Three-Dimensional Grading of Virtual Garment with Design Signature Curves

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Abstract. The key difference between tailoring and mass production is the use of a single size versus a size chart that contains difference sizes. In practice, the garment pattern of a reference size is made for the confirmation of style and sizing during the product development process. Then, garment patterns of other sizes are derived by this reference size using a technique of grading. In the flat-patterning techniques, there are three types of grading: rectangular (Cartesian coordinate), radio (polar coordinate) and line (localized Cartesian coordinate). All these methods suffer from the limitation of the increase of deformation as the sizes increase. In this article, I shall present a three-dimensional method of grading, which can maintain the styling and comfort characteristics of the wearers at different sizes. This is achieved by the concept of Design Signature Curve. After I present the concept, I shall also present an example as the verification.

Keywords: 3-D Grading, Design Signature Curve, Design, Fitting, Apparel.

1 Introduction

In the current computer-aided design (CAD) software with virtual fitting, the pattern designer can virtually sew the pattern and put it on the virtual mannequin to simulate the fitting. The virtual mannequin typically comes from the direct digitization of human subject or from parametric generation based on the data from a national size survey. The final virtual garment defines a second skin of the virtual mannequin. Once, the fitting of the reference size (i.e., the currently working mannequin) is confirmed, the grading process is typically executed separately on the flat-pattern to other sizes. It is known that the grading process is only effective within a small range of extrapolation. The fitting will be deformed as the sizes increase.

The current study aims to develop the Design Signature Curve (DSC) method to handle the grading process with the three-dimensional garment pattern, rather than the flat pattern. The concept of the DSC is to establish the fitting relationship between the garment and the mannequin or a model. Then, such fitting relationship is applied to the mannequin of other sizes. Hence, with this novel method, the deformation due to the size increase can be reduced. The fitting can be improved.

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In this article, I shall present the concept of Design Signature Curve and then an example as the verification. Finally, I shall discuss the potential extension to other garment parts.

2 Literature Review

Theoretically, if a garment can be unfolded directly from the virtual 3-D body, the grading process can be considered as an unfolding process on a virtual 3-D mannequin of different sizes. Hence, I shall focus the mathematical modeling of garment patterns, which can be traced back to as early as 1956. Mark and Taylor [1] presented a paper on the subject of the 3-D fitting of woven fabrics to the surfaces of revolution. The idea was subsequently taken up by Heisey. This study was completed by Samelson [2] in 1989. Since woven fabric is constructed by means of interlocking warp and weft yarns, Mark and Taylor considered the interlocking square unit of the woven fabric as four inelastic beams hanging more than four movable joints. Hence, when the fabric is laid on the 3-D surface, the beams move freely about the joint, and the angles between the beams change accordingly. In other words, the fitting process is based on the shearing property of the woven fabric. Heisey [3, 4, 5, 6] determined that the constraints on the shear angle was less than the shearability of the fabric, which can be measured using fabric objective measurement methods. Moreover, Heisey defined the rotational ridge to be the curve that connects the rotational maximum on each vertical section, above which the fabric will conform to the surface with minor interpolation around concave areas and below which the fabric will drape vertically. Samelson proved the theoretical condition that guarantee the existence of the garment pattern.

Efrat [7] utilized the concept of folding a pattern into a 3-D cone to approximate the fitting process. The work was subsequently taken up by Shen and Huck [8] in 1992. Efrat selected 17 crucial points on the front right panel, and 16 points for the back right panel for the upper body. Using the bust point as the origin of the geodesic polar coordinate system for the front panel, he measured the distance from the crucial points to the bust point along the surface, including the angles. Shen and Huck used Somatographic technique to input the physical data, and reported the potential of adapting such technology for the apparel industry.

Hinds and McCartney [9, 10] took a totally different approach to the fitting problem. They represented the digitized image of the human body as B-spline patches and further represented the 2-D pattern panel as a series of named sides, straight lines or curves, with an internal reference point on the panel, under a polar coordinate system.

