

# Three dimensional simulation of weft knitted fabric based on surface model

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## Abstract

In order to enhance the visual simulation effect of weft knitted fabric in weft knitting CAD system, a three dimensional surface model of weft knitted structures is developed and realized on the computer screen. It is assumed that the yarn centreline is continuous when it is stressed to bend, and the cross-section of yarn is circular and uniform. Three dimensional geometric models are created by using second order continuous NURBS curves. According to the trend of the yarn centreline, a surface model of the yarn is created by sweeping approach. With developing tools of Visual C++ and OpenGL graphics library, the surface model of loop is achieved by the method of mesh chips on computer screen, and the three dimensional simulation of weft knitted fabric is realized. The simulation effect based on surface model can be seen from the simulation results of basic weft knitted fabric.

*Keywords:* Weft knitting, Loop structure, NURBS; Simulation, Surface model

## 1 Introduction

By using computer aided design (CAD) technology, designers can easily design fabrics in virtual mode [1]. At the same time, the efficiency and quality of fabric design has been greatly improved, and the repeated process of knitting experimenting, proofing can be avoided. CAD systems are convenient tools for knitting fabric manufactures.

Loop modelling is the foundation of knitting CAD technology. Research on weft knitted fabric structure has continued for 70 years since the forties of the last century. Loop modelling is the foundation of knitting CAD technology. Research on weft knitted fabric structure has continued for 70 years since the forties of the last century. Many geometrical models have been created by researchers for plain knitted fabric [2], including those of Chamberlain [3], Peirce [4, 5], Leaf and Glaskin [6], Leaf [7], Munden [8, 9], Postle [10], Demiroz [11], Kurbak [12-14], Su Liu [15], Ranju Meng [16] and Yinglin Li [17,18]. The geometric model of loop basically perfects, which is the foundation for the simulation of fabric.

However, there are more problems in the fabric simulation. Kurbak carried out simulation of fabric using 3DS Max [12], which is convenient, but is not conducive to the development of CAD software. Su Liu [15] applied sphere function in OpenGL to achieve simulation of fabric, but this method is not conducive to physical attributes of model.

In this paper, loop geometrical model is created by using the NURBS spline curve [19-22], and the three dimensional simulation of the loop and fabric is realized by using the surface model.

## 2 The geometric modelling of plain loop

### 2.1 ANALYSIS OF LOOP STRUCTURE

Knitted structures are progressively built-up from row of intermeshed loops (as shown in Figure 1). The basic constitutional unit of knitted fabrics is the loop. It is a bending space curve. The plain loop is composed of needle loop, sinker loop and loop column [23, 24].

The loop model should be developed before the simulation of the knitted fabric. It is assumed that the yarn in the loop is uniform when the fabric is fully relaxed, the cross-section is circular and the loop is evenly symmetrical, which can be used to better describe the actual shape of the loop and the buckling state of the yarn in the loop, the centreline of the yarn should be a second order continuous spatial curve.

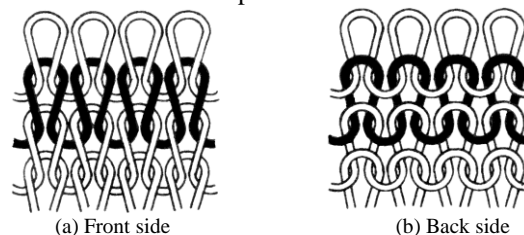
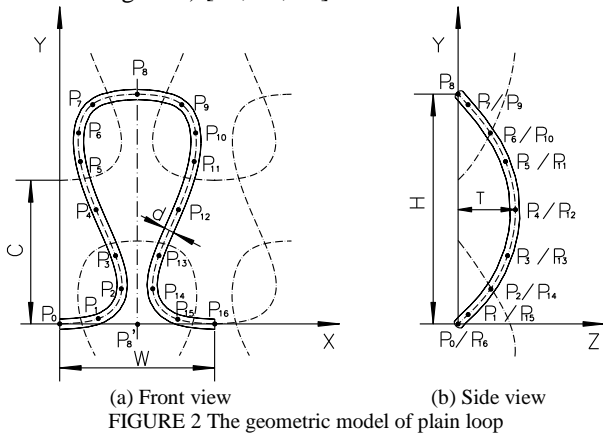


FIGURE 1 Plain knitted fabric

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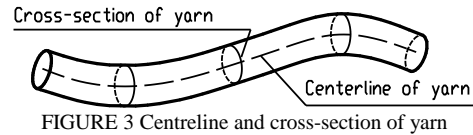
2.2 THE GEOMETRIC MODEL OF PLAIN LOOP

Plain loop is the basic unit of weft knitted fabric. The basic structure parameters of plain loop model are: the loop width  $W$ , the loop height  $H$ , the yarn diameter  $d$ , the thickness  $T$  of the fabric, and the course spacing  $C$  (as shown in Figure 2) [17, 23, 24].



