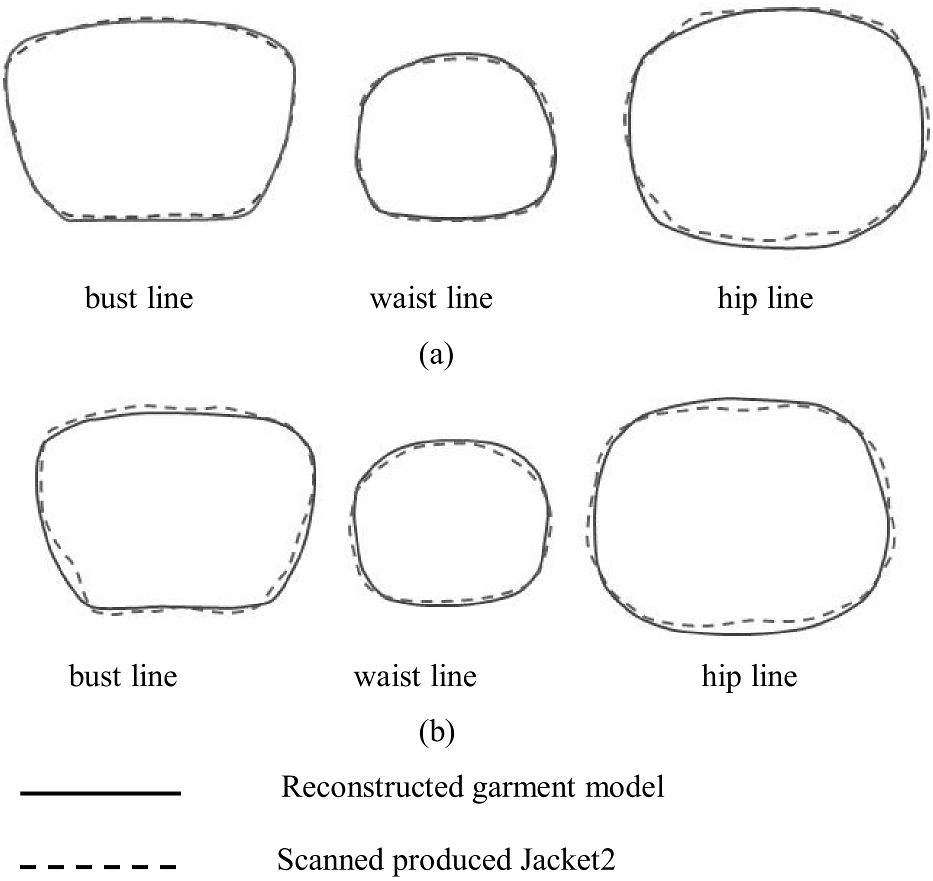


Figure 4.27 Comparison of the cross-sections of the constructed garment model and reproduced Jacket2: (a) 5AR; (b) 13AR

Table 4.2 Measurements for each garment model and made jacket (unit: cm)

Jacket	Body size	Bust line		Waist line		Hip line	
		model	jacket	model	jacket	model	jacket
Jacket1	9AR	94.0	94.3	80.5	80.9	104.9	103.1
	5AR	85.3	85.9	68.9	70.4	99.1	99.9
	13AR	98.0	97.9	83.4	84.4	107.9	107.4
Jacket2	9AR	93.6	94.0	78.8	78.4	99.1	98.2
	5AR	83.6	84.2	67.9	68.6	92.9	94.6
	13AR	96.6	97.2	82.9	83.6	102.3	102.5

4.5 Summary

In this study, a new method for creating upper garment models suitable for 3D pattern-making was developed. These models take into account ease allowance and silhouette by using 3D scans of a garment model being worn by a body. A basic garment model of a jacket bodice was made using the method. To confirm the model validity, the 3D pattern-making system was used to produce bodice patterns with the same seam lines as the model. This manufactured jacket bodice possessed a shape similar to the original, as well as silhouettes and ease allowances. Furthermore, a bodice pattern with seam lines that were different from the original ones was created, but that produced a bodice that also had a similar shape to the original. This confirmed that it was possible to make patterns that take into account ease allowance and silhouette by using a 3D scan of a garment model. The method also can be used to make new patterns with different seam lines.

A multiplication factor-based size-change method was also proposed in the study. The multiplication factors required were calculated between an actual garment worn on a body and the body shape. This was done for cross-sections in the front, back, and lateral directions. Using the multiplication factors, two new models for different body sizes were constructed. Patterns and garments were made using these models and their accuracies were confirmed also. The garments fitted on the bodies very well, demonstrating that the proposed method is applicable to make patterns for different size bodies. Furthermore, appropriate patterns in different sizes for a different garment were also obtained.

Using the proposed modeling method, it was able to make complex new garment models that take into account ease allowance and silhouette. The ability to size these models up or down using multiplication factors could be a substitute for the grading method for creating individually tailored garments.

References

1. Cho Y.S., Komatsu T., Inui S., Takatera M., Shimizu Y., and Park H., Individual pattern making using computerized draping method for clothing. *Textile Research Journal*, 2006. 76(8): 646-654.
2. Cho Y.S., Okada N., Park H., Takatera M., Inui S., and Shimizu Y., An interactive body model for individual pattern making. *International Journal of Clothing Science and Technology*, 2005. 17(1-2): 91-99.
3. ZHANG M., KAMIJO M., TAKATERA M., FURUKAWA T., and SHIMIZU Y., An Interactive Pattern Making and 3D Simulation System of Collars. *Kansei Engineering International*, 2000. 1(4): 1-10.
4. Imaoka H., Shibuya A., and Aisaka N., Automatic paper pattern making using mechanical development method of a curved surface on a plane surface. *Sen-i Gakka/shi*, 1989. 45.
5. Watanabe Y., Minoh M., and Sakaguchi Y., Ordering Your Cloth to Fit Yourself: A Custom-Clothing System by Using Virtual Environment. *JOURNAL-INSTITUTE OF ELECTRONICS INFORMATION AND COMMUNICATION ENGINEERS*, 1999. 82: 404-411.
6. House D.H. and Breen D.E., Cloth modeling and animation. Collision detection in cloth modeling, ed. R. Bigliani and J.W. Eischen. 2000, AK Peters, Ltd.
7. Kim S. and Park C.K., Parametric body model generation for garment drape simulation. *Fibers and Polymers*, 2004. 5(1): 12-18.
8. Takatera M. and Kim K., Improvement of individualized pattern making using surface flattening technique. *Journal of Fiber Bioengineering and Informatics*,

2013. 6(4): 467-480.

9. Cho Y.S., Komatsu T., Takatera M., Inui S., Shimizu Y., and Park H., Posture and depth adjustable 3D body model for individual pattern making. *International journal of clothing science and technology*, 2006. 18(2): 96-107.

10. Cho Y.S., Komatsu T., Park H., Inui S., Takatera M., and Shimizu Y., Computerized Pattern Making System Allowing Fabric Shear. *Textile Research Journal*, 2006. 76(8): 646-665.

