Extraction of 3D Curved Tight and Flared Skirt Shape Features Using Angle Curvatures

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Abstract

The 3D curved surface shapes of tight and flared skirts were predicted precisely by the angle curvatures (concentrated Gaussian curvature $Kc$, concentrated geodesic curvature $kc$, and concentrated mean curvature $Hc$), model sizes, skirt designs, and fabrics. All of the 72 skirts, encompassing 3 female body models (mean body sizes of Japanese women in their 20s, 40s, and 70s), 6 kinds of fabrics, tight skirts, and 3 kinds of flared skirts, were investigated with attention to the differences of the curved surface shapes in detail. It has been found that it is possible to predict the number of nodes on hemlines for these 72 skirts with the three totalized feature factors, $|\Sigma \pm Kc| + |\Sigma \pm kc| + |\Sigma \pm Hc|$, and weight (g/cm$^2$) × hemline length (cm), underlying the physical properties of fabric and model sizes, based on slightly high or high correlation coefficients ($r = 0.73$ to $r = 0.93$). Therefore, the number of nodes on hemlines of these 72 skirts can be calculated by these three totalized feature factors using a multiple regression analyzing technique, (multiple regression coefficient $R = 0.96$), based on higher prediction accuracy.

Key Words: 3D skirt drape curved shape, concentrated Gaussian curvature, concentrated geodesic curvature, concentrated mean curvature, nodes on hemlines

1. Introduction

The established method for finding the flare shape of a skirt uses the partial 2D hem or other line shapes on an approximately horizontal section [1, 2]. We also investigated the 2D flared hemline shape of skirts on the 3D model of a 20-year-old female body [3]. The skirt shape factor for short hemline length with simple drape shape showed high single correlation with the drape parameters of circular fabrics and skirts. However, we were not able to find the correlation between skirt shape factor for long hemline length with complicated drape shape and the drape parameters of circular fabrics and skirts [3].

Here, we aim to discover the features of 3D curved skirts of all area shapes and drape parameters, which are affected by body shape, fabric, and design factors, using an angle curvature method that references three curvatures: concentrated Gaussian curvature $Kc$, concentrated geodesic curvature $kc$, and concentrated mean curvature $Hc$. The samples consist of 72 skirts spanning 4 skirt styles, 3 models (bodies of women in their 20s, 40s, and 70s [4-6]), and 6 kinds of fabric. The 4 skirt styles of the 20s model and 6 kinds of fabric are the same samples in a previous paper [3]. The 3D curved shapes, including 3D nodes, drape, and flare shapes, of 72 skirts are displayed with positive, negative, and zero angle values of $Kc$, $kc$, and $Hc$ toward the developable skirt surfaces without darts and flat skirt surfaces. The 3D shapes of those curvatures are as follows: positive $Kc$ (denoted by $+Kc$); elliptical curved shape, negative $Kc$ (denoted by $-Kc$); hyperbolic curved shape, $Kc = 0$; developable surface curved shape without dart, positive $kc$ (denoted by $+kc$); convex line curved shape, negative $kc$ (denoted by $-kc$); concave line curved shape, $kc = 0$; straight line curved shape, positive $Hc$ (denoted by $+Hc$); mountain fold curved shape (convex surface shape), negative $Hc$ (denoted by $-Hc$); valley fold curved shape (concave surface shape), and $Hc = 0$; plane surface shape.

Therefore, $Kc$, $kc$, and $Hc$ represent the different values of drape parameters on the 72 3D skirt shapes, which are various combinations of 3D models of body shapes, flare length of hemlines, 6 fabrics, and node numbers. Single correlations between 3 curvatures and some drape parameters of all 72 skirt shapes are demonstrated. In addition, the node numbers of the 72 3D skirt shapes are calculated using 3D curvatures affected by three factors,
and some drape parameters based on multiple correlations that are inferred from the multi-purpose 3D tight and flared skirt design.