3 Three dimensional surface model of yarn

The basic idea of generating yarn model is to combine the yarn cross-section and the centreline into three dimensional yarn, using sweeping method namely to construct the tube surface along the centreline to indicate yarn [25, 26], as shown in Figure 3.



3.1 NURBS CURVES

Because NURBS (Non-Uniform Rational B-Splines) curve can be partially adjusted, and has good geometry characteristic as well as high flexibility, especially to meet the requirements of second order continuous [19-21]. It can simulate the trend of the centreline of the yarn well, so NURBS curve may be used to simulate yarn centreline.

3.1.1 NURBS curves description

NURBS is a mathematical method adopted to describe the free curves and surfaces. A NURBS curve can be formulated by a sub-rational polynomial function [26-28].

$$p(u) = \frac{\sum_{i=0}^n w_i d_i N_{i,3}(u)}{\sum_{i=0}^n w_i N_{i,3}(u)}, i = 0, 1, 2, \dots, n' \tag{1}$$

where  $w_i$  is the weight factor,  $d_i$  is the control point, and  $N_{i,k}(u)$  is the  $k$  standard B-spline basis functions.

3.1.2 Control points revolved inversely

According to NURBS method, the control points of curve can be revolved inversely by the given data points and then the shape of the curve can be derived by interpolation [29, 30].

3.1.3 NURBS derivative

The derivative of Formula (1) is:

$$P'(u) = \frac{\sum_{i=0}^n w_i d_i N_{i,k}(u)}{\sum_{i=0}^n w_i N_{i,k}(u)} \tag{2}$$

The key point is its basic function derivative, namely [27],

This paper uses the three dimensional loop geometric model which is developed with the data points (that loop passed through, determined according to the geometric characteristics of the loop) of the 17 type based on spline curves in the literature [18], and has made the improvement. The value of  $C$  is equal to  $0.86H$ . The proportional relationship between the  $X$ ,  $Y$ , and  $Z$  coordinates of data points and the loop structure parameters, such as width  $W$ , height  $H$  and thickness  $T$  are shown as Table 1.

TABLE 1 The proportional relationship between data points and the loop structure parameters

Data Points No.	X Coordinate	Y Coordinate	Z Coordinate
$P_0$	0	0	0
$P_1$	$0.2500W$	$0.0407H$	$0.1275T$
$P_2$	$0.3493W$	$0.2035H$	$0.5966T$
$P_3$	$0.3145W$	$0.3494H$	$0.8901T$
$P_4$	$0.2398W$	$0.4954H$	$0.9999T$
$P_5$	$0.1751W$	$0.6486 H$	$0.8930T$
$P_6$	$0.1488W$	$0.7874H$	$0.6193T$
$P_7$	$0.2190W$	$0.9230 H$	$0.2396T$
$P_8$	$0.5000W$	$H$	0
$P_9$	$0.7810W$	$0.9230H$	$0.2396T$
$P_{10}$	$0.8512W$	$0.7874H$	$0.6193T$
$P_{11}$	$0.8249W$	$0.6486H$	$0.8930T$
$P_{12}$	$0.7602W$	$0.4954H$	$0.9999T$
$P_{13}$	$0.6855W$	$0.3494H$	$0.8901T$
$P_{14}$	$0.6507W$	$0.2035H$	$0.5966T$
$P_{15}$	$0.7500W$	$0.0407H$	$0.1275T$
$P_{16}$	$W$	0	0

$$N'_{i,0}(u) = 0, \tag{3}$$

$$N'_{i,k}(u) = \frac{1}{u_{i+k} - u_i} N_{i,k-1}(u) + \frac{u - u_i}{u_{i+k} - u_i} N'_{i,k-1}(u) - \frac{1}{u_{i+k+1} - u_{i+1}} N_{i+1,k-1}(u) + \frac{u_{i+k+1} - u}{u_{i+k+1} - u_{i+1}} N'_{i+1,k-1}(u) \tag{4}$$

Formulae (3) and (4) indicate that the derivative of the basic function is also defined by recursive method [28]. Thus, we can calculate the first derivative of NURBS curves. Similarly, it can also be used to calculate the second derivative.

