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SPECIAL ISSUE PAPER

Draft-space warping: grading of clothes based on parametrized draft

Moon-Hwan Jeong* and Hyeong-Seok Ko*

Department of Electrical and Computer Engineering, Graphics and Media Lab, Seoul National University (SNU), 1 Gwanak-ro, Gwanak-gu, Seoul, South Korea

ABSTRACT

This paper presents a novel framework for garment grading. In CG, an extensive amount of study has been carried out to clothe human characters, but little attention has been taken to the grading problem itself. For the development of a grading technique, we obtained the insight from the process of drawing the patternmaking draft (sloper) in the clothing field. Noting that the draft can be completely determined by supplying the primary body sizes, we abstract the draft construction process as a computer procedure, which we call the *parametrized draft*. With the parametrized draft, we develop a grading method based on the draft-space warping, which takes three steps: (i) draft-space encoding, (ii) target draft construction, then (iii) draft-space decoding. The proposed grading method can be performed instantly for any given body without calling for the user's intervention. With experimental results, we show that the new grading framework can bring an improvement to garment grading. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS

garment grading; mean value coordinates; clothing simulation; clothing design retargeting

***Correspondences**

Moon-Hwan Jeong and Hyeong-Seok Ko, Department of Electrical and Computer Engineering, Graphics and Media Lab, Seoul National University (SNU), 1 Gwanak-ro, Gwanak-gu, Seoul, South Korea.
E-mails: ansghkss@snu.ac.kr, ko@graphics.snu.ac.kr

1. INTRODUCTION

In the clothing production, a garment is usually designed for a specific/standard body, and then the result is modified to fit different bodies. The latter part is referred to as grading. Without grading, the design cannot be appreciated by other bodies. Therefore, grading is very important in the clothing field. In CG, an extensive amount of work has been exerted to clothe human characters, but little study has been performed on the grading problem itself.

Although the word "design" is used comprehensively, in this work where the main focus is grading, we will use the term "garment design" more specifically; a garment design refers to a set of panels $[p_1, p_2, \ldots, p_N]$, which are stitched at the sides. Note that determination of the shape and size of the panels and the stitches among them forms the essential part of the garment design, but the color and prints of the textiles are irrelevant in the consideration of grading. In this work, the distinction between "patternmaking draft" and "panel" is needed. Patternmaking is the process of drawing the patternmaking draft (sloper) as shown in Figure 1 for the purpose of obtaining a panel. As shown in Figure 2, a panel is a piece of *cloth*, which is created on the basis of the patternmaking draft. In this work where the garment is reproduced with the CG technology, each panel has to be represented on the computer. Thus, speaking in terms of data, a panel is represented by a set of points and lines. For the given panel, a grading algorithm has to generate a new panel (i.e., a new set of points and lines), which supposedly fit the given target body.

The two grading methods, namely, the cut-and-spread method and the pattern shifting are in use in the current clothing industry [1]. When the original panel is given, those methods generate graded panels by applying translations to the panel vertices according to the predetermined directions by the predetermined amounts given in the rule table. We will call this sort of grading as *linear grading*, because the translations are usually made along a straight line. Unfortunately, the linear grading may not be an optimal treatment to accommodate nonlinear, nonplanar body variations. The aforementioned problem has been noted for a long time. In luxury brands, therefore, a grading expert makes further adjustments to the linearly graded results, which is typically a time-consuming and labor-intensive task. This paper is motivated from the author's belief that such nonlinearity can be better accounted for by a computer program rather than human hands.

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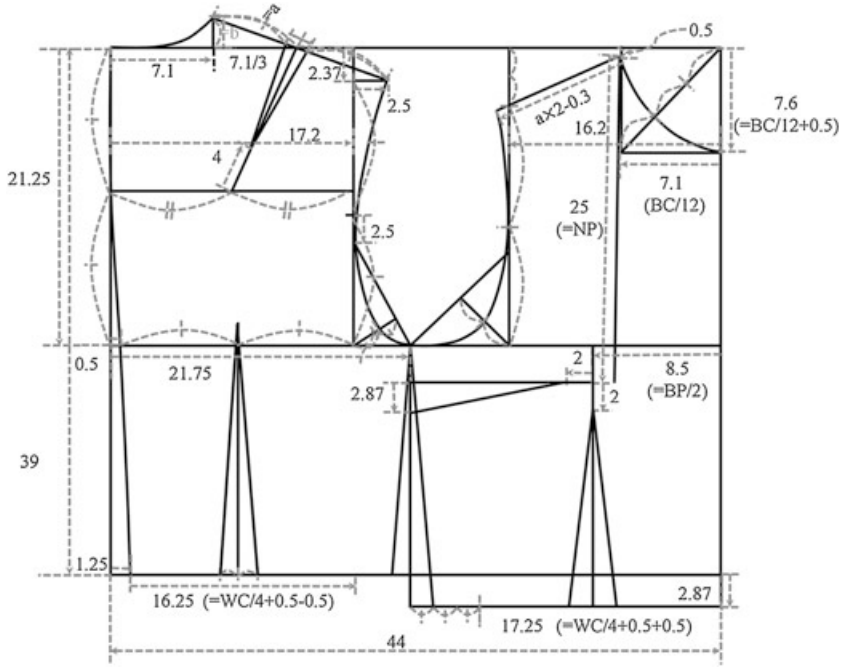