2. Experimental Method

1) The 3 body types are the standard Japanese measurements of women in their 20s, 40s, and 70s [4-6]. The total 12 skirt patterns of the 4 skirt styles, (tight, flare 1, flare 2, and flare 3 skirts), for the 3 models were made by computer using a non-tactile 3D body measuring instrument, (Body Line Scanner C9036-02, Hamamatsu Photonics Co., Ltd.), and the Masuda original automatic made-to-order pattern system [7, 8]. The 3 kinds of flared skirts for the 3 models were designed based on basic tight skirt patterns (front and back skirts), as shown in Fig. 1. Each of the body models and the 12 skirt patterns are shown in Table 1. The body length values of the women in their 20s, 40s, and 70s show mostly Japanese women’s clothes in sizes 9, 11, and 13. The 12 skirt patterns are the same as those of a previous paper using the model of the woman in her 20s [3]. In order to prevent the waistband from affecting the shape of the skirts, the upper part of the skirt and the bodice were sewn together using the same fabrics. The waist line and hip line on each tight skirt had ease length (2.3 cm to 3.0 cm) for clothing model using fabric with thickness.

2) The 6 kinds of fabric used here were the same as those in the previous paper [3] (cotton broad (A), tropical wool (B), tropical wool (C), etc.) and the body measurements of the women in their 20s, 40s, and 70s. The 12 skirt patterns are the same as those of a previous paper using the model of the woman in her 20s [3].

Table 1 Model and skirt pattern sizes.

| Model sizes | Skirt pattern sizes |
|-------------|---------------------|
| | items (cm) | Tight | Flare 1 | Flare 2 | Flare 3 |
| 20s | | a. back skirt length | 56.8 | |
| | | b. hem line length | 92.4 | 147.4 | 184.8 | 231.0 |
| | | c. flared length | 0.0 | 55.0 | 92.4 | 138.2 |
| 40s | | a. back skirt length | 52.5 | |
| | | b. hem line length | 94.4 | 141.0 | 188.8 | 236.0 |
| | | c. flared length | 0.0 | 46.6 | 94.4 | 141.6 |
| 70s | | a. back skirt length | 49.6 | |
| | | b. hem line length | 96.0 | 138.2 | 192.0 | 240.0 |
| | | c. flared length | 0.0 | 42.2 | 96.0 | 144.0 |

Easy lengths 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.

Fig. 1 Samples of 4 skirt types for 3 body models, 2D flat patterns, 3D skirt curved shapes, and 2D horizontal section curved node surfaces.
Fig. 2  Vertexes, edges, and faces of triangle meshed surfaces on the 2D and 3D skirts.

Fig. 3  Vertexes, edges, and faces of triangle meshed skirt surfaces on 2D flat pattern and 3D flared skirt.
polyester (C), cotton toile (D), polyester single-yarn twill (E) and polyester faille (F)). Table 2 shows the major mechanical parameters related to fabric drapability as measured by the KES system; these measurements are approximately the same as in the previous paper. The number of nodes of the 72 draped skirts’ hemlines (3 models × 4 style skirts × 6 fabrics) was measured.

3) Each of the 72 flat skirt patterns and fabric surfaces are constructed of triangle mesh using 300 points (vertexes), 840 edges, and 540 faces, as shown in Fig. 2. Each concentrated vertex angle of every triangle produced the deficit angles of the 72 3D skirts: \(Kc\) (by \(Kc = 360^\circ \times (2\pi) \times \sum \theta n\) on the interior area vertexes, \(kc\) (by \(kc = 180^\circ (\pi) \times \sum \theta n\) on the exterior boundary line vertexes (waist and hem lines), and \(Hc\) (by \(Hc = \sum \phi n / Li\) on the interior area vertexes and \(Hc = \sum \phi n / (Li-1)\) on the exterior boundary line vertexes) (Fig. 3).

Definitions of the angle value means are the same as the 3D curved shapes mentioned in the above introduction. Concentrated Gaussian curvatures showed elliptical (+\(Kc; \ Kc > 0\)), hyperbolic (−\(Kc; \ Kc < 0\)), and developable surface (\(Kc = 0\)) curved shapes; concentrated geodesic curvatures showed convex (+\(kc; \ kc > 0\)), concave (−\(kc; \ kc < 0\)), and straight (\(kc = 0\)) line curved shapes. The Gauss-Bonnet theorem [9] was used to find the total angle values of zero for the sum \(Kc\) and sum \(kc\) in the all area of skirts, as shown in Fig. 2. The Euler number [9] is zero, according to the values of the faces, vertexes, and edges, \((300 – 840 + 540 = 0)\), as shown in Fig. 2. In concentrated mean curvature \(Hc\), 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 (\(Hc = 0\)).

