A 3D Design System of Skirt Profile Based on OpenGL

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Abstract. Personalized customization is inseparable from effective communication between designers and consumers, which is often aided by 3D software. Based on the OpenGL graphics interface, this paper studies and developed a three-dimensional interactive skirt design system. This system can help designers and consumers quickly agree on the skirt profile and record the profile parameters. What's more, it can help designers design and produce clothes that are more in line with consumers' needs. The research process can be divided into four parts: the establishment of the skirt point cloud model, the triangular meshing of the point cloud model, the rendering of the triangular meshing model, and the development of the interactive interface. The design of skirt length, contour, and pleats can be parametric now with the realistic virtual visual effect. Therefore, this paper provides new ideas and methods for achieving the “what you see is what you get” skirt design concept.

Keyword. 3D interactive dress design; apparel CAD; apparel digitalized design; OpenGL.

1. Introduction
As the fashion industry has developed rapidly, consumers have an increasing aesthetic on clothing. This led to the emergence and popularity of personalized custom clothing [1]. Skirts are one of the most popular types of clothing for female consumers. Skirt designs must be more responsive with the continuous shortening cycles of clothing fashion.

“What you see is what you get” is an important design concept in apparel design. In fact, consumers are not participating in the design process nowadays in most of the dress designs both at home and abroad, let alone get to the essence of the concept, as designers are dominators and consumers passive receivers. The development of personalized customization marks the implementation of the “what you see is what you get” design concept. Consumers get involved in the design of clothing through clothing customization and change the final clothing products. However, in the customization process, consumers and designers cannot communicate efficiently due to their different perceptions of clothing, resulting to a disparity between consumers’ expectations and outcomes [2-3]. To this end, a three-dimensional virtual design system with interactive functions was developed as a bridge to link designers and consumers, enabling designers and consumers to reach a consensus within a shorter time and with more efficiency. So as to improve the efficiency in new product design. The 3D interactive dress design system will allow what consumers see conforms to designers’ and ensure that consumers get enough “what you see is what you get” customized experiences.

2. The Establishment of the Skirt Point Cloud Model

2.1. The Establishment of the Basic Skirt Profile
The cross section of the basic silhouette of the skirt is circular. In this case, the entire skirt consists of several circles with different radii. These circles are lined in different height and form the basic
silhouette of the skirt. Therefore, a series of circles at different height can be established through a cyclic algorithm, with the radius of each circle determined by the contour of the skirt. A three-dimensional array DressPoint [i][j][3] can be defined to store the point cloud coordinates. The trigonometric function equation of the point cloud model is:

\[
\begin{align*}
\text{DressPoint}[i][j][0] &= r \cdot \cos \alpha \\
\text{DressPoint}[i][j][1] &= h \\
\text{DressPoint}[i][j][2] &= r \cdot \sin \alpha
\end{align*}
\]  

(1)

Among them, integer variables i and j are used to mark points in the skirt point cloud, floating-point variable h to calibrate its height, and floating-point variable \( \alpha \) to calculate its coordinates. By changing the values of \( r \) and \( h \), different heights of circular point cloud data are generated, so as to establish a skirt contour point cloud. The simplified contour of the point cloud is shown in figure 1.

2.2. The Addition of Pleats to Skirt

Adding pleats onto skirts is a key step in the design, which will bring an elegant and smart design effect. The cross section of the skirt point cloud model generated by formula (1) is circular, hence it is necessary to add a fluctuation factor in formula (1) to generate controllable pleated effect for the section. Here we add pleats by adding the peak and trough effects of the sine function to the point cloud section. Through this correcting process, equation (1) evolves into:

\[
\begin{align*}
\text{DressPoint}[i][j][0] &= r \cdot \cos \alpha + m \cdot \cos \beta \cdot \sin \gamma \\
\text{DressPoint}[i][j][1] &= h \\
\text{DressPoint}[i][j][2] &= r \cdot \sin \alpha + m \cdot \sin \beta \cdot \sin \gamma
\end{align*}
\]  

(2)

Among them, \( \sin \gamma \) is a pleat simulation modeling function; \( \cos \beta \) is an x-coordinate correcting function, which can correct the pleat shape generated by the function \( \sin \gamma \) to the x-coordinate of the basic circular skirt; \( \sin \beta \) is a z-coordinate correction function, which can correct the pleat shape generated by the function \( \sin \gamma \) to the z-coordinate of the basic circular skirt. The floating-point variable \( m \) is the amplification factor of the correction effect, enabling parameterized design of the skirt. Figure 2 shows the corrected pleat size in parameterization design of skirt point cloud model and figure 3 shows numbers of pleats in parameterization design.

