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Virtual Garment Resizing and Capturing Based on the Parametrized Draft

매개변수로 표현된 드레프트를 기반으로 하는 가상 의복 리사이징 및 캡쳐링 방법

2016년 2월

서울대학교 대학원

전기·컴퓨터 공학부

정 문 환

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지도교수 : 고 형 석

이 논문을 공학박사 학위논문으로 제출함

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정문환의 공학박사 학위논문을 인준함

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Abstract

Virtual Garment Resizing and Capturing Based on the Parametrized Draft

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This dissertation presents novel frameworks for virtual garment resizing and capturing. In the clothing industry, ready-to-wear apparel is designed from standard body, and then it is resized to fit specific body. The resizing job is called grading. Grading requires specialized tailoring techniques and extremely time. We suggest fast and simple grading technique for virtual clothing. For generating virtual garment according to real garment, pattern designing and modeling knowledge are demanded. We propose a method which converts from real garment into virtual garment. There are in need of the virtual clothes grading and modeling methods in the animation and game productions, since costume design takes an important component in the process.

To perform grading job, we introduced retargeting technique which is widely utilized in the computer graphics field. Retargeting technique demands the mediator and the correspondence function. For the mediator of our method, we got the insight from the process of drawing the pattern-making draft. Noting that the draft can be completely determined by supplying the primary body sizes and the garment type, we implemented a computer module which performs the draft construction process. The module is called the *parameterized draft* module. Barycentric coordinates system is a reasonable method for making correspondence between garment drafts and panels on 2D. Among others, the Mean Value Coordinates (MVC) would be an excellent choice. We call this grading method *Draft-space Warping*. The proposed grading method can be performed instantly for any given body without calling for the user intervention. Our approach can minimize designer's specialized know-how and save performing time for the grading of real and virtual clothes. Also we suggest compensation techniques to improve the quality of grading. With experimental results, we show that the new grading framework can bring an improvement to garment grading.

Also, we investigated a method which can create the virtual garment from a single photograph of a real garment put on to the mannequin. Similar as our resizing method, we used pattern drafting theory in solving this problem. We utilize parameterized draft module which was introduced in draft-space warping. Then the capturing problem is reduced to find out the garment type and primary body sizes. We determine that information by analyzing the silhouette of the garment with respect to the mannequin. The method works robustly and produces practically usable virtual clothes which can be used for the graphical coordination.

Both methods are devised based on the pattern-making draft. Since proposed methods perform resizing and modeling jobs on 2D, we reduce computation time for the jobs. Although, we can get the plausible results.

Keywords: Virtual Garment, Resizing, Grading, Modeling, Barycentric Coordinate System, Photograph

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Chapter 1

Introduction

In the fashion industry, garment manufacturing have been the significant topic of research. Generally, the garment manufacturing framework [2] involves 5-steps: garment sketching, pattern designing, pattern grading, pattern sewing and inspection. The first step of the garment manufacturing is sketching the design of clothes. In this step, a fashion designer draws a flat sketch of the garment and annotates details for the specific design. After that, the pattern maker develops garment patterns from the flat sketch which is drawn before step. These patterns are based on the standard body size. Next step is pattern grading. The aim of grading is resizing patterns for different standard body sizes or a specific body size. In the pattern sewing step, each pattern is stitched. Last step is inspection. In this step, the garment is checked the sewing defects, erroneous creasing and non-matching threads. Also, the designer evaluates the design of the garment draping, garment pressure and garment air-gap. For passing final step, the making process requires many iterations of transferring garment design in patterns to draped design on the body, then back to patterns. These procedures call for technical knowledge of tailoring and a large amount of human intervention.

Various virtual clothing technologies help to make garment patterns and represent 3D draping design effectively and efficiently. Virtual garment means 2D polygons and 3D meshes which are represented clothes patterns in virtual environment. Virtual clothing can be used to clothe the characters appearing in the movies, animations and games [46]. It changes working practice in many companies in the clothing industry. The advancement of virtual clothing techniques is to be welcomed not only to graphics field, but to fashion field.

1.1 Virtual Clothing Techniques

In this section, we examine a brief general description of the virtual clothing techniques. We introduce how to perform garment modeling, simulation, rendering and texturing in the computer graphics field and the fashion field.

Garment Modeling Garment modeling techniques are utilized to represent the garment in a virtual environment. There are two types of cloth modeling methods: Drawing 2D patterns and constructing 3D meshes. Pattern makers and designers use computer-aided design (CAD) softwares such as Style-CAD, Lectra, Gerber, Optitex and DC-Suite in order to making and editing 2D garment pattern. Generally, ready-to-wear clothing is reflected in standard body size. In order to make clothes for various customers, the standard body size pattern would be graded into specific body sizes by a skillful tailor. These applications are used to assist drawing, editing, texturing and grading garment patterns on 2D. In the computer animation and game field, virtual garment is generated by using 3D modeling applications such as Blender, Maya and 3ds-MAX. It is same technique as other modeling objects like avatar, accessory, car, furniture and building. As there is not tailoring knowledge, these garments tend to consist of basic pattern meshes.

Garment Simulation In order to represent 3D dynamics and shape of the garment, fashion designer uses 3D draping software such as Qualoth, Marvelous, Optitex and DC-Suite. With the help of these software systems, checking the garment shape and evaluating a property of matter can be performed in virtual environment. These applications decrease time and cost when a garment is evaluated. In the graphics field, garment simulation reproduces dynamic behaviors of cloth in a virtual environment. There are three types of cloth simulation methods: physically based method, data-driven method and hybrid method. For implementing dynamic behaviors, physically based cloth simulation utilizes physical models such as mass-spring model [62] and energy model [7]. Since the method is based on the physics in the real world, the shape of draping garment looks like very realistic. However, the simulation quality is proportional to the number of the basic elements of the garment meshes, it calls for a lot of computational cost to represent fine details. To solve these problem, many researchers have been investigated various GPU-based techniques [72, 96]. Data-driven based cloth simulation utilizes precomputed data which is constructed from standard 2D clothing designs draped on 3D avatars with varying shape and pose [19, 85, 32]. These techniques do not well reflect the property of cloth material than direct physically-based simulation. In the hybrid clothing simulation [45, 43], coarse level garment meshes were draped physically-based cloth simulation. After that, fine-scale details are added on the coarse level garment meshes. Multi-grid approaches [59, 38] use multiple resolutions to reduce computing cost for solving a linear system. Hybrid clothing simulation is more efficiently rather than using physical based simulation solely.

Garment Rendering and Texturing Rendering and texturing techniques are needed to represent virtual garment more realistically. Rendering is the process for producing a 2D image from a description of a 3D scene [60]. Many ways have been investigated to describe reflection behavior of fabric texture on the virtual garment. These methods use the bidirectional reflectance distribution function(BRDF) which has the advantages to represent reflectance property of fabric such as anisotropy, fresnel behavior and non-Lambertian diffuse term [31, 6]. For constructing microfacet-based BRDF, reflectance data was captured from real garment [54, 86]. Small-scale texture and textile are significant part to produce the appearance of woven fabrics [90, 44, 36]. These methods consider the geometric model of the woven cloth.

1.2 Motivation

This dissertation consists of two parts: garment resizing and garment capture. In the garment resizing section, we introduce the garment resizing and our novel idea which helps to perform grading the clothes in the virtual environment. Next, we present the garment modeling method which can generate 2D garment pattern and 3D draping mesh from a photograph. Both methods are motivated from pattern-drafting knowledge.

1.2.1 Garment Resizing

In the clothing industry, pattern-maker draws garment pattern based on the standard body size, and then the resulted patterns are modified to fit different body sizes. The latter part is generally referred to as grading. Without grading, the design and fit can not be well appreciated by other bodies because each body size of individual is different from the standard body size which were used in the original garment design. Therefore, grading is the significant part in the fashion field.

Animation and game industry also necessitate the grading technique, since costume design is an important component in the process. In face, the variation of the bodies appearing in the animations or games is broader than the clothing production, because clothes often need to be worn by monsters or animals which has an extreme body sizes. Such bodies are difficult to cover with the conventional grading methods. Therefore, a new grading technique, which

Figure 1.1 Linear grading of bodice panel. Linear grading method performs the grading job by applying translations to a set of panel vertices according to predetermined directions.

transforms a given design to fit a particular body size, needs to be developed. In the computer graphics field, an extensive amount of work has been investigated to clothe human characters, but little study has been performed on the grading problem itself.

A garment refers to a set of panels $[p_1, p_2, \ldots, p_N]$. Note that determination of the shape and size of the panels forms the essential part of the garment design, but the color and the textiles are irrelevant in the consideration of grading. Speaking in terms of data, a panel is represented by the contour lines and interior points/lines. Focusing on a particular panel, a grading algorithm has to generate new contour lines and interior points/lines. The graded panels should fit to the specific body and preserve original design.

Some grading tools are provided with many computer softwares such as Style-CAD, Lectra, Gerber and Optitex, but the grading tool is a tedious process which requires a large amount of user's intervention and expert knowledge of the tailoring. The two grading methods, namely, the cut-and-spread method and the pattern shifting method are in use in the current clothing industry [34]. When an original panel is given, those methods perform the grading job by applying translations to a set of panel vertices according to predetermined directions, as shown in Figure 1.1. We will call this sort of grading as *linear grading*, since the translations are made along a straight line. Unfortunately, the linear grading may not be an optimal treatment to accommodate non-linear body variations and non-planar body surface. The above problem has been noted for a long time. Therefore, a grading expert makes further adjustments to the linearly graded results, which is typically a time consuming and labor-intensive task. This dissertation is motivated from the author's belief that such non-linearity can be better accounted for by a computer program rather than human hands.

In order to approach the problem from a different angle, grading is treated as retargeting problem which is used in deformation mesh and polygon. Retargeting method utilizes correspondence between object and mediator as shown in Figure 1.2. First, we define correspondence function between the source

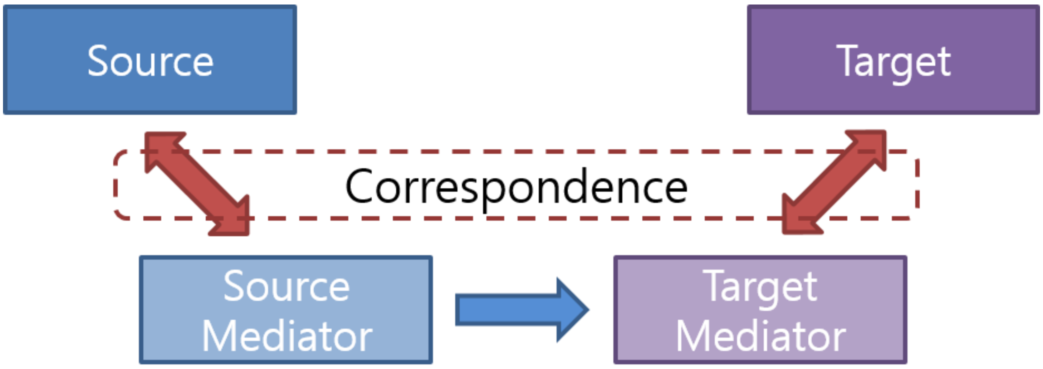

Figure 1.2 Framework of retargeting method. First, the correspondence is defined between the source object and the mediator. Next, the mediator is modified for the target object. Finally, we make the target object according to the modified mediator with the correspondence.

object and the mediator. Next, we modify the mediator for the target object. Finally, we make the target object according to the modified mediator with the correspondence function. Many researchers [55, 84, 15] introduced retargeting scheme for handling garment grading. In the previous works, 2D garment patterns are retargeted on 3D space because the mediator is 3D avatar. The result of these works is 3D garment mesh. But, only 2D panels can be used in the clothing production, therefore previous works need additional process such as pattern extraction [66, 67] which involves additional computation and distortion. We suggest novel approach which switches from garment grading to 2D polygon retargeting problem. We call the approach *Draft-Space Warping* [40], and call the retargeting step *draft-space encoding and decoding*. In order to do grading on 2D, we need a 2D mediator, which would be served as 3D avatar on 3D space.

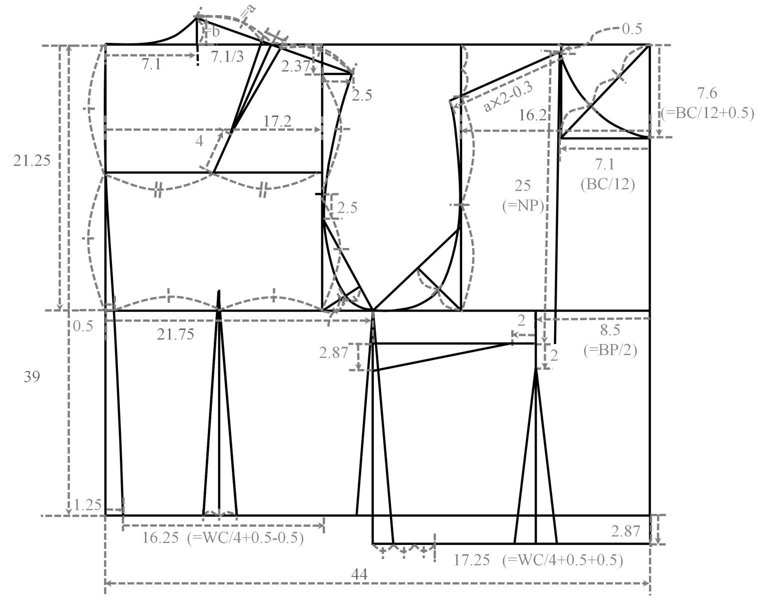

Figure 1.3 Bodice draft

PBS (unit:cm)	source
Bust Circumference	85
Waist Circumference	65
Hip Circumference	90
Waist Back Length	39
Bust Point to Bust point	17
Neck Point to Breast Point	24

Table 1.1 The primary sizes of bodice

The proper mediator and the corresponding function are demanded to get the satisfactory result in the retargeting method. For the mediator of grading problem, we got the insight from the process of drawing the pattern-making draft, an example of which is shown in Figure 1.3. Draft is the appropriate mediator for the proposed method. Because, the three facts, (1) draft can be designed from arbitrary body and (2) It can be drawn easily and instantly (3) It involves the tailoring knowledge, led us to the new framework. From the given primary body sizes (PBSs), a clothing expert can construct the draft by drawing points or straight/curved lines step by step. For example, Figure 1.3 is drawn from six sizes listed in Table 1.1: the bust, the waist, the hip circumference, the waist back length, the bust point to bust point, and the neck point to breast point. We note that the draft gives one of the possible solutions which perfectly meet the given primary sizes requirement and supposedly meet other (non-primary) sizes satisfactorily. Since the draft is completely determined from the primary body sizes, we can abstract the construction process as a procedure $D(*)$ which takes an arbitrary body then generates the draft for it. We call that procedure the *parameterized draft*. We implement a computer module which performs the parameterized draft procedure. We instantly draw a lot of drafts using the parameterized draft module. The input parameters of the module are garment type and PBSs. The result shown in Figure 1.3 is D(A) for a particular body A, whose PBSs are given in Table 1.1.

The quality of the draft-space encoding, which finds out the barycentric coordinates of a panel vertex with respect to the draft, is essential for the proposed method to successfully work. There are several choices [82, 68, 87, 27, 35] which can be employed for the draft-space encoding. We compare these barycentric coordinates that will be introduced in Chapter 4.3. And then we find that the *mean value coordinates* is an excellent choice.

Although construction of the parameterized draft can not be considered as a garment design, it can serve as a mediator which relates a garment design to the body, which forms the main idea of this work. If a parameterized draft is available, we can decompose the original problem of grading to the following five steps. The first step is the *Source Draft Construction*. In this step, we create the draft $D(A)$ by giving the PBSs of the source body. The second step is the *Panel Positioning*. We position the panels of the design ,which is constructed for the body A, on the draft $D(A)$. The third step is the *Draft-space Encoding*. We express each vertex (v_i) of the panel as a weighted sum of the vertices constituting the draft $D(A)$. Finding the weights can be viewed as encoding the panel point in the form of coordinates in the $D(A)$-space. That is how this step is called the draft-space encoding. The next step is the *Target Draft Construction*. By supplying the PBSs of the target body B, the parameterized draft generates the draft $D(B)$ for it. The final step is the *Draft-space Decoding*. In this step, we decode the correspondence, which created in the Draft-space Encoding step, with respect to $D(B)$ which will produce the graded version of the original design. This step corresponds to warping panels based on D(A)-to-D(B) discrepancy.

1.2.2 Garment Creating from a Photograph

Creation of virtual garments is demanded from various applications. This dissertation notes that such demand arises also from the consumers at home who would like to graphically coordinate the clothes in her closet to her own avatar. For that purpose, the existing garments need to be converted to virtual gar-

Figure 1.4 The setup for the garment capture.

ments.