All \(Kc\) and \(Hc\) values of all vertices for all six fabrics on all flat draped skirt patterns show the common 0 degrees (Fig. 2), regardless of the different shapes and sizes of the models’ bodies and skirt designs (Table 1). All \(kc\) values of the flat tight and flared skirt patterns and all \(Kc\) values of the tight skirt flat patterns for all six fabrics show common original degrees for each of the models’ body and skirt design shape and size (Fig. 1). Therefore, we were able to examine each feature of the 3D curved shapes for the body shape, fabric, and design factors as regards those flat pattern shapes using the variation of angle values.

3. Results and Discussion

3.1 Features of \(Kc\) and \(kc\) for 3D skirt shapes

3.1.1 3D Skirt curved shapes from the perspective of +\(Kc\), −\(Kc\), +\(kc\), and −\(kc\) values

The total value of sum \(Kc\) (\(\Sigma + Kc\) and \(\Sigma - Kc\)) and sum \(kc\) (\(\Sigma + kc\) and \(\Sigma - kc\)) for each of the 72 skirts represented identically zero, according to theory of the Gauss-Bonnet theorem as shown in Fig. 4. Therefore, we were able to extract the difference of the 3D skirt curved shape for the three factors, using the distribution value of \(Kc\) and \(kc\). Each distribution value of \(\Sigma + Kc\), \(\Sigma - Kc\), \(\Sigma + kc\), and \(\Sigma - kc\) was different between the 4 skirt styles, 3 models, and 6 fabrics. All of the \(\Sigma + Kc\) and \(\Sigma - Kc\) values of flare 2 and flare 3 skirts on each of the 6 fabrics for 3 models were higher than those values of the tight and flare 1 skirts. In all flare 1 skirts on all 3 models, the \(\Sigma + kc\) values were slightly lower than those values of each tight skirt, while the \(\Sigma - kc\) values were slightly higher than those values of each tight skirt. The \(\Sigma + kc\) values of all 54 flared skirts, (flare 1 to flare 3 on 6

Table 2  Mechanical parameters related to fabric drapability measured by the KES System.

| Samples       | B (g/ft²·cm²) | 2HB (g/ft²·cm³/degree) | G (g/cm²) | 2HG (g/cm²) | W (m²/g) | 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  | 0.497 | 49.8  |
| C Polyester tropical | 0.077 | 0.029                  | 0.62     | 1.67        | 11.65  | 0.34  | 50.7  |
| D Cotton toile | 0.127        | 0.172                  | 2.81     | 6.59        | 13.2   | 0.605 | 74.6  |
| E Polyester single yarn twill | 0.110 | 0.033                  | 0.52     | 0.59        | 15.23  | 0.394 | 48.2  |
| F Polyester single yarn twill | 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.
fabrics and 3 models), were slightly higher than or approximately the same as those of each tight skirt. However, all of the Σ-κc values of the tight skirts were higher than or approximately the same as those of all 54 flared skirts.

We were able to identify the 3D curved flared and drape skirt shapes by using each distribution value of Σ+κc shapes by using each distribution value of Σ+κc + Σ−κc. Each difference |Σ±κc| value between flare and tight skirts in 3 flare types on 3 models is shown in the separate 3 areas values bar graph and all 3 area total values are displayed in the table in Fig. 5. The 3 areas are the front skirt area (total of 81 vertices), the total of the right and left side skirt area (total of 138 vertices), and the front skirt area (total of 81 vertices). The different |Σ±κc| values show the (flared skirt - tight skirt) value of |Σ±κc|+|Σ±κc| Kc kc | values in flare 1 skirts were naturally lower negative |Σ±κc|+|Σ±κc| values on all fabrics, except for fabric F in back and side areas; the different values of fabric F in the front area were shown to have slightly lower positive values in all models. Therefore, the flare 1 skirts of fabric F in 3 models represented only total positive different |Σ±κc|+|Σ±κc| values of all areas that suggested the drape and flare shapes on flare 1 skirts, as shown in the table of Fig. 5. Although the flare 1 skirts of 5 fabrics, not including fabric F, in 3 models showed the total negative different |Σ±κc|+|Σ±κc| values of all areas, the flare 1 skirt curved shapes of fabric D in 3 models especially displayed the developable with a few drape and flare surfaces, yielding the highest negative different |Σ±κc|+|Σ±κc| values. The flare 1 skirt samples of fabrics D and F on the 40s model are shown in Fig. 6. In these samples, fabric D formed a shape with a large volume and few nodes (N = 5) and fabric F formed a shape with a slightly small volume and many nodes (N =