Figure 1. A patternmaking draft for the bodice.

Grading can be thought of as the following retargeting problem.

Given:

- A garment design, that is, a set of panels $\Phi(A) = [p_1, p_2, \ldots, p_N]$ prepared for a specific body A.
- The target body B whose specifics are given with the primary body sizes (PBSs). The PBSs of three example target bodies are shown in Table 1.

Find:

- A new version $\Phi(B) = [\hat{p}_1, \hat{p}_2, \ldots, \hat{p}_N]$, which comprises the same design, but fits to the target body B.

Figure 2. A set of panels created on the basis of the draft shown in Figure 1.

For the development of a grading technique, we obtained the insight from the process of drawing the patternmaking draft (or just draft from now on). From the given PBSs, a clothing expert can construct the draft by drawing points or straight/curved lines step by step. For example, Figure 1 is drawn from the first six PBSs of the source body shown in Table 1. Because the draft is completely determined from the PBSs, we can abstract the construction process as a computer procedure $D(*)$, which takes an arbitrary body then generates the draft for it. We call that procedure the *parametrized draft*. For example, Figure 1 is $D(A)$ for the body A summarized in the source column of Table 1.

2. RELATED WORK

In the computer graphics field, the study on the grading technique is in the early stage. Volino *et al.* [2] presented an interactive garment modeling system in which the garment could be edited in 3D, then its constituent 2D patterns can be extracted. Umetani *et al.* [3] presented a method in which the 3D garment and its constituent 2D patterns are coupled in such a way that an interactive modification of one results in immediate modification of the other. When viewed from the clothing industry, both methods are revolutionary, because they allow clothing construction in 3D and produce the 2D patterns of the fitted garment. However, we do not categorize them as grading techniques, because accommodating the body variations was not the main concern of those methods.

Wang *et al.* [4] proposed a garment retargeting method, which established the spatial relationship between the garment and the source body. The original garment is

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Table 1. The primary body sizes for the source and target bodies.

PBS (unit: cm)	Source	Target 1	Target 2	Target 3
Bust circumference	85.0	80.0	95.0	105.0
Waist circumference	65.0	60.0	75.0	85.0
Hip circumference	90.0	85.0	100.0	110.0
Waist back length	39.0	38.4	40.2	41.4
Bust point to bust point	17.0	16.4	18.2	19.4
Neck point to breast point	24.0	23.2	25.6	27.2
Skirt length	55.0	53.0	59.0	59.0
Hip length	19.0	18.4	20.2	21.4
Height	171.0	169.5	174.0	177.0
Front armhole circumference	20.2	19.6	21.4	22.6
Rear armhole circumference	21.4	20.8	22.6	23.8
Sleeve length	54.0	53.4	55.2	56.4
Wrist circumference	20.0	19.4	21.2	22.4

then retargeted to the target body following the spacial relationship established previously. Another automatic garment resizing method proposed by Meng *et al.* [5] solves the distortion problem of [4] by introducing a local geometry encoding technique. Recently, Brouet *et al.* [6] presented a garment transfer method performs garment grading by explicitly considering additional criteria such as the silhouette, fit, manufacturability.

In the goal, our work is the same with the aforementioned three 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 aforementioned methods, whereas the aforementioned methods make a direct retargeting of the garment in 3D with the subsequent pattern extraction process [7]; our method retargets each 2D panel to the graded version via the 2D patternmaking draft space, resulting in more utilization of the patternmaking expertise from the clothing field.

