Classification of 3D-body Curved Surface Shape of Adult Females in the Extensive Age Group Using Angle Curvatures

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Received 5 November 2018; accepted for publication 9 April 2019

Abstract

For the purpose of custom-made garment design, the 3D-body curved surface shapes of 1,348 females in an extensive age group were investigated using the angle values of three curvatures (\(K_c\), \(k_c\), and \(H_c\)) by multivariate analysis. The nine 3D shape types (three types in the 30s and 40s age groups, two types in the 50s age group, and one type of the 60s age group) were categorized by using each sum angle value of the elliptical (\(+K_c\)), the hyperbolic (\(-K_c\)), the convex (\(+H_c\)), and the concave (\(-H_c\)) curved shapes in ten areas. The different features of the 3D shape types mainly displayed higher or lower convex elliptical and concave hyperbolic curved shapes in the neck, shoulder, chest, sides of trunk, and arms areas. Age also factored into the 3D shape types, and was particularly notable in the differences between the higher convex elliptical curved shape of the 50s and 60s age groups and the lower convex elliptical curved shape of the 30s and 40s age groups in the abdomen, buttocks, and legs areas. Several 3D-body shape types were extracted in the concrete body forms and angle curvature values and were provided as useful information for numerically developing visual designs in custom-made garments.

Key Words: 3D-body curved shape classification, Elliptical and hyperbolic curved shapes, Convex and concave curved shapes, Adult females, Multivariate analysis

1. Introduction

A recent trend in the apparel industry is the move to custom-made sales and production that corresponds to individuals through digitization from many kinds of the small volume production. Currently, it is possible to sell in response to direct orders from consumers through digitization, which requires garments to be produced that reflect individual design and size information. Marketing based on personal size information such as ZOZOSUIT (ZOZO Inc.) and Sizer application developed recently by Sizer Technologies has also begun; however, marketing systems have not transformed production to be based on individual customization. In the current system, customization of garments by apparel manufacturers is limited to pattern development around a few body measurement dimensions—they are not original, tailor-made garments. In the near future, a production system capable of creating further high-quality original, custom garments is considered to be an inevitable requirement not only by the producers of such products, but also by the consumers. Currently in Japan, few apparel makers conduct custom-made sales based on the body sizes of many individuals (length and 3D-body information). In particular, it seems that there are almost no manufacturers developing garment design systems based on 3D-body shapes for individual draping.

If the approximate 3D-body model information close to the body shape of the consumer can be provided in various kinds, it is possible to perform virtual trial fitting by not only the garment size but also the 3D garment-wearing simulation by an approximate 3D-body model. For that purpose, it is necessary to have an analysis method that not only collects a large amount of 3D-body information but also can extract the 3D-body curved surface shape (abbreviation; 3D-body shape) itself as a numerical value.

Though the 3D-body measurement in HQL (Research Institute of Human Engineering for Quality Life) of Japan was carried out from 2004 to 2006 [1], the data of the 3D-body measurements were limited to the 3D-body areas. Although 3D model reconstruction from the 3D-body shapes by using the principal component analysis (PCA) [2] was proposed, there were not enough 3D-body shape samples. In addition, the analysis of the 3D-body and bodice shapes for custom-made purposes is often only analyzed through

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a combination of many 1D lengths [3–6]. For example, since three values of 3D coordinates (X, Y, Z) are used independently, they are limited to analysis of each 1D length of X, Y, and Z coordinates from (0, 0, 0). Even though the Y coordinate can measure the height values of the 3D-body, the 1D lengths of the vertex coordinates did not accurately display the 3D-body shape. That is, the accurate average 3D-body curved surface model cannot be generated, even by using corresponding vertex coordinates (X, Y, Z) of 3D-body data. The problem remains in the method of analyzing the 3D-body shapes and the 3D bodice shapes using 1D data of vertex coordinates (X, Y, Z).

Therefore, the authors have studied the 3D-body curved surface shape using the angle curvature values $Kc$ and $kc$ (where $Kc$ is the concentrated Gaussian curvature, and $kc$ is the concentrated geodesic curvature). As specific angle values, $Kc$ displayed the elliptical curved surface and hyperboloid shape of the 3D chest curved shape, etc., and $kc$ showed the degree of concave and convex curve bending of the neck line, etc. In previous studies [7–14], the 3D curved shapes of the 3D-body trunk and the 2D-fitting bodices in about 350 young men and women were extracted by using the angle of $Kc$ and $kc$. The value of the curvature due to the angle can also express the shape of the 2D garment pattern in the same manner as the 3D-body shape. However, it is necessary to study the mean curvature $Hc$ in order to extract the features of the concave and convex unevenness of the 3D-body. Previously, there was not enough 3D-body data of a wide-range age group to classify highly accurate 3D-body shapes. Regarding the concentrated mean curvature $Hc$, in the case of a 2D garment pattern laid flat, its value is zero and there is no irreregularity. Therefore, the $Hc$ can represent the feature differences of the fabrics in 3D skirt-curved shapes by the same 2D pattern [15–16].

The final objective of our research is to replicate, as closely as possible, the curved shape of a dressmaker’s 3D model and to develop patterns for custom-made garments. As the first step in this study, the 3D whole-body curved shapes of the 1,348 females from an extensive age group (18 to 84 years old) were investigated using the angle values of the three kinds of curvatures ($Kc$, $kc$, and $Hc$). The 3D-body curved surfaces were constructed on the same triangle meshed surfaces, 1,019 setting vertexes (X, Y, Z), 1,988 triangle meshes (faces), and 3,010 edges regardless of their body size. In accordance with the Gauss-Bonnet theorem [17], the total angle values of “–1080” of Sum $Kc$ and Sum $kc$ are found in all the 3D-body curved surfaces in all females. The differences in the 3D-body curved surfaces can be extracted by the distribution of the $Kc$ and $kc$ angle values on the 3D-body curved surfaces. The 3D bodies were divided into ten areas (neck, chest, etc.), and the features of the body curved surface shapes in each area were analyzed. The shape types, including participants’ ages, were categorize using the angle values of the positive $Kc$ (+$Kc$; elliptical curved shape), the negative $Kc$ (–$Kc$; hyperbolic curved shape), the positive $Hc$ (+$Hc$; convex curved shape), and the negative $Hc$ (–$Hc$; concave curved shape).