For the consumer, using the CAD programs for digitizing (i.e., identifying and creating the comprising cloth panels, positioning the panels around the body, defining the seams, extracting and mapping the textures, then draping on the avatar) her clothing collection is practically out of question. That job is difficult and cumbersome even for the clothing experts. This paper proposes a new method to instantly create the virtual garment from a single photograph of the existing garment put on to the mannequin, the setup of which is shown in Figure 1.4. We call the method *Garment Capture (GarmCap)* [39].

Millimeter-scale accuracy in the sewing pattern is not the quality this method promises. From insufficient information (thus easy to use), the method aims to create practically usable clothes that are just sufficient for the graphical outfit coordination. For the above purpose, the proposed method is very successful. As Figure 1.5 and other reported results demonstrate, the method creates prac-

(a) Input photograph (b) Result virtual garment

Figure 1.5 The proposed method GarmCap takes a photograph (a) and produces its 3D virtual garment (b).

tically usable clothes and works very robustly.

We attribute the above success to the following two novel approaches this paper takes: (1) silhouette-based and (2) pattern-based. The use of vision-based techniques is not new in the context of virtual garment creation. Instead of trying to analyze the interior of the foreground, however, this paper devises a garment creation algorithm that utilizes only the silhouette, which can be captured a lot more robustly. This robustness trades-off with the foreground details such as buttons or collars, but we give up them in this paper to obtain a practically usable technique.

Another bifurcation this paper makes is, instead of working directly in the 3D-shape space, it works in the 2D-pattern space. In fact, our method is based on the pattern drafting theory which is well established in the conventional pattern-making study [4]. The proposed method is different from sketch or photograph based *shape-in-3D-then-flatten* approaches in that it does not call for flattening of the 3D surfaces. Flattening of a *triangular mesh* cannot be done in the theoretical (differential-geometrical) sense thus inevitably introduces errors, which emerge as unnaturalness to keen human eyes. Our method's obviation of the flattening significantly contributes to producing more realistic results.

Since it is based on pattern drafting, our work is applicable only to the types of garments whose drafting is already acquired. In this work, the goal of which is to demonstrate the *potential* of the proposed approach, we limit the scope to simple casual designs (shirt, skirt, pants, and one-piece dress) shown in Figure 5.6.

1.3 Contribution

We suggested the framework which would easily perform grading based on the pattern-drafting theory. Also we proposed the garment capturing method which is the photograph-based virtual garment creation technique with the help of the pattern drafting theory. Particularly rewarding is that we introduce pattern drafting theory which make it possible to do resizing and creating panel on the 2D space. Proposed methods do not require pattern extracting step which brings on additional computations and distortions. Draft represents not only frontal garment design but also rear and laterals. Proposed draft-based approach can save time and memory. Nonetheless, we got the plausible results. The novel idea of utilizing pattern-drafting theory forms the main contribution of this work in the field of computer graphics and fashion.

1.4 Terminology

We present new grading and capturing frameworks in the clothing and computer graphics field. There are many terminologies of clothing fields in this paper. Now we introduce these terminologies and new notions.

- Pattern : Which is the template from the part of garment. It is composed of lines and points.
- Panel : A piece of cloth which is cut congruent to the pattern.
- Grading : The process which linearly expand or reduce the original pattern is designed to fit typical body size as shown in Figure 1.1.
- Draft : An early version of garment patterns. Figure 1.3 shows simple bodice draft.
- parameterized draft : The pattern is drafted according to PBSs.

- Primary body sizes (*PBSs*) : Which is set of each body size to create parameterized draft.
- Panel point (vertex) : The point (vertex) of panel.
- Draft point (vertex) : The point (vertex) of parameterized draft.

Chapter 2

Previous Work

Many researchers have investigated methods in order to show virtual garment in 3D computer animation and other applications. It represents both garment shape and properties of the fabric in computer graphics [79]. Garment shape is related to geometrical modeling and modification. Geometrical modeling is the process of making the garment in a virtual environment. Garment modification is the process which resize the garment. Properties of the fabric are involved in simulation and rendering. Simulation reproduce dynamic behaviors of cloth such as exterior force, interior energy [74, 7, 14, 81, 18], collision [13, 8, 30, 71] and hysteresis [57, 58]. Rendering [95, 6, 54, 86] and texture [1, 44, 25, 36] techniques are needed to implement realistic virtual garment.

This chapter surveys the various garment resizing [78, 76, 83, 15] and creating [75, 65, 12, 77] methods which are appropriate to the suggested research.

2.1 Garment Resizing

This section is divided into algorithms for garment grading and coordinates systems for draft-space encoding.

2.1.1 Algorithms for Garment Resizing

In the clothing field, computer cad system [52] which have been used for garment design and grading in order to dispose tedious process. In the computer graphics field, the study on the grading technique is in the early stage. Volino et al. [78] presented an interactive garment modeling framework in which the garment could be edited in 3D, then its constituent 2D patterns can be extracted. Umetani et al. [76] investigated a novel interactive tool in which the 3D garment and 2D patterns are coupled in such a way. Designers can interactively modify 2D/3D designs and immediately observe the results. When viewed from the clothing industry, both methods are revolutionary, since they allow clothing construction in 3D and produce the 2D patterns of the fitted garment. However, we do not categorize them as garment resizing techniques, as accommodating the body variations was not the main concern of those methods.

Wang et al. [83] provided a garment modeling scheme, called the automatic made-to-measure (AMM), which generates a garment mesh that fits to a given arbitrary body. Wang et al. [84] proposed a garment retargeting method which established the spatial relationship between the garment and the source body.

The original garment is then retargeted to the target body following the spatial relationship established above. This method produces fine results in the aspect of fitting body. However, since the garment generation algorithm is closely couple with the body shape, the result can have distortions when a loose garment is retargeted. Another automatic garment resizing method proposed by Meng et al. [55] solves the distortion problem of [84] by introducing a local geometry encoding technique. Recently, Brouet et al. [15] presented a garment transfer method performs garment grading by explicitly considering additional criteria such as the silhouette, fit and manufacturability.

In the goal, our work is same with the above methods; they develop methods that retarget a given garment design to fit the target body while preserving the original design. In the methodology, however, our work is different from the above methods; while the above methods make a direct retargeting of the garment in 3D with the subsequent pattern extraction process [66, 67], our method retargets each 2D panel to the graded version via the 2D pattern-making draft space, resulting in more utilization of the pattern-making expertise from the clothing field.

2.1.2 Methods for Draft-space Encoding

The essence of the draft-space encoding is expressing the position of each panel vertex as a weighted sum of the draft vertices. In this work, an underlying assumption is that, when grading a design, the weights should be preserved. A variety of such encoding schemes have been studied. One of the simplest approaches is triangular barycentric coordinates system (TBC) which encodes a position within a triangle in terms of the weighted sum of the three vertices. TBC has many desirable features including non-negativity, linear interpolation and smoothness. Furthermore it is easy to implement. Many researchers have utilized TBC and some attempted extension of it to fit for their own purposes. Hoppe et al. [33] developed a method which uses TBC to create correspondence between high and low resolution faces for mesh optimization. Warren developed TBC which can take arbitrary convex polygons [87] and arbitrary convex sets [88]. Meyer et al. [56] presented another generalization of TBC which can apply to irregular, convex n-sided polygons.

Derose et al. [23] presented a new form of dimensional coordinates. It is called the *Harmonic Coordinates* (HC), because it is produced as a solution of the Laplace equation. HC has attractive properties including interior locality and non-negativity. Therefore, it is advisable solution to make appropriate correspondence between the cage [1] and interior vertex of meshes. Joshi et al. [41] introduced HC to solve the problem of creating and controlling the volume deformation of character articulation. Jacobson et al. [37] developed a blending-based deformation technique, called the bounded biharmonic weights (BBW), in which the weights of the vertices are blended to minimize the Laplacian energy. BBW can support not only cages but also points and bones. BBW can be appropriate encoding method for handling exterior vertex. Lipman et al.[50] presented *Green Coordinate* which are motivated by Green's third in-

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[1] A geometrical structure with respect to which an arbitrary position around it is encoded

tegral identity. This coordinates system not only utilizes the vertices position, but reflects edges orientation in the polygon.

Floater [27] introduced a new coordinates system, called the *Mean Value Coordinates* (MVC), which was derived from the mean value theorem for harmonic functions. The mean value coordinates could encode a position with respect to an n-gon and it is smooth and easy to implement. Ju et al. [42] improved the applicability of MVC from closed 2D polygons to closed triangular meshes. Hormann et al. [35] demonstrated that MVC is well defined for arbitrary planar polygons. Langer et al. [47] improved MVC to be able to take 3D polyhedra. MVC was used many applications which are based on retargeting problem. The weights of MVC can have negative values when the n-gon is concave. Lipman et al. [49] introduced the positive mean value coordinates (PMVC) which guarantees to have positive weights everywhere including the interior or exterior of the cage. The key idea of PMVC originates from HC, therefore PMVC shows similar results with those of HC. GPU-based PMVC is developed by [23], which has been shown faster than HC. Among the above encoding methods, MVC and PMVC are the most relevant to our work. The details of those two methods will be introduced in Section 4.3.

2.2 Garment Modeling

In this section, we introduce algorithms for virtual garment creating from sketch, photographs and video stream. We also presents clothes classification method which have been investigated in computer vision field.

2.2.1 Garment Creating

Sketch-based method In the graphics field, there have been various studies for creating virtual garments. Turquin et al. [75] proposed a sketch-based framework, in which the user sketches the silhouette lines in 2D with respect to the body, which are then converted to the 3D garment. This framework used the distance between the 2D garment silhouette and the character model to estimate the variations of the distance between the garment mesh and the character in 3D. Decaudin et al. [22] proposed a more comprehensive technique that improved Turquin et al.'s work with the developability approximation and geometrical modeling of fabric folds. Since the output garment mesh is developable, it is easy to compute the corresponding 2D sewing patterns. The recent sketch-based method [63] is based on context-aware interpretation of the sketch strokes. The context-aware interpretation of garment sketches was used as constraint for creating believable garments. garment sketches We note that the above techniques are targeted to novel garment creation, not to capturing existing garments.

Marker based method Some researchers used implicit markers (i.e., printed patterns) in order to capture the 3D shape of the garment [73, 65, 89]. Tanie et al. [73] presented a method for capturing detailed human motion and garment mesh from a suit covered with the meshes which are created with retroreflective tape. In other to to increase the robustness, above method used various thresholds at each stage of reconstruction. Scholz et al. [65] used the garment on which a specialized color pattern is printed, which enabled reproduction of the 3D garment shape by establishing the correspondence among multi-view images. The system consists of eight cameras and two HMI lamps with soft-boxes. White et al. [89] used the color pattern of tessellated triangles to capture the *occluded part* as well as the folded geometry of the garment. We note that the above techniques are applicable to specially-created clothes but not to the clothes in the consumers' closet.

Marker free method A number of marker-free approaches have been also proposed for capturing garments from multi-view video capture [12, 77, 21, 69]. Bradley et al. [12] proposed a method that is based on the establishment of temporally coherent parameterization between the time-steps. Vlasic et al. [77] performed the skeletal pose estimation of the articulated figure, which was then used to estimate the mesh shape by processing the multi-view silhouettes. Aguiar et al. [21] took the approach of taking the full-body laser scan prior to the video-recording. Then, for each frame of the video, the method recovered the avatar pose and captured the surface details. Popa et al. [61] proposed a method to reintroduce high frequency folds, which tend to disappear in the video-based reconstruction of the garment. We note that the above multi-view techniques call for somewhat professional setup for the capture. Zhou et al. [97] presented a method that generates the garment from a single image. Since the method assume the garment is symmetric in front part and rear part, it is hard to generate realistic rear part of the garment. The result can be useful if the clothing expert applies some additional processing, but not quite sufficient for the graphical coordination of the garments.

2.2.2 Clothes Classification

In the computer vision field, the investigators have studied the classification of the garment from a photograph. Chen et al. [17] suggested a method which categorizes a garment and body into composite templates based on the sketches of the image. The method utilizes And/Or Graphs to account for the topological configurations. Berg et al. [10] proposed attribute classification technique from web images. The approach characterizes attributes according to types (color, texture, or shape) without hand labeled training data. Yang et al. [93] proposed a real-time clothing categories technique from surveillance videos. Bossard et al. [11] provided an upper body detectors which uses a multi-class learner based on an extended random forest. Dong et al. [24] utilize parselet, which is a set of basic clothes elements, to construct a deformable mixture parsing model. Manfredi et al. [53] introduced a general approach for color based retrieval and garment categorizations. Similar as our method, the approach performs segmentation with the help of mask. Liu et al. [51] suggested a weakly-supervised fashion parsing framework. The method uses an image-level color-category tags dataset as a traning set to assign both a color and a type of the garment. Yamaguchi et al. [91] proposed a clothing classifier which takes advantage of pose estimation [94] and superpixels [3] to analysis input image. For increasing overall accuracy, Yamaguchi et al. [92] developed above method [91] by using the retrieved images approach. Similar as And/Or Graph based method [17, 24], we utilize garment masks and a state machine to categorize a clothes of an input photograph.

Chapter 3

Background

In this chapter, we present the pattern-drafting theory which is the core of our research. We suggest guidelines on how to judge the quality of grading and capturing in the draft based method.

3.1 Introduction to the Pattern-drafting

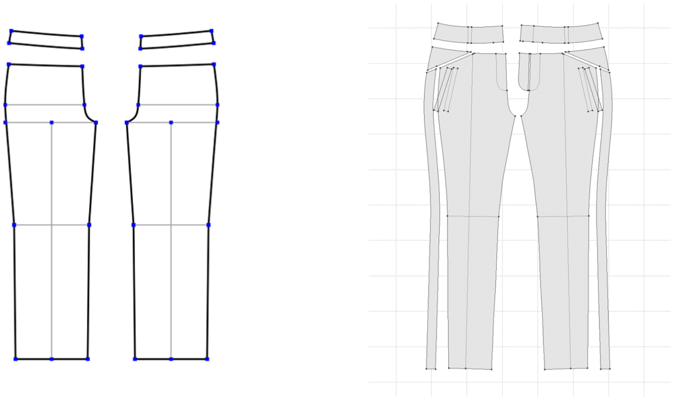
In the fashion field, draping and drafting have been used for the pattern-making [20, 16]. In the draping method, cloths are put on a dress form. And then it is constructed by cutting and pinning to specify garment design. To generate garment pattern, tailor draws line on the cloth and takes clothes to pieces. In general, muslin is utilized as draping cloth.

In drafting method, pattern maker imagines design as stereogram version and then draws planar figure. Drafting is known as the optimal solution to extract 2D drawing from the 3D garment design. In the fashion field, the pattern-drafting have been studied by the researchers, the tailors and the pattern makers. It calls for complex geometric knowledge. However, there exist pattern drawing methods based on the draft in the school, industry and institution. A draft is used as the starting point of many different garment patterns. Thus pattern maker tends to think that sketching pattern based on the drafting is more easy than draping.

Margin represents a gap between garment and body. It is important point for formative clothing. Margin is taken into account for disrobing, clothing and shape preserving. In order to grasp relation between garment and body, ergonomic and anatomic body segmentation are demanded [5]. For drawing draft, protrusion part on the body are projected to the front, side and rear directions. Dart presents non-linearity of the human body. For properly fitting, the lines and darts on the draft are drawn according to these items [26].

- Circumference line on the draft must be fit on the body without stretching and loosing.
- Bust, waist and hip circumference lines are aligned along the horizontal.
- There is proper gap between body and draft.
- The lines on the body should be stable.
- The draped draft has not fine wrinkle and stretch wrinkle.

In this work, the distinction between 'draft' and 'panel' is needed. Pattern-making is the process of drawing the pattern-making draft (sloper) as shown



(a) (b)

Figure 3.1 Draft (a) and panels (b). The black lines represent contour of draft and a gray line represents an auxiliary line for drawing draft. Each panels are described a gray polygon.

in Figure 3.1(a). The black lines represent contour of draft and a gray line represents an auxiliary line for drawing draft. In general, a design of draft is simple and it has not any ornament. Patterns are sketched from the draft. As shown in Figure 3.1(b), a panel is a piece of *cloth* which is created according to the contour of garment patterns. Each panels are described a gray polygon in Figure 3.1(b).

Another important requirement imposed for the pattern-making is that the result garment should fit to the body. For the fitting part, fashion field has been using the drafting from a long time ago [4]. Although in the details of each panel is varied from draft for design purpose, the primary body sizes such as the pants length and girth are kept the same.