11. Daanen H. and Hong S., Made-to-measure pattern development based on 3D whole body scans. *International Journal of Clothing Science and Technology*, 2008. 20(1): 15-25.

12. Cho Y.S., Tsuchiya K., Takatera M., Inui S., Park H., and Shimizu Y., Computerized pattern making focus on fitting to 3D human body shapes. *International Journal of Clothing Science and Technology*, 2010. 22(1): 16-24.

13. Chan A., Fan J., and Yu W., Prediction of men's shirt pattern based on 3D body measurements. *International Journal of Clothing Science and Technology*, 2005. 17(2): 100-108.

14. Jeong Y., Hong K., and Kim S., 3D pattern construction and its application to tight-fitting garments for comfortable pressure sensation. *Fibers and polymers*, 2006. 7(2): 195-202.

15. Kim S., Jeong Y., Lee Y., and Hong K., 3D pattern development of tight-fitting dress for an asymmetrical female manikin. *Fibers and Polymers*, 2010. 11(1): 142-146.

16. Hlaing E.C., Krzywinski S., and Roedel H., Garment prototyping based on scalable virtual female bodies. *International Journal of Clothing Science and*

Technology, 2013. 25(3): 184-197.

17. Troynikov O. and Ashayeri E. 3D body scanning method for close-fitting garments in sport and medical applications. HFESA 47th Annual Conference, Crows Nest, 2011.

18. Yang Y.C. and Zhang W.Y., Prototype garment pattern flattening based on individual 3D virtual dummy. *International Journal of Clothing Science and Technology*, 2007. 19(5): 334-348.

19. Mahnic M. and Petrak S., Investigation of the fit of computer-based parametric garment prototypes. *Journal of Fiber Bioengineering and Informatics*, 2013. 6(1): 51-61.

20. Digital Fashion Ltd. DressingSim LSX; Available from: http://www.dressingsim.com/, [Accsessed: March 20, 2016].

21. Apparel CAD | Toray ACS Ltd. Available from: http://www.toray-acs.co.jp/, [Accsessed: March 20, 2016].

22. Yuka and Alpha Co.,Ltd. Available from: http://yuka-alpha.jimdo.com/, [Accsessed: March 25, 2016].

23. Zeng X., Koehl L., Chen Y., Zeng X., Happiette M., Bruniaux P., Ng R., and Yu W., A new method of ease allowance generation for personalization of garment design. *International journal of clothing science and technology*, 2008. 20(3): 161-173.

24. Wang Z.H. (2008). A study of ease distribution in relation to jacket pattern alteration. Ph.D. Thesis, The Hong Kong Polytechnic University.

25. Thomassey S. and Bruniaux P., A template of ease allowance for garments based on a 3D reverse methodology. *International Journal of Industrial*

Ergonomics, 2013. 43(5): 406-416.

26. Bye E., LaBat K., McKinney E., and Kim D., Optimized pattern grading. *International Journal of Clothing Science and Technology*, 2008. 20(2): 79-92.

27. Wang Y. and Huang H., Three Dimensional Pattern Grading Based on Deformable Body Features and 3D Developable Surface. *Journal of Fiber Bioengineering and Informatics*, 2011. 4(2): 115-128.

28. Helen J.A., Patternmaking for fashion design. Third Edition. 1999, New Jersey, Prentice Hall.

Chapter 5

3D Garment-size Change Modeled Considering Vertical Proportions

Chapter 5 3D Garment-size Change Modeled Considering Vertical Proportions

5.1 Introduction

To meet the size and ease allowance requirements of garments, the general pattern grading is used to increase or decrease the basic pattern sizes, based on the average difference between sizes called size chart.

Although pattern grading brings convenience to develop different pattern sizes, it can reflect the body shapes to some extent. It still poses a "fit" problem for individuals.

Grading methods are applied to make various sizes of ready-to-wear for target consumers from the master size of a garment. In addition, to make a garment for different markets, it is necessary to consider a body representative of the target market. Even if the height is the same, the body proportions relating to girth and vertical measurements could differ.

Pattern grading is a process of proportionally increasing or decreasing the size of a master pattern according to a prescribed set of body measurements [1, 2]. However, when grading is employed to make a pattern of different sizes using a master pattern, the methodology depends on the garment type [2, 3]. In the grading process, the ease allowance, shape, and body proportions are important factors that affect the garment silhouette and comfort. However, garment patterns are often graded using a planar pattern and it is thus difficult to make a garment while keeping the silhouette of the master pattern, especially in the case of a garment with a curved surface[2, 4].

Nowadays, a three-dimensional (3D) garment surface flattening method is applied to pattern development [5-11]. These studies used 3D body measurements, body scanning data, or a free-form or parameterized deformation method to make a garment model. Kim [12] located landmarks and baselines automatically on the body surface to flatten the 3D body surface and obtain patterns. Wang and Huang [13] proposed the generation of various sizes of garment patterns by flattening 3D garments created from parameterized mannequins. Hsiao and Chen [14] and Apeagyei [15] presented methods for the surface reconstruction of 3D dress forms based on feature curves in horizontal directions for the clothing fit. Cichocka *et al.*, [16] generated parametric mannequins with ease allowance by modeling the human body. These models would work well for tight-fitting garments in sport and medical applications, and tightly follow the contours of the part of the body being covered.

However, those models are not applicable to a garment with complex ease allowance for styling and silhouette. Therefore, there remain many challenges in garment modeling, such as creating a complex 3D surface with dents, fitting body shapes, and preserving the original 3D shape for different bodies [17-19].

To create 3D garment model with complex ease allowance, a 3D garment modeling method was proposed in Chapter 4 using garment scanning data. A jacket bodice was made, and then it was scanned and scaled in the horizontal direction using multiplication factors to construct garment models for required body sizes with the same height. Using the obtained garment models, patterns for the jacket bodices were produced by employing a 3D pattern-making system. Jackets for different body sizes with the same height and vertical body proportions were made successfully. However, human body figures are different in not only the horizontal direction but also the vertical direction. Japanese adult bodies are classified by height and circumference in the Japanese Industrial Standards (JIS) as shown in Figure 5.1. In addition, standard bodies differ depending on race or nationality. It is therefore necessary to consider the change in the vertical measurements in accordance with different heights.

In this study, to make a garment model of different sizes for various body types, the garment modeling method were improved taking into account both vertical body proportions and the horizontal dimension.