The essence of the draft-space encoding is expressing the position of each panel vertex as a weighted sum of the draft vertices. A variety of such encoding schemes has been studied. One of the simplest approaches is triangular barycentric coordinates system (TBC). Many researchers have used TBC and attempted extension of it for their own purposes [8,9]. Floater [10] introduced the mean value coordinates (MVC), which could encode a position with respect to an n-gon. The weights of MVC can have negative values when the n-gon is concave. The harmonic coordinates [11] and the positive mean value coordinates (PMVC) [12] were proposed to achieve the non-negativity. Among the previous encoding methods, MVC and PMVC are the most relevant to our work. The details of those two methods will be introduced in Section 5.

3. INTRODUCTION TO THE PARAMETRIZED DRAFT

Patternmaking is the science to find out the panels, which constitute a given design. An important requirement imposed for the patternmaking is that the resultant garment should fit the target body. To answer for the fitting part, the fashion field has been using the drafting from a long time ago. In fact, drafting is a common element practiced from fashion schools. The fashion institutes (e.g., SADI, SMOD) have established their own ways of drafting the basic bodice, skirt, sleeve, pants, and so on. A draft is used as the starting point of many different designs. For example, virtually all the female tops can be derived from the basic bodice draft. We note that, when the drafting is developed as a computer procedure (parametrized draft), a draft can be constructed instantly, which can take tens of minutes even to an experienced patternmaker.

Although the idea itself is simple, we note that to our knowledge this work is the first attempt to utilize the parametrized draft for the purpose of grading. Conventionally, grading is used for mass production. For example, when a medium size garment is designed, grading is carried out 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, because 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 with ready-made garments. The authors believe that the proposed grading method based on the parametrized draft can be an important element for the realization of the mass customization.

4. DRAFT-SPACE WARPING

With the parametrized draft presented in Section 3, now, we develop a novel grading scheme, which we call the *draft-space warping* (DSW). 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

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positions invariant during the $D(A)$-to-$D(B)$ space warp. We assume that the design $\Phi(A)$ is created in reference to the draft $D(A)$ (the *panel-draft coupling assumption*), in which case the panels are already positioned on that draft.†

The DSW is carried out in three steps. In this section, we show how a single panel p_k is graded with the DSW. Then, the whole design can be graded by applying the same algorithm to each panel. Let P_{kj} $(j = 1, \ldots, L)$ be the vertices of the panel p_k. Let v_i $(i = 1, \ldots, M)$ be the vertices in the source draft $D(A)$.

Draft-space encoding: This step encodes the position of each panel vertex P_{kj} with respect to $D(A)$. In this work, we encode P_{kj} by expressing it as a linear combination of the draft vertices.

$$P_{kj} = \sum_{i=1}^{M} \lambda_i v_i . \quad (1)$$

More specifically, this step finds out the weight vector $(\lambda_1, \ldots, \lambda_M)$ for each panel vertex P_{kj}. When $M > 3$, (in most drafts $M >> 3$), 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 5.

Target draft construction: In this step, we generate the target draft $D(B)$ of the source body B, which is a trivial task when the parametrized draft is available. Let $\hat{v}_i$ $(i = 1, \ldots, M)$ be the vertices of the target draft $D(B)$.

Draft-space decoding: This step finds out the new vertex position $\hat{P}_{kj}$ of the graded panel $\hat{p}_k$. With the assumption that the relative position (i.e., encoding) of each panel vertex P_{kj} is invariant during the $D(A)$-to-$D(B)$ space warp, we compute $\hat{P}_{kj}$ with

$$\hat{P}_{kj} = \sum_{i=1}^{M} \lambda_i \hat{v}_i . \quad (2)$$

Here, the weights λ_i are the ones which were calculated in the draft-space encoding step.

The reason why the aforementioned simple encoding-then-decoding operation can perform the grading task can be attributed to the fact that the target draft (generated with the parametrized draft) already contains all the necessary scalings to cover the source-to-target body mismatches.