In fact, pattern-drafting is a common element practiced from fashion departments. SADI, SMOD and DCC has established their own ways of draft-

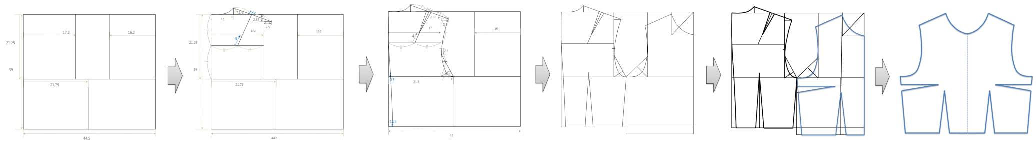


Figure 3.2 Intermediate steps for creating draft. The completed draft is drawn in blue.

ing the basic bodice, skirt, sleeve, pants, etc. In fact, drafting steps consist of the following types of operations which can be executed with no other input than the primary body sizes. For instance the bodice draft is designed from 6 primary body sizes: Waist Circumference, Bust Circumference, Waist-Back Length, Bust point-Bust point Length, Neck point to Breast point Length and Waist Front Length. Figure 3.2 shows a few intermediate steps until the final bodice draft is drawn.

- Drawing parallel/perpendicular lines
- Drawing curved line according to control points
- Dividing a line into two or three pieces of equal length
- Finding intersection point
- Symmetrizing points or lines
- Extending and reducing lines

If we decompose the drafting of Figure 3.2 into the above operations, it takes 73 operations, taking tens of minutes even to an experienced pattern-maker. But here we note that those operations are very basic to implement. For

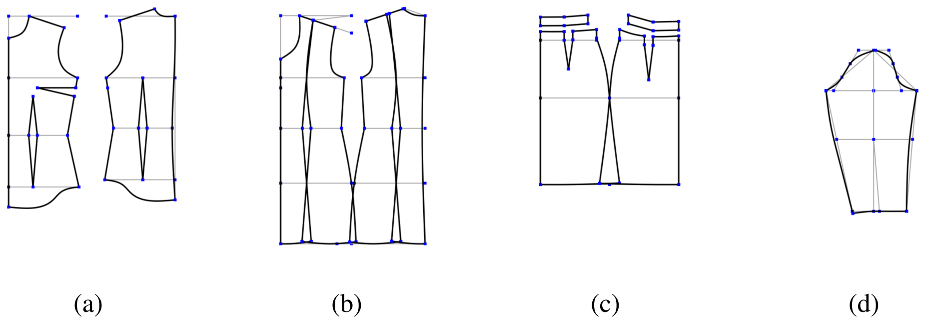

(a) (b) (c) (d)

Figure 3.3 Parameterized draft module can generate various type of drafts. (a): Basic Blouse, (b): Basic Onepiece, (c): High-Waist Skirt, (d): Sleeve .

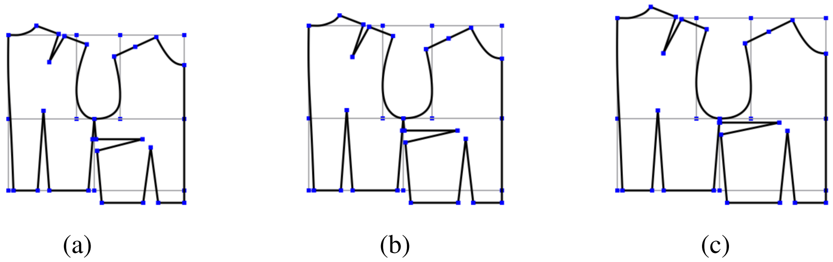

(a) (b) (c)

Figure 3.4 Parameterized draft module can generate various size of drafts. (a): 44-Size Bodice draft, (b): 66-Size Bodice draft, (c): 88-Size Bodice draft.

the application of the basic bodice drafting, for example, we can implement a computer module which takes. We call it *parameterized draft* module (PD-module), and call the application draft constructor.

Our parameterized draft module can create various drafts. Figure 3.3 shows basic blouse, basic one-piece, high waist skirt and sleeve draft which are generated by parameterized draft module. We can add a specific draft based on pattern-drafting books [29, 28, 48]. In the parameterized draft module, it is possible to create various size drafts by an adjustment of *PBS* parameters. Figure 3.4 presents 44, 66 and 88-size bodice drafts. The *PBS* parameters of these drafts are shown in Table 3.1.

PBS (unit:cm)	44	66	88
Bust Circumference	82.0	90.0	98.0
Waist Circumference	62.0	70.0	78.0
Hip Circumference	88.0	96.0	104.0
Waist Back Length	38.0	40.0	42.0
Bust Point to Bust point	16.4	17.6	18.8
Neck Point to Breast Point	24.4	25.6	26.8

Table 3.1 The *PBS* parameters

3.2 Judging the Quality in the Draft-based Method

Fitting The aim of garment grading is modifying the garment to fit the target body. In the other garment grading methods [84], [15], [55], measuring how much fitting is directly calculated by the distance between each vertex of garment mesh and each vertex of body mesh, therefore preserving the distance is important point of these grading method. In our method, we can generate parameterized draft which always fit to the target body. Therefore, each panel of garment would be graded in order to fit the target body, if encoding and decoding are processed according to proper coordinates system which keeps local position of vertex on the garment panel.

For the garment capturing, we find out primary body sizes from the input photograph. The fitting of garment is related to the size of panels. Our method generates garment panels from the draft which is drawn based on primary body sizes. The fitting quality is determined by how primary body sizes are exactly measured from the photograph.

Design Preserving design is another crucial property of garment grading, therefore fitted garment should be accorded with original garment design. But original garment design may be broken, since we try to fit the target body. The localization is necessary to preserve design, because the position of panel vertex must not be changed by modifying position of irrelevant draft vertex. We utilized mean value coordinates system [27], which to strengthen locality. According to our new scheme, each draft vertex has properly localized weights. Therefore, suggested framework is a reasonable method for maintaining garment shape.

Our garment capturing method utilized pattern-drafting theory for creating garment panels. We only describe the garment in our draft database. The overall design of generated panels is determined from garment type of source photograph. The primary body sizes can also represent details in garment design such as pants length, sleeve length and skirt width. A draft has front/side/rear design of garment panels. We can describe the design on the various side of the garment, even if our method uses a photograph which was taken in front side.

Chapter 4

Garment Resizing

This chapter presents our garment resizing method. With the parametrized draft module presented in Chapter 3, now we develop a novel grading scheme which we call the *draft-space warping* (DSW).

4.1 Problem Description

In the 3D based grading methods, retargeting is done by using optimization which is performed by keeping correspondence between position of garment vertex and position of body vertex [15]. These correspondence is represented offset vector or distance between a vertex of the garment mesh and vertices on the body surface mesh. Likewise, we suggest an approach for creating correspondence. Draft-space warping is performed on 2D, therefore the proposed approach is suitable for 2D garment panels. A garment consists of a number of panels $[p_1, p_2, \ldots, p_N]$ which are stitched together at the sides. Each panel

p_i is a cloth piece, but in terms of data, a panel is composed by a collection of points and lines. Grading can be thought of as the following retargeting problem.

Input to the DSW is the source panels $\Phi(A) = [p_1, p_2, \ldots, p_N]$ (i.e., the design constructed for the standard body A positioned in reference to the source draft $D(A)$. The position of the panels $p_1, p_2, \ldots, p_N$ with respect to the draft is important, because the essence of DSW is to keep the $D(A)$-relative positions invariant during the $D(A)$-to-$D(B)$ space warp. We assume that the design $\Phi(A)$ is drawn in reference to the draft $D(A)$ (the *panel-draft coupling assumption*), in which case the panels are already positioned on that draft.[1]

Figure 4.1 shows conception of problem description. In Figure 4.1, left side figures describe source (original) body/draft/panels and right side figures represent target (resized) body/draft/panels. DSW-grading utilizes the draft as mediator to resize the garment panels. The draft is generated from the primary body sizes using PD-module. There is a correlation among the body, the draft and the garment panels.

4.2 Overview

We present framework of Draft-space warping which is composed to 5 substeps as shown in Figure 4.2. Inputs of this process are source panels (light

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[1] When $\Phi(A)$ is not created in reference to the draft $D(A)$, then positioning of the panels with respect to that draft can be a problem. Since it is a common industry practice to perform panel creation in reference to a draft, making the panel-draft coupling assumption does not significantly limit the applicability of the proposed grading method.

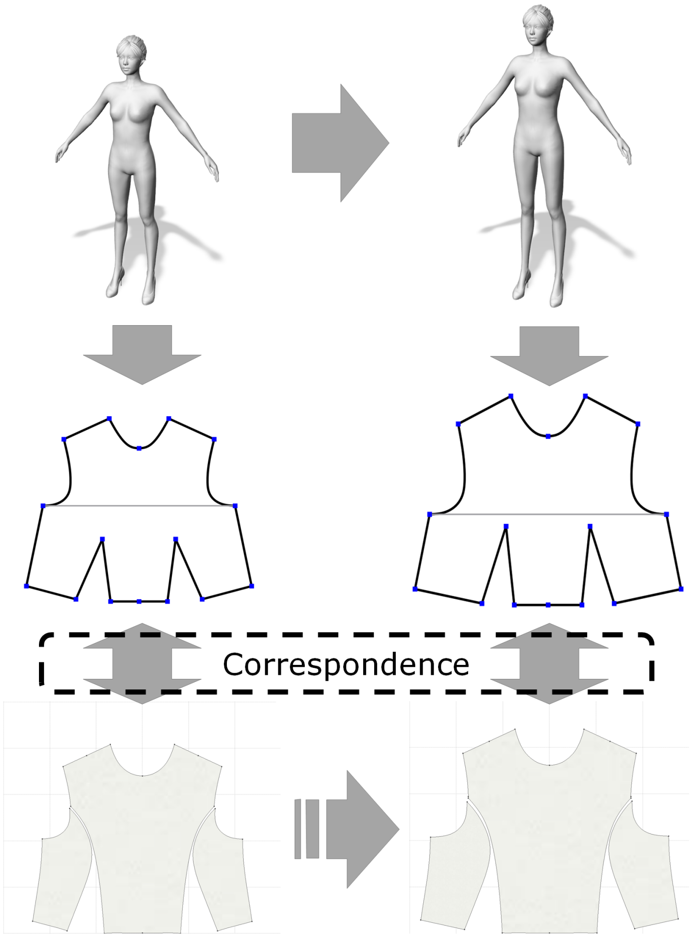

Figure 4.1 Problem description. Left Top: source body, Left Middle: source draft, Left Bottom: source (original) panels, Right Top: target body, Right Middle: target draft, Right Bottom: target (graded) panels.

gray) which are designed by professional designer to fit source body, outputs are graded panels (dark gray) which suppose to fit target body. As discussed in Chapter 3, source panels are closely related to the draft which is automatically generated by PD-module according to the primary body sizes. Draft-space encoding and decoding are represented by a linear combination of the draft vertices. For these reasons, performing draft space warping can be simple, fast

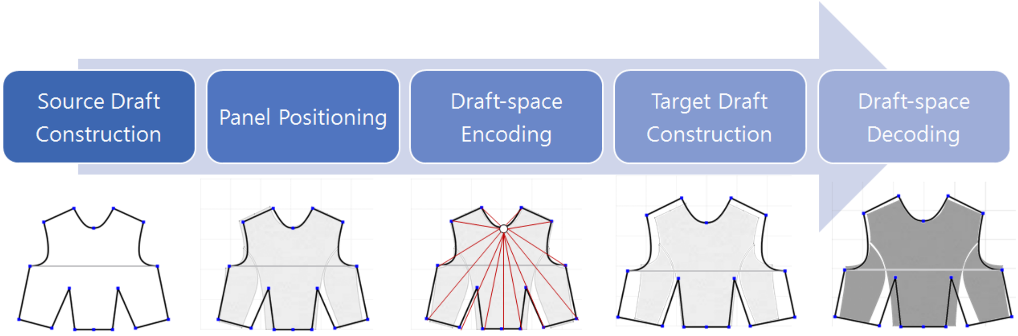

Figure 4.2 Framework of DSW-grading. Draft-space warping is composed to 5 sub-steps: Source Draft Construction, Panel Positioning, Draft-space Encoding, Target Draft Construction, Draft-space Decoding. The draft is drawn on lines and panels are described by polygons. In the Draft-space Encoding step, the vertex (circle) is represented weighted sum of draft vertices (red line).

and automatic.

Source Draft Construction In this step, we construct source drafts ($D(A)$) as shown in first figure in Figure 4.2. The shape of $D(A)$ is determined from the *PBSs* of the source body (A) and garment types[2]. Drawing draft can be automatically done by using parametrized draft module. We do not have to perform complex operation, just determine garment type and *PBSs*.

Panel Positioning In this step, we arrange the source panels on the draft. Since the essence of DSW is to keep the panel-to-draft relative position invariant during the source-to-target transformation, the position of the panels with respect to the draft is important. In the fashion field, panels were moved by expert tailors so that reference lines/points in the panels coincide with those

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[2] Garment types : bodice, jacket, skirt, dress, pants, sleeve, etc

of draft. In this step, first, we classify the panels according to garment type. After that, we make the group from classified panels. Panels were moved to match the center of AABB (Axis Aligned Bounding Box) of a garment panel group and that of a draft.

Draft-space Encoding We make correspondence between source draft vertices (v_i) and each panel vertex (P_j). We call this process *draft-space encoding*. This step encodes the position of each panel vertex P_j with respect to $D(A)$. More specifically, we encode P_j by expressing it as a linear combination of the draft vertices using barycentric coordinates system.

$$P_j = \sum_{i=1}^{M} \lambda_i v_i. \tag{4.1}$$

As a consequence of above linear combination equation, we find out the weight vector array $(\lambda_1, \ldots, \lambda_M)$ for each panel vertex P_j. Because most drafts are represented by polygon, the linear combination is not unique. Thus, encoding may not be well-defined. Fortunately, there have already been pioneering studies which can be applied to our draft-space encoding. The details of the draft-space encoding are postponed to Section 4.3.

Target Draft Construction In this step, we generate the target draft $D(B)$ according to *PBSs* of target body (B), which is a trivial task when the parametrized draft module is available. Let $\hat{v}_i$ $(i = 1, \ldots, M)$ be the vertices of the target draft $D(B)$. Target draft is designed to fit the target body, so the position of vertex

($\hat{v}_i$) differs from position of source draft vertex.

Draft-space Decoding This step finds out the new vertex position $\hat{P}_j$ of the graded panel $\hat{p}_k$. With the assumption that the relative position of each panel vertex P_j is invariant during the $D(A)$-to-$D(B)$ space warp, we compute $\hat{P}_j$ with

$$\hat{P}_j = \sum_{i=1}^{M} \lambda_i \hat{v}_i. \tag{4.2}$$

Here the weights λ_i are the ones which were calculated in the draft-space encoding step. The last figure in Figure 4.2 shows graded panels (dark gray) which are the outputs of our framework.

The reason why the above simple encoding and decoding operation can perform the grading task can be attributed to the fact that the target draft already contains all the necessary resizing to cover the target body.

4.3 Draft-Space Encoding and Decoding

In this section, we present the draft-space encoding and decoding method which is an important component in the development of the proposed grading framework DSW. The result of grading will depend on (1) the method used for the draft-space encoding, and (2) the implementation of the parameterized draft module. As the parameterized draft module is a simple adoption of clothing expertise, the only engineering part whose quality will affect the grading quality the draft-space encoding and decoding. We focus of the draft space encod-

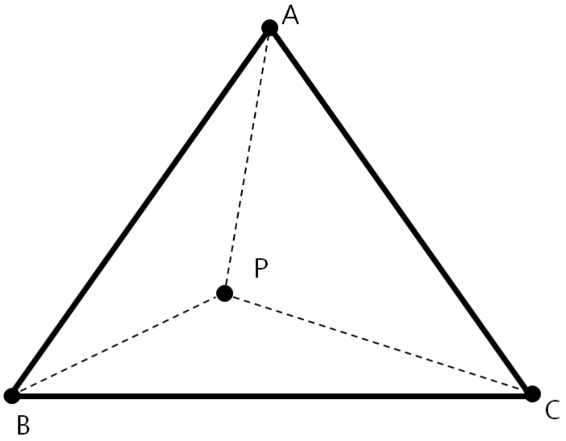


Figure 4.3 Triangular Barycentric Coordinates. A position P is represented as a linear combination of the triangle vertices A, B, and C

ing and decoding. This section reviews previously proposed candidates for the draft-space encoding, then concludes with an encoding method which best suits for the current purpose.

4.3.1 Triangular Barycentric Coordinates

One of the most popular methods is the *Triangular Barycentric Coordinates* (TBC) which have been used to represent a local position within a triangle [88]. In the TBC, referring to Figure 4.3, a position P is represented as a linear combination of the triangle vertices A, B, and C

$$P = \alpha A + \beta B + \gamma C, \tag{4.3}$$

with

$$\alpha + \beta + \gamma = 1 \tag{4.4}$$

where α, β, and γ are the weights of the linear combination. Those weights are in fact proportional to the areas of the triangles *PBC*, *PCA*, and *PAB*, respectively. Triangular barycentric coordinates is easy to implement and takes a low computational cost.

Unfortunately, a typical situation the draft-space encoding has to handle is the one shown in Figure 4.4, which is far from a triangle. It can have more than three vertices. Moreover, the polygon does not need to be convex due to properties of the garment. If we are to use the triangular barycentric coordinates in this situation, (1) first we have to triangulate the draft, then (2) record the triangle that encloses the encoded position as well as the barycentric coordinates with that triangle.

