Extraction of 3D Tight and Flared Skirt Curved Shapes by Relating Sensitivity Images and Physical Properties with 3D Curvature Values

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Received 15 May 2017; accepted for publication 22 September 2017

Abstract

The 72 3D skirt curved shapes, including the tight and 3 kinds of flared skirts, on 6 kinds of fabrics, were categorized by using the both evaluations of both sensitivity images and the physical properties for the fabrics and designs of the skirt. The sensitivity image evaluations by 80 young Japanese women were adopted into the five fabric and the six design curved shape images, while the eight design curved shape parameters and the six fabric curved shape parameters were adopted using the physical properties. Both evaluation values of the 72 skirts were analyzed using the principal component analysis (PCA), and the four PC scores were classified into four skirt curved shape types. Three flared skirt types (9 all hem length flared skirts of thin and light fabric F, 22 high hem length flared skirts, and 23 low hem length flared skirts) are part of the Lady & Feminine Image Style, which uses the different fabric curved shape images and physical property parameter values with the 3D curvatures. While the low hem length type of 18 all tight skirts is the Sharp & Modern Image Style with high tension, hard skirt shape, and the small flare node images that are based mainly on the low 3D curvature values. Furthermore, the predictions of the seven sensitivity images using the measurable physical property parameter values of the skirts were confirmed.

Key Words: 3D skirt curved shape, Sensitivity image, Physical property, Classification of skirts, Prediction of skirt shape images

1. Introduction

It is well known that the skirt fabric shape factors are extracted based on the fabric’s dynamic characteristics and sensitivity image evaluations using the subjective assessments in many previous reports [1-6]. In a previous report [7], the investigation of the 3D (three-dimensional) tight-fitting skirt curved shape was developed based on a virtual reality skirt of a made-to-order system without the fabric’s physical properties, and the four 3D tight-fitting skirt curved shape types were categorized using 3D curvatures of $Kc$ and $kc$ (where $Kc$ is the concentrated Gaussian curvature and $kc$ is the concentrated geodesic curvature) of the individual tight-fitting skirts of 1,044 females. Meanwhile, the features of the real 72 3D skirt curved shapes and drape parameters were examined for the physical properties of the design and fabric factors of the tight and 3 kinds of flared skirts (flare 1, flare 2, and flare 3) and the 6 kinds of fabric for the 3 body model shapes (bodies of women in 20s, 40s, and 70s [8-10]), using an angle curvature method that references the 3D curvature parameters of $|\Sigma Kc|+|\Sigma kc|$ (CKn) and $|\Sigma Hc|$ (CHn, where $Hc$ is the concentrated mean curvature) and the conventional fabric parameters Mn in a previous report [11] (see appendix Fig. Ⅰ, and Fig. Ⅱ). We revealed the usefulness of the 3D curvatures $Kc$, $kc$, and $Hc$ using the common angles for extracting the features of many virtual reality 3D tight-fitting skirt shapes [7] and for predicting the nodes on the 72 3D tight and flared skirt hemlines in physical properties [11]. However, there is no report concerning both the sensitivity images and the physical properties of the many real skirt 3D curved shapes for the fabrics, female body model sizes, and the 3D curvatures of the common angles.

In this research, the features of the fabric and design curved skirt shapes in both the sensitivity images’ DEn and the physical properties of CKn, CHn, and Mn [11] are examined for the purpose of extracting the useful data and information to develop a made-to-order system for a virtual-reality skirt that uses a real skirt shape and

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that supports communication between the retailers and consumers. We are able to realize the classification for extracting the 3D skirt curved shape types based on both the DE1 and the CKn, CHn, and Mn of the 72 real 3D skirt curved shapes. Furthermore, the predictions of the sensitivity images of the 72 3D skirt curved shapes are investigated using the physical property parameters of the 3D curvatures of the angle values and the conventional fabric parameters based on multiple correlation analysis.

2. Experimental Method

1) The 72 3D skirts are constructed by 3 Japanese women in their 20s, 40s, and 70s body models [8-10], 6 kinds of fabrics (cotton broad (A), tropical wool (B), tropical polyester (C), cotton toile (D), polyester single-yarn twill (E) and polyester faille (F)), with a total 12 skirt patterns for the 4 skirt styles, (tight, flare 1, flare 2, and flare 3 skirts) in previous paper [11], as shown in appendix Fig. 1 and Table 1. The 3D skirt curved shapes on the 3 models are measured by using a non-tactile 3D body measuring instrument (Body Line Scanner C9036-02, Hamamatsu Photonics Co., Ltd.). The nine-layer horizontal cross sections of the 3D skirts are displayed in appendix Fig. 3.

2) The sensitivity images’ DEn for the 72 skirt photographs (scale of 1 to 7), as shown in Table 2 and Fig. 1, are evaluated for the fabric curved shape images of DE1 to DE5 using the semantic differential (SD) method and the design curved shape images of DE6 to DE11 using the five-grade evaluation system method. The five fabric curved shape images are DE1. Tension (Low – High), DE2. Skirt shape (Soft – Hard), DE3. Flared node size (Small – Large), DE4. Flared node (Non uniform – Uniform), and DE5. Flared node (Not Acceptable – Fine), and the six design sensitivity images are DE6. Lady & Feminine Image Style, DE7. Sharp & Modern Image Style, DE8. Casual Image Style, DE9. Standard & Retro Image Style, DE10. Elegant Image Style, and DE11. Gorgeous Image Style in a previous report for the evaluating images of 3D female garments [12]. The respondents for the 11 DEn evaluations are 80 young females, ages 18 to 23.