Fig. 4 Total of sum Kc and sum κc values of 6 fabrics (A to F) on 4 skirt styles and 3 models.

3.1.2 3D Skirt curved shapes from the perspective of |Σ±κc|+|Σ±κc| values

The differences in drape and flare shape between the 6 fabrics and 3 model body shapes were examined using total absolute values of ΣKc and Σκc (|Σ+κc|+|Σ−κc|+|Σ+κc|+|Σ−κc|+|Σ+κc|+|Σ−κc|). Each different |Σ±κc|+|Σ±κc| value between flare and tight skirts in 3 flare types on 3 models is shown in the separate 3 areas values bar graph and all 3 area total values are displayed in the table in Fig. 5. The 3 areas are the front skirt area (total of 81 vertices), the total of the right and left side skirt area (total of 138 vertices), and the front skirt area (total of 81 vertices). The different |Σ±κc|+|Σ±κc| values show the (flared skirt - tight skirt) value of |Σ±κc|+|Σ±κc|.

Also displayed in the bar graph in Fig. 5, those different |Σ±κc|+|Σ±κc| values in flare 1 skirts were naturally lower negative values on all fabrics, except for fabric F in back and side areas; the different values of fabric F in the front area were shown to have slightly lower positive values in all models. Therefore, the flare 1 skirts of fabric F in 3 models represented only total positive different |Σ±κc|+|Σ±κc| values of all areas that suggested the drape and flare shapes on flare 1 skirts, as shown in the table of Fig. 5. Although the flare 1 skirts of 5 fabrics, not including fabric F, in 3 models showed the total negative different |Σ±κc|+|Σ±κc| values of all areas, the flare 1 skirt curved shapes of fabric D in 3 models especially displayed the developable with a few drape and flare surfaces, yielding the highest negative different |Σ±κc|+|Σ±κc| values. The flare 1 skirt samples of fabrics D and F on the 40s model are shown in Fig. 6. In these samples, fabric D formed a shape with a large volume and few nodes (N = 5) and fabric F formed a shape with a slightly small volume and many nodes (N =
The flared skirts of fabric F had higher total positive different \( |\Sigma \pm Kc| + |\Sigma \pm kc| \) values in all areas when compared to flare length volumes of flare 2 and flare 3 skirts of other fabrics in all 3 models. Those total positive different values were higher according to flare length values in flare 2 and flare 3 skirts 223.67 degrees to 948.15 degrees, 20s skirt < 40s skirt < 70s skirt. Conversely, the flared skirts of fabric D had lower total positive different \( |\Sigma \pm Kc| + |\Sigma \pm kc| \) values of all areas in only flare 3 skirts compared to other fabrics in all 3 models; those total positive different values were 423.18 degrees to 558.23 degrees, 20s skirt < 70s skirt < 40s skirt.

For each fabric other than fabric F with maximum different values and fabric D with minimum different values, those higher or lower different \( |\Sigma \pm Kc| + |\Sigma \pm kc| \) values in all areas were acknowledged as follows: for the 20s model, higher different values on fabric C of flare 2 and flare 3 skirts and lower different values on fabric B of flare 2 and flare 3 skirts; for the 40s model, higher different values on fabric A of flare 2 and flare 3 skirts and lower different values on fabrics B and E of flare 2 skirts and on fabric B of flare 3 skirts; for the 70s model, higher different values on fabric D of flare 2 skirt and fabric C of flare 3 skirts and lower different values on fabrics A and E of flare 2 skirt and fabric A of flare 3 skirts.

