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Realistic Rendering of Knitwear

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Abstract. Efficient and realistic rendering of knitwear is of great interest especially in the context of e-commerce. Computing geometry play key role in the generation of realistic images, and also has important application in real-time rendering. This paper presents a method for rendering realistic knitwear. Triangles are used to subdivide the yarn surface so that graphics can be obtained quickly and efficiently.

Keywords: realistic rendering, triangle subdivide, knitwear, computational geometry, computer graphics

1. Introduction

The history of knitwear is more than thousands of years. With the use of the computer, people begin to think about the simulation of knitwear. And, with the development of the Internet, there's a desire to render knitwear more efficiently and more realistic, because people can produce knitwear on the computer instead of on the machine. Thus, production of samples on the machine is eliminated, the time and money will not be spent unprofitably, also the errors on the design can be identified and eliminated more easily, and the design can be transmitted via e-mail or fax without spending time and money. So, The simulation of knitted fabric has been a major research interest in recent years.

2. Realistic Rendering of Knitwear

2.1. Background and related work

The 3D geometrical modeling of knitted fabric can be dated back to 1947, Peirce's model of plain knitted fabric. [1] Peirce assumed that the orthogonal projection of yarn path in the plain stitch consists of arcs connected with tangent lines. In 1949, Dalidovitch, [2] also investigated the plain knitted fabric and created a 3D geometrical model. In 1955, Leaf and Glaskin [3] criticized Peirce's model and created a new model by assuming that the orthogonal projection of yarn path in the plain stitch is formed of smoothly connected arcs. In 1960, Leaf [4] created another geometrical model by assuming the orthogonal projection of yarn path in the plain stitch is smoothly connected elastica curves. The recent work on the geometrical modeling of knitted fabric has focused on 3D representation with computer graphics. In 1996, Michael Meissner, Bernhard Eberhardt and Wolfgang Strasser [5] created a volumetric appearance model to visualize the knitted fabric. In 2000, A. Demiroz and T. Dias [6] implemented a program to generate a 3D graphical representation of plain knitted fabric with basic fabric parameters. In 2001, the computer scientists and engineers in Microsoft Research, China and the Institute of Software, Academia Sinica, China, Y. Q. Xu, EnhuaWuz et al., [7] simulated the structure and appearance of knitwear in such detail that fibers in the yarn can be seen. It is apparent that the yarn path in knitted fabrics is more complex. Most of the geometrical modeling work was done on the plain knitted structure.

2.2. Peirce's Stitch Model of Knitted Fabrics

In this paper,the 3D geometrical modeling of knitted fabric was based on Peirce's stitch model. Originally it is a compact stitch model. In that model, the wale spacing is 4 times the yarn diameter and the course spacing is $2\sqrt{3}$ times the yarn diameter, which are the minimum possible values. A loose plain stitch

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model can be obtained by increasing wale spacing and course spacing, based on Peirce's plain stitch model. The configuration of yarn paths is shown in figure 1.