3) The physical properties of the 3D curvature parameters CKn and CHn, and the conventional fabric parameter for Mn are as follows. CKn and CHn show the design curved shape parameters of CK1 to CK4 (|Σ±Kc|+|Σ±kc|) and CH1 to CH4 (|Σ±Hc|) in each area of the back, front, sides of the right and left, and all total areas of the 72 skirts, and Mn represents the fabric curved shape parameters M1 to M6 [11] (see Table 2, appendix Fig. 1 and appendix Fig. II). The 3D curvatures Kc, kc, and Hc of CKn and CHn in appendix Fig. II were found using the angles of the mesh triangles on the 72 3D skirts.

4) The angle values of those curvatures were calculated by computer from the coordinates (X, Y, Z) of 300 vertexes on each of the 72 3D skirts using the same previously used 3D measuring instrument.

5) The DEn, CKn, CHn, and Mn values of the 72 skirts are analyzed and correlated with the five fabric curved shape images DE1 to DE5 and the six design curved shape images DE6 to DE11.

3. Results and Discussion

3.1 Relationships between the fabric and design curved shape images

Table 1 shows single correlation values (Spearman’s rank correlation coefficient method) for the five fabric curved shape images DE1 to DE5 and the six design curved shape images DE6 to DE11.

| Image items                          | DE1. Tension (Low – High) | DE2. Skirt shape (Soft – Hard) | DE3. Flared node size (Small – Large) | DE4. Flared node (Non uniform – Uniform) | DE5. Flared node (Not acceptable – Fine) |
|--------------------------------------|---------------------------|-------------------------------|--------------------------------------|----------------------------------------|-----------------------------------------|
| DE6. Lady & Feminine Image Style     | -0.67 **                  | -0.72 **                      | 0.59 **                              | 0.09                                   | 0.64 **                                 |
| DE7. Sharp & Modern Image Style      | 0.78 **                   | 0.79 **                       | -0.57 **                             | 0.37 **                                | 0.00                                    |
| DE8. Casual Image Style              | -0.63 **                  | -0.65 **                      | 0.54 **                              | -0.14                                  | 0.32 **                                 |
| DE9. Standard & Retro Image Style    | 0.69 **                   | 0.72 **                       | -0.40 **                             | 0.49 **                                | 0.19                                    |
| DE10. Elegant Image Style            | -0.34 **                  | -0.39 **                      | 0.30 **                              | 0.41 **                                | 0.77 **                                 |
| DE11. Gorgeous Image Style          | -0.69 **                  | -0.72 **                      | 0.67 **                              | 0.11                                   | 0.56 **                                 |

Bold values show significant correlation coefficients ( **; p < 0.01, *; p < 0.05)
The three fabric curved shape images of DE1 to DE3 had significant relationships with all six design curved shape images of DE6 to DE11. The DE1. Low tension, DE2. Soft skirt shape, and DE3. Large flared node size fabric curved shape images represented the trend of DE6. Lady & Feminine Image Style \( (r = -0.67, r = -0.72, \text{and } r = 0.59) \), DE8. Casual Image Style \( (r = -0.63, r = -0.65, \text{and } r = 0.54) \), DE10. Elegant Image Style \( (r = -0.34, r = -0.39, \text{and } r = 0.30) \), and DE11. Gorgeous Image Style \( (r = -0.69, r = -0.72, \text{and } r = 0.67) \) design curved shape images. Conversely, the DE1. High tension, DE2. Hard skirt shape, and DE3. Small flared node size fabric curved shape images indicated the trend of DE7. Sharp & Modern Image Style \( (r = 0.78, r = 0.79, \text{and } r = -0.57) \) and DE9. Standard & Retro Image Style \( (r = 0.69, r = 0.77, \text{and } r = -0.40) \) design curved shape images.

However, the fabric curved shape images of DE4 and DE5 did not have significant relationships with all six design curved shape images of DE6 to DE11. The DE4. Uniform flared node fabric curved shape image somewhat displayed the trend of the DE7. Sharp & Modern Image Style \( (r = 0.37) \), DE9. Standard & Retro Image Style \( (r = 0.49) \), and DE10. Elegant Image Style \( (r = 0.41) \) design curved shape images. The DE5. Fine flared node fabric curved shape image arrived at the trend of DE6. Lady & Feminine Image Style \( (r = 0.64) \), DE8. Casual Image Style \( (r = 0.32) \), DE10. Elegant Image Style \( (r = 0.77) \), and DE11. Gorgeous Image Style \( (r = 0.56) \) design curved shape images.

The DE6. Lady & Feminine, DE8. Casual, DE10. Elegant, and DE11. Gorgeous Image Style design curved shape images with the DE5. Fine flared node fabric image were formed by the DE1. Low tension, DE2. Soft skirt shape, and DE3. Large flared node size fabric curved shape images. The DE1. High tension, DE2. Hard skirt shape, DE3. Small flared node size, and the DE4. Uniform flared node fabric curved shape images were used to evaluated the DE7. Sharp & Modern and DE9. Standard & Retro design sensitivity images.

We were able to determine that the fabric curved shape images of DE1 to DE3 influenced the design curved shape images of DE6 to DE11. Furthermore, the design curved shape images of DE6, DE10, and DE11 were affected by the fabric curved shape image of DE5.