### Table 1

| Items<sup>(1)</sup> | mean | SD  | unit | $r$  |
|-------------------|------|-----|------|-----|
| age               | 43.20| 17.84 | year | –   |
| stature           | 157.02| 5.98 | cm   | -0.35 <sup>**</sup> |
| posterior waist length | 38.00 | 2.35 | cm   | 0.24 <sup>**</sup>  |
| posterior shoulder length | 38.16 | 2.24 | cm   | -0.06 <sup>*</sup>  |
| bust girth        | 84.99| 7.40 | cm   | 0.31 <sup>**</sup>  |
| under bust girth  | 73.31| 6.47 | cm   | 0.40 <sup>**</sup>  |
| waist girth       | 68.63| 8.04 | cm   | 0.47 <sup>**</sup>  |
| abdominal girth   | 82.72| 7.96 | cm   | 0.45 <sup>**</sup>  |
| hip girth         | 92.12| 5.78 | cm   | 0.08 <sup>**</sup>  |
| maximum arm girth | 26.90| 3.29 | cm   | 0.18 <sup>**</sup>  |
| tight girth       | 50.82| 4.35 | cm   | -0.25 <sup>**</sup> |
| knee girth        | 33.85| 2.50 | cm   | -0.09 <sup>**</sup> |
| sleeve length     | 52.19| 2.75 | cm   | -0.15 <sup>**</sup> |
| body weight       | 52.29| 7.60 | cm   | 0.07 <sup>*</sup>  |

$r$: single relationship values between items and ages. <sup>**</sup>: $p < 0.01$, <sup>*</sup>: $p < 0.05$

### 2. Experimental method and theoretical background

#### 2.1 Female subjects for 3D-body shape measurement

The ages, body lengths, and weights of the female subjects for the 3D-body shape measurements are shown in detail in Table 1. The 1,348 females were selected by random sampling from a wide age range (18 to 84 years old). The age groups were as follows: young adult (18 to 29 years old), $N = 392$; early middle adult (30 to 44 years old), $N = 364$; latter middle adult (45 to 64 years old), $N = 368$; and old adult (65 to 84 years old), $N = 224$. The number of the subjects in the old adult group were slightly low. The single coefficient of correlation values ($r$) between the measurement items and ages is displayed in Table 1. The $r$ shows the significant values. The subjects in the old adult group mainly represent the following measurements: low stature, long posterior waist, long bust girth, under bust girth, waist girth, and abdominal girth, and low tight girth. However, the mean values of these body measurement items in all females were not significantly different (significance level 5%) from the mean values provided by HQL [1].

#### 2.2 3D-body surface shape curvature extraction using three angles ($Kc$, $kc$, and $Hc$)

The 3D-body shapes of the 1,348 Japanese females were measured with a 10-second scan method that used four sensor heads with a laser diode light source and a CCD camera of a non-tactile 3D-body measuring instrument (Body Line Scanner C9036-02, Hamamatsu Photonics Co., Ltd.). The 3D-body shape was produced as a high-density polygon of the wireframe model with 180 vertexes at intervals of 2.5 mm on a body surface. The 41 basic landmarks (human body measurement reference points of front and
back neck points, right and left side neck points, right and left bust points, etc.) and the 978 sub-landmarks for body measurement, based on garment pattern and design, were set on the 3D-body surfaces of Fig. 1. The 41 basic landmarks were affixed with seals on the body surface, and other sub-landmarks were marked on the body measuring lines (bust line, under-bust line, waist line, hip line, armscye line, shoulder length line, etc.); the dividing lines between areas were indicated using our automatic 3D-body measurement system. The homogenous curved surfaces for each subject were identically constructed, with a total of 1,019 setting vertexes (X, Y, Z) on 1,988 triangle meshes (faces) and 3,010 edges based on the basic measurement lines (e.g., neck, bust, waist) and the divided measurement lines in Fig. 1.

In this study, we examined the ten 3D-body surface areas: 1. neck, 2. shoulder, 3. chest, 4. abdomen, 5. back, 6. buttocks, 7. crotch, 8. left and right sides of trunk (denoted by “sides of trunk”), 9. legs, and 10. arms, excluding only the head area based on the garment design. The number of vertexes in the ten areas are shown in the table below.

| areas | vertexes |
|-------|----------|
| neck  | 72       |
| shoulder | 94      |
| chest | 112      |
| back | 86       |
| abdomen | 42      |
| crotch | 22       |
| buttocks | 49      |
| sides of trunk | 140 |
| legs | 212      |
| arms | 190      |
| Total | 1019     |

1. Basic and sub landmarks (1019 vertexes) on 3D-body surface
2. Curved shapes based on the 1988 faces and 3010 edges of 3D-body triangle mesh. These curved shapes are one case of the 3D-body model.

Fig. 1 Vertexes, edges, and faces of triangle meshed 3D-body surface and the 10 areas.

Appendix Figure I Three curvatures of triangle meshed 3D-body surface based on vertexes, edges, and faces [14-16].
in Fig. 1.

The concentrated vertex angle of every triangle produced the deficit angles of each 3D-body surface on the 1,348 females: \( Kc \) (by \( Kc = 360{}^\circ - (2\pi - \phi_n) \)) on the interior area vertexes, \( k_c \) (by \( k_c = 180{}^\circ - (\pi - \phi_n) \)) on the exterior boundary line vertexes (waist and hem lines), and \( Hc \) (by \( Hc = \phi_n / Li \)) on the interior area vertexes, and \( Hc = \phi_n / (Li + 1) \) on the exterior boundary line vertexes; these are demonstrated in appendix Figure I.

Appendix Figure I describes the detailed features of the three curvature surface shapes. Concentrated Gaussian curvatures showed elliptical (+\( Kc; Kc > 0 \)), hyperbolic (–\( Kc; Kc < 0 \)), and developable surface (\( Kc = 0 \)) curved shapes; concentrated geodesic curvatures showed convex (+\( k_c; k_c > 0 \)), concave (–\( k_c; k_c < 0 \)), and straight (\( k_c = 0 \)) line curved shapes. The Gauss-Bonnet theorem was used to find the total angle values of \(-1080^\circ \) (Euler number [17] \( \chi = 1019 \) vertexes – 3010 edges + 1988 faces = –3) for the sum \( Kc \) and sum \( k_c \) in the ten areas of the 3D-body surface, as shown in Fig. 1. The concentrated mean curvature \( Hc \) included the mountain fold curved shape (convex surface shape +\( Hc; Hc > 0 \)), valley fold curved shape (concave surface shape –\( Hc; Hc < 0 \)), and plane surface shape (\( Hc = 0 \)). The area curved shapes are displayed using some vertex curvatures with some faces as shown in the case of Fig. 1. Each combination curved shape is as follows; convex elliptical curved shape (\( \Sigma + Hc \) and \( \Sigma + Kc \)), concave elliptical curved shape (\( \Sigma - Hc \) and \( \Sigma - Kc \)), convex hyperbolic curved shape (\( \Sigma + Hc \) and \( \Sigma - Kc \)), and concave hyperbolic curved shape (\( \Sigma - Hc \) and \( \Sigma - Kc \)).