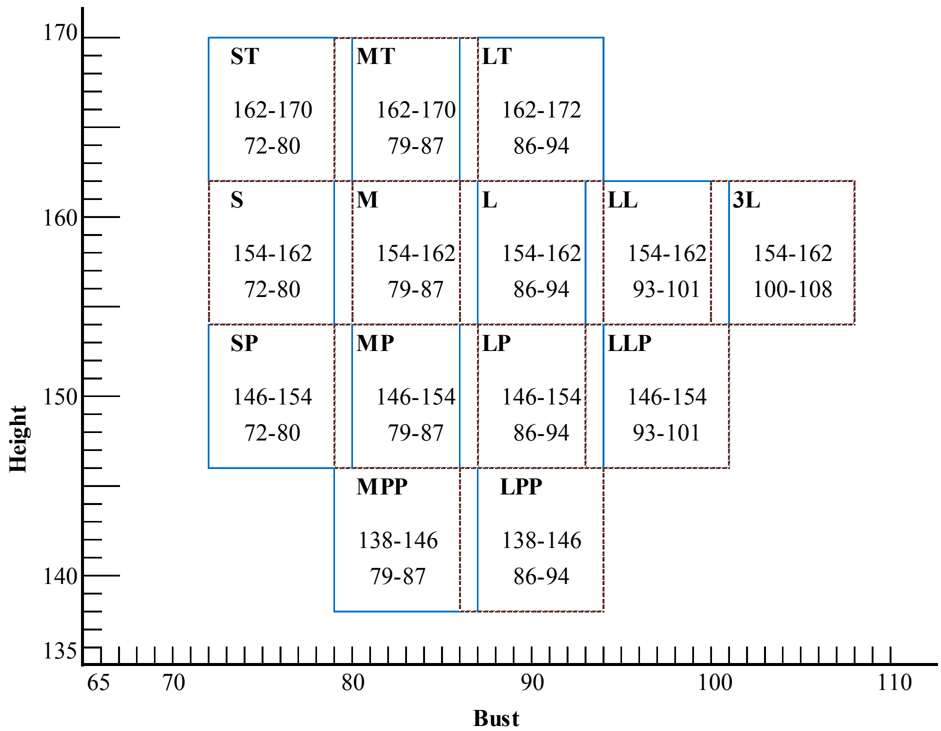


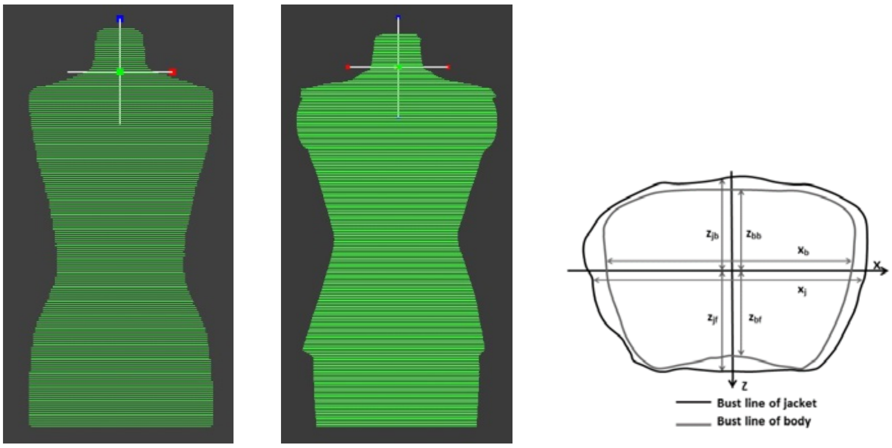
Figure 5.1 JIS women's body sizes. (JIS L4005)

5.2 Modeling Method for Different Model Sizes

A dress form and a body-fitting jacket were selected. They are respectively referred to as the Standard Body and Standard Jacket in this chapter. The horizontal multiplication factors for the relationship between the cross-sections of the Standard Jacket and Standard Body were obtained. Using the multiplication factors, another garment model was created that fits a target body obtained by expanding the target body horizontally and then expanding or contracting it vertically. Before expanding the body horizontally, the target body were expanded or contracted to adjust its vertical proportions to those of the Standard Body. The target body was then expanded using the multiplication factors. Afterward, the vertical proportions of the horizontally expanded target body were restored to the original proportions. Finally, the target body was deformed to construct the target jacket model.

5.2.1 Construction of the Basic Model and Obtaining Multiplication Factors for a Horizontal Cross-Section

3D surface data of the Standard Body and Standard Jacket worn on the body were obtained by scanning. The surface data were converted into a horizontal cross-sectional line model as shown is Figure 5.2 (a). A convex hull was applied to each cross-section to remove dents in the horizontal cross-section. The improved line model was converted into a polygon model, which was used as the basic garment model as shown in Figure 5.2 (b). Horizontal multiplication factors of the Standard Body and Standard Jacket were calculated using the distances between cross-sections in the forward, backward, and lateral directions for deformation in the horizontal direction as shown in Figure 5.2 (c).



(a) (b) (c)

Figure 5.2 Scheme of modeling method for horizontal size change: (a) Line model of a target body; (b) Basic garment model; (c) Calculation of multiplication factors

5.2.2 Construction of Garment Models Considering the Vertical Proportion

To adjust vertical proportions of the target body and Standard Body, the bodies were divided into three segments vertically, namely the front neck point (NP) to bust line (BL), the bust line to waist line (WL) and the waist line to hip line (HL) as shown in Figure 5.3 (a). The three vertical distances of NP–BL, BL–WL and WL–HL were measured to calculate and adjust the body vertical proportions for constructing garment model.

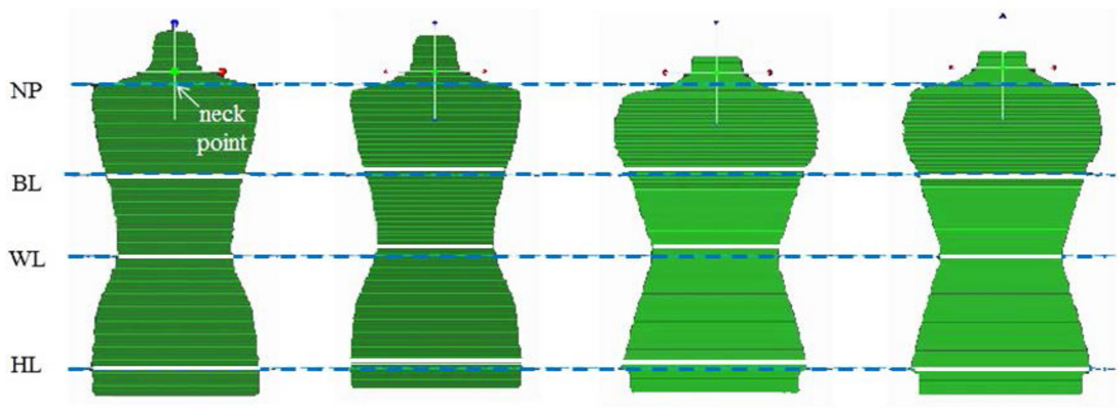
It contains 3 steps to adjust the target body vertical proportions for constructing garment model.

Step 1: Setting vertical proportion of target body as that of Standard body (Figure 5.3 (b));

Step 2: Appling horizontal multiplication factors to expand horizontal dimensions of target body to form a garment model (Figure 5.3 (c));

Step 3: Restoring vertical proportion to original target body (Figure 5.3 (d)).