However, triangularization brings another computational cost and accumulation error. Therefore, we have to take other coordinates system can be applied to *n*-gon.

4.3.2 Coordinates Systems for Polygon

Several techniques have been proposed which can directly encode a position with respect to a general *n*-gon without going through triangulation [82, 68, 87, 27, 35].

Suppose that v_1, $\cdots$, v_N are vertices on the plane (in the counter-clockwise

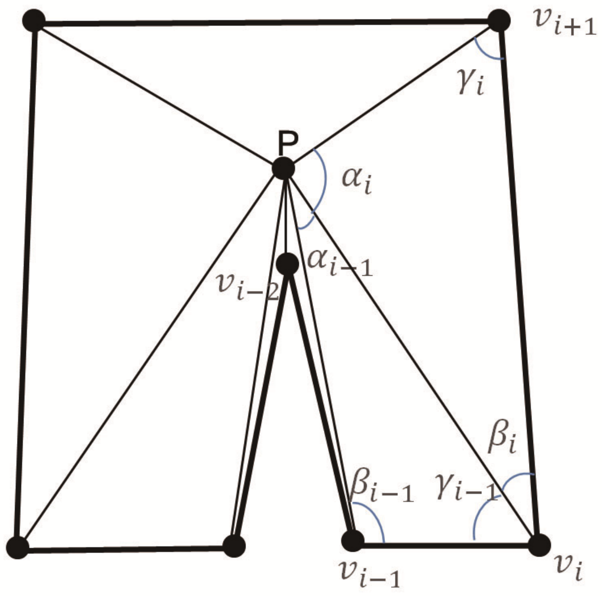


Figure 4.4 Coordinates system for polygon. P is expressed as a linear combination of the draft vertices(v_1, $\cdots$, v_N).

order), and we want to encode a position P on that plane as a linear combination of those vertices (Figure 4.4)

$$P = \sum_{i=1}^{N} \lambda_i v_i \tag{4.5}$$

with

$$\sum_{i=1}^{N} \lambda_i = 1 \tag{4.6}$$

λ_i presents each weight of each vertex(v_i) in linear combination. The sum of λ must be 1 for the purpose of shape conservation.

Wachspress Coordinates Wachspress [82] determines the weight λ_i for the vertex v_i by referring to the areas of the triangles.

$$\lambda_i = \frac{w_i}{\sum_{k=1}^{N} w_k}, \tag{4.7}$$

where

$$w_i = \frac{A(v_{i-1}, v_i, v_{i+1})}{A(v_{i-1}, v_i, P) A(v_i, v_{i+1}, P)} = \frac{\cot \gamma_{i-1} + \cot \beta_i}{||v_i - P||^2} \tag{4.8}$$

The weighting scheme satisfies the basic requirement of the encoding; When P is close to the vertex v_i, λ_i is close to one; If P happens to be on v_i itself, $\lambda_i = 1$. However, when the polygon is concave as shown in Figure 4.4, λ_i can have a negative value.

Green Coordinates Lipman et al.[50] introduced *Green Coordinate* which is motivated from Green's third integral identity and respect both the vertices position and edges orientation of the polygon.

$$P = \sum_{i=1}^{N} \phi_i v_i + \sum_{j=1}^{N} \psi_j n_j \tag{4.9}$$

$$\phi_i = \int_{\xi \in N(v_i)} \Gamma_i(\xi) \frac{\delta G(\xi, v_i)}{\delta n(\xi)} d\sigma_\xi, \quad i \in I_{vertex} \tag{4.10}$$

$$\psi_i = -\int_{\xi \in t_j} \delta G(\xi, v_i) d\sigma_\xi, \quad j \in I_{face} \tag{4.11}$$

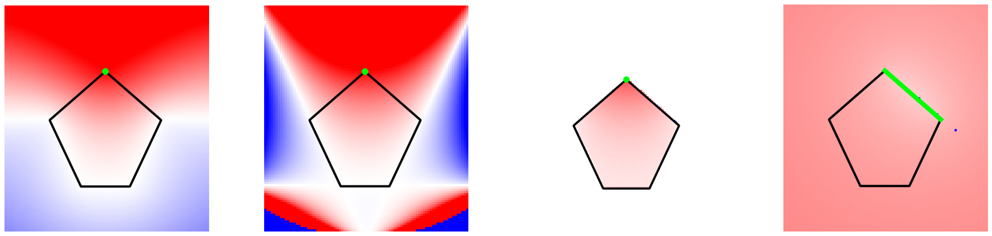
$$G(\xi, v_i) = \begin{cases} \frac{1}{(2-d)\omega_d} \|\xi - v_i\|^{2-d} & d \geq 3 \\ \frac{1}{2\pi} \log \|\xi - v_i\| & d = 2 \end{cases} \tag{4.12}$$

Denote by $N(v_i)$ the union of all faces in the 1-ring neighborhood of vertex v_i. t_j is the the face. ω_d is the area of a unit sphere. $G(\ ,\ )$ is the fundamental solution of the Laplace equation in R^d. Without additional treatment, the coordinates ϕ_i has discontinuities along the edges.

Mean Value Coordinates Floter [27] introduced a weighting scheme, so-called the *Mean Value Coordinates* (*MVC*)

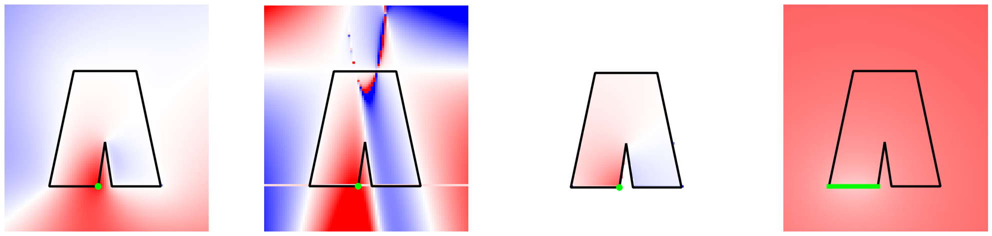
$$\lambda_i = \frac{w_i}{\sum_{k=1}^{N} w_k}, \quad w_i = \frac{\tan(\alpha_{i-1}/2) + \tan(\alpha_i/2)}{\|v_i - P\|^2} \tag{4.13}$$

where α_i is the angle made by v_i's and/or P as shown in Figure 4.4. The method is named that way because the weights are determined by applying the mean value theorem to the harmonic functions. When a panel point(P) is located in the draft, both $\alpha_i/2$ and $\alpha_{i-1}/2$ are less than 90 degrees. In this case, the weight w_i is positive. In addition to giving the positive weights, the encoding quality of MVC is superior to other methods as reported in [42], [35], [47]. With the MVC, the weights vary continuously across the interior and exterior of the draft.



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

Figure 4.5 Weight of the vertex/edge in encoding an arbitrary point in case of *convex polygon*. (a): Mean Value Coordinate, (B): Wachspress Coordinate, (C)/(D): Green Coordinate. Red/White/Blue indicates that v has a positive/zero/negative weight for that position, respectively.



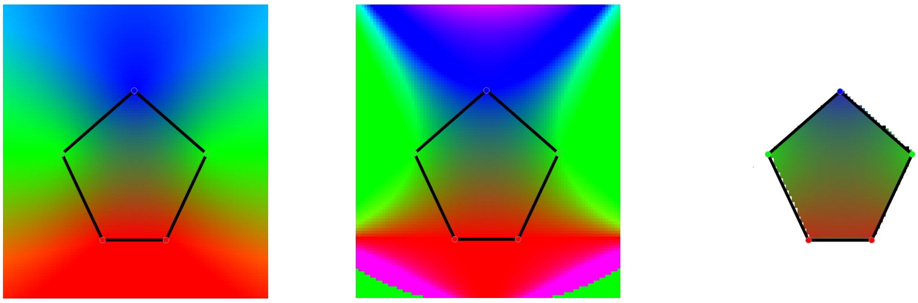
(a) (b) (c) (d)

Figure 4.6 Weight of the vertex/edge in encoding an arbitrary point in case of *concave polygon*. (a): Mean Value Coordinates, (B): Wachspress Coordinates, (C)/(D): Green Coordinates. Red/White/Blue indicates that v has a positive/zero/negative weight for that position, respectively.

4.3.3 Comparison

In the following, we compare the quality of the weight calculation in different methods.

Weight distribution Figure 4.5 shows weight distribution of each method in case of *convex polygon*. Red/White/Blue indicates that v has a positive/zero/negative weight for that position, respectively. In the Figure 4.5(a), we notice the mean



(a) (b) (c)

Figure 4.7 Color blending in case of *convex polygon*. (a): Mean Value Coordinates, (B): Wachspress Coordinates, (C): Green Coordinates.

value coordinates do not involve any jump discontinuity. Wachspress coordinates and green coordinates are smooth in the interior of the polygon. However, wachspress coordinates has jump discontinuities at the opposite side in exterior. Without additional treatment, green coordinates only handles inside part of the polygon.

The draft vertex has negative weight when the point is located on the invisible region. These negative weights may bring unexpected side effect. We suggested *omitted mean value coordinates* for achieving the non-negativity [40]. But, the weights could non-continuously across the draft in the omitted mean value coordinates. We notice that the negativity in MVC does not work harmfully for the draft-space encoding, since the draft and panels are symmetric.

Figure 4.6 shows weight distribution of each method in case of *concave polygon*. The weight has negative value(blue) when v is invisible. In the case of Wachspress, there are some discontinuities inside of the polygon.

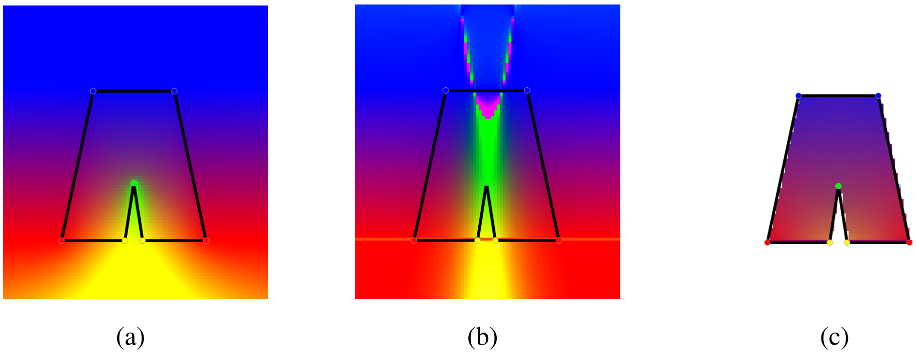
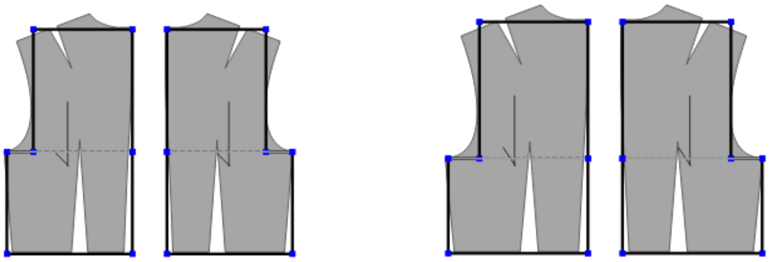

(a) (b) (c)

Figure 4.8 Color blending in case of *convex polygon*. (a): Mean Value Coordinates, (B): Wachspress Coordinates, (C): Green Coordinates.

Color Blending For comparing sensitivity and locality of the coordinates system, we performed color blending test. Color blending mixes source color of vertices of the polygon by using the coordinates system. In The results of color blending smooth inside of the convex polygon shown in as Figure 4.7. In case of mean value coordinates and green coordinates, the results of color blending smooth inside of the concave polygon that is similar as the result of convex polygon. However, we notice that the result of wachpress coordinates has discontinuity inside part of the polygon shown as Figure 4.8(b).

Continuity and simplicity are significant properties of correspondence function. Continuity is relevant to the quality of the result. Complex correspondence function causes performance degradation. Therefore, mean value coordinates could be a suitable approach for the encoding method of draft-space warping.



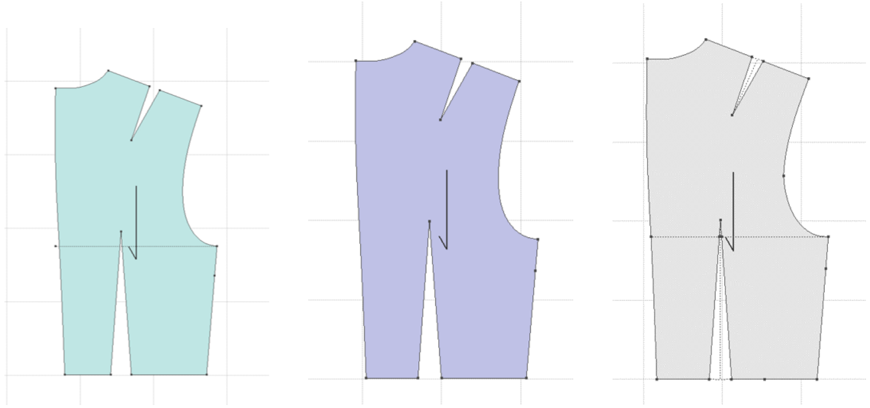
(a) (b)

Figure 4.9 DSW with base draft. The draft is represented by straight lines, the panel is expressed as gray polygon. (a): 55 size, (b): 77 size

4.4 Linear Grading using Base Draft

The quality of grading is associate with the proximity between the contour shape of input garment panels and that of parametrized draft. If we can not find suitable draft for the input garment panels, draft space warping method would utilize a base draft. Figure 4.9 shows a base draft for bodice. The base draft is the preliminary version of a particular draft. Since drawing draft is started from the base draft, *DSW* with the base draft can cover various input garments. A base draft is commonly determined a few parameters which are less than general draft, for example, a base draft of blouse use waist-back length, bust circumstance and waist circumstance for the input parameters.

Figure 4.10 shows original panels, graded panels which were generated from *DSW* with a base draft and a correlated draft. We notice that discrepancies between width and height of graded panels are under 5*mm*. *DSW* with base draft does not perform proper grading about some parts which are defined from specific parameters such as armhole, neckline and dart.According



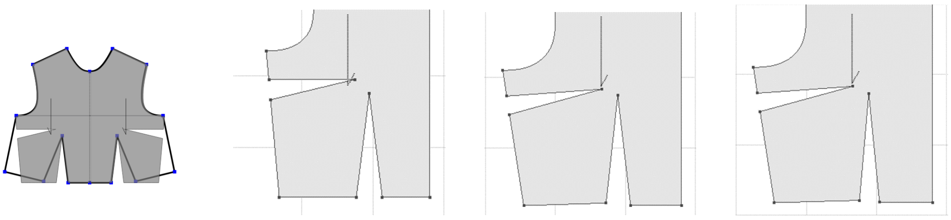
(a) (b) (c)

Figure 4.10 Compare the graded panel of our method with that of manual grading (a): Original panel (55 size), (b): *DSW* with a base draft (77 size), (c): *DSW* with a correlated draft (77 size)

to experiments, it seems the quality of the *DSW* with the base draft is similar to that of the linear grading. But, our method performs the grading work easily and instantly.

4.5 Dart Compensation

Since our method based on the draft, the correlation with a draft and panels is significant. The graded garment is not well fitted for target body unless there is the proper correlation between a draft and panels. Darts are folded wedges of fabric which are sewn to provide shape to clothes. A dart consists of an apex and two legs. The dart legs are stitched to represent a shallow cone which make convex/concave shape from flat fabric. Darts are utilized to fit the outline of the body in drafting.



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

Figure 4.11 DSW with dart compensation. The draft is represented by straight lines, the panel is expressed as gray polygon. (a): experiment environment, (b): source panel, (c): graded panel without dart compensation, (d): graded panel with dart compensation

We can solve above unfitting problem by increasing/reducing width between dart legs. We call this approach as *dart compensation*.

$$D_{new} = D_{old} + (m + C_{body} - C_{garment})/N_{dart} \tag{4.14}$$

Equation 4.14 shows how to calculate proper dart width (D_{new}). The symbol D_{old} presents dart width after our DSW-grading. The symbol m represents margin which makes proper gap between body and garment. In general, it is about $3cm$. The symbol C_{body} and $C_{garment}$ are PBSs of body and garment, especially horizontal line such as waist, bust and hip circumference. The symbol N_{dart} is a number of darts on the circumference line.