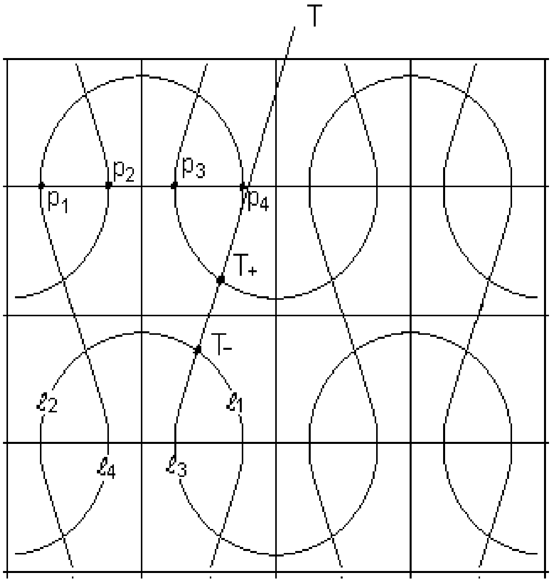

Fig.1 Peirce's model

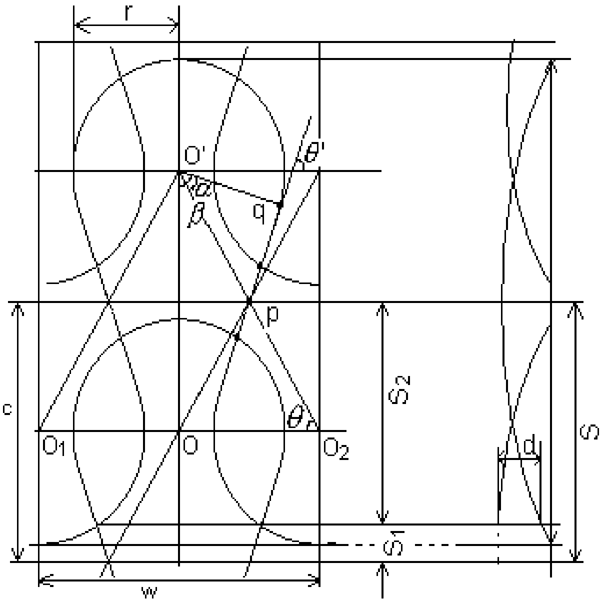

Fig.2 related parameters

To determine the relative positions of yarn, P_1 and P_2 is assumed to be the points that yarn axes l_2 and l_4 cross the plane of fabric at M (plane M is the side projection of the yarn path, shown in figure 2), the distance between P_1 and P_2 equals the diameter of yarn. As figure 1 shows, l_1 and l_2, l_2 and l_4 are symmetric, if we can obtain the equation of a single yarn, the structure of the whole stitch is clear.

So we focus on the equation of curve l_1. Shi yingzhong [8] has given the equation as blow:

$$\begin{cases} x = \begin{cases} \sqrt{r^2 - y^2} & (r\cos(\pi-\beta) \le y \le r) \\ ctg(\beta)(y+\frac{c}{2})+\frac{w}{4} & (-\frac{c}{2} \le y < r\cos(\pi-\beta)); \end{cases} \\ y = y \\ z = z_0 - R\left(1-\sqrt{1-(\frac{y+c/2}{R})^2}\right) & (-\frac{c}{2} \le y < r) \end{cases} \tag{1}$$

In Peirce's model, the side projection (along the course direction) of the yarn path is assumed to be arc, and the radius of this is noted as R. r refers to the radius of the loop, c and w are respectively the course spacing and wale spacing. β is shown in figure 2, and it can be calculated as:

$$\beta = \arccos\left(\frac{2r}{\sqrt{(\frac{w}{2})^2 + c^2}}\right) + \frac{\pi}{2} - arctg\left(\frac{2c}{w}\right) \tag{2}$$

2.3. The surface and the normal vector of the yarn

Since the equation of the yarn axes has been calculated, the next step is to get the surface of yarn. In this paper, the surface is assumed to be consisted of a set of rings, and the plane of the ring is vertical to the yarn axes, as shown in figure 3 and figure 4. Equation (1) can be noted as

$$\begin{cases} x = x(y) \\ y = y \\ z = z(y) \end{cases} \qquad -\frac{c}{2} \leq y < r \qquad ; \qquad (3)$$

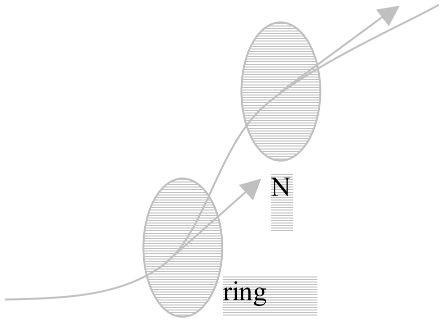

Fig.3 the rings along the yarn axes

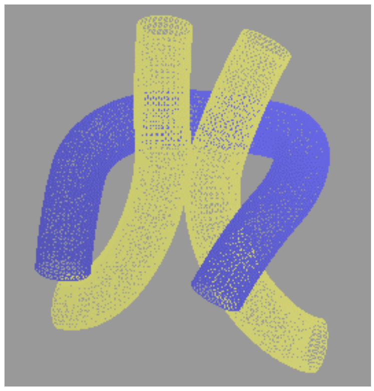

Fig.4 yarn composed by rings

The vector of yarn axes can be calculated :

$$V = \{x'(y), 1, z'(y)\} \qquad (4)$$

vector $\{x'(y).z'(y), z'(y), -(x'(y))^2 + 1\}$ and $\{-1, x'(y), 0\}$ is two orthogonal vectors，and they are orthogonal to vectors V as well. After normalization, Note them as $Norm1$， $Norm2$ respectively.