Bassett and Postle [11] designed a fitting scheme which was based on the shearing and bending properties of the woven fabric, and used a hemispherical shell as an approximation of the surface of the human body. This method was quite similar to that of Mark and Taylor, except it depended on the numerical approximation, whereas Mark and Taylor derived the analytic solution.

Wang [12, 13] reported her study on the relation between ease allowance and the garment shape of the X-style jacket. The proposed model divided the body cross-section into three sections by inserting a small segment of almost rectangular shape. By the introduction of such rectangular shape, one can avoid the negative value of radial ease.

Hu, Ding, Yu, Zhang and Yan [14] proposed using the hybrid intelligent method, based on genetic algorithm and artificial neural network to learn how to relate the fitting of a garment to the set of garment patterns. The artificial neural network was used to learn the relationship among body measurements to the fit values that were assigned by a human expert. Then, the genetic algorithm was adopted to calculate the optimal size.

Cho, Komatsu, Inui, Takatera, Shimizu and Park [15] presented a computerized draping method to develop the 2-D garment pattern. They represented the garment surface with a collection of triangles. Each triangle was unfolded, or mapped, to flat surface according to the fabric properties. Finally, these triangles were combined, and darts were created.

3 Design Signature Curve Method

The key concept of the Design Signature Curve method is to define the fitting relationship between the virtual garment and the virtual mannequin. Therefore, it is important to first define what is fitting, and how to measure fitting. Next, by integrating the regional fitting index one can define the overall fitting via a Design Signature Curve that contains the fitting information with respect to the height. Once this curve is defined, it represents the design requirement of the designer (Fig. 1). When another size is considered, one can apply this Design Signature Curve directly to the virtual mannequin and calculate the virtual garment satisfying the same fitting requirements. The technical detail will now be presented.

Firstly, the definition of fitting, that is adopted in this study, is based on the ease allowance, which is defined by the difference between the body and the garment (Fig. 2). There are two methods of measuring ease allowance. In a size chart, all the measurements are gross measurement, in the sense that a waist measurement is a girth measurement, rather than four separate regional arc length measurements of the left-front waist arc, right-front waist arc, left-back waist arc, and right-back waist arc. This is the traditional method. Furthermore, there is another method of measuring the ease allowance by measuring the radial difference between two surfaces at any specific angle. Naturally, since only a size chart is available, it is easier to work with the traditional definition of measuring the gross measurements.

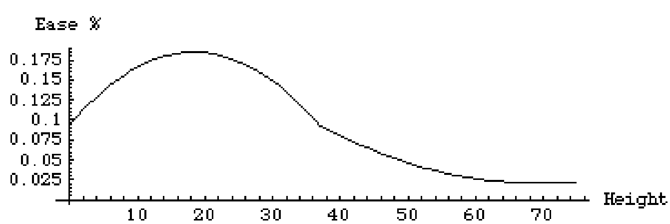

Fig. 1. Design Signature Curve

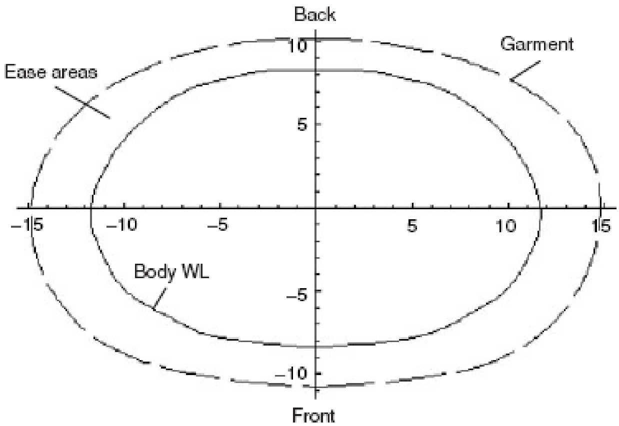

Fig. 2. Cross-sectional view of ease, body and garment

Secondly, a three-dimensional mannequin can be defined as an atlas of surface patches. The virtual garment, which is considered as the second skin of the virtual mannequin can be defined in the same way. The surface patch model that is adopted in this study is the bicubic Bezier tensor-product surface patch, defined as follow:

$$S(u, v) = P\, B_3(u)\, B_3(v)^T \tag{1}$$

$$B_3(t) = (B_{3,0}(t) = (1 - t)^3 \quad , B_{3,1}(t) = 3\,(1 - t)^2\, t \quad , \\ B_{3,2}(t) = 3\,(1 - t)\, t^2, B_{3,3}(t) = t^3) \tag{2}$$

In equation (1), S is the surface patch defined by the u- and v-parameters; $B_3(t)$ are the cubic Bernstein Basis functions in t; and P is the control matrix. Thus, the atlas of a surface is thus defined as a collection of S(u, v). Under this formulation, both the virtual mannequin and the virtual garment are atlases of bicubic tensor-product surface patches. As a simplification of the calculation, u-parameter corresponds to the cross-section while v-parameter corresponds to the vertical section (i.e., height). Typically, the body trunk is divided into layers of four connected patches, for example, left-front waist, right-front waist, left-back waist, and right-back waist. The number of surface patches should be strategically chosen, because if there are too many control points, the Design Signature Curve may not provide enough information to determine a unique solution [16].

Thirdly, the difference between the second skin and the virtual mannequin can be described as an ease allowance curve that varies with the height level (v-parameter). Such difference must be nonnegative. Since this second skin is a final design of the garment, it means that this difference is the ease allowance, which is also a styling ease, rather than the comfort ease or movement ease. For this reason, the functional relationship between the second skin and the virtual mannequin is called the Design Signature Curve and is defined by Equation (3).

$$DSC(v) = (\sum_i (\text{arclength}(SG(u, v)) - \sum_i (\text{arclength}(SB(u, v))) / \sum_i(\text{arclength}(SB(u, v) \quad (3)$$

$$\text{Arclength}(S(u, v)) = \int ds \quad (4)$$

In equation (3), SG and SB are the surface patches of garment and body respectively. Therefore, the DSC(v) sums up the total arc length of the garment, subtracts the total arc length of the body and then expresses as a percentage. In equation (4), the Arclength function measures the arc length of the boundary of the surface patch.