2.3 Analytical method of three angles (\( Kc, k_c, \) and \( Hc \)) on the ten areas of 3D-body curved surface

The total angle values of the sum \( Kc (\Sigma Kc) \) on the interior area vertexes and sum \( k_c (\Sigma k_c) \) on the exterior boundary line vertexes for the 1,348 females demonstrate the Gauss-Bonnet theorem (total angle values of the sum \( Kc \) and sum \( k_c \) are \(-1080^\circ \)). The \( \Sigma + Kc \) and \( \Sigma + Hc \) were counted as the sum positive values of \( Kc \) and \( Hc \), while the \( \Sigma - Kc \) and \( \Sigma - Hc \) were counted as the sum negative values of \( Kc \) and \( Hc \). The mean angle values of each four sum curvature value (\( \Sigma + Kc, \Sigma + Hc, \Sigma - Kc, \) and \( \Sigma - Hc \)) in each area in the case of the 1,348 females provides understanding of the 3D curved shape features of the ten areas. The \( \Sigma + Kc, \Sigma + Hc, \Sigma - Kc, \) and \( \Sigma - Hc \) are named the four sum curvature values.

The four sum curvature values in the ten areas of the 1,348 females are analyzed by means of PCA and cluster analysis (Ward style using squared Euclidean distance) using the principal component score (PCS) in multivariate regression statistics with the SPSS statistics program.

3. Results and Discussion

3.1 Theory and the features of the 3D curved surface shapes using the mean values of \( Kc, k_c, \) and \( Hc \)

The distribution differences between the sum \( Kc \) and sum \( k_c \) values on the 1,019 vertexes denote the features of each 3D-body shape. The sum \( Kc \) and sum \( k_c \) mean values of the 3D-body female shapes show the same SD value, \(-1062.21^\circ \) (SD = 39.03) and \(-17.79^\circ \) (SD = 39.03), in this study. The sum \( Kc \) and sum \( k_c \) mean values show the same SD values. Therefore, the total mean angle values of \(-1080.00^\circ \) (SD = 0.00) of the sum \( Kc \) and sum \( k_c \) in all females can be determined according to the Gauss-Bonnet theorem [19].

Table 2 shows the mean values of the four sum curvature values (\( \Sigma + Kc, \Sigma + Hc, \Sigma - Kc, \) and \( \Sigma - Hc \)) in each area and the single relationship values between the four sum curvature values in each area and age values. The \( \Sigma + Hc \) values were higher than the \( \Sigma - Hc \) absolute values in all areas, while the \( \Sigma + Kc \) and \( \Sigma - Kc \) absolute values varied in areas. The areas of the 1. neck, 2. shoulder, 6. crotch, 8. sides of trunk, 9. legs, and 10. arms had the higher hyperbolic (\( \Sigma - Kc \)) and convex (\( \Sigma + Hc \)) curved shapes, while the areas of the 3. chest, 4. back, 5. abdomen, and 7. buttocks displayed the higher elliptical (\( \Sigma + Kc \)) and convex (\( \Sigma + Hc \)) curved shapes. The common

Table 2

| interior areas (N = 1,348) | \( \Sigma + Kc \) | \( \Sigma - Kc \) | \( \Sigma + Hc \) | \( \Sigma - Hc \) |
|---------------------------|-----------------|-----------------|-----------------|-----------------|
| \( r \) (Age and 10 areas) | \( r \) (Age and 10 areas) | \( r \) (Age and 10 areas) | \( r \) (Age and 10 areas) |
| means | SD | means | SD | means | SD | means | SD |
| 1. neck | 25.60 | 29.89 | 0.18 ** | -151.43 | 24.72 | -0.29 ** | 162.71 | 39.66 | -0.02 | -56.83 | 31.20 | -0.31 ** |
| 2. shoulder | 178.71 | 28.19 | -0.02 | -206.36 | 36.12 | -0.04 | 751.76 | 82.05 | 0.01 | -160.78 | 63.10 | 0.02 |
| 3. chest | 202.50 | 33.70 | -0.04 | -170.06 | 31.15 | -0.14 ** | 699.36 | 46.25 | -0.33 ** | -76.66 | 30.73 | 0.04 |
| 4. back | 84.14 | 38.91 | 0.05 | -71.17 | 32.93 | -0.09 ** | 451.74 | 48.30 | 0.04 | 57.50 | 26.55 | -0.01 |
| 5. abdomen | 43.84 | 15.95 | 0.65 ** | -28.16 | 10.77 | 0.02 | 248.72 | 39.05 | 0.61 ** | 0.84 | 4.44 | -0.02 |
| 6. crotch | 11.64 | 11.10 | -0.33 ** | -280.48 | 27.89 | 0.08 ** | 143.05 | 33.73 | -0.10 ** | -35.59 | 14.56 | -0.06 * |
| 7. buttocks | 68.44 | 14.45 | -0.25 ** | -51.25 | 13.90 | 0.47 ** | 335.08 | 30.01 | 0.06 ** | 17.23 | 11.95 | 0.57 ** |
| 8. sides of trunk | 141.52 | 52.00 | 0.25 ** | -643.11 | 47.51 | -0.15 ** | 875.11 | 111.23 | 0.03 | -182.17 | 73.78 | -0.01 |
| 9. legs | 344.75 | 35.16 | -0.11 ** | -484.71 | 40.09 | -0.30 ** | 2911.44 | 23.41 | -0.24 ** | 1.34 | 14.06 | 0.02 |
| 10. arms | 291.51 | 51.29 | 0.30 ** | -368.41 | 65.20 | -0.23 ** | 2563.27 | 32.34 | -0.19 ** | -35.50 | 35.40 | -0.07 * |