These observed different \( |\Sigma \pm Kc| + |\Sigma \pm kc| \) values imply that the drape and flare surface shapes of some skirts vary according to fabric, flare length, and model body sizes (areas).

### 3.1.3 3D skirt curved shapes from the perspective of \(+Hc, -Hc, |\Sigma \pm Hc|\) values

The sum \(+Hc\) (\(\Sigma + Hc\)) and sum \(-Hc\) (\(\Sigma - Hc\)) values yielded the convex and concave surface shape results from flare and node variation on all 72 skirts, as shown in the bar graph in Fig. 7. Total absolute values of each sum value of \(+Hc\) and \(-Hc\) \((\Sigma + Hc, |\Sigma - Hc|)\) are drawn simultaneously in the line graph in Fig. 7. Considering the higher flare values from tight skirts to flare 3 skirts, the \(\Sigma + Hc, \Sigma - Hc,\) and \(|\Sigma \pm Hc|\) values of all skirts show a tendency to be higher regardless of fabric or models. However, the higher values of those three \(Hc\) were different according to fabric type. In all flared skirts, regardless of model, fabric F developed the
Fig. 7  Total of $\Sigma+Hc$, $\Sigma-Hc$, and $\Sigma=Hc$ values of 6 fabrics (A to F) on 4 skirt styles and 3 models.

Fig. 8  Comparison of total of absolute $Hc$ values ($\Sigma\pm Hc$) on 6 fabrics (A to F) and 3 models between flared skirts and tight skirt. Table shows the total values of 3 areas in each fabric and model. Bar graph shows separate area values in each fabric and model.
higher $\Sigma+Hc$, $\Sigma-Hc$, and $|\Sigma+Hc|$ values, while fabric D displayed the roughly lower $\Sigma+Hc$, $\Sigma-Hc$, and $|\Sigma+Hc|$ values. Of all the fabrics in Table 2, fabric F has the lowest drape coefficient ($D_s$) and another 5 fabric item parameter values. Contrarily, fabric D presented the highest or second highest of all the fabric parameters, except for weight value ($W$), in Table 2. The different values of [$\Sigma+Hc$] in fabrics A, B, and E among 3 models in flare 3 skirts are presented in the broken line graph of Fig. 7. The flare 3 skirts had the highest flaire length of each model. The flare lengths and skirt sizes (areas) conform to each model in the flare 3 skirts, while the weight values of the flare 3 skirts were great for fabrics A, B, and E (Table 2).

The drape and flare shape different values, (flared skirt to tight skirt), of the 6 fabrics and 3 models using total absolute values of [$\Sigma+Hc$] are shown in Fig. 8, as with the different [$\Sigma+Kc$]+[$\Sigma+kc$] values. The different [$\Sigma+Hc$] values of flared and tight skirts in 3 types of flared skirts on 3 models are displayed in 3 separate sections in the bar graph, while the table shows the total values of all 3 areas.

The 3 types of flared skirts had approximately the first or second highest values for fabric F and the lowest values for fabric D, as with the different [$\Sigma+Kc$]+[$\Sigma+kc$] values in Fig. 5. The other fabrics of higher or lower total different [$\Sigma+Hc$] values were found easily by separating the different [$\Sigma+Hc$] values into the 3 separate areas in the bar graph in Fig. 8. In examining the different [$\Sigma+Hc$] values of the flare 1 skirts, it was found that fabrics B and A of the 3 models had the higher or lower total different [$\Sigma+Hc$] values in the table in Fig. 8. The different [$\Sigma+Hc$] values of the side and front areas were higher than those of the back areas in a majority of the fabrics and models in the bar graph in Fig. 8. Fabric E, as well as fabrics B and F, had slightly higher different [$\Sigma+Hc$] values in the side and front areas of the 3 models.

