SHAPE ANALYSIS OF HUMAN BODY PARTS LINE USING LOG-AESTHETIC CURVED LINE

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ABSTRACT
Recently, many people have taken a physical exercise for their shape-up/beautiful body in the world. Deciding the goal of weight or size is easy, but its shape is very difficult. Then, we focus to relate the beautiful body shape with the log-aesthetic curved line. The log-aesthetic curved line has characteristic that the curvature is constant multiplier of curve length, and the natural shape object follows it. In this paper, we build up a hypothesis that the body line fitting the log-aesthetic curved line is curvaceous, and the body parts shape is determined for curvaceous parameter using the hypothesis. Firstly, the male body parts and female doll parts are captured, and compared the similarity of curvature to a log-aesthetic curved line. Afterwards, we investigate the curvaceous validity of physical exercise. The before and after exercise thighs are compared, and we analyze the curvaceous similarity of a log-aesthetic curvature for analyzing the correlation of physical exercise and curvaceous in 3 months.

1. INTRODUCTION
Recently, many people excise physical exercise for health or diet. They build or shape their body for curvaceous or shapely body, and shape partial body region such as the abdomen (waist), hip, and arm. However, deciding the goal of weight or size is easy, but deciding the goal shape is difficult. For example, he/she improve only the abdomen shape, or adjust the whole body balance. On the other hand, the weight and BMI (Body Mass Index) are set in the physical exercise for the purpose of health, but they are difficult (wrong value) for shapely body. “Curvaceous” or “Shapely” or “Beautiful” is a qualitative and vague parameter, and has many individual subjective. They have a different scale, namely, the shape of the body is curvaceous or ugly by individual subjective or scale.

Then, we focus on a log-aesthetic curved line [1]. Its curvature is constant multiplier of curve length, and the natural shape object (such as conches) follows it. It is expected the application for the artifact in design technology [2], [3]. The log-aesthetic curved line design is enough for the shaping or molding, but the analysis of human body shape is very few. In addition, the correlation of the curvaceous body and physical exercise has not been clarified yet.

In this paper, we build up a hypothesis that the body line fitting the log-aesthetic curved line is curvaceous, and the body parts shape is determined for curvaceous parameter using the hypothesis. Therefore, the curvaceous parameter is converted from the qualitative and vague parameter to the quantitative and definite parameter. It is expected the quantitative scale, and different from the individual subjective or preference. Firstly, the parts of the body and the doll is captured, and compared the similarity of curvature to a log-aesthetic curved line. Secondly, the before and after exercise thighs are compared, and we analyze the curvaceous similarity of a log-aesthetic curvature for investigating the correlation of physical exercise and curvaceous. We estimate the curvaceous validity of physical exercise.

2. SHAPE DECISION BY LOG-AESTHETIC CURVED LINE
A log-aesthetic curved line is usually used in industrial design, and applied for the artifact in design technology. It is used by 3D-CAD software for design efficiency and flexibility [2], but not applied physical human body shape. The expert’s design the model using the log-aesthetic curve line, and the function of finishing and efficiency is estimated [4], [5]. The design method is creating objects by rotation of a log-aesthetic curved line around an axis. In this result, a log-aesthetic curved line is efficient in 3D-CAD design, but the conventional curved lines (B-spline, Bezier, and NURBS) should be used also with it.

In this paper, we explain the estimation using a log-aesthetic curved line. The physical object surfaces are analyzed using it (here, the object need not be designed using it). The highlight line of physical object surface is abstracted, and its curvatures are compared to the log-aesthetic curvatures. The curvature
compared with some kinds of log-aesthetic curved lines like Figure 6 (a) - (b).

2.2 Analysis using logarithmic spiral

The polar coordinates of the logarithmic spiral are expressed by the equation (2).

\[ x = r \cos \theta \]  
\[ y = r \sin \theta \] 
\[ r = a \theta \] (a > 1)

Here, \( a \) is a coefficient, \( r \) is a polar radius, \( \theta \) is a polar angle, and \( N \) is a number of revolutions. Figure 1 shows the logarithmic spiral and the snail shell. The highlight line of snail shell corresponds to the logarithmic spiral line in Figure 1 (b). When the value of a change, the interval of both near circumferences and polar coordinates are changed.