*\( Kc \): positive \( Kc \) value denoting the elliptical curved shape; +\( Hc \): positive \( Hc \) value denoting the convex curved shape; -\( Kc \): negative \( Kc \) value denoting the hyperbolic curved shape; -\( Hc \): negative \( Hc \) value denoting the concave curved shape. The data is rounded off to the third decimal place. The bold numbers show the higher absolute values between \( \Sigma + Kc \) and \( \Sigma - Kc \) or \( \Sigma + Hc \) and \( \Sigma - Hc \): the single relationship values between the four sum curvature values (\( \Sigma + Kc, \Sigma + Hc, \Sigma - Kc, \) and \( \Sigma - Hc \)) and ages (\( *: p < 0.05, **: p < 0.01 \)). The bold \( r \) numbers show the high or slightly higher absolute values.
standard 3D curved shape in the adult females was represented by using the four sum curvature values as shown in Table 2.

In the case of the relationships between the four sum curvature values and the age values, the high or slightly higher r values show the \( \Sigma + Kc \) and \( \Sigma + Hc \) in the 5. abdomen area \((r = 0.65 \text{ and } r = 0.61) \) or \( \Sigma + Kc \), \( \Sigma - Kc \) and \( \Sigma - Hc \) in the 7. buttocks areas \((r = -0.25, \ r = 0.47, \text{ and } r = 0.57) \). Furthermore, the age values included the relationships with the lower r values of the \( \Sigma - Kc \) and \( \Sigma - Hc \) in the 1. neck area \((r = -0.29 \text{ and } r = -0.31) \), the \( \Sigma + Kc \) in the 8. sides of trunk area \((r = 0.25) \), the \( \Sigma - Kc \) and \( \Sigma + Hc \) in the 9. legs area \((r = -0.30 \text{ and } r = -0.24) \), and the \( \Sigma - Kc \) in the 10. arms area \((r = -0.23) \). As age became higher, we noted the significant shift to the 3D curved shape of the higher convex elliptical 5. abdomen and the higher concave hyperbolic 7. buttocks areas as if demonstrating the conventional protruding abdomen and slightly flat buttocks of old age.

### 3.2 Extraction of principal components for 3D-body curved surface shape

Table 3 shows the factor loading of the evaluation value of the 3D-body shape in each area from the PCA according to the mutual correlation coefficients. The seven principal components (PC1 to PC7) with the 3D-body shape eigenvalues of 1.800 or more are considered to be the major principal components. Table 3 shows the factor loading of the evaluation value of the 3D-body shape in each area from the PCA according to the mutual correlation coefficients. The seven principal components (PC1 to PC7) with the 3D-body shape eigenvalues of 1.800 or more are considered to be the major principal components.

The scores for PC1 to PC7 are abbreviated as PCS1 to PCS7. Each ratio. The contribution ratio values show the approximately 5%.

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the 2. back area displays the slightly higher values (0.450 to 0.458). PC3 represents the 2. back curved-shape component. The high PCS3 values are mainly due to the slightly higher elliptical (Σ + Kc) and convex (Σ + Hc) 2. back curved shape, and vice versa for the low PCS3 values.

PC4 (eigenvalue of 2.698 and contribution ratio of 6.745%)  
PC4 included the high or slightly higher positive or negative values of some of the four curvatures in the areas of the 1. neck, 2. shoulder, and 4. back. The two-factor loading of the Σ + Kc and Σ + Hc in the 1. neck area displays slightly higher values (0.536 to 0.560), and the four-factor loading of the Σ + Kc, Σ - Kc, Σ + Hc, and Σ - Hc in the 4. back area shows the high or slightly higher values (-0.454 to -0.637 and 0.570 to 0.673). PC4 represents the 1. neck and 2. back curved-shapes component. The high PCS4 values indicate the higher elliptical (Σ + Kc) and convex (Σ + Hc) 1. neck curved shape and the lower or slightly lower elliptical (Σ + Kc), hyperbolic (Σ - Kc), convex (Σ + Hc), and concave (Σ - Hc) 2. back curved shape, and vice versa for the low PCS4 values.

PC5 (eigenvalue of 2.485 and contribution ratio of 6.214%)  
PC5 included the slightly higher positive or negative values of the Σ - Kc and Σ - Hc in the areas of the 3. chest (0.429 to 0.499) and 10. arms curved shapes. PC5 primarily represents the 3. chest and 10. arms curved shapes components. The high PCS5 values indicate the slightly lower hyperbolic (Σ - Kc) and concave (Σ - Hc) 3. chest curved shape and the slightly higher hyperbolic (Σ + Kc) 10. arms curved shape, and vice versa for the low PCS5 values.

PC6 (eigenvalue of 2.097 and contribution ratio of 5.241%)  
PC6 included the slightly higher negative values of the Σ - Kc (-0.464) and Σ - Hc (-0.484) in the 1. neck area. PC6 represents the 1. neck area curved-shape component. The high PCS6 values indicate the slightly higher hyperbolic (Σ - Kc) and concave (Σ - Hc) 1. neck curved shape, and vice versa for the low PCS6 values.

PC7 (eigenvalue of 1.828 and contribution ratio of 4.570%)  
PC7 had slightly higher positive or negative values of the Σ - Kc (-0.472 and 0.685) and Σ + Hc (0.528) in the areas of the 8. sides of trunk and 10. arms. PC7 represents the 8. sides of trunk and 10. arms curved-shapes component. The high PCS7 values mainly indicate the slightly higher hyperbolic (Σ - Kc), convex (Σ + Hc), and concave (Σ - Hc) 8. sides of trunk curved shape and the higher convex (Σ + Hc) 10. arms curved shape, and vice versa for the lower PCS7 values.