Figure 4.11 shows an example of dart compensation. There is not close correlation between a bodice draft and bodice panels around waist line in Figure 4.11(a). Figure 4.11(b), 4.11(c), 4.11(d) presents an enlarged image of source panel, graded panel without dart compensation and graded panel with dart compensation, respectively. In Table 4.1, the margin between waist cir-

(unit:*cm*)	Source	DSW without DA	DSW with DA
WC (garment)	68.00	75.43	77.99
WC (body)	65.00	75.00	75.00
Margin	3.00	0.43	2.99

Table 4.1 Measurement of waist circumference (WC) in Figure 4.11. The source and graded waist circumference of body were based on the size 55 and 77, respectively.

cumference of body and garment is $3cm$ in case of source. The margin is reduced to $0.43cm$ in Figure 4.11(c). When the garment is *DSW* with dart compensation, the garment now has a proper margin. Figure 4.11(d) shows that the waist dart narrows to increase waist circumference of garment. Dart compensation may cause unexpected distortion in the garment. But we can optionally use it for fitting to the contour of the body.

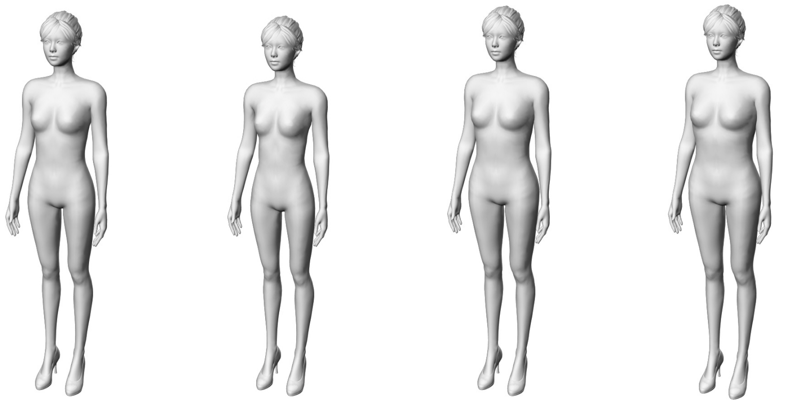
(a) (b)

Figure 4.12 Source dress. (a) panels, (b) draping snapshot.

4.6 Results

All demonstrations were performed on an Intel Core i7 3.20GHz CPU with a NVIDIA Geforce GTX570 GPU. To evaluate our method, we execute the PBSs analysis, the silhouette analysis, the garment strain analysis and the air-gap analysis for the simple one-piece as shown in 4.12. An one-piece consist of front/rear bodice, skirt and sleeve panels. We used a physically-based clothing simulator [14, 81, 18] and renderer [6] for the analyses.

For the above dress, running the whole DSW-grading algorithm including the draft-space encoding, target draft generation, and draft-space decoding took less than one millisecond. In case of manual grading, these works took about a hour per each dress. Therefore, we will not give any further time analysis for this work. Figure 4.13 shows the source body and three target bodies used for the experiments. The source body was designed based on the size 55 which



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

Figure 4.13 The source and three target bodies. (a): source body, (b): target 1 body, (c): target 2 body, (d): target 3 body.

PBS (unit:*cm*)	Source (55)	Target 1 (44)	Target 2 (66)	Target 3 (77)
Bust Circumference	85.0	80.0	90.0	95.0
Waist Circumference	65.0	60.0	70.0	75.0
Hip Circumference	90.0	85.0	95.0	100.0
Waist Back Length	39.0	38.4	39.6	40.2
Bust Point to Bust point	17.0	16.4	17.6	18.2
Neck Point to Breast Point	24.0	23.2	24.8	25.6
Skirt Length	55.3	53.4	57.2	59.1
Hip Length	19.0	18.4	19.6	20.2
Height	171.0	169.5	172.5	174.0
Front Armhole Circumference	20.2	19.6	20.8	21.4
Rear Armhole Circumference	21.4	20.8	22.0	22.6
Sleeve Length	57.0	56.4	57.6	58.2
Wrist Circumference	20.0	19.4	20.6	21.2

Table 4.2 The primary body sizes for the source and target bodies. The source PBSs was based on the size 55 which is a standard woman size. The target PBSs are referenced on size 44, 66 and 77, respectively.

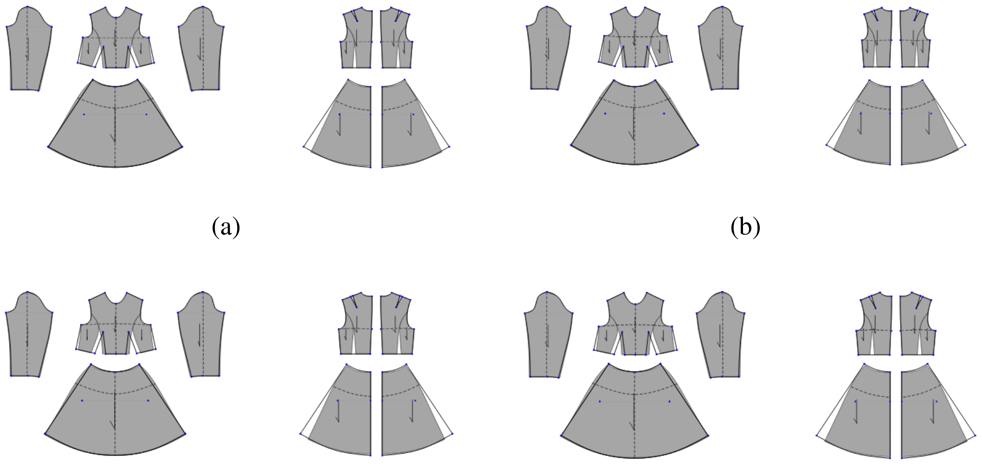
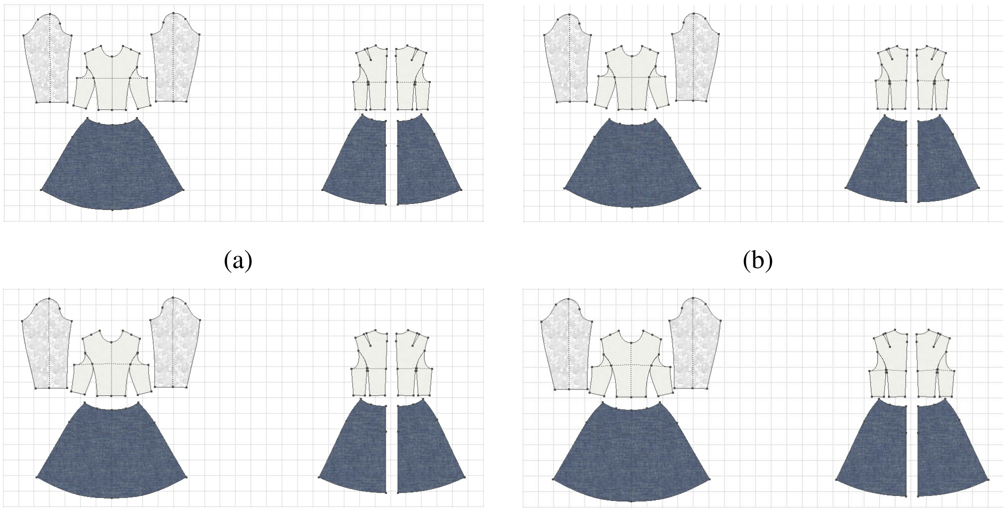

(a) (b)
(c) (d)

Figure 4.14 The source/target panels and drafts. Drafts and Panels are represented with black lines and gray polygons, respectively. Panels are presented (a): source, (b): target 1, (c): target 2, (d): target 3. The parametrized draft module generates source draft and target drafts for the each body.

is a standard woman body size. The size of target bodies are size 44, 66 and 77, respectively. The PBSs of those bodies are summarized in Table 4.2.

4.6.1 Generation of Target Drafts

Figure 4.14 presents the drafts which were generated by the parameterized draft module for the source and target bodies and the dress panels which are designed based on the source draft. We choose basic one-piece type as input of garment type of parameterized draft module. Table 4.2 describes specific PBSs which were used the PBSs as input parameter of parameterized draft module. Clothing experts judged that these drafts were successfully implemented based on the conventional drafting theory.



(a) (b)

(c) (d)

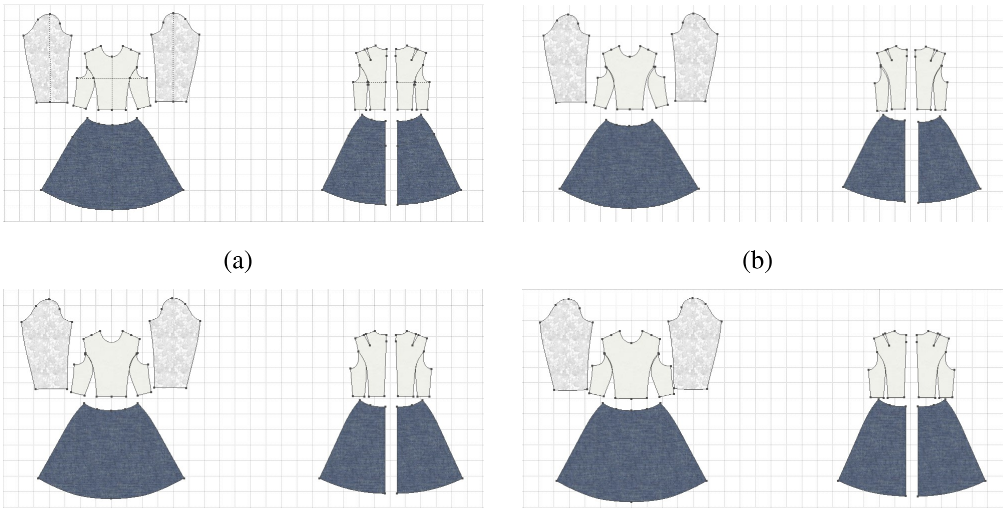
Figure 4.15 The garment panels of source dress and three DSW-graded dresses. (a): source panels, (b): DSW-graded panels for target 1, (c):DSW-graded panels for target 2, (d): DSW-graded panels for target 3.

4.6.2 Generation of Panels

Figure 4.15 shows the results of running the DSW-grading for Targets 1-3, respectively. Figure 4.16 presents the results of the manual grading for Targets 1-3, respectively. the manual grading is linear grading followed by hand adjustments and it took about an hour. Viewed in that scale, no particular difference is noticeable.

4.6.3 Primary Body Sizes Analysis

For quantitative evaluation, we measured PBSs on the graded garment panels. Table 4.3 shows the PBSs and discrepancies of each graded panels. The number in the parenthesis means the discrepancy between PBSs on the Table 4.1



(a)

(b)

(c)

(d)

Figure 4.16 The garment panels of source dress and three manually graded panels. (a): source panels, (b): manually graded panels for target 1, (c):manually graded panels for target 2, (d): manually graded panels for target 3

PBS (unit:*cm*)	Source (55)	Target 1 (44)		Target 2 (66)		Target 3 (77)	
		DSW	Manual	DSW	Manual	DSW	Manual
Bust Circumference	87.1(2.1)	82.2(2.2)	82.4(2.4)	92.1(2.1)	92.5(2.5)	97.2(2.2)	98.0(3.0)
Waist Circumference	67.0(2.0)	62.5(2.5)	61.9(1.9)	70.9(0.9)	67.0(2.0)	74.8(0.0)	77.4(2.4)
Waist Back Length	39.0(0.0)	38.4(0.0)	38.4(0.0)	39.6(0.0)	39.6(0.0)	40.2(0.0)	40.3(0.0)
Skirt Length	55.0(0.4)	53.0(0.4)	53.1(0.3)	56.9(0.4)	56.9(0.4)	58.8(0.0)	58.8(0.0)
Armhole Circumference	44.5(2.9)	43.4(3.0)	42.3(1.9)	45.7(2.9)	46.6(3.8)	47.0(0.0)	48.8(4.8)
Sleeve Length	57.0(0.0)	56.4(0.0)	56.4(0.0)	57.6(0.0)	57.6(0.0)	58.2(0.0)	58.8(0.6)
Wrist Circumference	20.0(0.0)	19.5(0.1)	19.3(0.1)	20.5(0.1)	20.6(0.0)	21.0(0.2)	21.3(0.1)

Table 4.3 The primary body sizes for the source and target dresses. We measured PBSs on the graded garment panels. The figure in the parenthesis means the discrepancy between PBSs on the Table 4.1 and PBSs on this table.

and PBSs on this table. All discrepancies have the absolute values. Figure 4.17 presents cumulative discrepancies of each target. In the case of DSW-grading, the discrepancies around waist is much more different from in the case of source than the discrepancies in manual grading. However, the difference be-

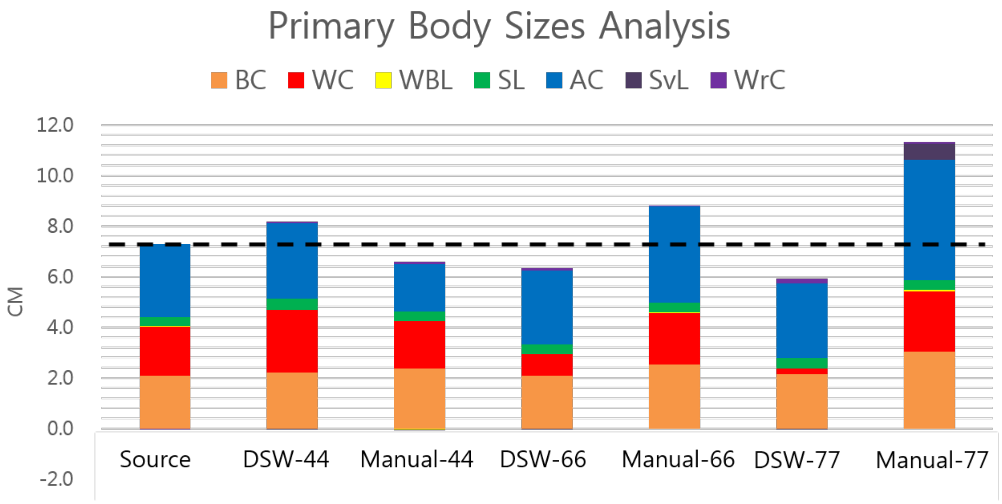


Figure 4.17 Primary body sizes analysis chart. Each bar graph describes cumulative discrepancies of each garment. BC, WC, WBL, SL, AC, SvL and WrC are abbreviations for bust circumference, waist circumference, waist back length, skirt length, armhole circumference, sleeve length and wrist circumference, respectively. The dashed line represents the value of cumulative discrepancy in source.

tween the cumulative discrepancy between source and DSW-grading are less than $2cm$. It is less than the difference between source and manual grading.

4.6.4 Silhouette Analysis

Figure 4.18, Figure 4.19 and Figure 4.20 show snapshots taken during the physically-based simulation of ungraded, DSW-graded and manually-graded versions, respectively. The results of ungraded show that each garment did not fit to each Target, it were too loose (Figure 4.18(b)) or tight (Figure 4.18(c) and Figure 4.18(d)). These mismatches are hard to recognize. Otherwise, the results of DSW-graded and manually-graded show that the garments well fitted

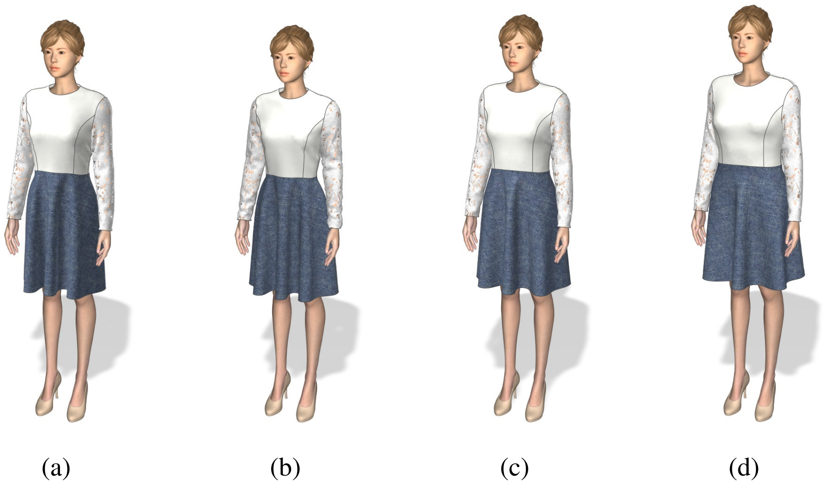

(a) (b) (c) (d)

Figure 4.18 The source dress and three ungraded dresses. We draped source garment in the source and target bodies. (a): Source, (b): Target 1, (c): Target 2, (d): Target 3

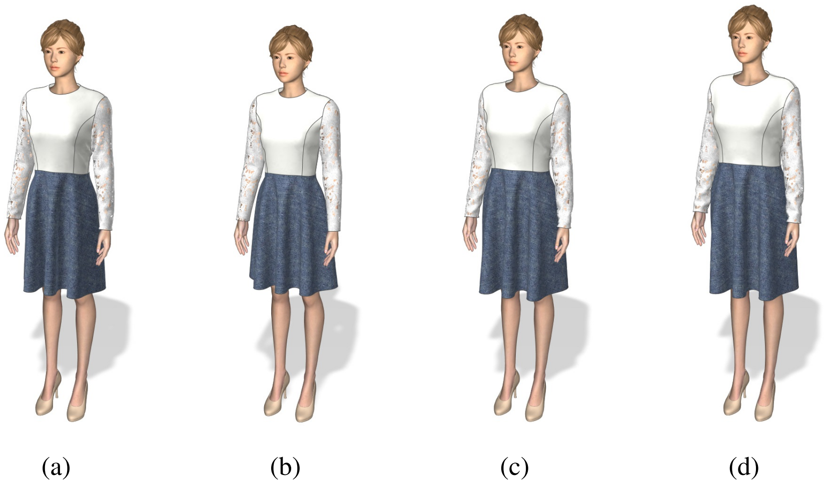

(a) (b) (c) (d)

Figure 4.19 The draping snapshot of source dress and three DSW-graded dresses. We draped DSW-graded garment in the source and target bodies. (a): source, (b): target 1, (c): target 2, (d): target 3.