The curvature can be calculated by the derivation. When the points \( r_1, r_2 \) on the curved line can be expressed by parameter \( u \), the curvature \( \rho \) is defined by the equation (3) using the unit vectors \( t_1 \) and \( t_2 \) point.

\[ \rho = \lim_{\Delta L \to 0} \left\| \frac{\Delta \mathbf{p}}{\Delta L} \right\| = \lim_{\Delta L \to 0} \left( \frac{\Delta p_x}{\Delta u} \right)^2 + \left( \frac{\Delta p_y}{\Delta u} \right)^2 \] (3)

Here, \( \Delta L \) is the curve length between \( r_1 \) and \( r_2 \). \( \Delta \mathbf{p} \) is a difference vector of \( \mathbf{p}_1 \) and \( \mathbf{p}_2 \), and \( p_x, p_y \) is composed of the unit vector \( \Delta \mathbf{p} \). The unit vector \( \Delta \mathbf{p} = (p_x, p_y) \) is expressed by equation (4) using the tangent vector \( t = (t_x, t_y) \) on the curved line.

\[ (p_x, p_y) = \left( \frac{t_x}{|t|}, \frac{t_y}{|t|} \right) \] (4)

Here, the tangent vector \( t \) is expressed by equation (5) using parameter \( u \).

\[ t = \left( \frac{dx}{du}, \frac{dy}{du} \right) \] (5)

2.3 Shape capture by camera and turntable

The object surface should be captured (measured) using camera and converted to 3D-CAD models, because a log-aesthetic curved line and the curved lines on object surface are compared. 3D-CAD model should be solid and surface data. Then, we construct the 3D-CAD model from the multiple viewpoints picture using Autodesk Remake software. First, a plastic (PET) bottle has taken photographs of multiple viewpoints like Figure 2. It is put on the center of the turntable. A camera is rotated the pitch angle ±45 degree, and in takes the photographs rotating each the yaw angle 10 degrees. The number of photographs is 72, and the CAD model is made from all photographs using Autodesk Remake software. Figure 3 shows the plastic bottle 3D solid model. The plastic bottle has high accuracy curved surface from Figure 3. Figure 4 shows the human doll solid model. The complicated shape like human body can be also constructed, and extracted the human body parts. However, the accuracy of doll’s curved surface is not the same as the plastic bottle. This is the reason why the doll’s shape is hard to capture because doll’s color is many and similar to the background.

3. COMPARISON OF CURVATURE USING LOG-AESTHETIC CURVED LINE

The similar curved line should be extracted from body parts, because the human body is composed of the different kinds of body parts shape. Namely, each the body parts should be separated and analyzed. The curved surface is extracted from human body parts of the surface (solid) model like Figure 5, and the highlight line on the surface is extracted and compared with some kinds of log-aesthetic curved line like Figure 6 (a) - (b).
using Rhinoceros software. Then, the point cloud data are extracted from the surface (solid) like Figure 6 (b) - (c), and it is fitting to B-spline surface by an approximation method like Figure 6 (c) - (d). The curvatures of the highlight (curved) line from B-spline surface in Figure 6 (d) and near log-aesthetic curved line are compared and analyzed. Then, we analyze the curvature change and error (separation).

### 3.1 Male right arm
First, the curved line of the male right arm is compared with a log-aesthetic curved line. The arm point cloud data are extracted from the right arm solid model using Autodesk Remake software. We select the male arm, because the male arm or other parts seems to be bold and little beautiful (aesthetic). Figure 7 shows the male model and the male right arm model. The arm is measured with high accuracy from Figure 7. Then, the point cloud are fitting to B-spline surface by an approximation method, and the highlight curved line is extracted from shoulder surface to list surface like Figure 7 (d) using Rhinoceros software. The curvature is compared with a log-aesthetic curved line. The right arm is bent at his elbow, because he has taken photographs in sitting down. We analyze the curvature of upper parts (from shoulder to elbow) and lower parts (from elbow to list). Both of the curvature changes are similar to logarithmic spiral, and compared with it. Figure 8 shows the curvature comparison of the male right arm and the logarithmic spiral. Some place of the arm curvature is similar to a logarithmic spiral in Figure 8 (a), but many places are different from it in Figure 8 (b). Then, we estimate the maximum error of curvature on the highlight line. The maximum curvature error (separation) of the upper arm parts is 0.70 rad/cm, the error of the lower parts is 0.75 rad/cm.