### 3.3 Classification of 3D-body curved surface shape

The 3D-body shapes of the 1,348 females are categorized into 9 clusters at a branching level of approximately 7.5 dendrograms. The number of females (87 ≤ N ≤ 285) in each cluster are considered using PCS1 to PCS7 (cumulative contribution ratio: 51.495%). Table 4 shows the mean and SD values of PCS1 to PCS7 and the mean age values in the 9 clusters. The mean and SD values of the four curved shape types of the elliptical (Σ + Kc), hyperbolic (Σ - Kc), convex (Σ + Hc), and concave (Σ - Hc) are displayed in the ten areas of each cluster in Table 5. Furthermore, the significant differences of the four curved shape types between each area’s mean value in 9 clusters and each area’s total four curvature mean values (Table 2) were determined by using a t-test in Table 5 (*: p < 0.05, **: p < 0.01). The different values of the four curved shapes were calculated as follows: the sum Σ + Kc or Σ + Hc positive value in each area of clusters minus the total Σ + Kc or Σ + Hc positive value in each area (Table 2), and the total Σ - Kc or Σ - Hc negative value in each area (Table 2) minus the sum Σ - Kc or Σ - Hc negative value in each area of clusters. Therefore, the bar graph of Fig. 2 shows the positive values for the high curved shapes and the negative values for the low curved shapes against the average of the four curved shapes in each of the 9 clusters using by the colored maps based on the four sum curvature values. The red-colored areas display the high convex elliptical curved shape of Σ + Kc and Σ + Hc, while the high concave hyperbolic curved shape areas of Σ - Kc and Σ - Hc are in dark blue.

The higher and slightly higher single relationship values between the PCS2 (r = -0.69) or PCS3 (r = -0.41) value and the ages are shown in Table 4. The PCS2 and PCS3 values represent the main principal components of the 3. chest, 4. back, 5. abdomen, 7. buttocks, and 9. legs in Table 3. The mean age values of each cluster are outlined as follows (all age groupings are approximate): Clusters 1, 2, and 8—women in their 30s; Clusters 3, 5, and 7—women in their 40s; Clusters 4 and 6—women in their 50s; and Cluster 9—women in their 60s (19.39 years old of the SD values). The mean age values among Clusters 1, 2, and 8 of the 30s age group, Clusters 3, 5, and 7 of the 40s group, and Clusters 4 and 6 of the 50s group have no significant differences (**: p < 0.01) with each cluster in the clusters of approximately same age, while the

Table 4: Mean and SD values of PCS1 to PCS7 and ages in each cluster.

| Clusters | PCS1 | PCS2 | PCS3 | PCS4 | PCS5 | PCS6 | PCS7 | Ages |
|----------|------|------|------|------|------|------|------|------|
| Cluster 1 | -0.17 | 0.45 | 0.62 | 0.12 | -0.95 | -0.91 | 0.68 | 31.26 |
| Cluster 2 | 0.72 | 0.53 | 0.60 | 0.54 | 0.69 | 0.76 | 0.76 | 10.65 |
| Cluster 3 | 0.85 | 0.16 | 1.40 | 0.59 | -0.26 | 0.64 | -0.03 | 31.90 |
| Cluster 4 | 1.07 | 0.89 | 0.84 | 0.94 | 1.12 | 1.79 | 1.19 | 14.44 |
| Cluster 5 | -0.16 | 0.37 | -0.70 | -0.36 | -0.40 | 0.19 | -0.20 | 42.47 |
| Cluster 6 | 0.58 | 0.70 | 0.53 | 0.73 | 0.81 | 0.79 | 16.45 |
| Cluster 7 | 1.03 | -0.69 | -0.18 | 0.06 | -0.51 | -0.61 | -0.87 | 53.47 |
| Cluster 8 | 0.69 | 0.81 | 0.83 | 0.44 | 0.87 | 0.80 | 0.95 | 15.98 |
| Cluster 9 | 0.72 | -0.64 | 0.03 | 0.63 | -0.20 | 0.56 | 0.00 | 30.75 |
| Cluster 10 | 0.61 | 0.95 | 0.72 | 0.69 | 0.83 | 0.86 | 18.01 |
| Cluster 11 | 0.56 | -0.56 | 0.07 | -0.73 | 0.68 | 0.23 | 0.55 | 44.67 |
| Cluster 12 | 1.02 | 1.09 | 1.35 | 1.26 | 0.92 | 1.08 | 0.80 | 19.39 |
| Cluster 13 | -0.45 | 0.85 | 0.13 | 0.07 | 0.89 | -0.05 | -0.57 | 34.10 |
| Cluster 14 | 0.98 | 0.68 | 0.65 | 0.69 | 0.66 | 0.90 | 0.63 | 14.44 |
| Cluster 15 | 0.34 | -1.26 | -0.74 | 0.26 | -0.63 | -0.19 | 0.70 | 63.94 |
| Cluster 16 | 0.78 | 0.73 | 0.77 | 0.66 | 0.80 | 0.92 | 1.05 | 10.81 |

* Kindred and white bordered values show PCS by to PCS7 of approximately (0.05): the single relationship values between the PCS1 to PCS7 values and ages (***: p < 0.01). The bold r numbers show the slightly higher or high absolute values.
mean age value in Cluster 9 of the 60s group was different from all the other eight clusters. Each mean age value of the age groups presented a significant difference (**: p < 0.01), namely, between: Each of the 30s age groups (clusters 1, 2, and 8) and each of the 40s age groups (clusters 3, 5, and 7). Each of the 40s age groups (clusters 3, 5, and 7) and each of the 50s age groups (clusters 4 and 6). Each of the 50s age groups (clusters 4 and 6) and each of the 60s age groups (clusters 1, 2, and 8).

**Approximate 30s: Clusters 1, 2, and 8**

In Cluster 1 (N = 134, mean age values = 31.26 years old), PCS2, PCS3, PCS5, and PCS6 show slightly higher positive and negative mean values (0.45 to 0.62 and -0.91 to -0.95) in Table 4. In the case of the four sum curvature mean values (Σ + Kc, Σ – Kc, Σ + He, and Σ – He) of Cluster 1 in Table 5, the main 3D curved shape features reflect the areas of the 1. neck, 2. chest, 3. back, 4. abdomen, 5. buttocks, 6. sides of trunk, and 7. arms. From the main results, the significantly higher or lower mean values (**: p < 0.01) in Table 5 are as follows: the lower elliptical (Σ + Kc) and convex (Σ + Hc) 5. abdomen curved shape, the higher hyperbolic (Σ – Kc) and concave (Σ – Hc) 7. buttocks curved shape, the lower the higher four sum curvature 8. sides of trunk curved shape, and the lower elliptical (Σ + Kc) and hyperbolic (Σ – Hc) 9. arms curved shape. The features of the 3D-body shape in Cluster 1 are represented by the different mean values on the bar graph and the colored 3D-body shape of Fig. 2. One type of the 3D-body shapes from the mean values of the 30s age group especially includes the higher convex elliptical and concave hyperbolic curved shape, indicated by the white and light blue-colored 3. chest area, with the lower convex elliptical and concave hyperbolic curved shape represented with the white- and light blue-colored 8. sides of trunk area, and the mainly lower elliptical and hyperbolic curved shape creating the white, pale red, and pale blue colors in the 10. arms area.