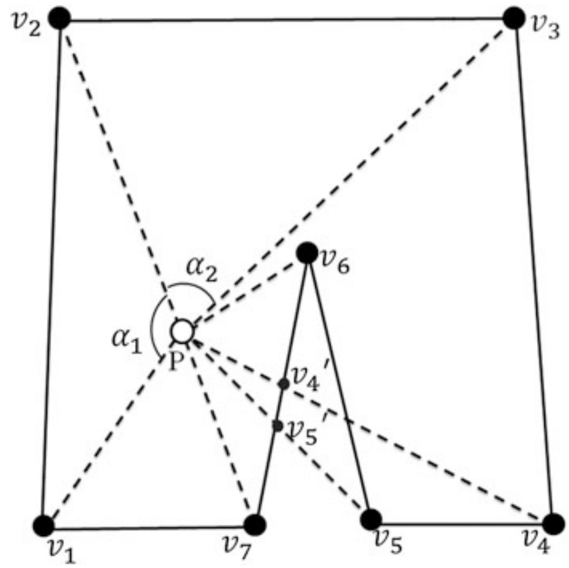

Figure 3. Calculating the mean value coordinates.

5. DRAFT-SPACE ENCODING

In this section, we present the draft-space encoding method, which is an important component in the development of the proposed grading framework DSW. This section reviews previously proposed candidates for the draft-space encoding, then concludes with an encoding method, which best suits for the current purpose.

The TBC is one of the most popular methods, which have been used for encoding a position within a triangle. Unfortunately, a typical situation the draft-space encoding has to handle is the one shown in Figure 3, which is far from a triangle.

Several techniques have been proposed, which can directly encode a position with respect to a general n-gon without going through triangulation [9,10,13]. Suppose that an n-gon consists of M vertices $v_1, \ldots, v_M$ on the same plane (in the counterclockwise order), and we want to encode a position P on that plane as a linear combination of those vertices (Figure 3)

$$P = \sum_{i=1}^{M} \lambda_i v_i \ , \ \sum_{i=1}^{M} \lambda_i = 1. \quad (3)$$

Floater [10] introduced a weighting scheme, so-called the MVC.

$$\lambda_i = \frac{w_i}{\sum_{k=1}^{N} w_k} \ , \ w_i = \frac{\tan(\alpha_{i-1}/2) + \cot(\alpha_i/2)}{\|v_i - P\|^2}, \quad (4)$$

where α_i is the angle made by v_i's and/or P as shown in Figure 3. The method is named that way because the

†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. Because 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.

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weights are determined by applying the mean value theorem to the harmonic functions. The encoding quality of MVC is reported superior to other encoding methods [13].

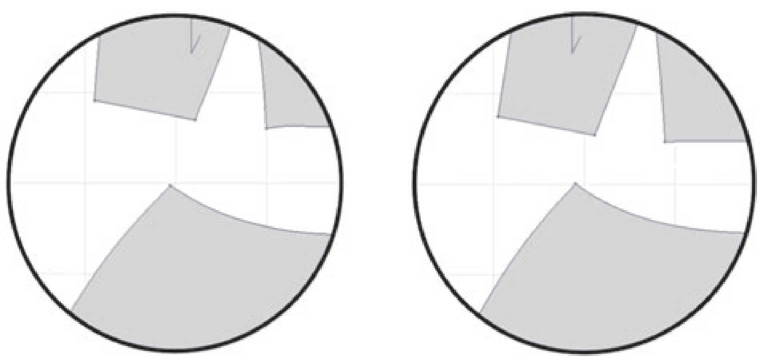
When the n-gon has concavity as in the case of Figure 3, with the MVC, the weights for the invisible vertices (for example, in Figure 3, v_4 and v_5) can have negative values. Lipman *et al.* [12] proposed the PMVC to cope with that problem, in which the linear combination does not include v_4 and v_5 but includes their clamped versions v'_4 and v'_5. A variation the authors additionally experimented in this work for achieving the non-negativity was omitting those vertices in the summation. We will refer to this variation the *omitted mean value coordinates* (OMVC). PMVC and OMVC exhibit different behaviors in coping with the concavities but both show reasonable encoding performances.

We turn to another challenge in the development of the draft-space encoding method. In designing a garment, a panel vertex may in general come exterior to the draft. More specifically, a panel vertex may not lie within the convex hull of the draft vertices. Therefore, another characteristic the draft-space encoding method should equip is the capability of handling the outliers.

If the non-negativity should be imposed in encoding the outliers, then it is imperative to create a number of extra vertices (we call them the *ghost vertices*) in addition to the original draft vertices. We have experimented several ways of creating ghost vertices in the context of PMVC and OMVC. But neither of them produced satisfactory results. For both PMVC and OMVC, the weights could vary noncontinuously across the draft. More fundamentally, (i) the ghost vertices are extraneous information,

(a) Source (b) Target 1 (c) Target 2 (d) Target 3

Figure 4. The source and three target bodies: (a) Source, (b) Target 1, (c) Target 2, and (d) Target3.