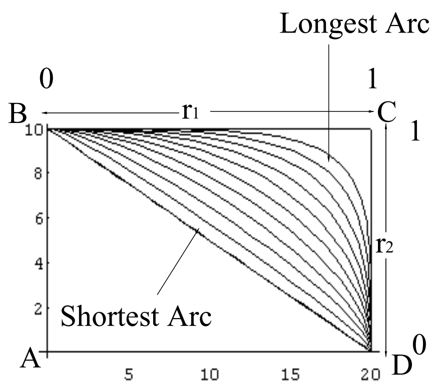

Fig. 3. Reconstruction of arc that satisfy the system of equations

4 Virtual Grading

In fact, the construction of the DSC is very straightforward. However, the Virtual Grading, i.e., the reconstruction of the second skin from the DSC, requires special strategy. Firstly, since a SDC contains the information of extra girth measurement at different height level, and it is the sum of the differences of each curve segments along the circumference, the value must be subdivided and appropriated to each curve segment so that they can be modified individually. Secondly, on a v- cross-section of the bicubic Bezier patch, it is a cubic Bezier curve, which contains two end points and two control vertices. The positions of both control points must be calculated to match the expanded arc length. Additional conditions must be used. For example, it is canonical to require the body to be at least C^1 continuous at the connecting endpoints of neighboring patches. Such condition forces the trajectory of a control point to collide with the line of (BC) or (CD), $P_{i,2}$–$P_{i,3}$(=$P_{i+1,0}$)–$P_{i+1,1}$, which is the geometric representation of the C^1 continuity (Fig. 3). Thirdly, the position of a control point has three coordinates. Although the height has been fixed by the v-parameter, there are two values, x- and y- coordinates to be determined. Luckily, under the C^1 continuity requirement, the ratio between x and y is fixed by the slope of the line segment $P_{i,2}$–$P_{i,3}$(=$P_{i+1,0}$) –$P_{i+1,1}$, a unique position of control point can be determined. Finally, it is possible to have two or more configurations of control vertices yielding the same arc length. If the second skin should maintain the similar shape structure (r_1 and r_2) of the underlying body, the ratio between the distances of the control points to the neighboring endpoints should be maintained. Then, the solution is unique, smooth and matches with the underlying body shape.

Table 1. The algorithm of the Virtual Grading

Step	Action
1.	For each key cross-section do
2.	Distribute the DSC(v) proportionally according to the arc length ratio of each cross-sectional curve segment
3.	For each curve segment do
4.	Move the position of control vertices to shoot for the new arc length; the trajectory of the movement must collide with the original tangent lines at the end points respectively. i.e. The set of defining equations: New_garment_girth(v) = body_girth(v) * (1 + DSC(v)); C^1 continuity at both end points; Shoot while maintaining similar shape proportion. i.e. If multiple solution exist for the set of equations, select the solution that matches with the body shape.
	End each curve segment; End each key cross-section

Fig. 4. Mannequin

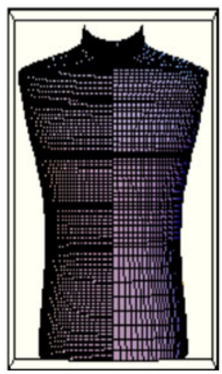

Fig. 5. Digitized image of a mannequin

5 Worked Example

The Virtual Grading of a man's T-shirt is now presented as a verification of the proposed method. The mannequin being used is a male top body without hands (Fig. 4). The white tapes are the reference lines for the pattern unfolding process. The shoulder reference line is for the dart reference. The digitized image of the mannequin is shown in Fig. 5.

A T-shirt is drafted with the standard ease amount of according to the body measurements of the mannequin on a Lectra Modaris system (Fig. 6 and Fig. 7). The set of patterns was made into a sample and was digitized into a virtual garment. This process is indispensable because Lectra system supports only the virtual fitting visualization, without the output of the required ease data at each height level.

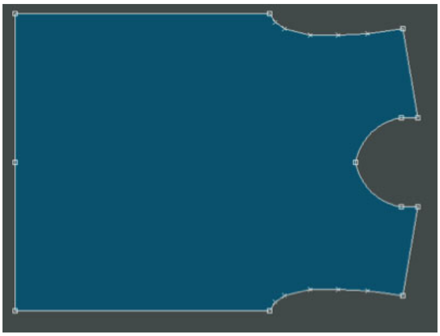

Fig. 6. Unfolded T-shirt pattern (back)

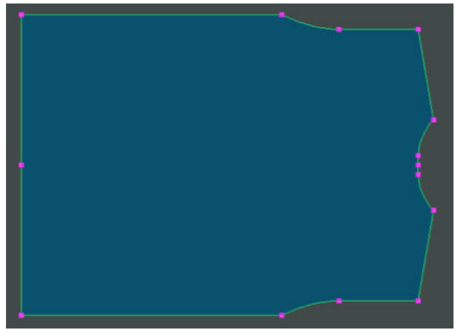

Fig. 7. Unfolded T-shirt pattern (front)

In Fig. 8, a cross-sectional view of the ease at the chest level is displayed. The outer red line is the garment while the inner red line is the body. The Design Signature Curve is then calculated according to Table 2. For the next size, if the ease percentage is maintained, the new body measurements of the T-shirt can be calculated as in Table 3. The cross-section view of the chest is displayed in Fig. 9. The outer broken blue line is the garment while the inner broken blue line is the body. It can be observed that the fitting remains similarly in both sizes. The corresponding Design Signature Curve is presented in Fig. 10. In this curve, the origin is set at the hip level, measuring upward. Hence, the x-axis is the height. Moreover, the y-axis is the XI, the “Ease %.”