In Cluster 2 (N = 113, mean age values = 31.90 years old), PCS1, PCS3, PCS4, and PCS6 included the high and slightly higher positive mean values (0.50 to 1.40). The four sum curvature mean values of Cluster 2 in Tables 4 and 5 (**: p < 0.01) are presented in the features of the 1. neck, 2. shoulder, 3. chest, 6. croth, 7. buttocks, 8. sides of trunk, and 9. arms. The main features of the 3D-body shape in Cluster 2 are represented by the different mean values on the bar graph and the colored 3D-body shape of Fig. 2. Two types of the 3D-body shapes from the mean values of the 30s age group especially includes the higher convex elliptical and concave hyperbolic curved shape, indicated by the red- and dark blue-colored 3. chest area, with the lower convex elliptical and concave hyperbolic curved shape represented with the white- and light blue-colored 8. sides of trunk area, and the mainly lower elliptical and hyperbolic curved shape creating the white, pale red, and pale blue colors in the 10. arms area.
| Cluster | $N$ | Age (years) |
|---------|-----|-------------|
| Cluster 1 | 134 | 31.26 |
| Cluster 2 | 113 | 31.90 |
| Cluster 3 | 285 | 42.47 |
| Cluster 4 | 126 | 53.47 |
| Cluster 5 | 170 | 42.57 |
| Cluster 6 | 189 | 50.75 |
| Cluster 7 | 88 | 44.67 |
| Cluster 8 | 156 | 34.10 |
| Cluster 9 | 87 | 63.94 |

Fig. 2 Different $\Sigma + Kc$, $\Sigma + Hc$, $\Sigma - Kc$, and $\Sigma - Hc$ mean values between each cluster and total areas and sample 3D-body curved shape by the colored maps based on the four sum curvature values.
9. legs, and 10. arms curved shapes. The second type of the 3D-body shape for the 30s age range is displayed as follows: the higher elliptical \((\Sigma + Kc)\) and convex \((\Sigma + Hc)\) and lower concave \((\Sigma – Hc)\) 1. neck curved shape is shown in the red and whitish light blue; the lower elliptical \((\Sigma + Kc)\) and the higher hyperbolic \((\Sigma – Kc)\) and concave \((\Sigma – Hc)\) 2. shoulder curved shape is shown in the whitish light red and light blue; the higher four sum curvature 3. chest and 7. buttocks curved shapes are in the red and the dark blue; the higher elliptical \((\Sigma + Kc)\), convex \((\Sigma + Hc)\), and concave \((\Sigma – Hc)\) 6. crotch curved shape is shown in the red and light blue; the higher elliptical \((\Sigma + Kc)\) and convex \((\Sigma + Hc)\) 9. legs curved shape in the red; and the higher elliptical \((\Sigma + Kc)\) and the lower concave \((\Sigma – Hc)\) 10. arms curved shape is red. This 3D-body shape type displayed the many clear red- and dark blue-colored areas present.

In Cluster 8 \((N = 156, \text{mean age values} = 34.10 \text{years old})\), PCS1, PCS2, PCS5, and PCS7 included the higher and slightly higher positive or negative mean values (-0.45 to -0.65 and 0.80 to 0.85). The features of the 3D-body shapes in the areas of the 1. neck, 2. shoulder, 3. chest, 4. back, 5. abdomen, 7. buttocks, 8. sides of trunk, and 10. arms are displayed as the higher or lower four sum curvature mean values in Table 4 and Table 5 (**: \(p < 0.01\)). The third type of the 3D-body shapes for the 30s age group is displayed as follows: the lower hyperbolic \((\Sigma – Kc)\) and the higher convex \((\Sigma + Hc)\) 1. neck curved shape is designated in the pale light blue; the higher hyperbolic \((\Sigma – Kc)\) and lower convex \((\Sigma + Hc)\) 2. shoulder curved shape is in pale blue; the lower elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and concave \((\Sigma – Hc)\) 3. chest curved shape is shown in the whitish pale red and light blue; the lower elliptical \((\Sigma + Kc)\) and concave \((\Sigma – Hc)\) 4. back, 5. abdomen, and 10. arms curved shapes are the whitish pale red and the light blue; the higher elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and concave \((\Sigma + Hc)\) and lower concave \((\Sigma – Hc)\) 7. buttocks curved shape are designated by the separated clear red and the white; and the lower elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and convex \((\Sigma + Hc)\) 8. sides of trunk curved shape painting is the whitish pale red and light blue. Furthermore, these feature mean values in Cluster 8 were approximately lower than those mean values of other clusters, except for those mean values in Cluster 3.

The 3D-body shape features of the three types for the 30s age group were as follows: Cluster 1 has the type in which the 3. chest area is the high convex elliptical and concave hyperbolic curved shape but the other areas have the low convex elliptical and the concave hyperbolic 8. sides of trunk curved shape and the lower convex elliptical 10. arms curved shape; Cluster 2 is the high or slightly higher 3D curved shape type which has the convex elliptical and the concave hyperbolic 3. chest and 7. buttocks, the convex and concave elliptical 6. crotch, and the convex elliptical 9. legs; and Cluster 8 has the low 3D curved shape type except for the higher 7. buttocks curved shape, which is the convex elliptical and the hyperbolic 3. chest and 8. sides of trunk, and the concave elliptical 5. abdomen.

**Approximate 40s: Clusters 3, 5, and 7**

In the case of the features of the 3D-body shape for the 40s age group in Clusters 3, 5, and 7, Cluster 3 \((N = 285, \text{mean age values} = 42.47 \text{years old})\), with the large number of 285 models, shows the nearly standard 3D-body shape type by the only lower PCS3 mean values and the low different mean values on the many areas because of the mean values of all clusters in Fig. 2. Furthermore, there were the slightly lower elliptical \((\Sigma + Kc)\) and convex \((\Sigma + Hc)\) 1. neck, 3. chest, 4. back, and 5. abdomen curved shapes shown by the pale red and light blue colors, the slightly low elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), convex \((\Sigma + Hc)\), or concave \((\Sigma – Hc)\) 6. crotch to 10. arms curved shape, creating the whitish or pale red and light blue; the higher hyperbolic \((\Sigma + Kc)\) and concave \((\Sigma – Hc)\) 1. neck curved shape shown in the light blue; and the higher elliptical \((\Sigma + Kc)\) and convex \((\Sigma + Hc)\) 2. shoulder curved shape in the red and dark blue.