(a) DSW grading (b) Manual grading

Figure 5. Magnified view of the draft-space warping and manual grading in the case of Target 3: (a) draft-space warping grading and (b) manual grading.

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which is not in the original patternmaking expertise, and (ii) creating them ruins the clear decomposition between the draft construction and the draft-space encoding, which is the key attraction of the proposed grading framework. Therefore, we conclude to give up the non-negativity in the development of the draft-space encoding.

When we decide not to create ghost vertices, then we can rule out PMVC and OMVC from the candidates, because neither of them are capable of expressing the outliers. Interestingly, among the encoding methods, which have been proposed so far, we find that the MVC, which can have negative weights, is to our knowledge an optimal choice when the outliers are considered as well as the concavities. We find that the negativity of MVC does not work harmfully for the draft-space encoding. With the MVC, the weights vary continuously across the interior and exterior of the draft.

6. RESULTS

We implemented the method presented in this paper on an Intel Core i7 3.20 GHz CPU with a NVIDIA Geforce GTX560 GPU. To test the proposed grading method, we constructed two outfits, a one-piece and a minidress as shown in Figures 6 (4a) and 10(a). The one-piece was used for the silhouette analysis, the garment pressure

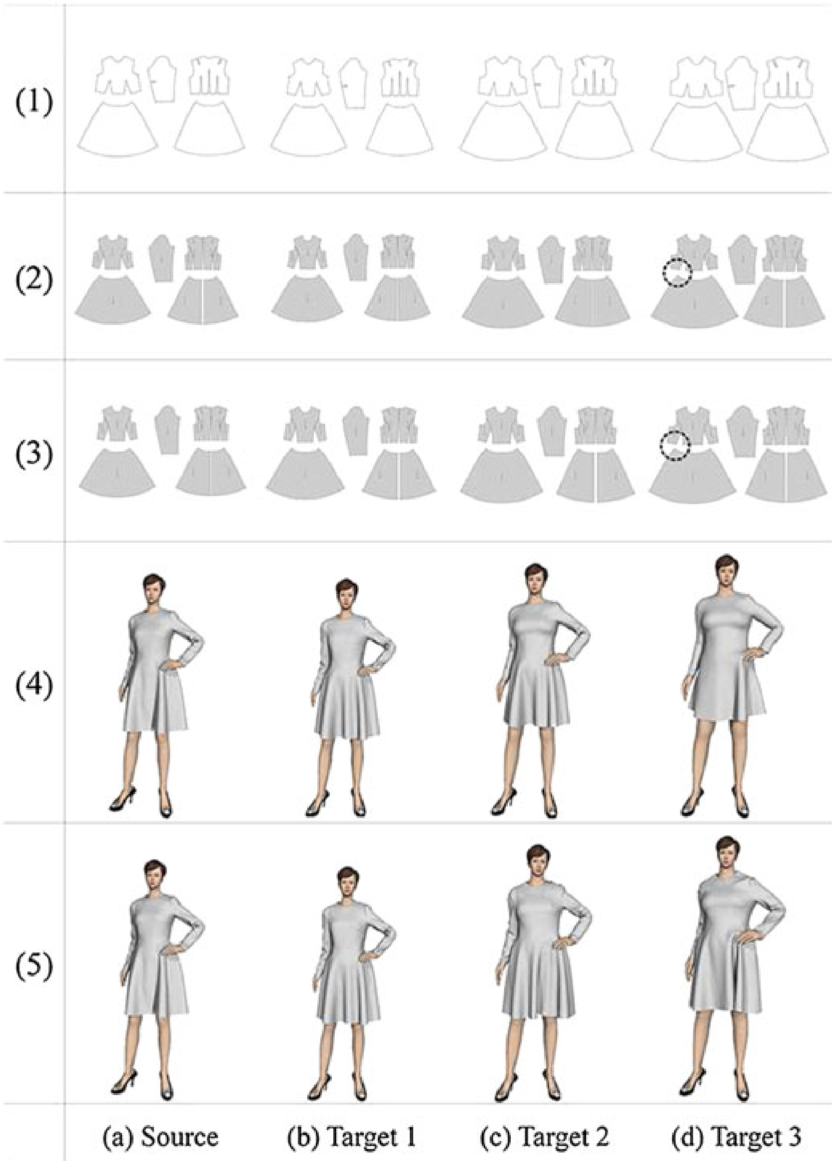

Figure 6. Result figures 1: (a) Source, (b) Target 1, (c) Target 2, and (d) Target3.