The different [$\Sigma+Hc$] values of the flare 3 skirts were higher than those of the flare 2 skirts for the total and the individual areas of the 3 models, according to the flare lengths displayed in Table 1. The different [$\Sigma+Hc$] values of both flare 2 and flare 3 skirts in all fabrics and models were approximately the highest values in the side area with the most vertexes, as shown in Fig. 8. Fabrics F and D had the highest or lowest different [$\Sigma+Hc$] values of all fabrics of both flare 2 and flare 3 skirts, but it was not the definite different features for other fabrics.

These observed different [$\Sigma+Hc$] values suggest that the drape and flare surface shapes of some skirts vary according to fabrics, flared lengths, and model body sizes (areas), just as the different [$\Sigma+Kc$]+[$\Sigma+kc$] values suggest. This method can predict the drape and flare surface shape features of some skirts by considering the curvature values of [$\Sigma+Kc$]+[$\Sigma+kc$] and [$\Sigma+Hc$], the fabric, and the flared lengths, according to the model body sizes (areas).

### 3.2 Relationships between nodes on the hemlines and feature quantities of 3D curvatures, skirt sizes, and physical properties of fabrics

The number of nodes on the hemlines were measured as the drape and flared surface shapes of all 72 skirts as shown in Table 3. The number of nodes on the hemlines are displayed as a total and as individual counts for the flare 1 to flare 3 skirts and the tight skirt. The total number of nodes on the hemlines of the tight skirt without flared length were understandably zero or low values of 1 to 3, and these nodes appeared mainly on the hemlines of the back areas for all models. On the other hand, all of the flared skirts had higher numbers of nodes on the hemlines, according to the flared lengths from the flare 1 to flare 3 skirts of each model and fabric. The side areas to the left and right of all flared skirts had higher node counts than those of the tight skirts.

In all flared skirt types and models, fabric F displayed roughly the highest number of nodes, while fabric D showed approximately the lowest number of nodes. These results are similar to the case of the [$\Sigma+Kc$]+[$\Sigma+kc$] in Fig. 5 and [$\Sigma+Hc$] in Fig. 7 and Fig. 8 for fabric

| Table 3 | Simple correlation coefficient (r) values between the number of nodes and [$\Sigma+Kc$]+[$\Sigma+kc$] or [$\Sigma+Hc$] or physical properties of fabrics or flared skirt sizes. |
|---------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $|\Sigma+Kc|+|\Sigma+kc|$ | Number of nodes |
| r       | Total | Back | Right side | Front | Left side |
| Front   | 0.68 ** | 0.59 ** | 0.57 ** | 0.66 ** | 0.50 ** |
| Right side | 0.59 ** | 0.45 ** | 0.55 ** | 0.49 ** | 0.47 ** |
| Back    | 0.73 ** | 0.62 ** | 0.63 ** | 0.67 ** | 0.56 ** |
| Left side | 0.63 ** | 0.53 ** | 0.55 ** | 0.62 ** | 0.46 ** |
| Total   | 0.73 ** | 0.61 ** | 0.63 ** | 0.68 ** | 0.55 ** |
| $|\Sigma+Hc|$ | Number of nodes |
| r       | Front | Right side | Back | Left side |
| Front   | 0.87 ** | 0.70 ** | 0.79 ** | 0.70 ** | 0.73 ** |
| Right side | 0.91 ** | 0.70 ** | 0.84 ** | 0.72 ** | 0.75 ** |
| Back    | 0.92 ** | 0.69 ** | 0.83 ** | 0.76 ** | 0.78 ** |
| Left side | 0.89 ** | 0.65 ** | 0.83 ** | 0.69 ** | 0.80 ** |
| Total   | 0.93 ** | 0.71 ** | 0.85 ** | 0.75 ** | 0.79 ** |
| Thickness T, mm | -0.22 | -0.26 | -0.15 | -0.25 | -0.08 |
| Weight W, g/cm² | -0.08 | -0.06 | -0.01 | -0.26 | -0.02 |
| Bending rigidity B, g·cm²/cm | -0.23 | -0.23 | -0.15 | -0.27 | -0.12 |
| Drape Ds (%) | -0.19 | -0.18 | -0.17 | -0.15 | -0.11 |
| Weight (g/cm³) x Hem line length (cm) | 0.75 ** | 0.54 ** | 0.74 ** | 0.48 ** | 0.68 ** |

*; $P<0.05$, **; $P<0.01$
F (higher curved shape values) and fabric D (lower curved shape values) in flared skirts and all models.