So the equation of the ring can be calculated:

$$P = P_0 + r_1 \cdot Norm1 \cdot \sin t + r_2 \cdot Norm2 \cdot \cos t \qquad 0 \leq t < 2\pi \qquad (5)$$

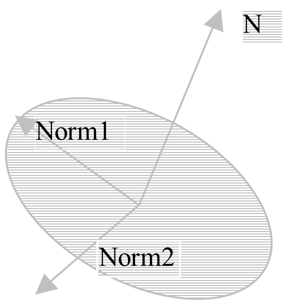

Fig.5 orthogonal vectors

In Peirce’s Stitch Model, the yarn section can be considered as circle. And in many other models, there are many assumption about the section form such as partial. we use default value $r_1 = r_2$ in equation (5).when necessary, we can adjust r_1 and r_2 easily to get a partial section, and we can get more complex section if alter eqution (5).figure 6 shows four different section when r_1 and r_2 changes.

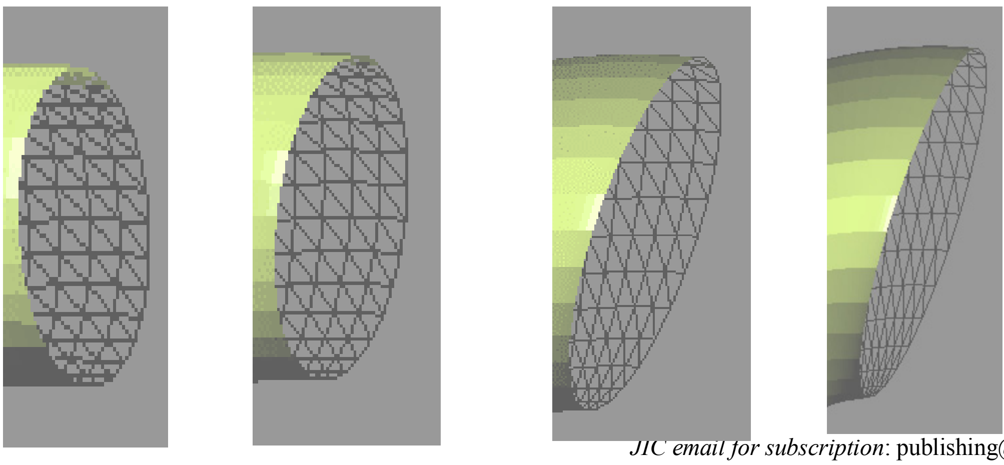

Fig.6 varies yarn section

while the coordinate position of the point along the ring is calculated, the unit normal vector of the surface at these points can also be calculated. That is:

$$N_P = Norm1 * \sin t + Norm2 * \cos t \qquad 0 \le t < 2\pi \qquad (6)$$

this normal vector will be used to calculate the illumination brightness later.

2.4. Realistic rendering of the yarn

2.4.1 Surface presentation and illumination

In Computer Graphics, smooth surface is always substituded by a set of discrete polygons, so that the computing cost can be reduced. The side effect is that the surface may looks like a polyhedron, this is because different polygons have different normal vectors, when illuminated, they have various brightness. So the variance of the normal vector of the adjacent polygons must be controlled in a moderate range. In image rendering, illumination play key role to one's the feeling about realistic. If there's no illumination, the image looks unreal, as shown in figure 7. And when illuminated, the image will looks more realistic, shown in figure 8.