### 3.2 Female doll spine
Next, the curved line of the female doll spine is compared with a log-aesthetic curved line. The point cloud data of the spine are also extracted from the spine solid model using Autodesk Remake software. We select the female spine, because the female body parts from neck to hip seems to be beautiful (aesthetic). However, the real female spine could not be taken a photograph, then the female doll is substituted for beautiful model. Figure 9 shows the female model and the female spine model. The spine is measured with high accuracy from Figure 9. Then, the point cloud are fitting to B-spline surface by an approximation method, and the highlight curved line is extracted from neck to hip like Figure 9 (d). The curvature is compared with a log-aesthetic curved line. The curvature analysis is separated to upper spine, lower spine, waist, and hip, because the spine (back) is composed of many complicated shapes and different curved lines. Figure 10 shows the curvature comparison of the female spine and the logarithmic spiral and involute curved line. The curvatures of the lower spine and waist curved line compare with involute curved line in Figure 10 (b), (c). This is the reason why the curvature distributions are not similar to logarithmic spiral, bit similar to the involute curved line. From Figure 10, any places of the spine curvature are similar to a log-aesthetic curved line, but any places are different from it. The near curved line to a log-aesthetic curved line is waist and hip, the farthest curved line is lower spine. It is different from an involute curved line and a logarithmic spiral.
3.3 Comparison of Male and Female body parts

After that, we estimate the body parts using the maximum error of curvature. Table 1 shows the maximum curvature error of male arm and female spine for a log-aesthetic curved line. We think the lower maximum curvature error (separation) is near curvaceous. From Table 1, the most similar curved line for curvature change is female hip, and female hip and waist are more similar than male arm. Therefore, we conclude the female body parts are more curvaceous (similar) a log-aesthetic curved

![Figure 7: Male right arm shape](image)

![Figure 8: Curvature comparison of right arm](image)

![Figure 9: Female doll spine shape](image)

![Figure 10: Curvature comparison of doll spine shape](image)
line than male body parts predictably. We guess the female hip has many well-rounded parts and gently-sloping roundness, and their factor is connected with a log-aesthetic curved line.

4. CURVATURE CHANGE OF BODY PARTS BY PHYSICAL EXERCISE

The quantitative aesthetical estimation of body shape can be analyzed, but the correlation of the change body shape and physical exercise is unidentified. If it is clarified, the physical exercise and shape-up exercise may be useful for shapely (aesthetical) body. Then, we investigate the curvature change of male right thigh by physical exercise. The subject is one 30’s male, 178cm height, 80 kg weight. First, the maximum curvature error of the right thigh is calculated. Second, the subject runs 30 minutes 3 times a week in physical exercise. After that, the thigh is captured and the curvature change is calculated once every month, and the exercised used calories are calculated using Google Fit. Figure 11 shows the scheme of the physical exercise and thigh capture. Here, the other factors (the amount of a meal, basal metabolic rate, walking used calories) are excluded. Figure 12 shows the male right thigh solid model of before and after physical exercise. The visual shape change is hard to find from Figure 12. Table 2 shows the change of maximum curvature error once every month in physical exercise. The curvature of thigh is changing and aesthetic little by little from Table 2. In addition, the error is increasing (getting worse) in 3rd month, because the use calories are decreasing. This is the reason why the factor of personal error and lifestyle habit may be exist. In future works, we will investigate more subjects and other body parts, and calculate the entire surface of body parts not only highlight lines.

5. CONCLUSIONS

In this paper, we build up a hypothesis that the body line fitting the log-aesthetic curved line is curvaceous, and the body parts shape is determined for curvaceous parameter using the hypothesis. First, the definition of a log-aesthetic curved line is explained, and we suggest the method of shape capture using the camera and the turntable. Second, the parts of male right arm and doll spine are captured, and compared the similarity of curvature to a log-aesthetic curved line. In this result, the most similar curved line for curvature change is female hip, and female hip and waist are more similar than male arm. Therefore, we conclude the female body parts are more curvaceous (similar) a log-aesthetic curved line than male body parts predictably. Third, the before and after exercise thighs are compared and analyzed the curvaceous similarity of a log-aesthetic curvature for investigating the correlation of physical exercise and curvaceous. We estimate the curvaceous validity of physical exercise. In this result, the visual shape change is hard to find, but the curvature
of thigh is changing and aesthetic little by little. In future works, we will investigate more subjects and other body parts, and calculate the entire surface of body parts not only highlight lines.

**Table 2: Curvature error changing**

<table>
<thead>
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<th>Week</th>
<th>Month</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
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<td>1st</td>
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<td>320</td>
<td>282</td>
<td>600</td>
</tr>
<tr>
<td>2nd</td>
<td></td>
<td>905</td>
<td>855</td>
<td>135</td>
</tr>
<tr>
<td>3rd</td>
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<td>282</td>
<td>700</td>
<td>0</td>
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<tr>
<td>total</td>
<td></td>
<td>1507</td>
<td>1837</td>
<td>735</td>
</tr>
</tbody>
</table>

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**REFERENCES**