### Table 2  Factor loadings of sensitivity images and physical properties for 72 3D skirt

| Evaluated items | PC1     | PC2     | PC3     | PC4     | PC5     |
|-----------------|---------|---------|---------|---------|---------|
| Fabric curved shape images |         |         |         |         |         |
| DE1. Tension (Low → High) | -0.904 | 0.062  | 0.145  | 0.300  | 0.034  |
| DE2. Skirt shape (Soft → Hard) | -0.908 | 0.062  | 0.079  | 0.337  | 0.009  |
| DE3. Flared node size (Small → Large) | 0.703 | 0.436  | -0.036 | -0.331 | -0.041 |
| DE4. Flared node (Non uniform → Uniform) | -0.270 | -0.033 | 0.048  | 0.034  |         |
| DE5. Flared node (Not acceptable → Fine) | 0.272 | -0.014 | 0.924  | -0.041 | -0.007 |
| Sensitivity images |         |         |         |         |         |
| DE6. Lady & Feminine Image Style | 0.840 | 0.117  | 0.325  | -0.338 | -0.103 |
| DE7. Sharp & Modern Image Style | -0.837 | -0.131 | 0.232  | 0.302  | 0.019  |
| DE8. Casual Image Style | 0.742 | 0.188  | 0.040  | -0.549 | -0.125 |
| DE9. Standard & Retro Image Style | -0.650 | 0.057  | 0.504  | 0.219  | -0.150 |
| DE10. Elegant Image Style | 0.501 | 0.033  | 0.743  | -0.009 | -0.124 |
| DE11. Gorgeous Image Style | 0.887 | 0.172  | 0.338  | 0.041  | -0.042 |
| Design curved shape images |         |         |         |         |         |
| CK1. \( |x|=Kc; |y|=ak \) in back area | 0.796 | -0.018 | 0.005  | 0.514  | 0.014  |
| CK2. \( |x|=Kc; |y|=ak \) in front area | 0.849 | -0.104 | -0.097 | 0.394  | -0.039 |
| CK3. \( |x|=Kc; |y|=ak \) in side area | 0.754 | -0.171 | -0.090 | 0.494  | -0.079 |
| CK4. \( |x|=Kc; |y|=ak \) in all total of area | 0.850 | -0.109 | -0.067 | 0.499  | -0.040 |
| Design parameters |         |         |         |         |         |
| CH1. \( |x|=Hc \) in back area | 0.925 | 0.018  | 0.015  | 0.254  | 0.008  |
| CH2. \( |x|=Hc \) in front area | 0.968 | -0.053 | -0.082 | 0.065  | 0.012  |
| CH3. \( |x|=Hc \) in side area | 0.969 | -0.083 | 0.027  | 0.071  | 0.035  |
| CH4. \( |x|=Hc \) in all total of area | 0.983 | -0.043 | -0.013 | 0.128  | 0.020  |
| Physical properties |         |         |         |         |         |
| Fabric curved shape parameters |         |         |         |         |         |
| M1. Number of nodes N | 0.947 | -0.063 | -0.043 | -0.137 | -0.025 |
| M2. Thickness | -0.161 | 0.933  | -0.079 | 0.165  | -0.120 |
| M3. Weight | -0.043 | 0.484  | 0.128  | 0.011  | 0.848  |
| M4. Bending rigidity | -0.150 | 0.930  | -0.023 | 0.140  | -0.064 |
| M5. Drape Ds | -0.143 | 0.861  | -0.116 | 0.164  | -0.356 |
| M6. Weight=skirt hem length | 0.846 | 0.344  | 0.031  | 0.081  | 0.855  |
| Eigenvalues | 13.79  | 3.20   | 2.72   | 1.98   | 1.07   |
| Contribution ratios (%) | 55.15  | 12.78  | 10.89  | 7.91   | 4.29   |
| Cumulative contribution ratios (%) | 55.15  | 67.93  | 78.82  | 86.73  | 91.02  |

Bold values show factor loading of approximately |\( >=0.5 \)| (rounded off to one decimal place) or more.
3.2 Principal components of the sensitivity image and the physical property evaluation values

The comprehensive principal components of the values for the sensitivity images’ DEn and the physical properties CKn, CHn, and Mn of the 72 3D skirt curved shapes were examined by means of PCA. The quantification mean values of the sensitivity image’ DEn values of 80 females were applied to PCA. Table 2 shows the factor loadings of the principal components PC1 to PC5 of DEn, CKn, CHn, and Mn values. The total cumulative contribution ratio was high 91.02% (Eigenvalues > 1.0). Each factor was extracted as follows.

PC1 involved the high or slightly higher positive values (0.501 to 0.983) of the fabric curved shape image DE3, the design curved shape images of DE6, DE8, DE10, and DE11, the design curved shape parameters of CK1 to CK4, CH1 to CH4, and the fabric curved shape parameters of M1 and M6. The high or slightly higher negative values (-0.650 to -0.908) were found for the fabric curved shape images of DE1 and DE2 and the design curved shape images DE7 and DE9. PC1’s eigenvalue was 13.79, and it accounts for 55.15% of the higher contribution ratio.

PC1 represented the comprehensive and detailed features of the 72 3D skirt curved shapes for the sensitivity image and physical property evaluations. The higher PCS1 values indicated DE6. Lady & Feminine, DE8. Casual, DE10. Elegant, and DE11. Gorgeous Image Style images with DE1. Low tension, DE2. Soft skirt shape, and DE3. Fine flared node images based on the high values of mainly |Σ±Kc| and DE3. Large flared node images based on the high values of |Σ±Kc|. The higher PCS3 values indicated DE7. Sharp & Modern and DE9. Standard & Retro Image Style image and the slightly higher positive values of CK1 and CK4. The higher PCS4 values were vice versa for DE8 and |Σ±Kc|.