### 3.2 THE CENTERLINE OF YARN

#### 3.2.1 Definition of the centreline of yarn

We presume that the centreline of yarn is represented by a space curve C whose parametric equation is determined by the formula [25, 28]:

$$\begin{cases} x = x(t) \\ y = y(t) \\ z = z(t) \end{cases} \quad (0 \leq t \leq 1), \tag{5}$$

If it is represented by vector equation, the result is:

$$r = r(t) = x(t)i + y(t)j + z(t)k, \tag{6}$$

Each function of the formulas has the first and the second order continuous derivative, namely,  $r(s) \in C^2$ .

#### 3.2.2 Tangent vector of the centreline of yarn.

It is assumed that  $r(t_0)$  which is short for point  $t_0$  represents any point on the curve C. The tangent vector at point  $t_0$  of the curve C is:

$$\frac{dr}{dt} = r'(t) = x'(t)i + y'(t)j + z'(t)k, \tag{7}$$

where,  $x'(t) = \frac{dx}{dt}, y'(t) = \frac{dy}{dt}, z'(t) = \frac{dz}{dt}, \tag{8}$

According to the arc length parameter method, the standard tangent vector T at point of the curve C is:

$$T = \frac{dr}{ds} = \frac{dr}{dt} \cdot \frac{dt}{ds} = \frac{r'(t)}{|r'(t)|} = t_x(t)i + t_y(t)j + t_z(t)k, \tag{9}$$

Hence,

$$t_x(t) = \frac{dx}{dt} / \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}, \tag{10}$$

$$t_y(t) = \frac{dy}{dt} / \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}, \tag{11}$$

$$t_z(t) = \frac{dz}{dt} / \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}, \tag{12}$$

#### 3.2.3 Normal vector of the centreline of yarn

The unit vice normal vector B at point  $t_0$  of curve C can be written as:

$$B = b_x \cdot i + b_y \cdot j + b_z \cdot k, \tag{13}$$

where the B value can be obtained according to formula as follows [26]:

$$B = \frac{r'(t) \times r''(t)}{|r'(t) \times r''(t)|}, \tag{14}$$

The unit main normal vector N at point  $t_0$  of curve C can be written as:

$$N = \frac{dT}{ds} = n_x i + n_y j + n_z k, \tag{15}$$

where the N value can be obtained according to formula as follows [26]:

$$N = B \times T = \frac{r'(t) \times r''(t) \times r'(t)}{|r'(t) \times r''(t)| \cdot |r'(t)|}, \tag{16}$$

#### 3.2.4 The cross-section of yarn

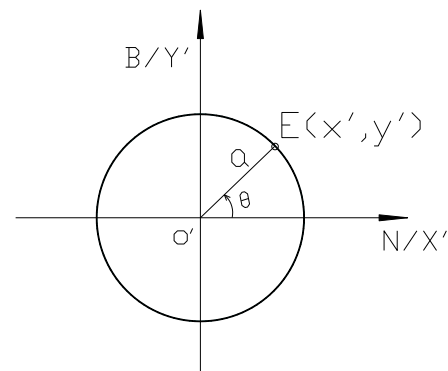


FIGURE 4 Cross-section circle of yarn

In the normal plane that the any point  $O'$  of curve  $C$  is located, we treat the main normal vector  $N$  as  $X'$  axis, vice normal vector  $B$  as  $Y'$  axis, and point  $O'$  as the origin point to construct a plane coordinate system. The circle with centre point  $O'$  and radius  $a$  is the cross-section circle of yarn, which is shown in Figure 4. The parametric equation of any point  $E$  on the circle is as follows ( $\theta$  is a parameter):

$$\begin{cases} x' = a \cos \theta \\ y' = a \sin \theta \end{cases} \quad (0 \leq \theta < 2\pi), \quad (17)$$

According to Formulae (9-12,14,16), in order to get the tangent vector  $T$ , the main and vice normal vector  $N$ ,  $B$  of the curve  $C$ , the first derivative  $r'(t)$  and the second derivative  $r''(t)$  are needed to calculate, therefore, the derivative of the centreline of the yarn is equal to the derivative of NURBS curve [27,28].