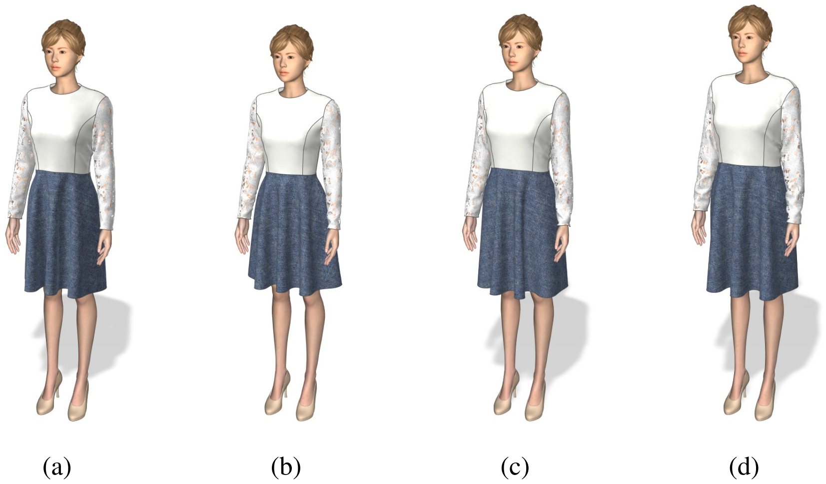
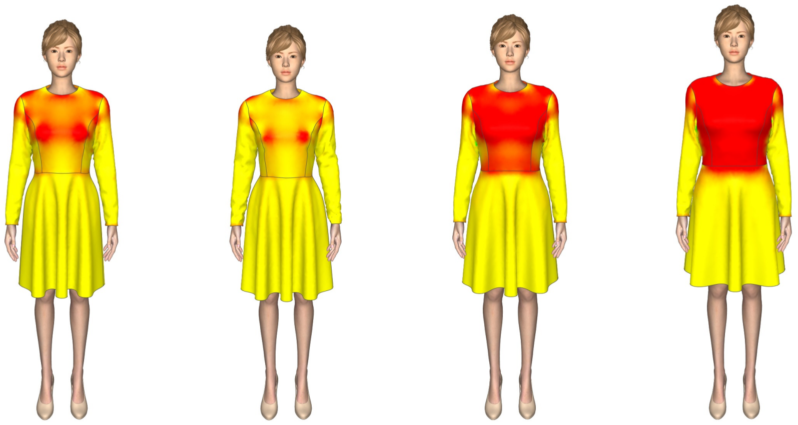


Figure 4.20 The source dress and three Manually graded dresses. We draped Manually graded garment in the source and target bodies. (a): Source, (b): Target 1, (c): Target 2, (d): Target 3

Targets as shown in Figure 4.19 and 4.20. The results of DSW-graded is almost indistinguishable from those of manually-graded. We also note that the silhouette of the source design is kept quite well in the graded results.

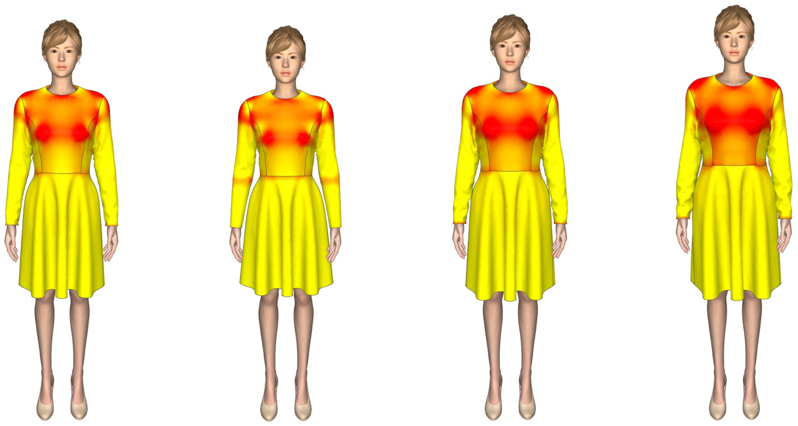
4.6.5 Strain Analysis

During the physically-based clothing simulation, the simulator could calculate the cloth strain value distribution on the garment to further analyze the fitting mismatches. Figure 4.21, 4.22 and 4.23 show the strain distribution in the ungraded, DSW-graded, manually-graded versions, respectively. The highest and lowest strain energy were represented to red and yellow. In the ungraded version, the strain energies in target 1 is low around bodice, but the strain energies in target 2 and 3 is high around bodice. It differs from the strain distribution of



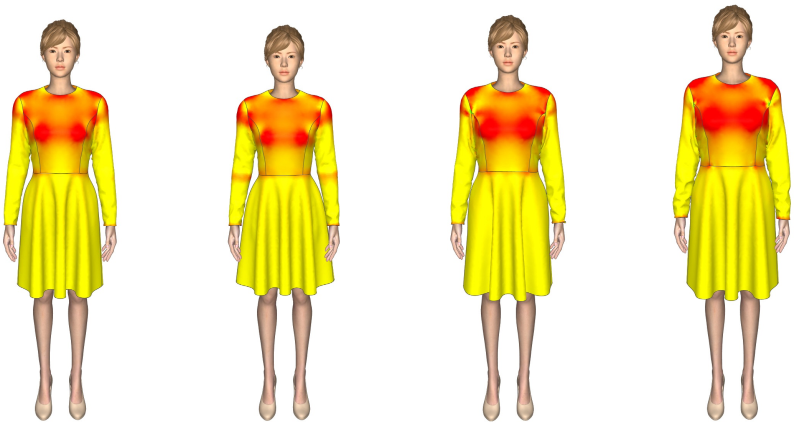
(a) (b) (c) (d)

Figure 4.21 Strain distribution on the source dress and three ungraded graded dresses. The highest and lowest strain were represented to red and yellow. (a): source, (b): target 1, (c): target 2, (d): target 3.



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

Figure 4.22 Strain distribution on the source dress and three DSW-graded dresses. (a): source, (b): target 1, (c): target 2, (d): target 3.



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

Figure 4.23 Strain distribution on the source dress and three manually graded dresses. (a): source, (b): target 1, (c): target 2, (d): target 3.

source. The strain distribution in DSW-graded and manually-graded versions were similar as source.

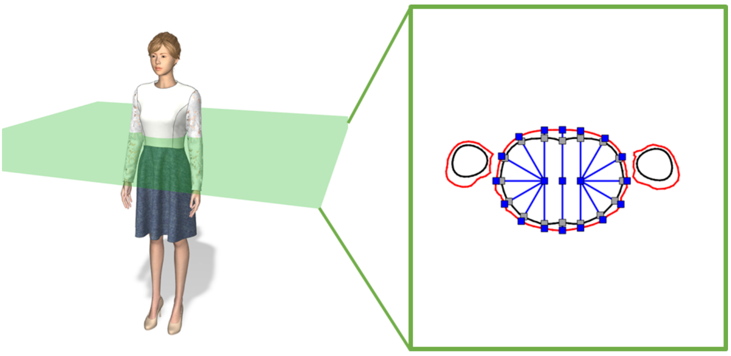


Figure 4.24 Air-gap analysis. The body and the garment cross-sections are shown in black and red contour lines, respectively

4.6.6 Air-Gap Analysis

During the physically-based simulation, we put a horizontal plane and obtained the cross-sections it makes with the body and the garment. In Figure 4.24, the body and the garment cross-sections are shown in black and red contour lines, respectively. When those cross-sections are available, the air-gap ratio R can be defined as

$$R = \frac{A_{\text{garment}} - A_{\text{body}}}{A_{\text{garment}}}, \tag{4.15}$$

where A_{garment} and A_{body} are the areas enclosed by the garment and body the cross-sections.

Figure 4.25 plots the air-gap ratio at different elevations from hip to bust. The air-gap ratio of the source dress on the source body is plotted with red solid line. The air-gap ratio for the ungraded, DSW-graded, and manually-graded versions are solid, dashed, dotted lines. The results for the Targets 1-3 are shown in blue, green, and violet, respectively. It was observable that

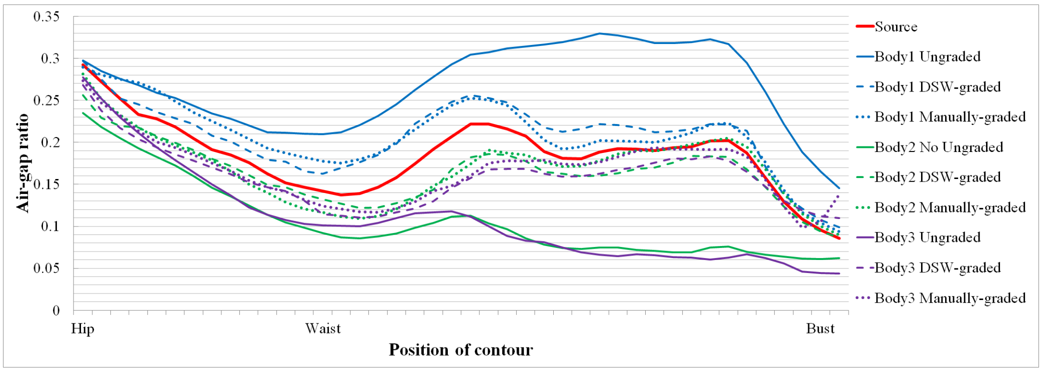
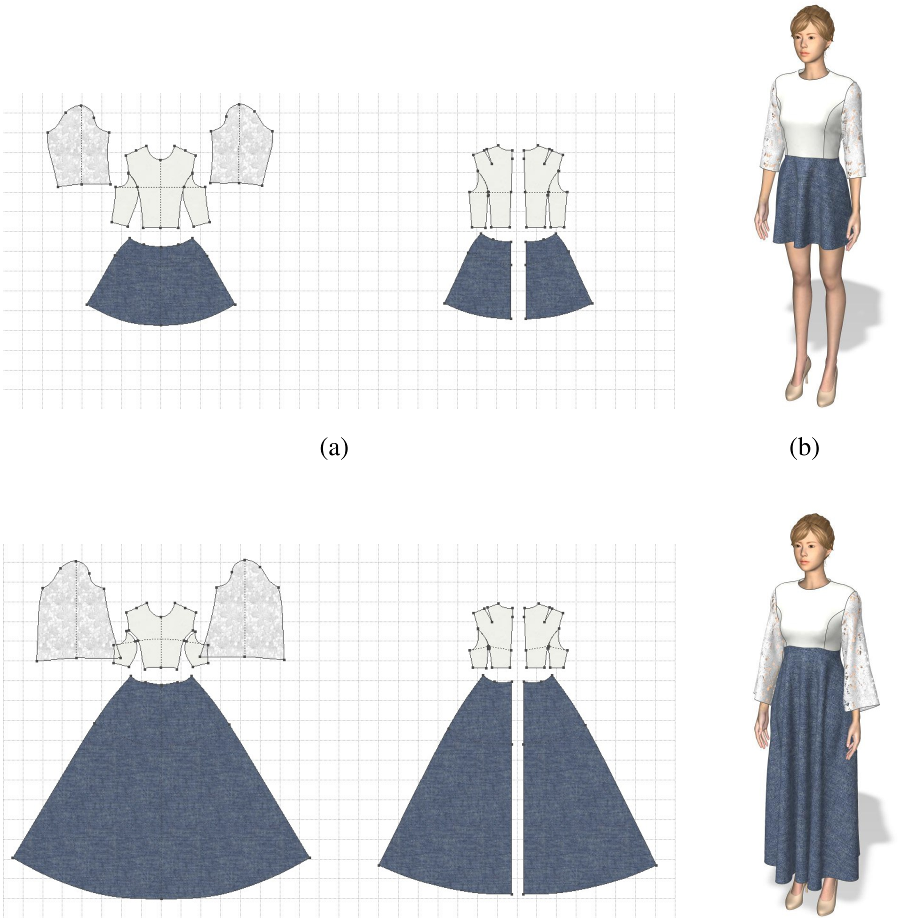


Figure 4.25 Comparison of the air-gap ratio in various graded results

the air-gap ratio of the non-grading version was significantly different from the DSW-graded and manually-graded versions. But, the air-gap ratio of both DSW-graded and manually-graded versions were similar to that of the source dress/body.

4.6.7 Redesign using DSW

We redesign the garment using our DSW-grading method. Figure 4.26 shows the redesigned dress from the source dress as shown in Figure 4.12(a). We reduce the skirt and sleeve length for generating short skirt and short sleeve. We can also create high-waist dress by decreasing the waist-back length and increasing the skirt length. It is easy to make loose/tight sleeve with adjusting wrist circumference. We generate new design garment as adjustment of PBSs.



(a) (b)

(c) (d)

Figure 4.26 Redesigned dresses. We modified the skirt and sleeve to short skirt and short sleeve. (a) Panels (b) Draping snapshot. We resigned the garment to high-waist and loose sleeve. (a) Panels (b) Draping snapshot.

4.7 Discussion

The objective of our research was to investigate fast and accurate grading framework. We considered that the retargeting method is an appropriate approach. We introduced the parameterized draft as the mediator of the retargeting method. The parameterized draft always fits to the given body, also we can make easily by using draft constructor. As source garment is generated from draft, there is close relation between parameterized draft and source garment. After investigating a few candidates for the draft-space encoding, we concluded that the mean value coordinates is an optimal choice. Each point of garment panel is represented by linear combination of that draft, and the weight function was calculated according to MVC.

The proposed method has been implemented and tested for grading a few garments. The primary body sizes analysis, the silhouette analysis, the strain analysis, and the air-gap analysis were performed on the graded results. We verified that the results are indistinguishable from the manually-graded results in the quality but taking much less time. For these reasons, our method satisfy the judging the quality of garment grading as presented in Section 3.2. In this work the grading quality was analyzed only with the physically-based simulator. As a future work, for the industrial validation of the method, the grading quality needs to be tested with real garments by putting them on the real subjects.

Our method has two main limitations. First, we always need parameterized draft DB, since our method is based on draft. Although we can use base draft when there is not proper draft for input source garment, quality of the result is lower than result of using suitable draft. Fortunately, we can easily find proper parameterized draft, because general garment panels are made based on the draft which can serve as parameterized draft. Another limitation is negativity of our encoding method. It may make some artifact when the draft is not convex.

4.8 Conclusion

This study suggests a novel framework for garment grading. For the development of the grading technique, we got the insight from the process of drawing the pattern-making draft. Although the idea itself is simple, we note that proposed approach is the first attempt to utilize the parametrized draft for the purpose of grading. Noting that the draft can be completely determined from the primary body sizes, we abstracted the draft construction process as a procedure which we call the parameterized draft. With the parametrized draft, we developed the grading method which takes five steps: source draft construction, panel positioning, draft-space encoding, target draft construction and draft-space decoding. Proposed method can perform the grading job instantly, and the result quality comes close to that of manual grading by a skilled tailor.

Chapter 5

Garment Capture from a Photograph

This chapter presents our garment capturing method. The method instantly generates the virtual garment from a single photograph of the existing garment which is draped on the mannequin.

5.1 Overview

Our virtual garment creation is based on the drafts. Conventionally, there exists a draft for each garment type. Figure 5.1 shows a typical draft for the one-piece dress. The whole set of the panels can be obtained by symmetrizing, mirroring, or making some variations to the draft.