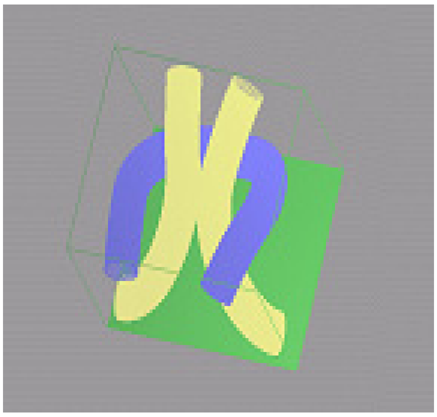

Fig.7 yarn before illumination

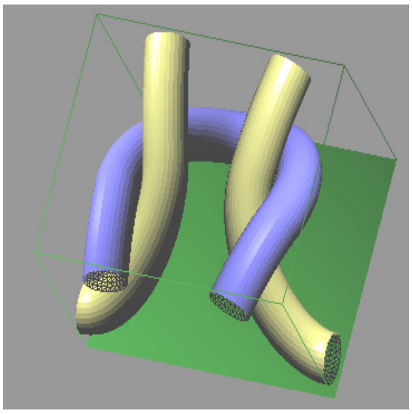

Fig.8 yarn after illumination

In this paper, triangles are used to simulate the surface of the yarn, and the normal vector value in one triangle is constant. The illumination brightness can be calculated if we know the normal vector, suppose the lighting brightness is given. Image can be rendered on the screen now.

2.4.2 Triangle subdivide according to the normal vector

In some local area, if the variance of the normal vectors of two adjacent triangles exceeds the threshold that we set before, it indicates that the image quality is low. To settle this problem, A mechanism of normal vector variant detection should be set up, to detect the problem and resolve it. The resolution is to split the triangle into sub triangle. The procedure of subdivide triangle are as follow:

First, calculate the normal vector of the common vertex:

$$N = \alpha_1 N_1 + \cdots + \alpha_n N_n$$

$$\alpha_1 + \cdots + \alpha_n = 1$$

here $N_1, \cdots, N_n$, $i = 1, \cdots, n$ represents all the unit normal vectors which owns the same vertex.

Then, calculate the variance of the normal vector :

$$\Delta N_i = \frac{|N \cdot (N - N_i)|}{|N|^2}, \quad i = 1, \cdots, n$$

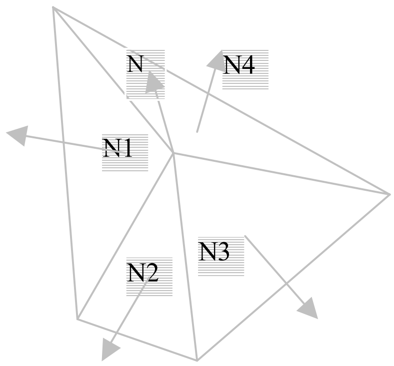

Fig.9 calculate the variance of normal vector

When the variance of the normal vector exceeds the threshold that we expected, The triangle should then be subdivided. Note the normal vector at the vertex of the sub triangles as:

$$N_a = uN_B + (1-u)N_C \qquad u = aC / BC$$

$$N_b = vN_A + (1-v)N_C \qquad v = bC / AC$$

$$N_c = wN_A + (1-w)N_B \qquad w = cB / AB$$

The coordinate position of new vertex a , b , c can be calculated easily.

To simplify the procedure, set $u = v = w = \frac{1}{2}$.

So, a triangle is divided into four sub triangles, and the vertexes of the four sub triangles have their own properties respectively: the coordinate position and normal vector.

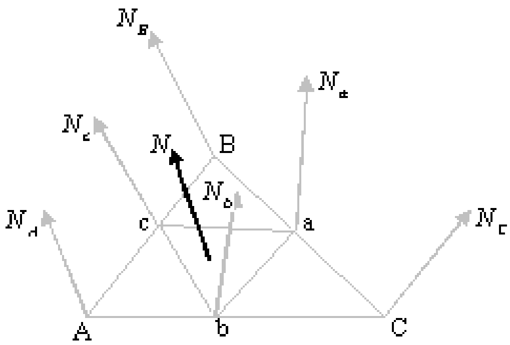

Fig.10 split a triangle into four parts

To avoid destroy the original data structure, List is strongly recommended to be used here instead of Array to store the new information, include new point and new normal vector.