PC2 included the high or slightly higher positive values of the fabric curved shape parameters of M2 to M5. The higher PCS2 values indicated the high or slightly higher values of M2. Thickness, M3. Weight, M4. Bending rigidity, and M5. Drap Ds, and the lower PCS2 values were vice versa for M2 to M5. PC2’s eigenvalue was 3.20, and it accounts for 12.78% of the contribution ratio. PC2 represents the physical factor of the the fabric curved shape parameters.

PC3 involved the high or slightly higher positive values of the sensitivity images of DE4, DE5, DE9, and DE10. The higher PC3’s eigenvalue was 2.72, which accounts for 10.89% of the contribution ratio. The higher PCS3 values indicated DE9. Standard & Retro and DE10. Elegant Image Style images with DE4. Uniform flared node and DE5. Fine flared node images, and the lower PCS3 values were vice versa for DE4, DE5, DE9, and DE10. PC3 represents the sensitivity image factor of the high or low skirt images for the Elegant and Standard & Retro Image Style with good or no-good fabric curved shape images for the flared node. Although the fabric curved shape images of DE4 and DE5 were not extracted in the PC1, the two fabric curved shape images were recognized for the design curved shape images of DE9 and DE10, including the single correlation coefficients (r = 0.41 to r = 0.77) in Table 1.

PC4 had the slightly higher negative values of DE8. Casual Image Style image and the slightly higher positive values of CK1 to CK4, except for CK2 in the front area. PC4’s eigenvalue was 1.98, and it accounts for 7.91% of the slightly low contribution ratio. The lower PCS4 values indicated DE8. Casual Image Style design image with the higher values of mainly |Σ±Kc|, and the higher PCS4 values were vice versa for DE8 and |Σ±Kc|. PC4 represents the factor of the high or low Casual Image Style design shape image by reflecting the low or high design curved shape parameter |Σ±Kc|.

PC5 included only the high positive value of M3. Weight. PC5’s eigenvalue was 1.07, and it accounted for 4.29% of the low contribution ratio. The four factors of PC1 to PC4 were confirmed in both the sensitivity images’ DEn for fabric and design curved shape images, and the physical properties CKn, CHn, and Mn of the design and fabric curved shape parameters in the tight and flared skirt shapes. Therefore, the detailed features of the 72 3D skirt curved shapes were researched using the four PC scores.

Table 3  Mean values of the PCS1 to PCS4 and 72 3D skirts in each cluster.

| Clusters | PCS1 | PCS2 | PCS3 | PCS4 | Skirts |
|----------|------|------|------|------|--------|
| Cluster 1 | 0.77 | -1.77 | -0.45 | -0.34 | N=9 20F1 to 20F3 40F1 to 40F3 70F1 to 70F3 |
| Cluster 2 | 0.85 | 0.57 | -0.37 | 0.56 | N=22 20A3 to 20E3 40A3 to 40E3 40A2, 40D2 70A3 to 70E3 70A2, 70B2, 70D2,70E2,70A1 |
| Cluster 3 | -0.03 | 0.43 | 0.47 | -1.04 | N=23 20A1 to 20E1 40A1 to 40E1 40B2, 40C2, 40E2 70B1 to 70E1 |
| Cluster 4 | -1.38 | -0.36 | 0.07 | 0.81 | N=18 20A0 to 20F0 40A0 to 40F0 70A0 to 70F0 |

Abbreviations of the varieties of skirts: 20, 40, and 70 = 20s, 40s, and 70s models, 0 = tight skirts, 1 to 3 = flare 1 to flare 3 skirts, A to F; fabrics. Underlined and bold mean values show approximately |σ=0.6|. (rounded off to one decimal place) or more.
3.3 Classification of the 72 3D skirt curved shapes using the sensitivity images and the physical properties

The four PC scores (PCS1 to PCS4) were categorized into four clusters representing the 4 skirt curved shape types by using cluster analysis in Table 3. Fig. 1 illustrates the samples of the skirts and the nine-layers horizontal cross sections of the 3D skirts of appendix Fig. 1. The mean values and the significance test (**; p<0.01, *; p<0.05) for each cluster of DEn, CKn, CHn, and Mn are represented in Table 4.

Cluster 1 (N=9, all hem length flared skirts of fabric F): The positive PCS1 and high negative PCS2 values determined the skirt features (see Table 3). The features of Cluster 1 were indicated by the low M2 to M5 values in Table 4 from the high negative PCS2 value (-1.77), and the low DE1 and DE2 values and the high values of DE6, CK1 to CK4, CH1 to CH4, and M1 from the positive