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analysis, and the air gap analysis. The minidress was use to demonstrate that the proposed method can process complex garments. We used a physically-based clothing simulator for the previous analyses, which is developed on the basis of [14].

For both of the aforementioned dresses, running the whole grading algorithm including the draft-space encoding, target draft generation, and draft-space decoding took less than 1 ms. Therefore, we will not give any further time analysis for this work. Figure 4 shows the source body and three target bodies used for the experiments. The PBSs of those bodies are summarized in Table 1. For the one-piece experiment, the source draft shown in Figure 6 (1a) was created for the source body using the parametrized draft. Referring to the draft, a fashion designer created the source panels shown in Figure 6 (2a). These panels were the input to the proposed grading system.

6.1. Generation of Panels

Figure 6 (2)(b–d) shows the results of running the DSW grading for Targets 1–3, respectively. Figure 6 (3)(b–d) shows 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 1 h. Viewed in that scale, no particular difference is noticeable. In a magnified

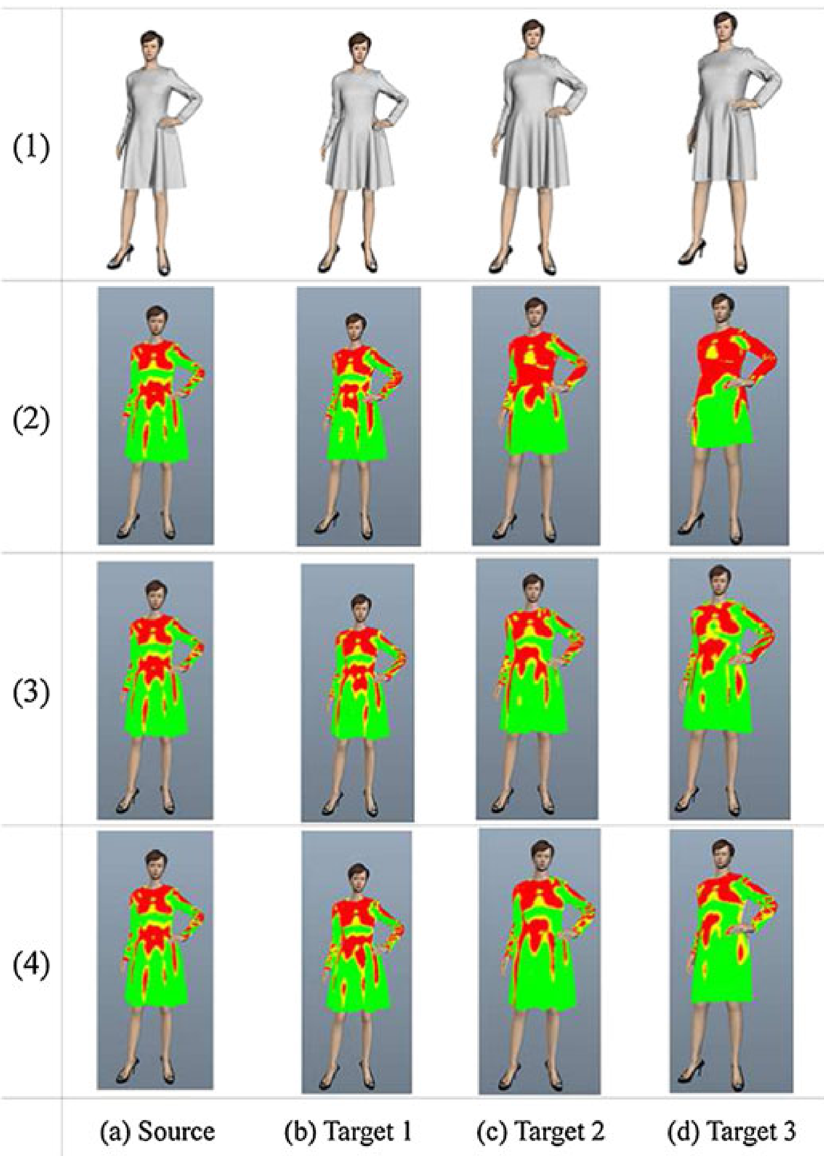

Figure 7. Result figures 2: (a) Source, (b) Target 1, (c) Target 2, and (d) Target3.

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view, some differences are noticeable, Figure 5 showing one example. It was difficult for a grading expert to tell which is the better result.

