PATTERN RELATED ISSUES IN THE MODELLING OF DEFORMED OVER SURFACE WARP KNITTED STRUCTURES WITH LONGER UNDERLAPS

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ABSTRACT

The yarn level modelling of warp knitted structures is a complex process. For structures placed on the plane, it is well investigated and there are a few software solutions and papers reported. This paper considers the simulation of warp knitted structure, deformed in the 3D space. Especially the modelling of the areas of high curvature are detailed observed. Underlaps with longer lengths makes an unreal visualization for simulation results. Different pattern with different length of the underlaps are modelled with original algorithm developed by the authors. Modelling and visualization problems in the areas with long underlaps are discussed and possible solutions are proposed.

KEYWORDS

3D simulation; Modelling; Curved surface; High curvature; Visualization; Fabric structure.

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INTRODUCTION

In the era of continuous development of digital textiles, more and more scholars have focused on the simulation of fabrics. In the course of fabric simulation, 3-dimensional(3D) simulation has made a great progress in the recent years, which has become increasingly important in numerous application areas in production. 3D simulation is commonly used in fabric design, apparel design, etc., which is convenient for designers and consumers to obtain visualization results, helping us better understand the shape and structure of fabrics.

There are many softwares on the market for clothing design with fabric display, such as *Clo3D*, *Marvelous Designer*, *Revobit*, etc. All of them use texture mapping methods to add textures to clothing. Similarly, many scholars used texture mapping, transferring the flat patterns to complex models [1-3]. But the detailed textile structure was not well represented.

Yarn-level 3D simulation solved this problem well. Researchers conducted studies on flat fabrics. Peng et al. [4] simulated the weft knitted pattern and proposed the loop deformation. The structures of various types of flat warp-knitted fabrics were well demonstrated by 3D simulation [5]. Based on this, Liu et al. [6] added the jacquard parameters to simulate more complex warp knitting patterns. The above simulation research on flat fabrics had laid a good foundation for warp knitting simulation.

For knitted products with complex shapes, Yuksel et al. [7] meshed the existing models. Different shapes of meshes corresponded to different knitting structures. Wu et al. [8] labeled those meshes with knitting direction, filling the meshes with similar matching loops. Also loop force deformation were well analyzed to reach a more detailed result [9,10]. These 3D simulation above focused on weft knitted fabrics, which was a good reference for our research of warp knitted fabric simulation.

The authors also paid attention to the warp knitted fabric simulation. Renkens et al. [11] modelled the double needle-bed warp knitted fabrics using a mathematical method. Liu et al. [12] spread out a double-layer fabric and then rolled it into a tube with geometry calculation. They mainly discussed the fabric tube shape rather than the stitch details. Many flat models with stitch shape details were mentioned in the Kyosev's book [5,14]. Also, warp knitting stitch size was measured and the stitch model was established [14]. But only stitch main body was sized and underlaps were out of consideration.

During the simulation development and the practical experience with model simulation by ourselves, we find that some pattern related issues need to be improved when we establish the fabric models according to different knitting parameters for patterns.