| Table 4 | Mean values of the Dn, CKn, CHn, and Mn in each cluster. |
|---------|----------------------------------------------------------|
| Fabric curved shape images | Evaluated items | Means | t-test (Clus: Cluster) |
| | | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Clus 1 | Clus 1 | Clus 2 | Clus 2 | Clus 3 | Clus 3 | Clus 4 | Clus 4 |
| DE1. Tension (Low — High) | 7.30 | 6.77 | 2.98 | 4.21 | | | | | | | | | |
| DE2. Skirt shape (Soft — Hard) | 7.17 | 6.28 | 2.71 | 4.13 | | | | | | | | | |
| DE3. Flared node size (Small — Large) | 3.00 | 3.65 | 3.46 | 2.18 | | | | | | | | | |
| DE4. Flared node (Non uniform — Uniform) | 2.96 | 2.97 | 3.38 | 3.47 | | | | | | | | | |
| DE5. Flared node (Not acceptable — Fine) | 3.01 | 3.05 | 3.36 | 3.00 | | | | | | | | | |
| DE6. Lady & Feminine Image Style | 3.82 | 3.80 | 3.87 | 2.94 | | | | | | | | | |
| DE7. Sharp & Modern Image Style | 2.30 | 2.27 | 2.58 | 3.66 | | | | | | | | | |
| DE8. Casual Image Style | 2.79 | 2.76 | 2.82 | 2.17 | | | | | | | | | |
| DE9. Standard & Retro Image Style | 3.08 | 3.10 | 3.24 | 3.44 | | | | | | | | | |
| DE10. Elegant Image Style | 3.06 | 3.07 | 3.14 | 2.87 | | | | | | | | | |
| DE11. Gorgeous Image Style | 2.62 | 2.85 | 2.58 | 2.04 | | | | | | | | | |
| Design curved shape images | | | | | | | | | | | | | |
| CK1. | | 257.16 | 317.83 | 155.76 | 149.62 | | | | | | | |
| CK2. | | 278.10 | 287.15 | 153.55 | 119.89 | | | | | | | |
| CK3. | | 476.47 | 473.79 | 320.26 | 321.02 | | | | | | | |
| CK4. | | 1011.73 | 1078.77 | 629.57 | 590.53 | | | | | | | |
| CH1. | | 1231.49 | 1353.61 | 754.26 | 301.34 | | | | | | | |
| CH2. | | 1482.49 | 1462.95 | 947.76 | 338.42 | | | | | | | |
| CH3. | | 2174.72 | 2183.91 | 1638.58 | 992.52 | | | | | | | |
| CH4. | | 4888.70 | 5000.47 | 3340.59 | 2722.29 | | | | | | | |
| Design cured shape parameters | | | | | | | | | | | | | |
| CK1. 2xKk | | 9.56 | 8.55 | 6.52 | 1.72 | | | | | | | |
| CK2. 2xKk | | 9.63 | 0.67 | 0.43 | 0.41 | | | | | | | |
| CH1. 2xKk | | 104.50 | 136.96 | 138.02 | 131.97 | | | | | | | |
| CH2. 2xKk | | 3.89 | 10.21 | 9.53 | 8.53 | | | | | | | |
| CH3. 2xKk | | 28.78 | 62.77 | 58.29 | 55.73 | | | | | | | |
| CH4. 2xKk | | 19091.84 | 30049.94 | 22047.88 | 12440.06 | | | | | | | |
| Fabric cured shape parameters | | | | | | | | | | | | | |
| M1. Number of nodes N | | 9.56 | 5.55 | 6.52 | 1.72 | | | | | | | |
| M2. Thickness | | 0.23 | 0.47 | 0.43 | 0.41 | | | | | | | |
| M3. Weight | | 104.50 | 136.96 | 138.02 | 131.97 | | | | | | | |
| M4. Rounding rigidity | | 3.89 | 10.21 | 9.53 | 8.53 | | | | | | | |
| M5. Drape Ds | | 28.78 | 62.77 | 58.29 | 55.73 | | | | | | | |
| M6. Weight/skirt hem length | | 19091.84 | 30049.94 | 22047.88 | 12440.06 | | | | | | | |

Underlined values show significant minimum means with the proviso that the DEn means is approximately 2.5 or less. Bold values show significant maximum means with the proviso that the DEn means is approximately 3.5 or more. (** : p<0.01; * : p<0.05)
PCS1 value (0.77). Furthermore, the all 9 flared skirts of flare 1 to flare 3 for all 3 models (20s, 40s, and 70s) show the thin and light fabric F in appendix Table 1. Cluster 1 is extracted from the Lady & feminine of the low tension and soft fabric curved shape image type based on the physical properties of the high values of 3D curvatures ($\Sigma+K_c$) and number of nodes with the same fabric F of the lowest fabric parameters M2 to M5 values in physical property shown in Fig. 1.

Cluster 2 (N = 22, flare 3 and some flare 2 skirts of fabrics A to E): The positive PCS1 value (0.85) showed the DE6. Lady & feminine Image Style, based on the high values of CK1 to CK4, CH1 to CH4, M1, and M6. Weight × skirt hem length with the all fabrics A to E, excluding fabric F. Almost all flare 3 and some flare 2 skirts of the high hem length values in the 3 models were categorized in Cluster 2 of Table 3. The common features of the flare skirt types between Cluster 1 and Cluster 2 were expressed by the nearly DE6. Lady & feminine of the DE3. Large flare node curved shape image type, represented a trend of DE6. Lady & feminine Image Style with the high values of 3D curvatures ($\Sigma+K_c$) and number of nodes, and Weight × skirt hem length of fabrics A to E.

Cluster 3 (N = 23, flare 1 and some flare 2 skirts of fabrics A to E): The high negative PCS4 value (-1.04) presented the skirt features. The PCS3 value (0.47) in Cluster 3 had a slightly higher positive mean value than those of the other three clusters (-0.45 to 0.07). The many categorized skirts were the flare 1 and some flare 2 skirts of the almost low or average hem length in the 3 models. The Cluster 3 skirt type with the low 3D curvatures CKn ($\Sigma+K_c$), excluding CK3 in response to the high negative PCS4 value represented a trend of DE6. Lady & feminine Image Style with DE3 to DE5 of large, uniform, and fine flare node fabric curved

Table 5  Linear multiple regression equations of the fabric and design sensitivity images using the physical properties.