6.2. Silhouette Analysis

Figures 6 (4–5) and 7 (1) show snapshots taken during the physically based simulation of the 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 6 (4) b) or tight (Figure 6 (4) (c–d)). Otherwise, the results of DSW-graded and manually graded show that the garments well-fitted targets as shown in Figures 6 (5) and 7 (1). The results of DSW-graded are 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 of Figure 6 (5) and (1).

6.3. Pressure Analysis

During the physically based clothing simulation, the simulator could calculate the cloth-to-body pressure distribution across the garment. Figure 7 (2–4) shows the pressure distribution in the ungraded, DSW-graded, and manually graded versions, respectively. The highest and lowest pressures were shown in red and green. In the pressure distribution, the ungraded version was noticeably different from the DSW-graded and manually graded versions, but the latter two versions were similar. We also note that the pressure distribution of the source design is kept quite well in the graded results of Figure 7 (3) and (4).

6.4. 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 8, the body and the garment cross sections are shown in gray and red, respectively. When those cross sections are available, the air gap ratio R can be defined as

$$R = \frac{A_{\text{garment}} - A_{\text{body}}}{A_{\text{garment}}}, \tag{5}$$

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

Figure 9 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 ratios for the ungraded, DSW-graded, and manually graded versions are solid, dashed, and dotted lines, respectively. The results for the Targets 1–3 are shown in blue, green, and violet, respectively. It was observable that the air gap ratio of the non-grading version was significantly different from the DSW-graded and manually graded versions. But, the air gap ratios of both DSW-graded and manually graded versions were similar to that of the source dress/body.

6.5. Handling Complex Garments

We applied our method to a somewhat complex dress shown in Figure 10(a). The proposed DSW grading algorithm successfully generated the graded versions for arbitrary bodices as shown in Figure 10(b–d).

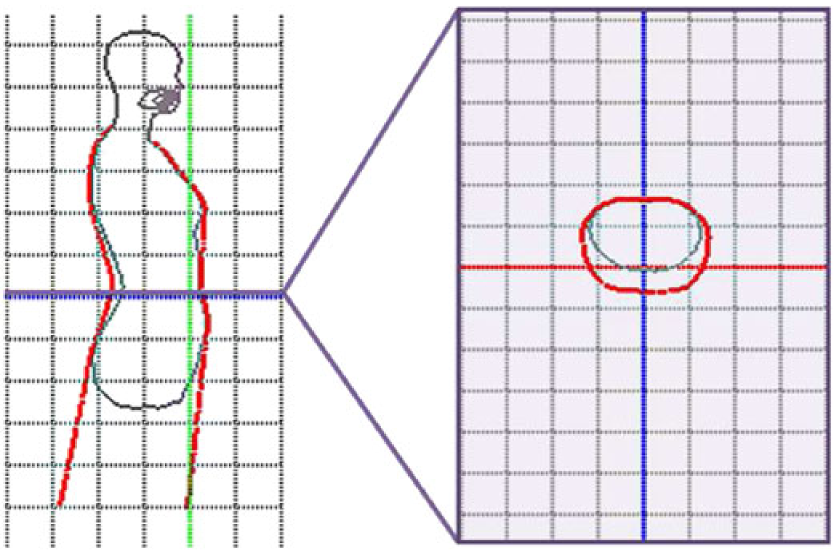

Figure 8. Air gap analysis.

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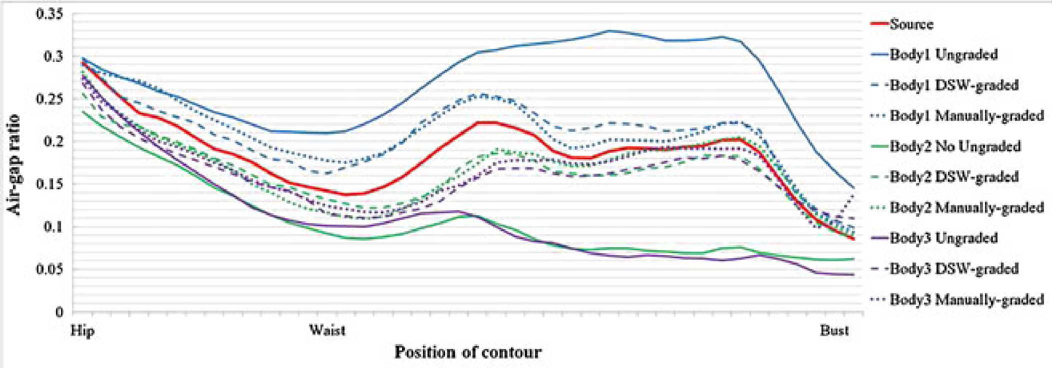

Figure 9. Comparison of the air gap ratio in various graded results.