EXPERIMENTAL

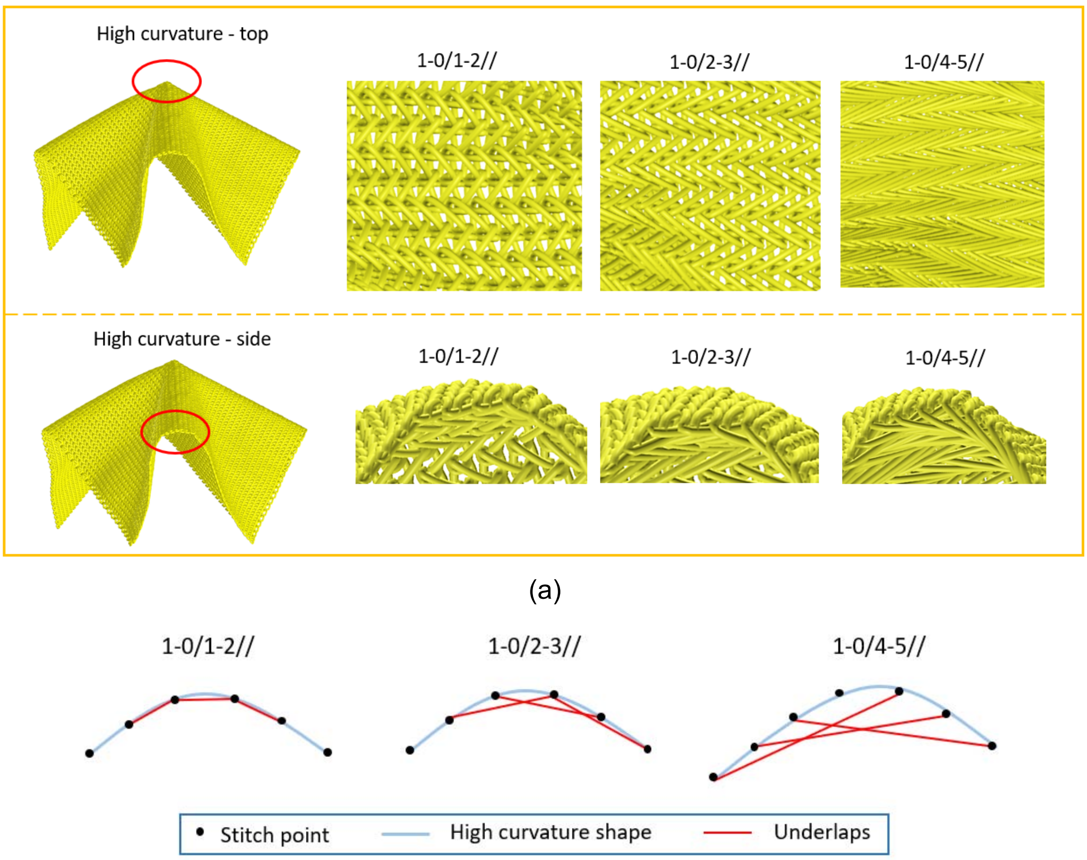
Modelling basis

In this paper, we develop our research based on our previous works[12,15]. The tubular fabric was spread out into a plane. And a spatial relationship of the stitch grids between the tube mesh and the plane mesh was derived to mapping the stitch coordinate on the tube. Then geometry tubes in Three.js, a lightweight cross-browser JavaScript library, were used to realize the fabric simulation.

Pattern related issues

Although the simulation results are good, we find some patterns related issues need to be improved. Figure 1 shows an example from our previous work[15], As we all know, the stitches in the warp knitted fabrics are connected with underlaps. But different patterns are made of different chain notation. Some underlaps is short, like the structure 1-0/1-2//. Some underlaps are longer like 1-0/2-3// and 1-0/4-5//, whose underlaps span several wales. There are high curvature areas at when fabrics are rolled into a tube in Figure 1(a). Stitches are simulated well with the 8-points model. But the underlap is lying in an unusual place, especially for longer underlaps.

For a better visualization, we extract the underlap paths from a side view in Figure 1(b). In the structure 1-0/1-2//, the underlap is short so that they fit tightly to the deformed surface. But as the underlaps get longer in 1-0/2-3// and 1-0/4-5//, whose underlaps cross over several wales, the space become larger between underlaps and deformed surface. It is because the connecting yarns between two stitches are simulated by a straight line with two points. Actually, stitches on a real-world fabric fit well to the surface within the common underlap lengths. For a more realistic simulation results, some improvements need to be made.



(b)

Figure 1. Pattern related issues with high curvature and long underlaps in 3D simulation: (a)simulation results with different underlap length [15]; (b) Statement of underlaps with different lengths on the high curvature shape.

Methods

The stitch grids not always in the same plane as mentioned in Section 2.2. The long underlaps are overhang from the deformed surface. But the number of points on the underlap is changed to avoid unnecessary calculations.

Figure 2 is a schematic from the top view, where the fabric is bent into a curved surface. Figure 2(a) shows two stitches on a plane fabric, the straight underlap is exactly on the fabric surface. Figure 2(b) shows stitches on the same curvature surface. The vertical vectors of stitch grid that toward the outside of the model surface is represented as green lines. When the vector angle of two connected stitches is larger, the underlap is father away from the fabric surface. In Figure 2(c), the deformed surfaces have different curvature with two stitch vertical vector remains the same. The higher the curvature is, the more inaccurate the simulated underlap is.