We introdeced that the drafting can be done from the input of just a few parameters in Chapter 3.1. For the case of the one-piece dress draft shown in

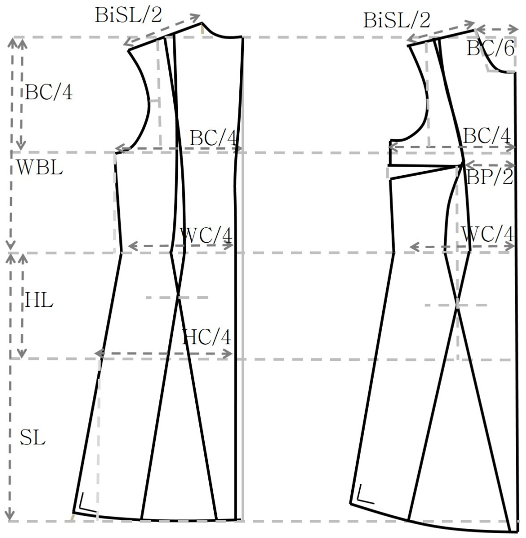


Figure 5.1 The one-piece dress draft, which can be determined from the primary body sizes summarized in Table 5.1

Acronym	Meaning
WBL	Waist Back Length
HL	Hip Length
SL	Skirt Length
BiSL	Bishoulder Length
BP	Bust point to bust point Length
BC	Bust Circumference
WC	Waist Circumference
HC	Hip Circumference

Table 5.1 The primary body sizes for the one-piece dress draft

Figure 5.1, the required input parameters are eight primary body sizes which are summarized in Table 5.1. Since this work performs the garment capture in the context of pre-acquired drafts, the problem of converting the photographed garment to a 3D virtual garment can be reduced to the problem of identifying the garment type and the PBSs.

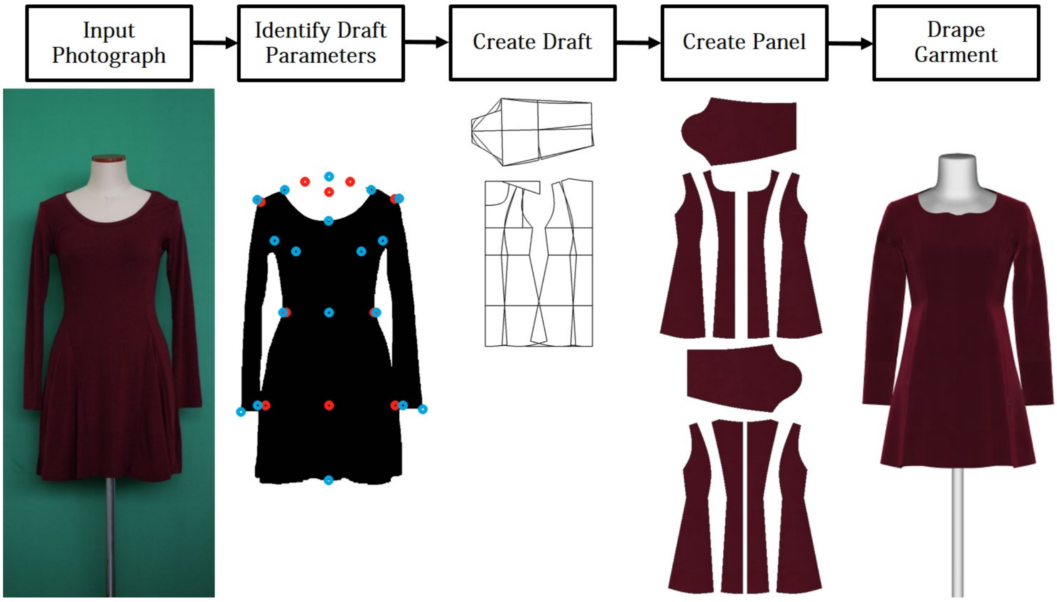


Figure 5.2 The steps the proposed garment capture technique (*GarmCap*).

Figure 5.2 overviews the steps of our garment capture technique (*GarmCap*). From the given photograph, it first extracts the garment silhouette. Based on the garment silhouette, it identifies the garment type and PBSs, which enables creation of the sized draft. Then, it can generate the comprising panels. Finally, it performs the physically-based simulation [14, 81, 18] on the 3D mannequin or avatar.

5.2 Garment Capture

This section presents each of the steps overviewed in Figure 5.2.

5.2.1 Off-line Photographing Set up

Our photographing setup (Figure 1.4) consists of a camera and a mannequin such that the photograph can be taken from the front. The positions of both the camera and the mannequin are fixed, so that the photographs taken with and without the garment can have pixel-to-pixel correspondence. We use the green background screen, which facilitates extraction of the foreground objects. In order to minimize the influence caused by the shadow, we tried to use lights of ambient nature as much as possible. We preprocessed the mannequin (scanned, graphically modeled, and stored into an OBJ file) to obtain its complete 3D geometry as well as its PBSs such that we can establish the relationship between real world distance and pixel distance.

5.2.2 Obtaining the Garment Silhouette

The first step of the GarmCap is the garment silhouette extraction, that is based on GrabCut [64] method. We already have the *mannequin mask* M_M obtained from the mannequin image. We can get the *exposed mask* M_E, the non-garment region of the input photograph. Subtracting M_E from M_M gives us the base mask M_B. Figure 5.3(a) shows the base mask of the input photograph in Figure 5.2. By supplying this base mask, now the GrabCut can produce the garment silhouette without any user interaction. Figure 5.3(b) shows the garment silhouette taken from the input photograph of Figure 5.2 according to the above procedure.

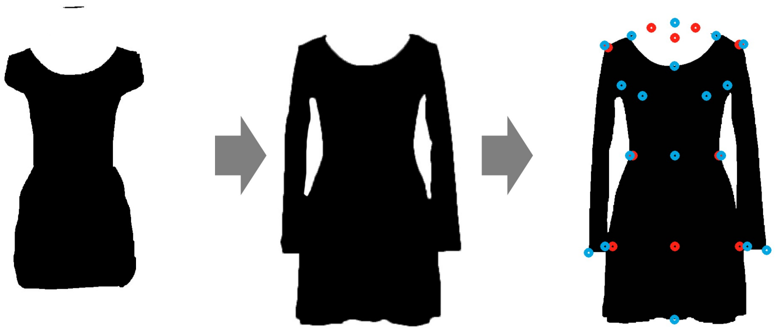

(a) (b) (c)

Figure 5.3 The steps for obtaining the garment silhouette and landmarks: (a) base mask, (b) garment silhouette, (c) mannequin-silhouette landmark points (red) and garment-silhouette landmark points (blue)

5.2.3 Identifying the Garment Type

With the garment silhouette extracted in Section 5.2.2, we identify the garment type from the choices in the current garment type DB (shirt, skirt, pants and one-piece dress) by searching the closest match with *Shape Context* [9] matching. Shape Context is a method to measure shape similarity between images.

$$C_{i,j} = \frac{1}{2}\sum_{k=1}^{K}\frac{[g(k)+h(k)]^2}{g(k)+h(k)} \tag{5.1}$$

where i is a point on the input garment silhouette image (e.g., Figure 5.3(b)), j is a point on the silhouette image in the DB. The method compares the shape contexts bitween i and j to compute a similarity cost $C_{i,j}$. A function $g(k)$ and $h(k)$ present the K-bin histogram at i and j, respectively.

After the garment type is identified, when needed, we sub-classify the type. For example, a garment is identified as a skirt, we further sub-classify it whether it is “A-line” or “H-line”. For the case of the shirt, we sub-classify it whether according to the sleeve and neckline. The sub-classification is done in the similar way as described with Equation 5.1.

5.2.4 Identifying the PBSs

A few points on the silhouette of the mannequin are pre-registered as the *mannequin-silhouette landmark points (MSLPs)*. Garmcap identifies them and labels them with red circles as shown in Figure 5.3(c). Then, GarmCap labels a few feature points of the photographed garment with blue circles as shown in Figure 5.3(c). We call them the *garment-silhouette landmark points (GSLPs)*. For the center waist and bust points, the MSLPs and GSLPs coincide, thus the red circles are hidden behind the blue ones. But In general there can exist some discrepancy. For example, the discrepancy at the waist left and waist right, although they are in 2D, informs the ease at the waist. Note that the sleeve ends and the skirt end exist only as GSLPs, and indicate the length of the sleeves and the skirt.

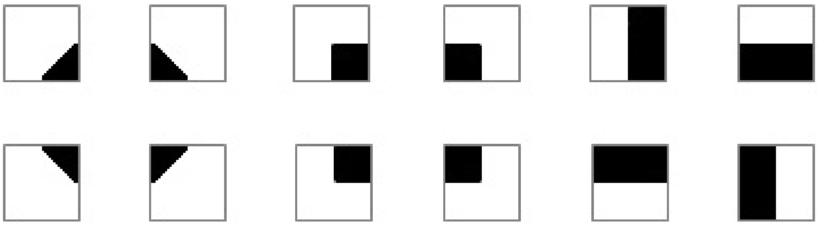


Figure 5.4 Filters for identifying the GSLPs.

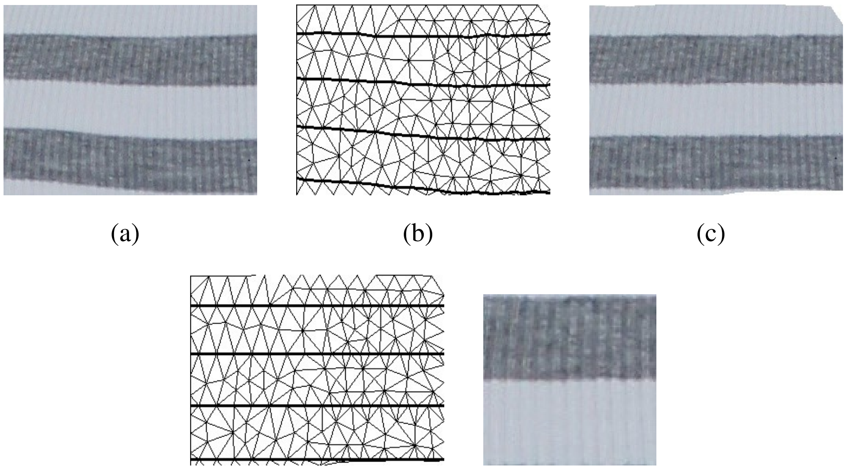
To identify the GSLPs from the garment silhouette, we search the candidate spots of the silhouette image according to

$$\arg\min_{M_L} \|M_F - M_L\|, \tag{5.2}$$

where M_F is one of the filters shown in Figure 5.4, M_L is the square fraction of the silhouette image. The filters are similar as haar features. Note that the above minimization is not mislead by the local minima since the searching is performed a domain which is around a MSLP. By performing the above search for the silhouette image with the transformation T in Equation 5.1 being applied, we do not need to consider the size mismatch here. Now, we can get the PBSs of the garment based on the GSLPs identified above. For the circumferences, we reference the geometry of the scanned mannequin body.

5.2.5 Texture Extraction

This section describes how we extract one-repeat texture from the input image. Texture is a significant part of the garment without which the captured result would look monotonous. Note that our work is not based on vision-based reconstruction of the original surface, but it reproduces the garment by pattern-based construction and simulation. In that approach, the conventional texture extraction (i.e., extracting the texture of the whole garment) produces poor results. The proposed method calls for extraction of an undistorted one-repeat texture. We propose a simple texture extraction method that can approximately produce visual impression of the original garment in the limited cases of regular patterns consisting of straight lines.



(a) (b) (c)

(d) (e)

Figure 5.5 Extraction of the texture: (a) original image, (b) triangle mesh, (c) deformed image, (d) deformed mesh, (e) one-repeat texture

We eliminate the distortion first and then extract one-repeat texture from undistorted image. We extract the lines by applying the sobel filter, then construct a 2D triangle mesh based on the extracted lines as shown in Figure 5.5(b). We apply the deformation transfer technique [70] to straighten the above mesh.

To apply the deformation transfer method, we define the affine transformation T as

$$T = \widetilde{V} V^{-1} \tag{5.3}$$

for each triangle, where V and $\widetilde{V}$ represent undeformed and deformed triangle matrices, respectively. Using only the smoothness term E_S and the identity term E_I,

$$E_S = \sum_{i=1}^{|t|} \sum_{j \in adj(i)} \left\| T_i - T_j \right\|_F^2 \tag{5.4}$$

$$E_I = \sum_{i=1}^{|t|} \| T_i - I \|_F^2 \tag{5.5}$$

we formulate the optimization problem as

$$\min_{\widetilde{V}_1 \cdots \widetilde{V}_n} E = w_S E_S + w_I E_I \tag{5.6}$$

$$\begin{aligned} subject\ to\ \ y_{\widetilde{V}_i} &= y_{\widetilde{V}_j} \quad (i, j \in L_h) \\ x_{\widetilde{V}_i} &= x_{\widetilde{V}_j} \quad (i, j \in L_v) \end{aligned}$$

where w_S and w_I are the user controlled weights, L_h and L_v are horizontal and vertical lines, respectively, and $y_{\widetilde{V}_i}$ is y coordinate of vertex i. We use weights $w_S = 1.0$ and $w_I = 0.001$ as in [70]. The optimization produces straightened results as shown in Figure 5.5(c) and 5.5(d). Now, one-repeat texture (Figure 5.5(e)) can be extracted by selecting the four corner points of the texture along the parallel straight lines.

5.2.6 Generating the Draft and Panels

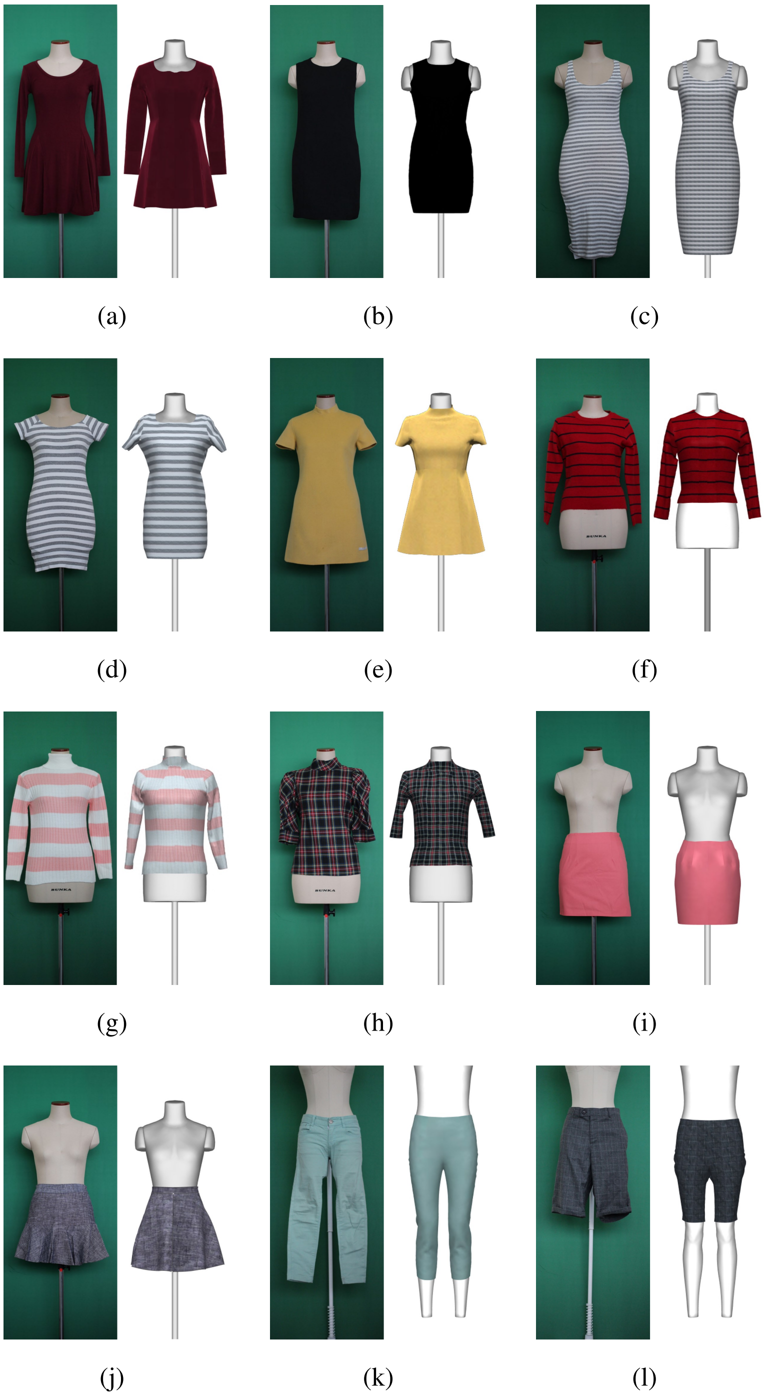
After we get the garment type and the PBSs, we create the panels by supplying them to the parameterized drafting module. We map the one-repeat texture on the panels. Each garment type has the information on how to position and create seams between the panels. Each panel has the 3D coordinate for positioning. We has the index of the line pairs for stitching. After positioning and seaming panels, we perform the physically based clothing simulation [7, 8, 80].

5.3 Results

We implemented the proposed garment capture method on a 3.2 GHz Intel Core(TM) i7-960 processor with 8GB memory and a Nvidia GeForce GTX 560Ti video card. We ran the method to the left images of Figure 5.6. The right side images of Figure 5.6 show the results produced with GarmCap. For the physically-based static simulation, we set the mass density, stretching stiffness, bending stiffness, friction coefficient to $0.01 g/cm^2$, $100 kg/s^2$, $0.05 kgcm^2/s^2$, 0.3, respectively, for the experiments shown in this chapter. Running the proposed method took about three seconds per garment excluding the static simulation.