The multiplication factors were extracted from the Standard Body and Standard Jacket as described in Chapter 4, they corresponded to the Standard Jacket vertically. However, the vertical proportion of the target body as shown in Figure 5.3 (a) is not corresponding to that of Standard Body. To expand the target body in horizontal direction forming garment model using multiplication factors for corresponding position, before applying the horizontal expansion, the vertical distances of the three segments of the target body were adjusted to those of the Standard Body using a constant multiplication factor as shown is Figure 5.3 (b). The target body was then deformed horizontally by applying the horizontal multiplication factors as shown is Figure 5.3 (c). Finally, after the vertical dimensions of the deformed body were restored to the original dimensions, a line model of the garment were constructed as shown is Figure 5.3 (d). The deformed line model was converted to a polygon model to develop patterns.



(a) (b) (c) (d)

Figure 5.3 Process of modeling method for vertical size change: (a) Target body; (b) Setting vertical proportion of target body as that of Standard Body; (c) Appling horizontal multiplication factors; (d) Restoring vertical proportion to original of target body

After constructing a 3D garment model, a 3D pattern-making system [20] was used to flatten the 3D surface to two-dimensional (2D) patterns. Covering and flattening methods were adopted to develop patterns for bodies of different sizes.

5.3 Experimental

Experiments were conducted to verify the validity of the proposed method. The Standard Jacket bodice and Standard Body were selected and scanned using a 3D scanner (Hamamatsu Photonics K.K., Shizuoka, Body Line Scanner) to obtain 3D surface data. The horizontal multiplication factors of the relationship between the Standard Body and Standard Jacket bodice were calculated.

Three target bodies with different vertical proportions were selected to construct garment models. To verify the effect of adjusting the vertical proportions, garment models were also made without adjusting the vertical proportions.

After garment models were constructed, a 3D pattern-making system [20, 21] was used to develop patterns. The weft and warp grainlines were set at the same position as for the Standard Jacket bodice, and almost the same cutting lines as those on the garment models were set in the 3D pattern-making process.

Patterns were sewn carefully to make jacket bodices with certain ease allowance. Because it is focused on jacket bodice parts, all the garment models and patterns were developed without lapel, collar and sleeve parts.

Made jacket bodices were compared in terms of their silhouette, ease distribution and measurement using the 3D scanning shape data.

A Japanese female body, 9AR body (Kypris 9AR, Kiiya Co., Ltd., Tokyo, Japan) and a jacket bodice without a collar and sleeves fitted to the body were selected for the Standard Body and Standard Jacket; these are shown in Figure 5.4.

Three different dress forms (Body 1, Body 2 and Body 3) with different horizontal dimensions and vertical body proportions were used as target bodies in making patterns. Photographs and measurements of the dress forms are presented in Figure 5.5 and Table 5.1.

(a)

(b)

Figure 5.4 Standard Body and Standard Jacket [20]: (a) Standard Body; (b) Standard Jacket bodice

All jacket bodices were carefully made from cream-colored wool fabric (fabric weight: 149.0 g/m^2) with adhesive interlinings (fabric weight: 72.8 g/m^2) fused to each part. Jacket names and modeling methods for target bodies are listed in Table 5.2.

(a)

(b)

(c)

Figure 5.5 Photographs of three dress forms: (a) Body 1; (b) Body 2; (c) Body 3

Table 5.1 Measurements of three different dress forms

Dress form	Measurement (cm)							
	BL	WL	HL	CB	SNP–BP	NP–BL	BL–WL	WL–HL
Standard Body	87.0	63.0	93.0	38.0	22.5	13.0	16.0	20.0
Body 1	87.0	67.0	94.0	40.5	24.0	15.0	16.5	18.0
Body 2	82.0	59.0	87.0	40.0	24.0	16.5	15.5	19.0
Body 3	90.2	66.0	94.0	43.0	22.5	17.0	17.7	18.5

Annotation: CB denotes the surface length from the center back neck point (cervical vertebra) to the waistline, SNP–BP denotes the surface length from the side neck point to the bust point, NP–BL denotes the vertical interval from the front neck point to the bust line, BL–WL denotes the vertical interval from the bust line to the waist line, and WL–HL denotes the vertical interval from the waist line to the hip line.

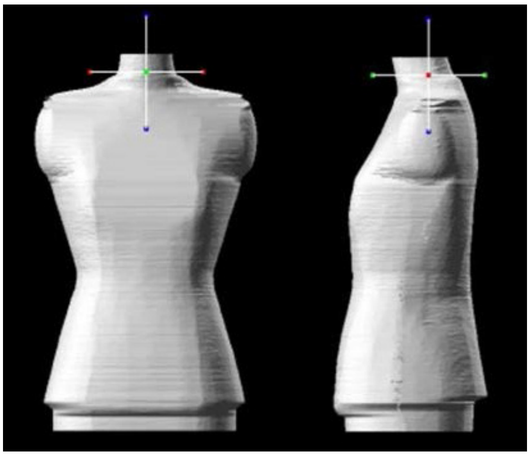
Table 5.2 Jacket name and modeling method for target body

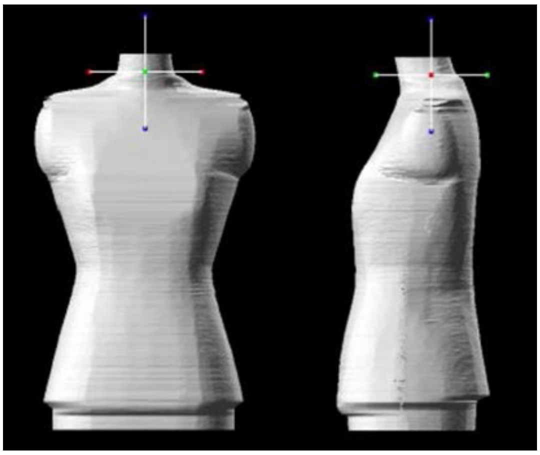
Modeling method / Target Body	With adjustment of the vertical proportion	Without adjusting the vertical proportion
Body 1	JK1	JK1N
Body 2	JK2	JK2N
Body 3	JK3	JK3N