| Criterion variate | Linear multiple regression equation | R     | AIC   | p < 0.01 |
|-------------------|-------------------------------------|-------|-------|----------|
| DE1. Tension      | $YDE1 = 0.0017XCK1 + 0.0005XCH1 - 0.0009XCH2 - 0.0006XCH3 - 0.1357XM1 + 4.5143$ | 0.949 | 7.208 | **       |
| (Low — High)      | S.P.R.C.: $XCK1 = 0.222$, $XCH1 = 0.343$, $XCH2 = -0.624$, $XCH3 = -0.222$, $XM1 = -0.508$ |       |       |          |
| DE2. Skirt shape  | $YDE2 = 0.0017XCK1 + 0.0024XCK3 + 0.0006XCH1 - 0.0009XCH2 - 0.0013XCH3 - 0.1198XM1 + 4.4020$ | 0.960 | 3.361 | **       |
| (Soft — Hard)     | S.P.R.C.: $XCK1 = 0.206$, $XCK3 = 0.168$, $XCH1 = 0.362$, $XCH2 = -0.598$, $XCH3 = -0.490$, $XM1 = -0.481$ |       |       |          |
| DE3. Flared node  | $YDE3 = -0.0036XCK2 - 0.0027XCK3 - 0.0004XCH1 + 0.0006XCH2 - 0.0200XM3 + 0.0372XM4 + 0.0001XM6 + 0.4064$ | 0.887 | 48.348 | **       |
| size (Small — Large) | S.P.R.C.: $XCK2 = -0.538$, $XCK3 = -0.2334$, $XCH1 = -0.294$, $XCH2 = 0.504$, $XM3 = -0.622$, $XM4 = 0.209$, $XM6 = 1.297$ |       |       |          |
| DE6. Lady & Feminine Image Style | $YDE6 = -0.0009XM6 - 0.0029XCK3 + 0.0014XCH3 + 0.0510XM1 + 0.0149XM4 + 2.683$ | 0.863 | 6.432 | **       |
| S.P.R.C.: $XCK1 = -0.1806$, $XCK3 = -0.356$, $XCH3 = 0.908$, $XM1 = 0.356$, $XM4 = 0.118$ |       |       |          |
| DE7. Sharp & Modern Image Style | $YDE7 = 0.0025XCK1 - 0.0010XCH2 - 0.0743XM1 - 0.0289XM4 + 3.8987$ | 0.915 | 11.841 | **       |
| S.P.R.C.: $XCK1 = 0.397$, $XCH2 = -0.840$, $XM1 = -0.395$, $XM4 = -0.1752$ |       |       |          |
| DE8. Casual Image Style | $YDE8 = -0.0009XCK1 - 0.0093XCK2 - 0.0019XCK3 + 0.0004XCH3 + 0.0548XM1 - 0.0070XM3 + 0.0295XM4 - 0.0036XM5 + 0.00001XM6 + 0.3475$ | 0.907 | -72.840 | **       |
| S.P.R.C.: $XCK1 = -0.300$, $XCK2 = -0.290$, $XCK3 = -0.369$, $XCH3 = 0.385$, $XM1 = 0.587$, $XM3 = -0.474$, $XM4 = 0.359$, $XM5 = -0.220$, $XM6 = 0.642$ |       |       |          |
| DE11. Gorgeous Image Style | $YDE9 = -0.0019XCK3 + 0.0002XCH1 + 0.0010XCH3 - 0.0392XM1 + 0.3068XM2 - 0.0051XM3 + 0.00003XM6 + 2.0184$ | 0.902 | -23.169 | **       |
| S.P.R.C.: $XCK3 = -0.253$, $XCH1 = 0.239$, $XCH3 = 0.709$, $XM1 = -0.296$, $XM2 = 0.087$, $XM3 = -0.243$, $XM6 = 0.506$ |       |       |          |

Yn of criterion variate and Xn of explanatory variate shown Table 1, Table 3, and appendix Fig. II. S.P.R.C.: standard partial regression coefficient: R: multiple correlation coefficient. AIC: Akaike information criterion. N = 72 3D skirts
shape images, as illustrated in Table 4 and Fig. 1.

Cluster 4 (N = 18, all tight skirts of all fabrics A to F): The high negative PCS1 value (-1.38) and positive PCS4 value (0.81) determined the only tight skirt group on all 3 models. The tight skirt curved shape type displayed the DE7. Modern & standard and DE9. Standard & Retro Image Style with the DE1 to DE4 of the high tension, hard, and the small flare node images for the low values of the 3D curvatures CKn and Chn (Σ±Kc+Σ±kc) and (Σ±Hc), M1. Number of node, and M6. Weight×skirt hem length, as illustrated in Table 4 and Fig. 1. Cluster 4 indicates the different features of the fabric and design curved shape image and physical property parameter values between the tight skirt and the other flared skirts.

3.4 Prediction for the fabric and design curved shape images by the physical properties in the 72 3D skirt curved shapes using multiple regression analysis

The prediction for the fabric and design curved shape images of the 72 3D skirts were confirmed by using those fabric and design shape parameters of the physical properties because we were able to categorize the four 3D shirt curved shape types in both the sensitivity images and physical properties. Table 5 reveals the seven criterion variates \( Y_n \) (DE1 to DE3, DE6 to DE8, and DE11) of the linear multiple regression equations and the high R (multiple correlation coefficient) values of approximately 0.90. The explanatory variates \( X_n \) of the equations for each \( Y_n \) using the stepwise method are the values for the physical properties of CKn, Chn, and Mn for all 72 tight and flared skirts. All DE1 to DE3, DE6 to DE8, and DE11 image values of the 72 skirts were able to predict with sufficient accuracy by many \( X_n \) values using the combination physical properties of CK1 to CK3, CH1 to CH3, and M1 to M6 in the measured values, predictive values, and residual values of Table 6.

Furthermore, we extracted the skirt sensitivity image types in each cluster of Table 3 and Table 4 for DE1 to DE3, DE6 to DE8, and DE11 images in Table 6. The residual values of DE1 to DE3, DE6 to DE8, and DE11 in each cluster were -0.11 to 0.11, without the significant differences between the measured and predictive values on the significance level of 1%. Almost all predictive DE1 to DE3, DE6 to DE8, and DE11 images in each cluster of Table 6 were able to display their images in each cluster of Table 3.