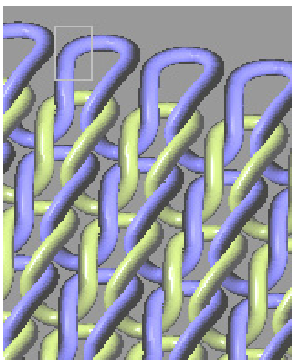

Fig.11 long distance examine

Figure 11 show a high quality image, but close examine will find it's no smooth at all, as shown in figure 12. So we should split some triangles into sub triangles. The image quality is improved now, as shown in figure 13.

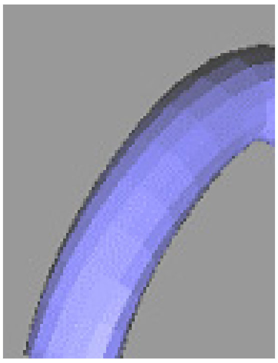

Fig.12 close examine

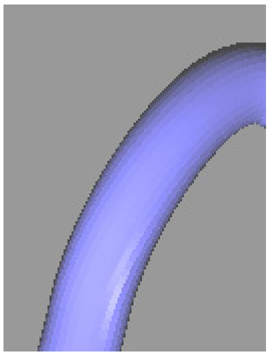

Fig.13 subdivide the triangles

2.4.3 The procedure of rendering the knitwear

Here gives the step we used to render the knitwear in this paper :

1. Select a knitwear model. Peirce's Plain Stitch Mode is selected in this paper .
2. Collect the necessary data, such as the course spacing and wale spacing of a stitch and the yarn diameter, etc.
3. Calculate the equation of yarn axes, Calculate the point and normal vector and store them into Matrix respectively. In order to achieve real-time rendering, Calculate the derivatives should be avoided, for it's a cost assuming job. we use

$$V[i] = \{ctrlpnt0[i+1][0] - ctrlpnt0[i][0],\\ ctrlpnt0[i+1][1] - ctrlpnt0[i][1],\\ ctrlpnt0[i+1][2] - ctrlpnt0[i][2]\}$$

   instead of $V = \{x'(y), 1, z'(y)\}$,

   here *ctrlpnt*[][] is the known value stored in the matrix.

4. Applies coordinate transformation , get yarn ℓ_2, ℓ_3, ℓ_4 according to yarn ℓ_1, so the information of a whole stitch is ready.
5. Calculate the normal vector in the yarn surface, and then calculate the illumination according to the given lighting position and brightness.

5.1 If the variance of the normal vector exceeds the threshold, some triangles should be subdivided if high quality image is required. The threshold should changes when view distance changes.

6. Rendering a stitch.
7. Trough coordinate transformation, Other stitches can be rendered according to given pattern.
8. Rotation can be applied to the knitwear now, to get the idealized view angle.

Experiment shows that the knitwear rendering cost approximately 2 seconds , closed to real time, and has a fine image quality, as shown in figure14 and figure 15.

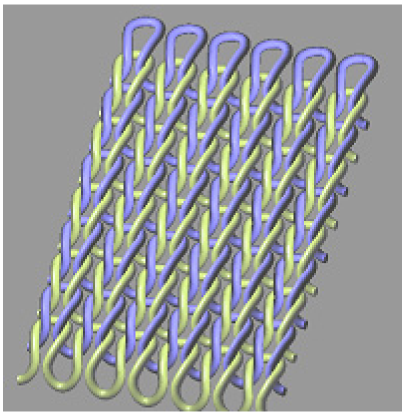

Figure 14

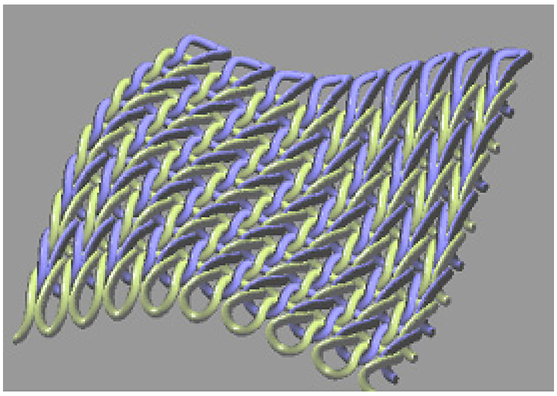

Figure 15

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