5.4 Results and Discussion

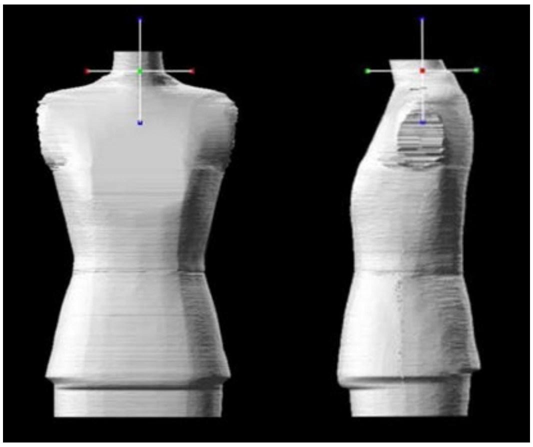
5.4.1 Result for Modeling and Pattern

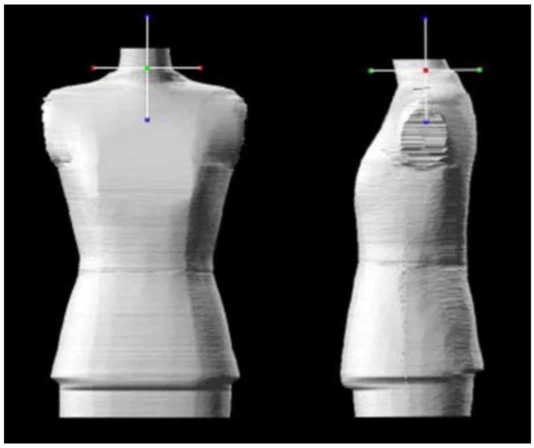
Three garment models were successfully constructed taking into account both horizontal dimensions and vertical body proportions; they are shown in Figure 5.6 (a), (c) and (e). To verify the effect of adjusting the vertical proportion, garment models without adjusting the vertical proportions were also constructed as shown in Figure 5.6 (b), (d) and (f). Patterns were developed for all models using the flattening method proposed in Chapter 3 as shown in Figure 5.7.



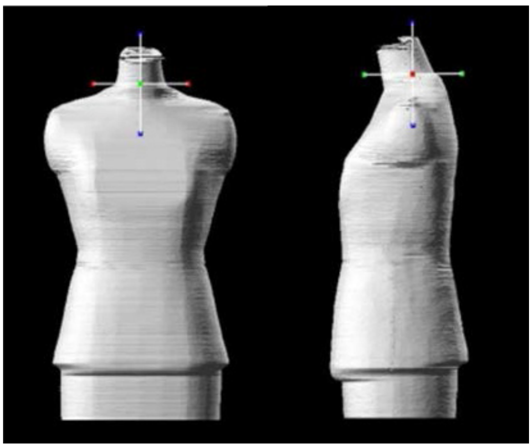


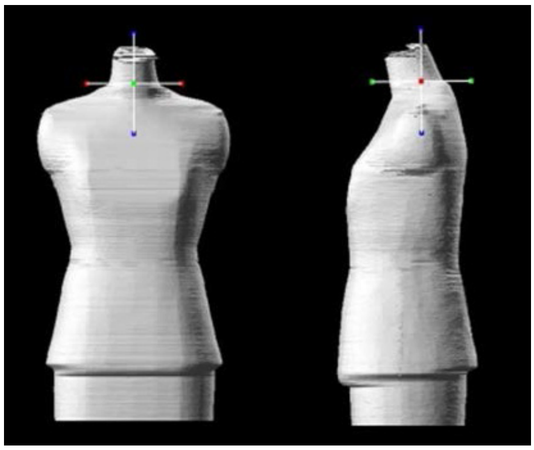
(a) (b)





(c) (d)





(e) (f)

Figure 5.6 Jacket models obtained with and without adjusting vertical proportions: (a) Model for JK1; (b) Model for JK1N; (c) Model for JK2; (d) Model for JK2N; (e) Model for JK3; (f) Model for JK3N

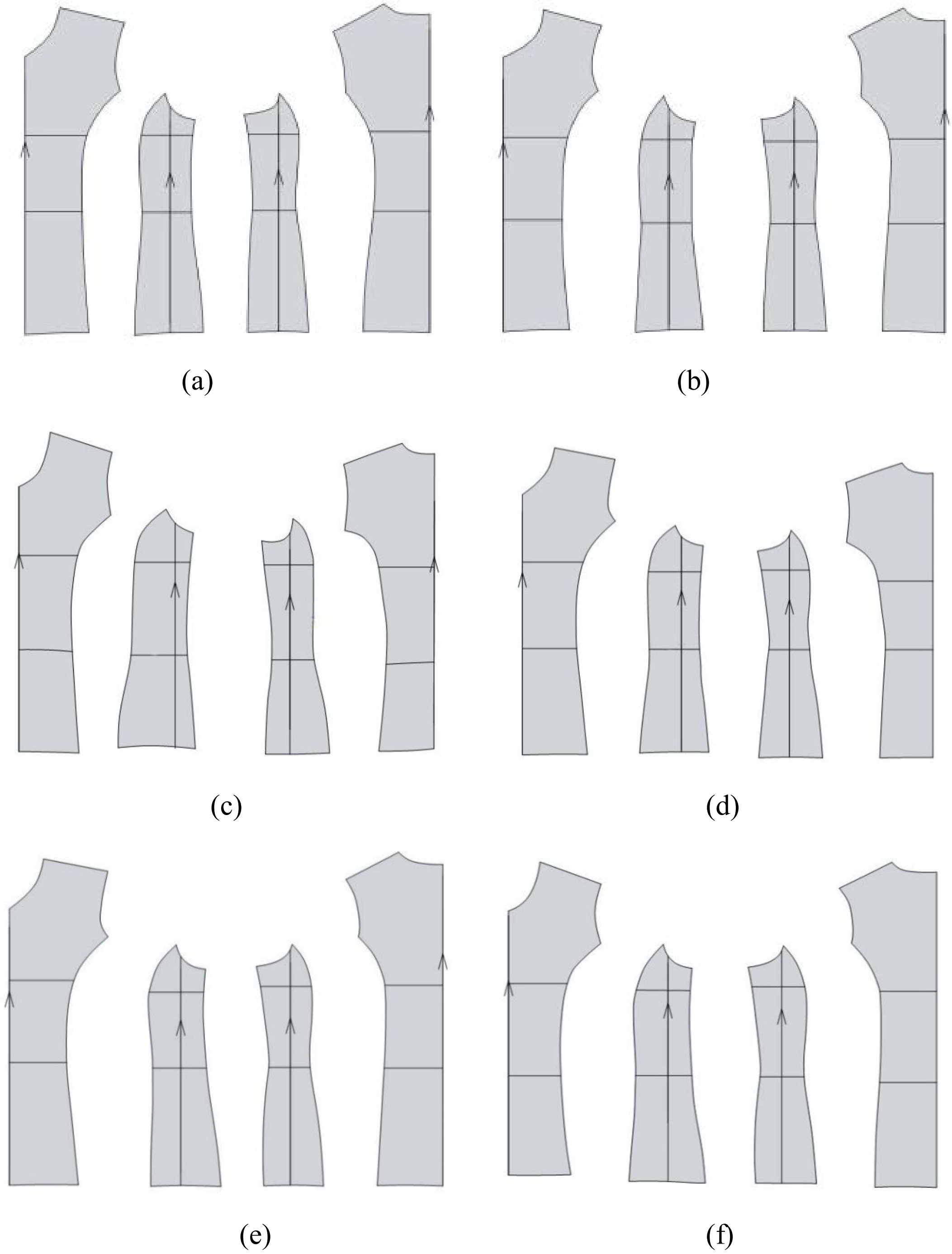


Figure 5.7 Jacket patterns obtained with and without adjusting vertical proportions: (a) Pattern for JK1; (b) Pattern for JK1N; (c) Pattern for JK2; (d) Pattern for JK2N; (e) Pattern for JK3; (f) Pattern for JK3N

5.4.2 Fit Analytics

Jacket bodices were made using the developed patterns. The jackets put on the dress forms are shown in Figure 5.8 – Figure 5.10.