We were able to confirm the comprehensive features of the 72 skirts based on the tight and flare 1 to flare 3 types in the clusters of Table 3 and Table 4 and the prediction effects of the 72 skirt fabric and design images of DE1 to DE3, DE6 to DE8, and DE11 in Table 5 and Table 6. However, some linear multiple regression equations in Table 5 included many explanatory variates. Furthermore, it will be necessary to examine the 3D and 2D (two-dimensional) curved

| Predictive items | N = 72 | Cluster 1 (N = 9) | Cluster 2 (N = 22) | Cluster 3 (N = 23) | Cluster 4 (N = 18) |
|------------------|-------|-----------------|------------------|------------------|------------------|
| DE1. Tension     |       |                 |                  |                  |                  |
| Low - High       | m. values | 3.11 ± 0.74 | 2.30 ± 0.33 | 2.67 ± 0.42 | 2.98 ± 0.27 |
|                  | p. values  | 3.11 ± 0.70 | 2.37 ± 0.29 | 2.69 ± 0.39 | 2.98 ± 0.33 |
|                  | residuak  | 0.00 ± 0.23 | -0.07 ± 0.24 | -0.02 ± 0.34 | 0.00 ± 0.17 |
| DE2. Skirt shape |       |                 |                  |                  |                  |
| Soft - Hard      | m. values | 2.92 ± 0.80 | 2.12 ± 0.34 | 2.48 ± 0.44 | 2.71 ± 0.34 |
|                  | p. values  | 2.92 ± 0.77 | 2.17 ± 0.32 | 2.48 ± 0.43 | 2.74 ± 0.36 |
|                  | residuak  | 0.00 ± 0.22 | -0.05 ± 0.18 | 0.01 ± 0.30 | 0.03 ± 0.21 |
| DE3. Flared node size | m. values | 3.14 ± 0.65 | 3.00 ± 0.22 | 3.65 ± 0.36 | 3.46 ± 0.27 |
| Small - Large    | p. values  | 3.14 ± 0.58 | 2.98 ± 0.21 | 3.67 ± 0.23 | 3.36 ± 0.22 |
|                  | residuak  | 0.00 ± 0.30 | 0.02 ± 0.32 | -0.02 ± 0.36 | 0.10 ± 0.20 |
| DE6. Lady & Feminine Image Style | m. values | 3.61 ± 0.46 | 3.82 ± 0.25 | 3.80 ± 0.30 | 3.87 ± 0.26 |
|                  | p. values  | 3.61 ± 0.40 | 3.84 ± 0.23 | 3.87 ± 0.23 | 3.73 ± 0.19 |
|                  | residuak  | 0.00 ± 0.23 | -0.02 ± 0.14 | -0.08 ± 0.29 | 0.14 ± 0.20 |
| DE7. Sharp & Modern Image Style | m. values | 2.72 ± 0.60 | 2.30 ± 0.20 | 2.27 ± 0.21 | 2.58 ± 0.23 |
|                  | p. values  | 2.72 ± 0.55 | 2.32 ± 0.29 | 2.33 ± 0.29 | 2.60 ± 0.25 |
|                  | residuak  | 0.00 ± 0.24 | -0.02 ± 0.20 | -0.06 ± 0.31 | -0.02 ± 0.20 |
| DE8. Casual Image Style | m. values | 2.64 ± 0.30 | 2.79 ± 0.14 | 2.76 ± 0.12 | 2.82 ± 0.12 |
|                  | p. values  | 2.64 ± 0.27 | 2.76 ± 0.12 | 2.78 ± 0.12 | 2.78 ± 0.12 |
|                  | residuak  | 0.00 ± 0.13 | 0.03 ± 0.12 | -0.02 ± 0.13 | 0.04 ± 0.14 |
| DE11. Gorgeous Image Style | m. values | 2.53 ± 0.42 | 2.62 ± 0.36 | 2.85 ± 0.36 | 2.58 ± 0.31 |
|                  | p. values  | 2.53 ± 0.38 | 2.65 ± 0.29 | 2.92 ± 0.21 | 2.50 ± 0.20 |
|                  | residuak  | 0.00 ± 0.18 | -0.04 ± 0.13 | -0.07 ± 0.23 | 0.08 ± 0.16 |

Clusters shown Table 2 and Table 3. t-test: significant differences between the measured and predictive values (***: p<0.05, **: p<0.01). m. values: measured values, p. values: predictive values
surface physical properties of CKn and CHn on many fabrics, garments, and body models by reason of using the common angles, as in previous reports [7, 11], in order to realize the automatic made-to-order system of the individual and real 3D skirt curved shapes with the 2D skirt patterns corresponding to the client’s preference. For future practical application, it is necessary to develop the research using deep learning method predictions based on big data in the future.

4. Conclusions

Comprehensive evaluations of 3D curved shapes for the total 72 skirts (tight and 3 kind of flared) were examined by the sensitivity images and physical properties with 3D curvature values. The 72 3D skirts of the bodices women in their 20s, 40s, and 70s and six kind of fabrics were evaluated by the design and fabric curved shapes for the 11 sensitivity images’ DEn and the 14 physical properties of the eight 3D curved parameters (Cluster 1 to Cluster 4) were extracted by means of principal component and cluster analyses.

The first classification factor was the skirt curved design images and physical properties, tight (low) or flare (high) hem length between Cluster 4 and Cluster 1 to Cluster 3. The next classification factors of the three flared skirt types displayed the same design curved shape image of DE6. Lady & Feminine Image Style and the different fabric and design curved shape images and physical properties of DE1 to DE5, CKn, CHn, and Mn.