While the feature specifics of the 3D-body shapes in Cluster 5 and 7 were confirmed by the 2. shoulder, 4. back, 8. sides of trunk, and 10. arms areas, Cluster 5 \((N = 170, \text{mean age values} = 42.57 \text{years old})\) shows the positive PCS5 (0.68) and PCS7 (0.90) mean values. The 3D surfaces display the lower elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and convex \((\Sigma + Hc)\) 2. shoulder curved shape, as shown with the whitish pale red and the pale blue; the lower four sum curvature 4. back curved shape in the whitish pale red and the light blue; and the higher elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and convex \((\Sigma + Hc)\) 8. sides of trunk and 10. arms curved shapes creating the red and the light blue.

Conversely, Cluster 7 \((N = 88, \text{mean age values} = 44.67 \text{years old})\) includes the total higher or lower PCS mean values (-0.56 to -2.25 and 0.55 to 0.97), except for PCS6 mean values. Cluster 7 especially represents the higher elliptical \((\Sigma + Kc)\), hyperbolic \((\Sigma – Kc)\), and convex \((\Sigma + Hc)\) 2. shoulder and 4. back curved shape, shown in the pale red and the light blue in wide areas.

Moreover, physical symmetry was seen in Cluster 7, similar to the difference between right and left shoulder height and back areas in Fig. 2. The unevenness of the ages in Cluster 7 is the highest, with an SD value of 19.39 years old ranging from 18 to 84 years old. The 3D curved shape features of Cluster 7 are influenced by poor posture. Hereafter, posture—including round shoulders and laterality, etc.—need to be examined by means of the 3D-body shapes and the coordinates of the point \((X, Y, Z)\).

The 3D-body shape features of the three types for the 40s age group are as follows: Cluster 3 is the nearly standard 3D curved shape type with the higher four sum curved 1. neck and 2. shoulder shapes and the slightly lower curved in many areas shapes; Cluster 5 has the low 3D curved shape type except for the higher or slightly higher 8. sides of trunk and 10. arms curved shapes; and Cluster 7 has the feature 3D curved shape about 2. shoulder and 5. back with the higher convex elliptical and hyperbolic curves as a result of postures.

**Approximate 50s: Clusters 4 and 6**

In the case of the features of the 3D-body shape for the 50s age
group in Clusters 6 and 4, Cluster 6 (N = 189, mean age values = 50.75 years old) shows positive PCS4 (0.83) and PCS6 (0.56) with negative PCS1 (-0.72) and PCS2 (-0.54), while Cluster 4 (N = 126, mean age values = 53.47 years old) has positive PCS1 (1.03) and PCS5 (0.51) with negative PCS2 (-0.69), PCS6 (-0.61), PCS7 (-0.87).

Cluster 6 displays the higher elliptical (Σ + Kc), hyperbolic (Σ – Kc), and convex (Σ + Hc) 1. neck and 2. shoulder curved shape, shown in the pale red and the light blue; the higher elliptical (Σ + Kc) and convex (Σ + Hc) 5. abdomen curved shape is red; and 3. chest, 4. back, 7. buttocks, 8. sides of trunk, and 10. arms curved shape with the two or three combination low values of the elliptical (Σ + Kc), hyperbolic (Σ – Kc), convex (Σ + Hc), and concave (Σ – Hc) are represented by the pale red and dark blue.

Cluster 4 included all the lower curved (Σ + Kc, Σ – Kc, Σ + Hc, and Σ – Hc) 2. shoulder shape, creating the almost white or pale; the higher elliptical (Σ + Kc) and convex (Σ + Hc) 3. chest curved shape is the top red and the surrounding light blue; the higher elliptical (Σ + Kc) and convex (Σ + Hc) 5. abdomen curved shape is the red and light blue; the higher elliptical (Σ + Kc) and convex (Σ + Hc) with the lower hyperbolic (Σ – Kc) and concave (Σ – Hc) 7. buttocks curved shape creating the pale red and whitish light blue; the higher hyperbolic (Σ – Kc) and the lower concave (Σ – Hc) 8. sides of trunk curved shape shown in the pale red and light blue; and the higher elliptical (Σ + Kc) and hyperbolic (Σ – Kc) with the lower convex (Σ + Hc) 9. legs and 10. arms curved shapes are in the red and dark blue.

The 3D-body shape features of the two types for the 50s age group were extracted as follows: Clusters 6 and 4 had the 3D common body shapes of the higher convex elliptical 5. abdomen, while the high and low 3D-body shapes were reversed in some features. Cluster 6 was the low 3D-body shape type, which is the areas of the 3. chest, 4. back, 7. buttocks, 8. sides of trunk, and 10. arms, with the low being some curvature values except for the higher convex elliptical and hyperbolic 1. neck and 2. shoulder curved shapes and the higher convex elliptical 5. abdomen curved shape. Cluster 4 had the high 3D-body shape type which is the 3. chest, 4. back, and 5. abdomen, with some high curvature values aside from the lower four curvatures 2. shoulder curved shapes and the areas of the 7. buttocks, 8. sides of trunk, 9. legs, and 10. arms which have some lower curvature values.

Approximate 60s: Cluster 9

In Cluster 9 (N = 87, mean age values = 63.94 years old) for the 60s age group, PCS2, PCS3, PCS5, and PCS7 included the higher and slightly higher positive or negative mean values (-0.63 to -1.26 and 0.70). The features of the 3D curved shape show the higher or lower hyperbolic (Σ – Kc), convex (Σ + Hc), and concave (Σ – Hc) reverse 1. neck and 2. shoulder shaped curves, creating the slightly dark blue and the whitish blue; the higher elliptical (Σ + Kc), hyperbolic (Σ – Kc), and the lower convex (Σ + Hc) 3. chest curved shape is shown by the pale red and light blue; the higher elliptical (Σ + Kc) and the convex (Σ + Hc) 5. abdomen and 10. arms curved shapes are indicated in red; the lower four curvature 7. buttocks curved shape are in the white and pale red; the higher four curvature 8. sides of trunk curved shape is in the clearly red and light blue; the lower elliptical (Σ + Kc), the convex (Σ + Hc), and the higher hyperbolic (Σ – Kc) 9. legs curved shape is shown in red and dark blue.