Table 2. Table of ease at different levels

Girth Measurement	Body Measurement (BM) (cm)	T-shirt Measurement (GM) (cm)	Ease (%) = (GM-BM)/BM
Neck	45	46	2.2%
Chest	106	116	9.4%
Waist	98	116	18.4%
Hip	106	116	9.4%

Table 3. Table of ease at different levels after grading

Girth Measurement	Body Measurement (BM) (cm)	T-shirt Measurement (GM) (cm)	Ease (%) = (GM-BM)/BM
Neck	4	48	2.2%
Chest	111	121.5	9.4%
Waist	103	112.7	18.4%
Hip	111	121.5	9.4%

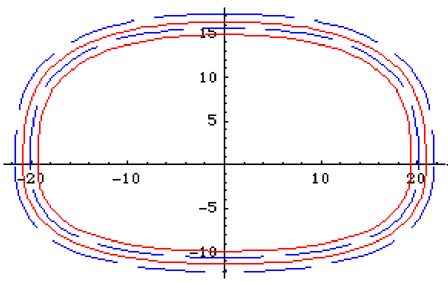

Fig. 8. Cross-section view of ease

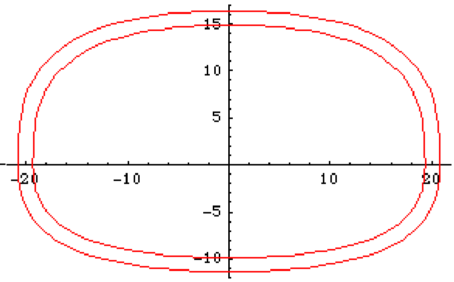

Fig. 9. Cross-section of view of graded ease

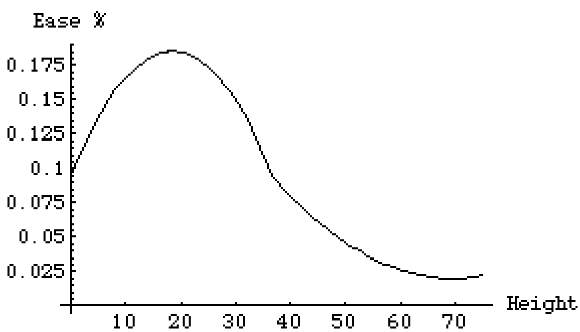

Fig. 10. Design Signature Curve

6 Result and Discussion

The purpose of virtual grading is to generate new patterns for other sizes by maintaining the similar fitting ease. In this article, the ease percentage is preserved. The computation of the ease percentage involves the calculation of the difference in the girth measurements of the virtual mannequin and the second skin, and then expresses in the form of percentage. Next, the cross-sectional styling ease can be measured at different height levels. When the full height level of the second skin is processed, the Design Signature Curve is obtained. It should be noted that there are two types of Design Signature Curve, the Angular Design Signature Curve (i.e., fixed angle) and the Holistic Design Signature Curve (i.e. total styling ease on a cross-section). Certainly, the Angular Design Signature Curve can produce a more accurate second skin, but the Holistic Design Signature Curve matches with the common practice of the styling ease in the apparel industry. When the SDC is applied to generate new second skin for other sizes, the variational method must be used because there are conditions to be expressed as equations and must be satisfied. In this article, both methods will be presented and discussed.

In the present example, only a bodice is used. Other garment parts, such as the sleeves and the collar, can be treated similarly as long as the second skin is considered as an offset surface of the body.

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