Cluster 1 (N = 9, all hem length flared skirts of fabric F): DE6. Lady & feminine Image Style with low tension and soft shape fabrics images type was based on the high values of 3D curvatures of CKn and CHn, M1. Number of nodes, and the same hin and light fabric F with the low values of M2 to M5 fabric parameters.

Cluster 2 (N = 22, all flare 3 and some flare 2 skirts of fabrics A to E): The main flaerd skirts of the high hem length of DE6 with the large flare node images type was based on the high values of 3D curvatures of CKn and CHn, M1, and M6. Weight×skirt hem length.

Cluster 3 (N = 23, all flare 1 and some flare 2 skirts of fabrics A to E): The main flaerd skirts of the low hem length of DE6 with the flare node of large, uniform, and fine images type was based on the low 3D curvature CKn values, excluding CK3.

Cluster 4 (N = 18, all tight skirts of all fabrics A to F): The tight skirts of DE7. Sharp & Modern and DE9. Standard & Retro Image Style with the high tension, hard skirt shape, and the small and uniform flare node images type was based on the low values of 3D curvatures of CKn and CHn, M1, and M6.

We confirmed the predictability of the seven sensitivity images DE1 to DE3, DE6 to DE8, and DE11 (criterion variates \( Y_n \) of the linear multiple regression equations) using the measurable physical properties CKn, CHn, and Mn for all 72 tight and flared skirts (explanatory variates \( X_n \)) with the high R values of approximately 0.90.

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 (2015-2017), and Challenging Research (Exploratory) No. 17K18626 (2017-2019).

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Most part of this paper was presented at the International Symposium on Fiber Science and Technology in Tokyo, 2014 [13].
Flare 1 = (TBL + length based on development tight skirt darts) × 2, Flare 2 = (TBL × 2) × 2, Flare 3 = (TBL × 2.5) × 2. Samples of 4 style type skirt patterns to 20s model. Total of 3 model skirts made 12 patterns (back and front skirts).

Samples of 4 3D body models to clothe tight skirts of fabric A.

| Model sizes | Skirt pattern sizes |
|-------------|--------------------|
| items (cm)  | Tight | Flare 1 | Flare 2 | Flare 3 |
| 20s stature 158.7  | a. back skirt length | 56.8 | 92.4 | 147.4 | 184.8 | 231.0 |
| bust girth 83  | b. hem line length | 92.4 | 147.4 | 184.8 | 231.0 |
| waist girth 62  | c. flared length | 92.4 | 147.4 | 184.8 | 231.0 |
| hip girth 89.4  | (c = b.Flare - b.Tight) | 92.4 | 147.4 | 184.8 | 231.0 |
| 40s stature 154.7  | a. back skirt length | 52.5 | 94.4 | 141.0 | 188.8 | 236.0 |
| bust girth 86.3  | b. hem line length | 94.4 | 141.0 | 188.8 | 236.0 |
| waist girth 69.7  | c. flared length | 94.4 | 141.0 | 188.8 | 236.0 |
| hip girth 91.9  | (c = b.Flare - b.Tight) | 94.4 | 141.0 | 188.8 | 236.0 |
| 70s stature 146.7  | a. back skirt length | 49.6 | 96.0 | 138.2 | 192.0 | 240.0 |
| bust girth 87.5  | b. hem line length | 96.0 | 138.2 | 192.0 | 240.0 |
| waist girth 74.1  | c. flared length | 96.0 | 138.2 | 192.0 | 240.0 |
| hip girth 93.3  | (c = b.Flare - b.Tight) | 96.0 | 138.2 | 192.0 | 240.0 |

Ease length on waist line and hip line of 3 model skirts, Waist lines of all 72 skirts = 2.4 cm; Hip lines of 18 tight skirts = 2.5 cm to 3.0 cm.

Appendix Fig. 1 Samples of 4 skirt types on 3 body models, 2D flat patterns, 3D skirt curved shapes, 2D horizontal section curved node surfaces, and sizes of 3 models and skirt patterns [7].
Appendix Fig. II  Vertexes, edges, and faces of triangle meshed skirt surfaces on 2D flat pattern and 3D flared skirt [7].

Appendix Table 1  Mechanical parameters related to fabric drapability measured by KES-System [7].

| Samples          | B (gf · cm²/cm) | 2HB (gf · cm/cm) | G (gf/cm/degree) | 2HG (gf/cm) | W (mg/cm²) | T (mm) | Ds (%) |
|------------------|-----------------|------------------|-------------------|-------------|------------|--------|--------|
| A Cotton broad   | 0.118           | 0.124            | 3.72              | 4.51        | 12.38      | 0.497  | 82.9   |
| B Wool tropical  | 0.067           | 0.033            | 1.36              | 1.37        | 16.29      | 0.407  | 49.8   |
| C Polyester      | 0.077           | 0.029            | 0.62              | 1.67        | 11.65      | 0.34   | 50.7   |
| Polyester        | 0.127           | 0.172            | 2.81              | 6.59        | 13.2       | 0.605  | 74.6   |
| Cotton toile     |                |                  |                   |             |            |        |        |
| D Polyester      | 0.110           | 0.033            | 0.52              | 0.59        | 15.23      | 0.394  | 48.2   |
| Polyester        |                |                  |                   |             |            |        |        |
| E Polyester      | 0.019           | 0.007            | 0.34              | 0.64        | 10.43      | 0.226  | 28.3   |

The static drape coefficient (Ds) was calculated from these mechanical parameters.