### 3.2.5 The surface model of yarn

As the yarn is considered to be formed by the sweeping of cross-section circle along the centreline, and a series of cross-section circulars is distributed on the discrete points of the centreline, we can construct the surface of the yarn on the basis of the adjacent cross-section circles.

According to formula (6),  $C:r=r(s)$  is a space curve of arc length parameter  $s$ ,  $\{k(s), \tau(s), T(s), N(s), B(s)\}$  are the Curvature, Torsion and Frenet frame of the curve  $C$  respectively [25]. Assuming  $K(s) < 1/f$  ( $f$  is a positive constant), we create the surface  $S$ :

$$\rho(s, \theta) = r(s) + a[N(s)\cos\theta + B(s)\sin\theta]. \quad (18)$$

In the formula,  $s$  represents the parameter in the centre line direction,  $\theta$  represents the parameter of the cross-section circular direction, the surface obtained in this way is usually called tube surface [25]. The tube surface can be used to represent the yarn surface whose position in the world coordinate system OXYZ is shown in Figure 5, where  $P$  is a normal plane that any point  $O'$  on the centreline of the yarn is located,  $N$  is the main normal vector,  $T$  is the tangent vector,  $B$  is the vice normal vector,  $OO'$  is the vector of any point  $O'$  on the centre line of yarn,  $OE$  is the vector of any point  $E$  on the cross-section circle, their vector relationships are as follows:

$$OE = OO' + O'E, \quad (19)$$

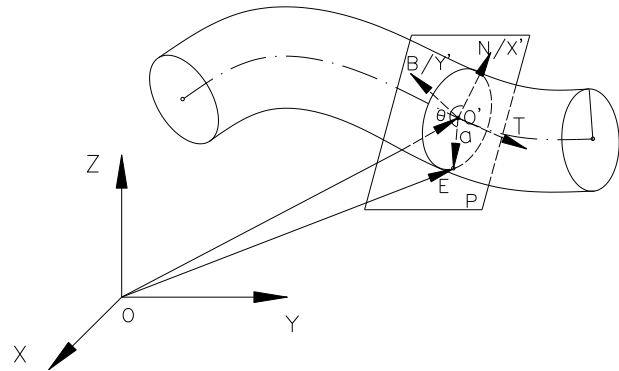


FIGURE 5 Surface model of yarn

In equation (15),  $r(s)$  can be obtained according to the geometry model of the centreline of the loop with NURBS function, after its derivative, then according to the equations (11) and (13),  $B(s)$  and  $N(s)$  can be obtained, thus the coordinate of any point  $E$  whose corresponding angles is  $\theta$  on the cross-section circle with centre point  $O'$  and radius  $a$  of the curve  $C$ . On the basis of this, the wireframe model, and surface model of the yarn can be constructed.

## 4 Simulation realization and discussion

### 4.1 SIMULATION STEP

Visual C++ and OpenGL are used to program the surface loop model [26, 31]. Based on the geometric model of the loop and the three dimensional surface yarn modelling, the three dimensional computer simulation of the plain loop can be achieved by programming, the algorithm is as follows:

Step 1 To input the information of the structural parameters of the loop, such as loop width, loop height, thickness, yarn diameter, colour etc.

Step 2 To calculate the coordinates of the coordinate value of data points on the loop unit respectively.

Step 3 To calculate the coordinate value of the data points on the loop and inversely to calculate the coordinate value of the controlling points of NURBS.

Step 4 To calculate the coordinate value of each interpolation point on the loop according to the controlling points by using NURBS.

Step 5 Based on the loop centreline, calculate the coordinates of discrete points at yarn cross-section.

Step 6 Lighting is set in order to increase the three dimensional effect of loop model.

Step 7 Use the drawing function of OpenGL, rendering loop model.

### 4.2 SIMULATION RESULTS

#### 4.2.1 The centreline of loop model

When setting the parameters of loop, the interpolation points on the loop can be calculated by using NURBS

curves, and then the loop centreline can be obtained with the OpenGL of drawing line function, as shown in Figure 6.