Figure 5.6(a) shows experiments, a left figure is input photograph and a right figure is captured image of GarmCap. Our experiments included five dresses (Figure 5.6(a)−(e)), two sweaters (Figure 5.6(f)−(g)), one shirt (Figure 5.6(h)), one H-line skirt (Figure 5.6(i)), one A-line skirt (Figure 5.6(j)), and two pairs of pants (Figure 5.6(k)−(i)). Some input garments have stripe or check textile.

There exist some discrepancies between captured and real garments. We measured the discrepancies in the corresponding PBSs of the 2D panels of



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

(j) (k) (l)

Figure 5.6 Input photograph (left) vs. captured result (right). The captured result was obtained by performing physically-based draping simulation on the 3D mannequin model.

captured garments and real garments. For the garments experimented in this chapter, the discrepancy was bounded by $3cm$.

The proposed method reproduces the shoulder strap (Figure 5.6(b), (c)) and the necklines (Figure 5.6(a)-(h)) quite well. The method captures loose-fit garments (Figure 5.6(a), (e), (j)) as well as normal-fit garments (Figure 5.6(b), (c)) very successfully. In capturing tight-fit garments, however, GarmCap may not accurately represent the tightness of the garment because the silhouette analysis cannot tell how much the garment is stretched. Due to above problem, for example, some wrinkles are produced in the captured result of Figure 5.6(i). Although we reference the geometry of the scanned mannequin body to measure circumstance, there are some discrepancies around limbs as shown in Figure 5.6(h), (l).

Intrinsically, the proposed method can not capture the input garment accurately when its draft does not exist in the database. In Figure 5.6(j), whereas the skirt has pleats at the bottom end, our method produces an A-line skirt since the pleated skirt is not in the database. In spite of the missing pleats, we note that the results are visually quite similar.

Solid color textiles (Figure 5.6(a), (b), (e), (i), (k)) are well captured. In case of basic type one-piece (Figure 5.6(c), (d)) and blouse (Figure 5.6(f)), stripe textiles are continuous. But, we notice discontinuity in case of the highneckline blouse (Figure 5.6(g), (h)).

Figure 5.7 shows the side and rear views of the virtual garment shown in Figure 5.6(a). The shape of garment looks like real one-piece. The neck line

Figure 5.7 The side and rear view of Figure 5.6(a).

of the rear view does not same as front view. We note that the result is quite plausible from other views although the method referenced only the frontal image. We attribute the success to the fact that GarmCap is based the pattern drafting theory.

Figure 5.8 The 2D panels for the captured virtual garment shown in Figure 5.1.

Figure 5.8 shows the panels which have been automatically created for the captured garment in Figure 1.5. The garment panels are composed of two front bodice panels, two rear bodice panels and two short sleeve panels. These pan-

Figure 5.9 Draping captured garment on the avatar.

els are mapped a blue stripe texture which was generated in texture extraction process (Section 5.2.5).

Figure 5.9 shows a few results which are put on to the avatar. We drape the virtual garment on the avatar which has same *PBSs* as mannequin at the input photograph.

5.4 Discussion

The aim of presented study is to investigate the method which captures the virtual garment from a photograph. The virtual garment which was captured from the input photograph looks quite similar to the real garment. The method did not require any panel-flattening procedure, which contributed to obtaining realistic results. GarmCap also extracted the one-repeat texture in some limited cases based on the deformation transfer technique [70].

Our garment categorization method is based on the state machine which is similar as And/Or graph [17, 24]. Many clothes classifier have been investigated in the computer vision field [3, 93, 91, 92, 53]. These methods categories a garment as several types. The input garment is draped on the body which has arbitrary size and pose. Our method detects a garment type from a frontal clothes image. In the our garment classifier, the input garment is draped on the static mannequin. Therefore, the input image of our method is more limited than that of previous methods. However, we can detect more various type of garment through sub-classification. Our approach can measure an approximate size of the garment.

The proposed method captures garment properties from a silhouette image. Therefore, the method is difficult to represent the non-silhouette details of the garment such as wrinkles, collars, stitches, pleats and pockets. It would be challenging for the method to represent complex dresses (including traditional costumes). In the future, we plan to investigate the methods for more comprehensive garment capture techniques that can represent the above features. We utilize basic OpenCV technique [9] for measuring PBSs and finding garment type. If we use state of the art technique, we could get more plausible results.

5.5 Conclusion

In this work, we proposed a novel method *GarmCap* that generates the virtual garment from a single photograph of a real garment. The method got the insight from the drafting of the garments in the pattern-making study. Garm-

Cap abstracted the drafting process into a computer module, which takes the garment type and PBSs to produce the draft as the output. For identifying the garment type, GarmCap matched the photographed garment silhouette with the selections in the database. The method extracted the PBSs based on the distances between the garment silhouette landmark points. Since draft involves front/side/rear side design, the result looks plausible from an arbitrary direction although we created the virtual garment based on the front image.

Chapter 6

Conclusion

In the fashion field, a garment is composed with panels which involve a design. Many applications in the fashion industry help to perform drawing, resizing, manufacturing and draping cloth pattern. In the film and game industry, a garment is represented by a tremendous number of meshes. Resizing and modeling virtual garment on 3D requires a large amount of human intervention. We developed the resizing (grading) and capturing techniques with the help of the pattern-drafting theory. We implemented draft constructor called for $Parameterized\ draft$, which takes the garment type and PBSs. This dissertation deals with two methods which perform grading and capturing virtual garments, respectively.

First, we proposed a novel framework which performs grading job. $Draft-Space\ Warping\ (DSW)$ is the first approach which utilizes the parametrized draft to resize the clothes. DSW-grading can perform grading job for arbitrary body, not only linear grading, since parameterized draft module can construct various drafts according to arbitrary PBSs. Because DSW-grading performs on the 2D, the method do not involve converting dimension steps such as physically-based simulation and pattern extraction. Also, the virtual garment in 2D uses small number of the vertices to represent shape of panel by comparison with 3D. Therefore, our approach is able to reduce computational cost. Consequently, DSW-grading lead to minimizing knowledge intensive work and saving performing time for garment grading. Conventionally, grading is used for mass production. For example, when a medium size garment is designed, grading is done for obtaining the large and small versions of it. The proposed grading framework based on the parametrized draft is far more powerful than the conventional grading, since it can instantly perform grading for any body size without calling for the user's intervention. In clothing, mass customization has been conceived as a dream technology which can provide made-to-measure quality garments at the cost comparable to ready-made garments. The authors believe that the proposed grading method can be an important element for the realization of the mass customization.

Second, we investigated a novel method *GarmCap* which captures the virtual garment from a single photograph. GarmCap utilizes parameterized draft to create the garment pattern. Parameterized draft requires garment type and PBSs to produce the draft. For identifying the garment type, GarmCap searched the photographed garment silhouette in the database using *Shape Context* method. To identify PBSs, we measured the distances between the garment silhouette landmark points. We extracted the one-repeat texture for more plausible results. The captured virtual garment looks quite similar as the real garment in the input photograph. The method did not require any panel-flattening procedure, which contributed to obtaining realistic results. Although we captured the virtual garment from the frontal image, the result is plausible even when it is viewed from an arbitrary view.

Both methods used parameterized draft module for grading and capturing the garment. The quality of output is affected by that of drafts database. We would add a specific draft to get the suitable result as needed, when we face with exceptional cases. We suggested additional approaches to overcome above problem. We utilized the base draft to handle exceptional cases in DSW-grading method. When GarmCap generates the garment, PBSs are used for helping to describe the comprehensive design of virtual garment. The further direction of this study will be to suggest a method which can apply to more comprehensive garment.

Appendix A

Implementing Local Coordinates Systems

In this section, we present pseudo codes for helping to implement local coordinates systems. We introduced three coordinates systems in the Section 4.3.

$$P = \sum_{i=1}^{N} \lambda_i v_i \tag{A.1}$$

Before interpreting pseudo code, we introduce notations in Equation A.1.

- v_i : Position of the i-th vertex in polygon.
- P : Position of the point which would be replesented linear combination of vertices.
- λ_i : Normalized weight of the i-th vertex.

Wachspress Coordinates Algorithm 1 shows how to determine λ_i in the *Wachspress coordinates* [82]. The weight λ_i is the normalized value of w_i. w_i is calculated by referring to the areas of the triangles. We can get the areas of the triangles from the cross product. The magnitude of the cross product indicates the area of the parallelogram having $v_1 - v_0$ and $v_2 - v_0$ as sides. The area of triangle $v_0 v_1 v_2$ is half of the area of the parallelogram. It is replesented in Algorithm 1 Line 14.

Algorithm 1 Pseudo Code for Wachspress Coordinates

```
 1: procedure WACHSPRESS COORDINATES
 2:     for each vertex $v_i \in N$ do
 3:         $A_1$=calArea($v_{i-1}$,$v_i$,$v_{i+1}$)
 4:         $A_2$=calArea($v_{i-1}$,$v_i$,$P$)
 5:         $A_3$=calArea($P$,$v_i$,$v_{i+1}$)
 6:         $w_i$=$A_1/(A_2 * A_3)$
 7:         $sum_w$+=$w_i$
 8:     end for
 9:     for each weight $w_i \in N$ do
10:         $\lambda_i$=$w_i/sum_w$
11:     end for
12: end procedure
```

Algorithm 2 Calculate Trinagle Area

```
1: procedure CALAREA
2:     return 0.5*cross($v_1 - v_0$, $v_2 - v_0$)
3: end procedure
```

Algorithm 3 Pseudo Code for Green Coordinates

```
procedure GREEN COORDINATES
    for each vertex $v_i \in N$ do
        $a$=$v_i$-$v_{i+1}$
        $n_x$=$a_y$
        $n_y$=-$a_x$
        $b$=$v_i$-$P$
        $Q$=$a_x * a_x + a_y * a_y$
        $S$=$b_x * b_x + b_y * b_y$
        $R$=$2.0 * dot(a,b)$
        $BA$=$dot(n,b)$
        $V$=$4.0 * S * Q - R * R$
        $L_0$=$\log S$
        $L_1$=$\log(S+Q+R)$
        $A_0$=$\arctan(R/SRT)/SRT$;
        $A_1$=$\arctan((2*Q+R)/SRT)/SRT$;
        $A_10$=$A1 - A0$;
        $L_10$=$L1 - L0$;
        $\psi_i$=$\sqrt{Q}/(4.0*\pi)*((4.0*S-(R*R/Q))*A_10+(R/(2.0*Q))*L_10+L_1-2)$
        $\phi_{i+1}$-=$(BA/(2.0*\pi))*((L10/(2.0*Q))-A_10*R/Q)$
        $\phi_i$+=$(BA/(2.0*\pi))*((L10/(2.0*Q))-A_10*(2.0+R/Q))$
        $sum_\psi$+=$\psi_i$
    end for
    for each weight $w_i \in N$ do
        $\psi_i$/=$sum_\psi$
    end for
end procedure
```

Green Coordinates We get the weight for vertex(ψ_i) and the weight for edge(ϕ_i) using Algorithm 3. a is the different vector between v_i and v_{i+1}. n indicates the normal vector which is perpendicular to the vector a. b presents the different vector between v_i and P. Q and S represent a^2 and b^2, respectively. R is double the dot product between a and b, and BA is the dot product between n and b. After that, we get the ψ_i and ϕ_i form calculation formulas. The weight for vertex ψ_i is normalized to conserve the shape.

Algorithm 4 Pseudo Code for Mean Value Coordinates

```
procedure MEAN VALUE COORDINATES
    for each vertex $v_i \in N$ do
        $Vec_1 = P - v_{i-1}$
        $Vec_2 = P - v_i$
        $Vec_3 = P - v_{i+1}$
        $len = mag(Vec_2)$
        $normalize(Vec_1)$
        $normalize(Vec_2)$
        $normalize(Vec_3)$
        $\cos\alpha_{i-1} = dot(Vec_1, Vec_2)$
        $\sin\alpha_{i-1} = cross(Vec_1, Vec_2)$
        $\cos\alpha_i = dot(Vec_2, Vec_3)$
        $\sin\alpha_i = cross(Vec_2, Vec_3)$
        $\alpha_{i-1} = \arctan(\sin\alpha_{i-1}, \cos\alpha_{i-1})/2$
        $\alpha_i = \arctan(\sin\alpha_i, \cos\alpha_i)/2$
        $\tan_{i-1} = \tan(\alpha_{i-1})$
        $\tan_i = \tan(\alpha_i)$
        $w_i = (\tan(\alpha_{i-1}) + \tan(\alpha_i))/len$
        $sum_w += w_i$
    end for
    for each weight $w_i \in N$ do
        $\lambda_i = w_i/sum_w$
    end for
end procedure
```

Mean Value Coordinates Algorithm 4 presents the pseudo code which determines the weight λ using mean value coordinates. In Equation 4.13, λ_i is calculated based on angles α_i, α_{i-1} and length between v_i and P. We measure the algle by using vector product. Similar as other algorithms, the weights are normalized.

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초 록

본 논문은 가상의복 리사이징 및 캡쳐링에 관한 새로운 방법론을 제시한다. 의복 산업에서는 기성복의 경우 표준 신체 치수에 맞게 디자인 된 다음 특정한 신체 치수로 수정된다. 이러한 리사이징 과정을 그레이딩이라 부른다. 그레이딩은 전문적인 의복 제단 기술이 요구 되며 매우 번거로운 작업이다. 본 논문에서는 가상의복에 대한 빠르고 쉬운 그레이딩 방법을 제안한다. 한편, 실제의복을 참조하여 가상의복으로 만들기 위해서는 재단 및 모델링 기술이 필요하다. 위의 과정 역시 많은 시간과 의복 패턴 제도에 관한 심화지식을 요구한다. 본 논문에서는 앞의 문제를 해결하기 위해 실제의복을 가상의복으로 변환하는 기술도 소개한다. 비단 의류산업에서 뿐만 아니라, 애니메이션 및 게임 산업에서도 의복 디자인의 중요성이 증가함에 따라 가상의복의 그레이딩 및 모델링 기술에 대한 요구가 점차 늘어나고 있다.

본 논문에서는 그레이딩 작업을 수행하기 위해 컴퓨터 그래픽스 분야에서 널리 사용되는 리타겟팅 기술을 도입하였다. 리타겟팅 기술은 매개체와 대응함수를 필요로 한다. 본 논문에서는 패턴 매이킹 드레프트 제도 과정을 참조하여 적합한 매개체를 고안했다. 제안한 방법의 구현을 위해 매개변수 드레프트라는 드레프트 생성 컴퓨터 모듈을 개발하였다. 매개변수 드레프트 모듈은 주요 신체 치수와 드레프트 종류를 입력 받아 드레프트를 제도한다. 무게중심 좌표계 시스템은 2차원상에서 가상의복의 드래프트와 패널 간 대응 관계를 형성하기에 좋은 방법이다. 여러 무게중심 좌표계 시스템 중 평균값 좌표계 시스템은 본 논문에서 고안한 방법에 가장 적합하다. 위 그레이딩

방법을 드레프트 공간 왜곡(*Draft-space Warping*) 기술이라 부른다. 제안한 방법은 주어진 특정 신체에 맞게 이용자의 조정 작업 없이 그레이딩 작업을 즉각적으로 수행한다. 보다 양질의 그레이딩 결과물을 얻기 위해 고안 된 몇 가지 보상기법도 제안한다. 위 방법은 실제의복 및 가상의복의 그레이딩 작업 수행에서, 의상디자이너의 전문 지식을 최소화하며 작업시간 또한 줄여준다.

또한 본 논문은 한 장의 마네킹에 입혀진 실제 의복사진에서 가상의복을 생성할 수 있는 방법을 소개한다. 앞에서 제안한 그레이딩 방법과 유사하게, 위 문제를 해결하기 위해 패턴 드레프팅 이론을 도입하였다. 따라서 가상의복 캡쳐링 문제를 의복의 종류와 주요 신체 치수를 찾는 문제로 간단화 할 수 있었다. 의복의 종류와 주요 신체 치수는 사진 속의 의복의 실루엣과 마네킹을 분석하여 얻는다. 위 방법은 기본적인 의상에 대해 안정적으로 동작하며, 그래픽 코디네이션에 적합한 가상의복을 생성한다.

두 방법 모두 패턴 드레프트 이론의 기반하에 고안 되었다. 기존 3차원에서 수행되던 그레이딩 및 모델링 작업을 2차원에서 수행하여 계산 시간을 크게 감소 시켰음에도 불구하고, 보다 정확한 결과를 얻을 수 있었다.

주요어: 가상 의복, 리사이징, 그레이딩, 모델링, 무게중심 좌표계 시스템, 사진 기반

Keywords: Virtual Garment, Resizing, Grading, Modeling, Barycentric Coordinate System, Photograph

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