(a)

(b)

Figure 5.8 Jacket bodices for Body 1: (a) JK1; (b) JK1N

(a)

(b)

Figure 5.9 Jacket bodices for Body 2: (a) JK2; (b) JK2N

(a)

(b)

Figure 5.10 Jacket bodices for Body 3: (a) JK3; (b) JK3N

As shown in Figure 5.8, JK1 looks better and has fewer wrinkles in the upper bust, armpit and back when compared with JK1N. Without taking into account the vertical proportions, the position of the jacket's bust line does not correspond to the body's bust line. The bust line of JK1N is higher than that of Body 1. Thus, the upper parts of the bust line have wrinkles owing to a large amount of ease, and the lower part of the bust line is stretched and has wrinkles. In the case of Body 2, JK2 looks better than JK2N. Similar to the case for Body 1, there are wrinkles in the upper parts of the bust line. Constriction of the side line of JK2 is similar to that of the Standard Jacket bodice in Figure 5.4. However, the constriction of JK2N is angular and not similar to that of the Standard Jacket bodice. This is due to the difference in the waist line between the jacket and body. The results for JK3 and JK3N are similar to those of JK2 and JK2N. It is thus necessary to realize better fitting and fewer wrinkles using the multiplication factors for the horizontal dimension and adjustment for the vertical proportion.

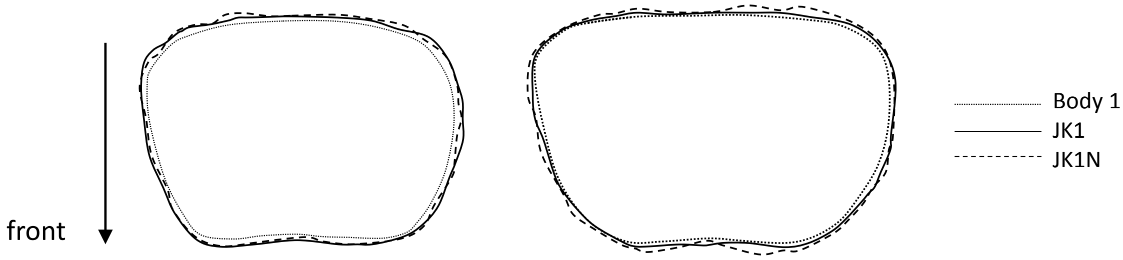
Table 5.3 gives the measurements and ease allowance of the bust line, waist line and hip line for target bodies and jackets with and without adjusting vertical proportions. The ease amount of the waist for JK1N is greater than that of JK1 and the ease amount of the hip is less than that for JK1. The side line of JK1N is thus straighter than that of JK1. Likewise, JK2N has a straighter side line than JK2. In the case of JK3N, the ease amount of the bust is larger than that of JK3 even though the ease amounts of the waist and hip for JK3N are smaller than those for JK3. Therefore, the proportions of jackets without adjustment of the vertical proportions were unbalanced, resulting in a poorly fitting shape and wrinkles.

To show these differences graphically, cross-sectional shapes of jackets in the upper and lower parts of the bust line were compared. The cross-sectional shapes 5 cm below and 5 cm above the bust line were measured; these cross-sections referred as the under-bust and upper-bust cross-sections respectively. The shapes are compared in Figure 5.11 – Figure 5.13 Under-bust and upper-bust cross-sections of JK1N, JK2N and JK3N show more undulation than those of JK1, JK2 and JK3. The undulations correspond to wrinkles of JK1N, JK2N and JK3N in Figure 5.8 – Figure 5.10.

Table 5.3 Measurements and ease allowances of the bust line, waist line and hip line for three bodies and jackets with and without adjusting body vertical proportions

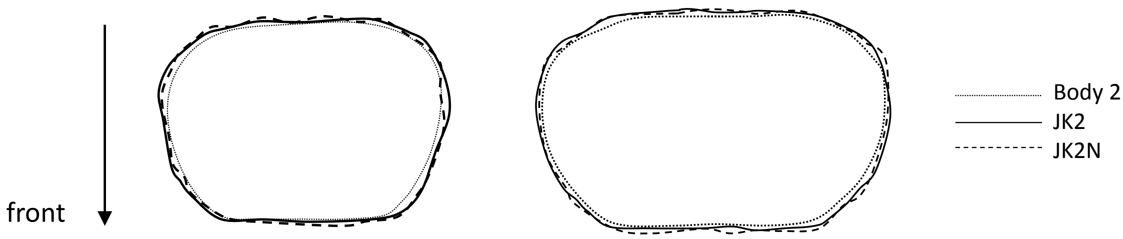
Target body	Measurement	Body (cm)	Jacket name	Jacket (cm) (percentage ease)	Jacket name	Jacket (cm) (percentage ease)
Standard Body	Bust	87.0	Standard Jacket bodice	94.3 (8.4%)		
	Waist	63.0		80.9 (28.4%)		
	Hip	93.0		103.1 (10.9%)		
Body 1	Bust	87.0	JK1	94.9 (9.1%)	JK1N	95.5 (9.8%)
	Waist	67.0		83.9 (28.4%)		86.6 (29.2%)
	Hip	94.0		104.7 (11.4%)		102.5 (9.0%)
Body 2	Bust	82.0	JK2	95.1 (9.7%)	JK2N	87.8 (7.1%)
	Waist	59.0		74.5 (26.3%)		76.6 (29.8%)
	Hip	87.0		100.4 (15.4%)		98.6 (13.3%)
Body 3	Bust	90.2	JK3	98.0 (8.6%)	JK3N	100.3 (11.2%)
	Waist	66.0		82.9 (25.6%)		81.0 (22.7%)
	Hip	94.0		105.2 (11.9%)		102.0 (8.5%)

The measurements and ease allowance for target bodies and jackets are given in Table 5.4. Under-bust lines of JK1N, JK2N and JK3N have less ease than those of JK1, JK2 and JK3. This is because the distance of NP–BL is shorter on the Standard Body (13 cm) than for the other bodies (15–17 cm) as shown in Table 5.1. Under-bust parts of JK1N, JK2N and JK3N have less ease for forming a smooth surface under the bust. These parts were thus pulled. Wrinkling then occurred and produced the undulating lines in Figure 5.11–Figure 5.13. Meanwhile, upper-bust lines of JK1N, JK2N and JK3N had more ease than JK1, JK2 and JK3, which also caused the undulating lines. These results show that the jackets made without adjusting the vertical body proportions do not fit bodies having different proportions.