Table 4 shows simple correlation coefficient (r) values between the number of nodes and |Σ±KC|+|Σ±kc| or |Σ±Hc|, or physical properties of fabrics or the skirt sizes, (weight (g/cm^2) × hemline length (cm)), for all 72 skirts. The r values for the number of nodes and |±KC|+|±kc| or |Σ±Hc| or the skirt sizes were significant (**, P < 0.01). The high or higher positive r values (r=0.73 to r=0.93) were extracted in each total value between the number of nodes and |Σ±KC|+|Σ±kc| or |Σ±Hc| or the skirt sizes. The result of those r values suggest that the number of nodes of all 72 skirts can be explained by the 3D curved shape values of |Σ±KC|+|Σ±kc| and |Σ±Hc|. The flared skirt sizes are a reflection of the skirt’s flare curved values, model bodies’ sizes, and the physical properties of fabric, including the weight.

3.3 Prediction for the number of nodes on the hemlines of the tight and flared skirts by 3D curvature values and the skirt sizes using multiple regression analysis

The criterion variate Y of the linear multiple regression equation is the number of nodes (Node) on all of the 72 tight and flared skirts. The explanatory variate Xn of the equation using the stepwise method is the values for |Σ±Hc| (X1), |Σ±KC|+|Σ±kc| (X2), and Weight (g/cm^2) × Hemline length (cm) (X3: skirt sizes) for each tight and flared skirt (Fig. 4 and Fig. 7).

The Y (Node) equation for predicting the number of nodes is as follows: (R = 0.9639, Akaike information criterion = 190.2633, F = 297.3182 **, **, significant at 0.01 level).

Y (Node) = 0.0032 X1 − 0.0060 X2 − 0.0001 X3 + 0.7962 (Constant term)

Partial regression coefficient: X1 = |Σ±Hc|, X2 = |Σ±KC|+|Σ±kc|, X3 = Weight (g/cm^2) × Hemline length (cm)

Standard partial regression coefficient: X1 = 1.5456, X2 = -0.5378, X3 = -0.1589

These data lead us to the conclusion that the number of nodes on the hemlines of the 72 skirts can be predicted by the three totalized feature factors (X1, X2, and X3) based on the curvatures, body sizes, and physical properties of the fabric.

Detailed features of 3D curvatures, 3D body shapes, and physical properties of fabrics on the waist to hemlines are under way.

4. Conclusions

The 3D curved shapes of the total 72 skirts (tight, flare 1, flare 2, and flare 3 skirts × models of the bodies of women in their 20s, 40s, and 70s × fabrics A to F) were measured by computer using a non-tactile 3D body-measuring instrument. The angle values of the coordinates (X, Y, Z) of the 300 vertexes on each 3D surface of the 72 skirts on 3D body models were calculated, and the mechanical parameters and shape factors of 6 fabrics were measured and calculated by the KES system. The different features of the 3D curved surface shapes of the tight and 3 flared skirt styles with the model body sizes and the physical properties of fabric were obtained by using three angle curvatures: concentrated Gaussian curvature Kc, concentrated geodesic curvature kc, and concentrated mean curvature Hc. The different 3D curved shapes of drape and flared skirts were able to determine the specific values in detail. The curvatures of |Σ±KC|+|Σ±kc| and |Σ±Hc| of longer length 3D flared skirts without darts for making curved shape on the 2D patterns are higher than those of the 3D tight skirts with darts on the 2D patterns, and the differences in those curvature values are shown in the differences between polyester faille (F) and cotton toile (D).

Therefore, the three totalized feature factors of |Σ±KC|+|Σ±kc|, |Σ±Hc|, and weight (g/cm^2) × hemline length (cm) underlying the skirt shape factors, the physical properties of fabric and model sizes, each yielded a slightly high or high correlation (r = 0.73 to r = 0.93) with the number of nodes on the hemlines of 72 skirts. A multiple regression equation having the highest prediction value (R = 0.96) for the number of nodes on hemlines was devised using the three totalized feature factors.

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