The 3D-body shape features of the 60s age group demonstrated the higher convex elliptical 5. abdomen, the lower all sum curvature 7. buttocks, the higher all sum curvature 8. sides of trunk, the lower convex elliptical, and the higher hyperbolic 9. legs curved shapes.

The features of the 3D curved shapes in the 5. abdomen and 7. buttocks areas show the same trend according to ages as the 3D tight-skirt curved shapes of the 1,044 females [17]. Although we extracted the 3D-body shape types, some problems exist regarding 3D-body length sizes, 3D-body shape images, 2D pattern development using the 3D convex bodice model, etc., including male garments.

4. Conclusions

In an effort to create a personalized 3D dressmaker’s model with an individualized curved surface shape for custom-made garments, the 3D curved surface shapes of 1,348 females from a wide-ranging age group were investigated using each four sum angle curvatures—elliptical (Σ + Kc), hyperbolic (Σ – Kc), convex (Σ + Hc), and concave (Σ – Hc) curved shapes—in ten body areas. In each vertex point on the 3D-body interior surface, the Kc demonstrated the concentrated Gaussian curvature (by Kc = 360° (2π) – Σθn) on the interior area vertexes, while Hc showed the concentrated mean curvature (by Hc = Σθn /Li on the interior area vertexes).

The features of the standard 3D-body shape were represented by using the mean angle values of the ten areas. All ten areas formed the higher convex (Σ + Hc) curved shapes, while a few had concave (Σ – Hc) curved shapes. The neck and crotch areas showed the main the hyperbolic (Σ – Kc) and convex (Σ + Hc) curved shapes, and the shoulder and sides of trunk had all four curved shapes with the higher convex (Σ + Hc). Although the chest, back, abdomen, and buttocks areas displayed the main elliptical (Σ + Kc) and convex (Σ + Hc) curved shapes, the feature of the chest curved shape included the higher Σ + Kc and Σ + Hc values and the higher different values between Σ + Hc and Σ – Hc. The legs and arms areas show the main elliptical (Σ + Kc), hyperbolic (Σ – Kc), and higher convex (Σ + Hc) curved shapes.

The seven principal components (PC1 to PC7) were extracted by each four sum angle curvatures in each area by means of the PCA according to the mutual correlation coefficients. The eigenvalues of 1.800 or more are presented and comprised 51.495 % of the cumulative contribution ratio. The seven components were as follows: PC1; the 2. shoulder and 3. chest areas, PC2; 5. abdomen
and 7. buttocks areas in the front and back lumbar region, PC3; the 2. back curved shape areas, PC4; the 1. neck and 2. back areas, PC5; the 3. chest and 10. arms areas, PC6; the 1. neck area, and PC7; the 8. sides of trunk and 10. arms areas.

The 3D-body shapes of the 1,348 females are categorized into 9 clusters by PCS1 to PCS7 of the scores for PC1 to PC7. The mean age values of the 9 clusters separated approximately 30s of Clusters 1, 2, and 8, the approximately 40s of Clusters 3, 5, and 7, the 50s of Clusters 9 and the approximately 60s of Cluster 9.

The three 3D-body shape types of the 30s age group were as follows: Cluster 1 (N = 134, mean age values = 31.26 years old); the 3D curved surface shape of the higher convex elliptical and concave hyperbolic 3. chest area but the other the areas of the low convex elliptical and the concave hyperbolic 8. sides of trunk area and the lower convex elliptical 10. arms area; Cluster 2 (N = 113, mean age values = 31.90 years old); the high 3D curved surface shape of the higher convex elliptical and the concave hyperbolic 3. chest and 7. buttocks areas, the higher convex and concave elliptical 6. crotch areas, and the higher convex elliptical 9. legs area; Cluster 8 (N = 156, mean age values = 34.ten years old); the low 3D curved surface shape of the convex elliptical and the hyperbolic 3. chest and 8. sides of trunk areas, and the concave elliptical 5. abdomen area.

The three 3D-body shape types of the 40s age group were as follows: Cluster 3 (N = 285, mean age values = 42.47 years old); the nearly standard 3D curved shape of the higher four curved 1. neck and 2. shoulder areas and the slightly lower curved many areas; Cluster 5 (N = 170, mean age values = 42.57 years old); the low 3D curved shape except for the higher or slightly higher curved 8. sides of trunk and 10. arms areas; Cluster 7 (N = 88, mean age values = 44.67 years old); the 3D curved shape of the higher convex elliptical and hyperbolic 2. shoulder and 5. back areas with relation to posture.

The two 3D-body shape types with the common higher convex elliptical 5. abdomen of the 50s age group were as follows: Clusters 6 (N = 189, mean age values = 50.75 years old); the main low 3D-body shape type of the lower some curved the 3. chest, 4. back, 7. buttocks, 8. sides of trunk, and 10. arms areas and the higher some curved 1. neck, 2. shoulder, and 5. abdomen areas; Clusters 4 (N = 126, mean age values = 53.47 years old); the high 3D-body shape of the higher some curved the 3. chest, 4. back, and 5. abdomen areas.

The 3D-body shape type of the 60s age group is shown in Clusters 9 (N = 87, mean age values = 63.94 years old) of the higher convex elliptical 5. abdomen area, the lower all four curved 7. buttocks area, the higher all four curved 8. sides of trunk area, and the lower convex elliptical and the higher concave 9. legs area.

The information of the female 3D-body shape type could be determined based on the 3D curved surface shape and individual age by using the angle curvatures.

Acknowledgements
This work was supported by JSPS KAKENHI Grant-in-Aids for Scientific Research Numbers of (A) No. 22240075 (2010–2012), (B) No. 25282013 (2013–2015), (C) No. 15K00759 (2016–2018), (B) No. 18H00964 (2018–2020), and JST A-Step (2017–2018). Furthermore, part of the 3D-body data was retrieved through a collaborative research process with Onward Holdings Co., Ltd.

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Journal of Textile Engineering (2019), Vol.65, No.4, 55 – 65