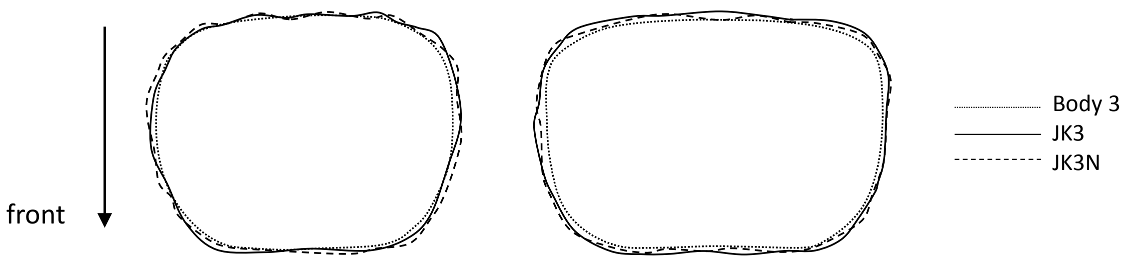
(a) (b)

Figure 5.11 Comparisons of cross-sections for Body 1, JK1 and JK1N: (a) Under-bust; (b) Upper-bust



(a) (b)

Figure 5.12 Comparisons of cross-sections for Body 2, JK2 and JK2N: (a) Under-bust; (b) Upper-bust



(a) (b)

Figure 5.13 Comparisons of cross-sections for Body 3, JK3 and JK3N: (a) Under-bust; (b) Upper-bust

Table 5.4 Measurements and ease allowance of under the bust and the upper bust for three bodies and jackets

Target body	Measurement	Body (cm)	Jacket name	Jacket (cm) (percentage ease)	Jacket name	Jacket (cm) (percentage ease)
Standard Body	Upper bust	90.5	Standard Jacket bodice	95.1 (5.1%)		
	Under bust	74.1		84.9 (14.6%)		
Body 1	Upper bust	88.1	JK1	92.6 (5.1%)	JK1N	95.0 (7.8%)
	Under bust	73.5		84.4 (14.8%)		82.8 (12.6%)
Body 2	Upper bust	88.2	JK2	92.8 (5.2%)	JK2N	96.1 (9.0%)
	Under bust	71.9		82.0 (14.0%)		81.3 (13.1%)
Body 3	Upper bust	92.5	JK3	97.0 (4.9%)	JK3N	100.3 (8.43%)
	Under bust	78.5		90.3 (15.0%)		88.7 (13.0%)

Therefore, it can be concluded that, in 3D garment modeling and pattern-making, not only the horizontal dimensions but also the body vertical proportions should be taken into account to make appropriate patterns for bodies of different sizes and proportions. The proposed method can therefore be used as a method of changing size, especially in creating individualized garments or garments for different targets.

5.5 Summary

In this study, a new method of upper-body garment modeling was proposed to perform 3D pattern-making for different body sizes and vertical proportions. So that a garment model fits a target body in terms of both the girth and vertical proportion, the target body is expanded horizontally and then expanded or contracted vertically using preliminarily obtained horizontal multiplication factors and a vertical proportion adjustment.

To verify the validity of the proposed method, jacket models for three bodies of different sizes and proportions were made. By developing the models, bodice patterns were obtained and bodices of jackets were sewn. In addition, to confirm the effect of adjusting vertical proportions, these bodices of jackets were compared with those obtained without adjusting vertical proportions.

With the proposed method, jacket bodices were successfully made and were fitted on the target bodies while preserving the original shape. Jackets bodices made without taking into account the vertical proportions had many wrinkles and shapes that were deformed owing to the different vertical proportions. The poor fit was also seen in cross-sections around the bust line.

The results indicate that the proposed method is effective in 3D garment modeling for different sizes and vertical proportions of bodies. The body vertical proportion is a factor that cannot be neglected in 3D garment modeling.

The proposed method is applicable to size changes and grading when making individually tailored garments or ready-to-wear garments for different targets.

References

1. Cooklin G., Pattern Grading for Women's Clothes. 1991, Oxford, England, Wiley-Blackwell.
2. Price J. and Zamkoff B., Grading techniques for fashion design. Second Edition. 1996, New York, Fairchild Publications.
3. Lim H. and Istook C.L., Automatic Pattern Generation Process for Made-to-Measure. *Journal of Textile and Apparel, Technology and Management*, 2012. 7(4): 1-11.
4. Bye E., LaBat K., McKinney E., and Kim D., Optimized pattern grading. *International Journal of Clothing Science and Technology*, 2008. 20(2): 79-92.
5. Cho Y.S., Okada N., Park H., Takatera M., Inui S., and Shimizu Y., An interactive body model for individual pattern making. *International Journal of Clothing Science and Technology*, 2005. 17(1-2): 91-99.
6. Cho Y.S., Komatsu T., Inui S., Takatera M., Shimizu Y., and Park H., Individual pattern making using computerized draping method for clothing. *Textile Research Journal*, 2006. 76(8): 646-654.
7. Imaoka H., Shibuya A., and Aisaka N., Automatic paper pattern making using mechanical development method of a curved surface on a plane surface. *Sen-i Gakka/shi*, 1989. 45.
8. Zhang M., Kamijo M., Takatera M., Furukawa T., and Shimizu Y., An Interactive Pattern Making and 3D Simulation System of Collars. *Kansei Engineering International*, 2000. 1(4): 1-10.
9. In H.S. and Tae J.K., Interactive garment pattern design using virtual scissoring method. *International Journal of Clothing Science and Technology*, 2006. 18(1):

31-42.

10. Kim C.H., Sul I.H., Park C.K., and Kim S.M., Automatic basic garment pattern generation using three-dimensional measurements. *International Journal of Clothing Science and Technology*, 2010. 22(2/3): 101-113.

11. Yang Y.C. and Zhang W.Y., Prototype garment pattern flattening based on individual 3D virtual dummy. *International Journal of Clothing Science and Technology*, 2007. 19(5): 334-348.

12. Kim S., Analysis of human body surface shape using parametric design method. *International Journal of Clothing Science and Technology*, 2015. 27(3): 434-446.

13. Wang Y. and Huang H., Three Dimensional Pattern Grading Based on Deformable Body Features and 3D Developable Surface. *Journal of Fiber Bioengineering and Informatics*, 2011. 4(2): 115-128.

14. Hsiao S. and Chen R., A study of surface reconstruction for 3D mannequins based on feature curves. *Computer-Aided Design*, 2013. 45(11): 1426-1441.

15. Apeagyei P.R., Application of 3D body scanning technology to human measurement for clothing Fit. *International Journal of Digital Content Technology and its Applications*, 2010. 4(7): 58-68.

16. Cichocka A., Bruniaux P., and Frydrych I., 3D Garment Modelling-Creation of a Virtual Mannequin of the Human Body. *Fibres & Textiles in Eastern Europe*, 2014.

17. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part I: Projection. *Textile Research Journal*, 1990. 60(11): 690-696.