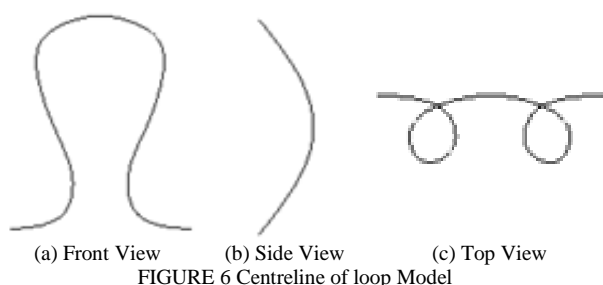


FIGURE 6 Centreline of loop Model

#### 4.2.2 The wireframe of loop model

Based on the loop centreline, the points of cross-section circular are calculated, the wireframe of loop model is drawn with the line function of OpenGL, see Figure 7.

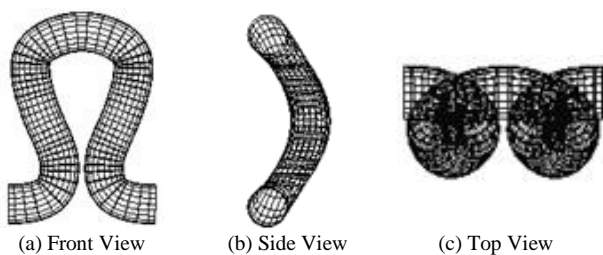


FIGURE 7 Wireframe of loop model

#### 4.2.3 The surface of loop model.

Based on the loop cross-section circle, the surface of loop model is drawn by mesh chips, see Figure 8.

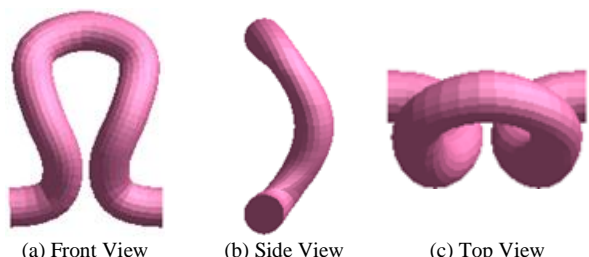


FIGURE 8 Surface of loop model

#### 4.2.4 The plain structure simulation

Comparing the simulation results of the plain structure based on the simulation of the loop with the real fabric, the effect is shown in Figure 9.

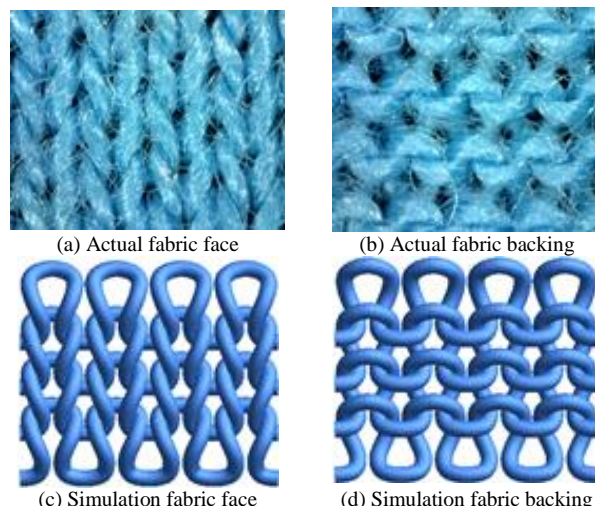


FIGURE 9 Actual fabric and Simulation result

### 4.3 DISCUSSION

According to Figure 9, the simulation results are relatively close to the actual fabric, it shows that's feasible to create surface model by using the NURBS curve, and has strong adaptability to the change of loop shape. The deficiency is that the use of mathematical tools is difficult.

Through constructing the loop model by surface model, although the process is with more trouble than method of sphere, but change more in its shape in cross-section, can also use the texture mapping technology, and can conveniently set the physical attributes. It is conducive to the development of CAD software.

### 5 Conclusions

The following conclusions can be drawn from the study: In this work, a three dimensional surface loop model is developed using NURBS curve and surface model of OpenGL mesh chips. This three dimensional model is successfully used to represent plain structure of weft knitted fabrics on the computer. Simulation results of knitted structures show that the NURBS curves and surface modelling by mesh chips have perfect realistic effect. By changing the shape of cross-section, using the surface model by mesh chips, complex cross-sectional shape of yarn can be obtained, for example, the yarn with twist. The yarn surface model by mesh chips is recommended to obtain more realistic representations of knitted structures in further research work in this area. In addition, by using texture mapping, the real yarn images are mapped to the surface of the three dimensional yarn models.

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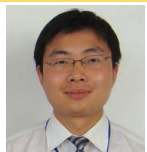
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