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

Figure 10. Draping the minidress on the source body and arbitrary bodies.

7. CONCLUSION

In this work, we presented a novel framework for garment grading. For the development of the grading technique, we obtained the insight from the process of drawing the patternmaking draft. Noting that the draft can be completely determined from the PBSs, we abstracted the draft construction process as a procedure, which we call the parametrized draft. With the parametrized draft, we developed the grading method, which takes three steps: (i) draft-space encoding, (ii) target draft construction, then (iii) draft-space decoding. After investigating a few candidates for the draft-space encoding, we concluded that the MVC is an optimal choice.

The proposed method has been implemented and tested for grading a few garments. The silhouette analysis, the pressure 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. 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.

Realization of mass customization in the fashion field requires a grading technique, which can generate the graded results for the given PBSs without any user's intervention. We note that the proposed grading framework based on the parametrized draft meets such condition and can bring a remarkable improvement to the clothing field.

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REFERENCES

1. Horlamus T. Making sense of pattern grading. *Threads* 2008; **101**: 66–70.
2. Volino P, Cordier F, Thalmann NM. From early virtual garment simulation to interactive fashion design. *Computer-Aided Design* 2005; **27**: 593–608.
3. Umetani N, Kaufman DM, Igarashi T, Grinspun E. Sensitive couture for interactive garment modeling and editing. *ACM Transactions on Graphics* 2011; **30**: 1–12. 90.
4. Wang CCL, Wang Y, Yuen MMF. Design automation for customized apparel products. *Computer-Aided Design* 2005; **37**: 675–691.
5. Meng Y, Wang CCL, Jin X. Flexible shape control for automatic resizing of apparel products. *Computer-Aided Design* 2012; **44**: 68–76.
6. Brouet R, Sheffer A, Boissieux L, Cani MP. Design preserving garment transfer. *ACM Transactions on Graphics* 2012; **31**: 1–11. 36.
7. Sheffer A, Praun E, Rose K. Mesh parameterization methods and their applications. *Foundations and Trends in Computer Graphics and Vision* 2006; **2**: 105–171.
8. Hoppe H, DeRose T, Duchamp T, McDonald J, Stuetzle W. Mesh optimization. In *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques*. ACM, New York, NY, 1993; 19–26.
9. Warren J, Schaefer S, Hirani AN, Desbrun M. Barycentric coordinates for convex sets. *Advances in Computational Mathematics* 2007; **27**: 319–338.
10. Floater MS. Mean value coordinates. *Computer Aided Geometric Design* 2003; **20**: 19–27.
11. Joshi P, Meyer M, DeRose T, Green B, Sanocki T. Harmonic coordinates for character articulationg. *ACM Transactions on Graphics* 2007; **26**: 11–19. 71.
12. Lipman Y, Kopf J, Cohen-Or D, Levin D. Gpu-assisted positive mean value coordinates for mesh deformations. In *Proceedings of the Fifth Eurographics Symposium on Geometry Processing*. Eurographics Association, Aire-la-Ville, Switzerland, 2007; 117–123.
13. Hormann K, Floater MS. Stable but responsive cloth. *ACM Transactions on Graphics* 2006; **25**: 1424–1441.
14. Choi K-J, Ko H-S. Stable but responsive cloth. *ACM Transactions on Graphics* 2002; **21**: 604–611.

AUTHORS' BIOGRAPHIES

Moon-Hwan Jeong received his BS degree in the School of Electrical Engineering from Ajou University in 2011 and MS degree in the School of Electrical Engineering and Computer Science from Seoul National University, Korea, in 2013. Since 2011, he is in the doctoral course in the School of Electrical Engineering and Computer Science from SNU. His primary research interests are in physically based animation and computational mathematics.

Hyeong-Seok Ko is a professor in the Department of Electrical and Computer Engineering at Seoul National University. He received B.A. and M.S. degrees in Computer Science from Seoul National University in 1981 and 1985, respectively. He received a Ph.D. degree in Computer and Information Science from the University of Pennsylvania. He is the director of Digital Clothing Center at the same university, and has been developing physically based techniques for reproducing clothes, hair, deformable solids, and fluids.

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