18. Heisey F., Brown P., and Johnson R.F., Three-Dimensional Pattern Drafting Part

II: Garment Modeling. *Textile Research Journal*, 1990. 60(12): 731-737.

19. Umetani N., Kaufman D.M., Igarashi T., and Grinspun E., Sensitive couture for interactive garment modeling and editing. *ACM Trans. Graph.*, 2011. 30(4): 90.

20. Zhang J., Innami N., Kim K., and Takatera M., Upper garment 3D modeling for pattern making. *International Journal of Clothing Science and Technology*, 2015. 27(6): 852-869.

21. Zhang J., Kim K., and Takatera M., Three-dimensional garment-size change modeled considering vertical proportions. *International Journal of Clothing Science and Technology*, 2016. 28(5): In printing.

Chapter 6

Summary and Future Work

Chapter 6 Summary and Future Work

In this thesis, I have reached the respected achievements for constructing proper 3D garment model and making patterns. The achievements, limitation and suggested future work will be summarized in this chapter.

6.1 Summary

In Chapter 1, the background to the work was introduced.

Chapter 2 gave the literature review, the previous studies and published works concerning 3D modeling and pattern-making were summarized.

In Chapter 3, the methodology of 3D pattern-making process is described, from 3D data scanning to garment model and model size-change. A multiplication factor method was proposed to construct garment model taking into account both the horizontal body dimensions and vertical body proportions.

In Chapter 4, the theory and method described in Chapter 2 were applied to make garment models and patterns. The horizontal multiplication factors were calculated using 3D scanning data of the Standard Body and Standard Jacket. Then the multiplication factors were used to expand target bodies for constructing garment model. Patterns and garments were made to verify the validity of the modeling method. It indicated that the proposed method is capable of making garment models and patterns.

In Chapter 5, vertical proportions and horizontal dimensions of body were both taken into consideration to make appropriate patterns for various sizes of target bodies.

The vertical body proportions of target bodies were calculated for making proper garment models working with the multiplication factor method. The result showed that, the proposed modeling method is applicable to proper garment models for various body sizes.

6.1.1 Conclusions

In three-dimensional (3D) garment modeling and pattern-making, ease distribution is important to make proper models, but it is difficult to determine the ease distribution in different parts. In the study, two real garment bodices with the suitable fit, shape and silhouette were selected for pattern development. The bodices were fitted to a designated dummy body and scanned. Upper garment basic models were constructed for 3D pattern-making using the scanned data. To confirm the proposal, two bodice patterns were produced to inspect the validity of the modeling method, one with the original seam lines and the other with seam lines that differed from the original ones, and then compared them with the original jacket bodice. The patterns were sewn to reproduce the selected jacket bodies. By the results, reproduced jacket bodies had a similar shape, silhouette and ease amount. That is to say, the proposed method is an effective garment modeling approach using the scanned 3D data of a garment.

To construct garment models for making different size bodies, multiplication factor method was applied to expand the body model to form garment model, which contains certain ease allowance. Multiplication factors of cross-sectional dimensions (in the front, back, and lateral directions) between the basic garments were calculated for modeling. Using the multiplication factors, two different size garment models were constructed using the 3D scanned data of different size dummies, and the model was employed to make patterns and garments.

The reproduced jackets had similar shapes, silhouettes and ease allowances to the original jacket. Two garments of different sizes for each original jacket were made using the multiplication factors, and these garments also had similar silhouettes to the original jacket.

In addition, body shape differs depending on race or nationality. To make a well-fitted garment for a different market or different target, body vertical proportions should be taken into consideration to make appropriate patterns for bodies of different besides horizontal dimensions. Garment models were constructed taking into account both horizontal dimensions and vertical proportions using the multiplication factor method.

The vertical body proportions of target bodies were also calculated to make proper garment models working with the multiplication factor method. A target dress form was deformed using multiplication factors and vertical body proportions to construct a garment model that fitted the dress form. The method was verified using three different dress forms. The bodices of the jackets were compared with those obtained without adjusting vertical proportions.

Employing the proposed method, jacket bodices were made and fitted on target bodies while preserving the original shape. Jackets bodices made without considering vertical proportions had many wrinkles and deformed shape and poor fit around the bust line owing to the different vertical proportions. The vertical proportion is thus an important factor in the three-dimensional garment modeling of garments of different size fitted on a body.

Cross-sections of the body and made upper garment were extracted from 3D scanned data to evaluate garment fit. The result showed that the proposed modeling method is applicable to proper garment models for various body sizes.

6.1.2 Value of this Study

The study proposed a 3D garment modeling method using multiplication factors. It is capable of making proper upper garment model for 3D pattern-making. This model takes into account ease allowance, shape and silhouette, body sizes and vertical proportions.

This modeling method has the capability to make complex new garment models. And it can be used to make individual tailored garments or ready-to-wear garments for different targets.

The ability to size these models up or down using multiplication factors could be a substitute for the grading method.

6.1.3 Limitations

Although, this study achieved the expected results, there are some limitations that should be made a breakthrough to reach new achievements.

In this 3D pattern-making system, covered 3D surface could be cut by cutting lines or planes to generate patterns. Because of the development restrictions in the system, darts cannot be inserted freely, in some parts, such as the armpit, it has to make a segmentation to generate darts under the armpit, as shown in Figure 4.13 in Chapter 4. In the process of segmenting in 3D and combining in the plane, the desired pattern shape will be changed, that may lead to a garment fit problem.

The proposed method is capable of making various size garments for different bodies concerning ease, shape and silhouette. However, it is not applicable to some complex garment styles, such as fold, pleats, intricate drape.

The limitations of the proposed method also need to be analyzed for the sake of further improvement.

6.2 Future Work

I this study, a garment modeling method and a model size change method were proposed, some potential research areas are recommended for future work as following:

1. Application to other garment types;

2. Application to other body shapes.

6.2.1 Application to Other Garment Types

In this study, it was focused on the bodice part of the jacket, without collar and sleeves. Upper garment models for jacket bodices were successfully made. This method is applicable for other types of garment, such as shirts with collar and sleeves, individualized sleeves, loose-fit skirt and pants.

Various size garments for different sizes and shapes can be made by applying the proposed method.

6.2.2 Application to Other Body Shapes

Standard female bodies from different countries were employed to make garment model in this study. Actually, human bodies are different each other, including some special body figures, such as pregnant woman, humpbacked body, pigeon breast and obesity body. The proposed method is a good solution to making individualized garments for these special figures. The modeling method is applicable to a large range of body figure for various uses.

Published Papers

This thesis based on the following published papers:

1. Jun Zhang, Noriaki Innami, KyoungOk Kim, Masayuki Takatera, Upper garment 3D modeling for pattern making. International Journal of Clothing Science and Technology. Volume 27, Issue 6: pp.852-869, 2015.

2. Jun Zhang, KyoungOk Kim, Masayuki Takatera, Three-dimensional garment-size change modeled considering vertical proportions. International Journal of Clothing Science and Technology. Volume 29, Issue 1: pp.84-95, 2017.

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