![Figure 1. A diagram of a basic skirt silhouette point cloud.](image1.png)

![Figure 2. Different sizes of pleat.](image2.png)
2.3. Parametric Transformation of the Skirt Point Cloud

The skirt contour design is also crucial to the final design effect. The formation of skirt contour depends on the distribution of circular radii of different heights. These circles with different heights and varied radii are lined regularly in a three-dimensional space, forming the overall contour of the skirt. The outer contour of the skirt is generally smooth in curve with limited number of folds. Here the third-order Bezier curve is used to change the skirt contour. The function expression of the third-order Bezier curve is:

\[ P(t) = (1 - t)^3 \cdot P_0 + 3t \cdot (1 - t)^2 \cdot P_1 + 3t^2 \cdot (1 - t) \cdot P_2 + t^3 \cdot P_3 \]  \hspace{1cm} (3)

Among them, \( P_0 \), \( P_1 \), \( P_2 \) and \( P_3 \) are the four control points of the third-order Bezier curve. Through them, the curve can be freely shaped to design the skirt contour as one’s will. \( P(t) \) is the point coordinate on the curve, and \( t \) is the independent variable of the curve function.

The third-order Bezier curve function introduces circular radii of different heights, and the point clouds that make up the entire skirt can be distributed according to the curve, thereby completing the contour design of the skirt point cloud. Figure 4 shows the correction effect of the third-order Bezier curve on the skirt point cloud.

3. The Triangular Meshing of Skirt Point Clouds

After the point cloud model is generated, it needs to be triangle meshed. The more the number of points in the point cloud model, the finer the triangular mesh model established, and the calculation of the model will consume more system resources [4-5]. The point cloud data of the skirt model established here has 9 groups, each group with 200 data points. During the final step – rendering, the point cloud model must be triangle meshed in the first place. This is achieved by triangle pairing the point cloud data of two adjacent layers. As shown in figure 5, among the four adjacent points A, B, C, and D, points A, B, and C constitute a triangle \( \Delta ABC \), and points C, B, and D constitute a triangle \( \Delta CBD \). The order of the three vertices of the triangle is counterclockwise.
Figure 5. Triangle meshing of the point cloud.

In this way, all points of the point cloud model are triangular meshed. Figure 6 shows the triangle meshing model of the skirt point cloud.

Figure 6. The triangle meshing model under different perspectives.

4. The Rendering of the Skirt Point

In order to render the triangle meshing skirt model, a normal vector needs to be added for each point in the triangle mesh model [6-7]. Assuming there is a triangular mesh point A, here all triangular mesh surfaces passing through point A will be traversed and their normal vectors will be calculated. The average value of the normal vectors is used as the normal vector of point A.

Suppose there is a plane passing through three points A, B, and C, and their coordinates are \((x_1, y_1), (x_2, y_2), (x_3, y_3)\). The normal vector \(\text{nor}_i\) calculation expression of this plane can be expressed as:

\[
\begin{align*}
    x_n &= \frac{a}{r} \\
    y_n &= \frac{b}{r} \\
    z_n &= \frac{c}{r}
\end{align*}
\]

Among them, \(x_n\), \(y_n\), and \(z_n\) are coordinate components of the surface normal vector \(\text{nor}_i\), and there are:

\[
\begin{align*}
    a &= (y_2 - y_1) \cdot (z_3 - z_1) - (y_3 - y_1) \cdot (z_2 - z_1) \\
    b &= (x_3 - x_1) \cdot (z_2 - z_1) - (x_2 - x_1) \cdot (z_3 - z_1) \\
    c &= (x_2 - x_1) \cdot (y_3 - y_1) - (x_3 - x_1) \cdot (y_2 - y_1)
\end{align*}
\]

\[
c = \sqrt{a^2 + b^2 + c^2}
\]

As shown in figure 7, there are \(j\) planes passing through point A, and the calculation equation of the normal vector \(\text{nor}_A\) of point A is:

\[
\text{nor}_A = \frac{1}{j} \sum_{i=0}^{j} \text{nor}_i
\]

By adding a normal vector to each point of the triangle mesh of the dress, the rendering effect of the three-dimensional model of the dress is shown in figure 8.
5. The Development of Skirt Interactive Design System

The interactive design of skirts requires an interactive design interface. Here a number of sliders serve as the basics of entry point for parameterized point cloud, and performs skirt interaction design and skirt basic parameter setting in the OpenGL virtual environment. When the design is completed, the software will directly export the data including skirt length, contour, pleat and design rendering to provide preference for producing the skirt samples. Figure 9 shows the interactive design section. Through this interactive skirt design software, a series of skirt designs can be achieved, and the design rendering of some styles are shown in figure 10.

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**Figure 7.** The calculation equation of the normal vector.

**Figure 8.** The rendering effect under different perspectives.

**Figure 9.** Interactive design section.
6. Conclusion
This paper developed a 3D interactive dress design system in the OpenGL environment. By entering different parameters of the skirt, we can perform the 3D virtual design, obtain 3D presentation in real time, and export the skirt design data. This further implements the costume design concept "what you see is what you get". In this way, the design process is simple and efficient with an excellent algorithm response and a clear software simulation effect. This method provides new ideas and methods for digitalized skirt design.

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