In order to solve this problem, some control points are added to the underlap model, modifying the stitch model as shown in Figure 3. The points connecting the underlaps is very near to the stitch bottom center that can almost be ignored, so the underlap is regarded as an edge of the underlap triangle when calculating the added points. The underlap is divided into several segments. Because the triangles including the underlap segments are similar triangles, added points can be calculated by Eq.1 according to the wale distance ratio. Thus, the underlap can be pulled from the original shape, fitting the deformed surface well. In this example, the distance ratio $e = \frac{w}{4w} = 0.25$.

$$\begin{cases} P = e \times (P_2 - P_1) + P_1 \\ e = (P - P_1)/(P_2 - P_1) \end{cases} \quad (1)$$

Where, P is the added point, P_1 and P_2 are stitch points connecting underlap, *e* is the distance ratio.

In the other case, the stitches are on the bent fabric, not on the regular tube. There is an example for fabrics knitted by 1-0/4-5// in Figure 4. Different from the round fabric, the added points depend on the normal vectors of stitches. All the normal vectors are towards the same side of the fabric.

Seeing the Figure 4 - Vector relationship, bent Ⅰ is the occasion where the normal vector angle α is less than 180°. $\boldsymbol{V}_1$, $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$ are the normal vectors of stitches. When the vector angle α_1 is larger than the value β, added points are put on the underlap lapping pass these two stitches. β is a specified angle value. The details of a tested yarn are shown in underlap triangle. And $\boldsymbol{V}_2$ becomes the first vector to compose the vector angle with the normal vector of the next stitch. For $\boldsymbol{V}_2$ and $\boldsymbol{V}_3$, the angle α_2 is less than the value β, so there is no added point at this position. Then it continues combining with the next stitch vector. When calculating the added points on the plane fabric, the underlap is also regarded as an edge of a triangle according to Eq.1. In bent Ⅱ, when the angle α_2 of two normal vectors $\boldsymbol{V}_4$ and $\boldsymbol{V}_5$ is larger than 180°, the underlap is at the other side of the fabric. The added points are directly added on the underlap. Then $\boldsymbol{V}_5$ Then it continues combining with the next stitch vector.

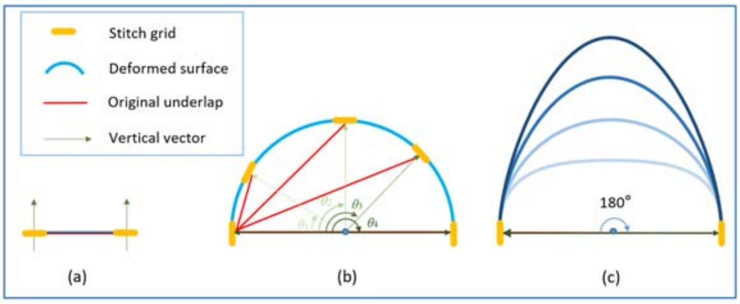


Figure 2. Stitch statement and the underlap positions. (a)Plane fabric; (b)Stitches on the same curvature surface; (c)The same stitches with different curvature surfaces.

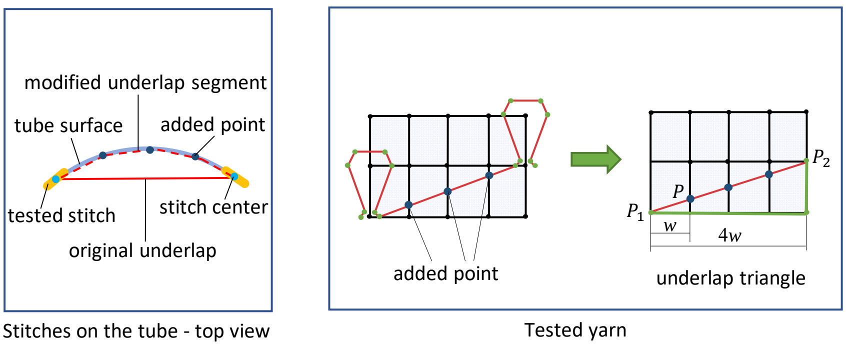


Figure 3. The modified stitch models with added control points on the underlap.

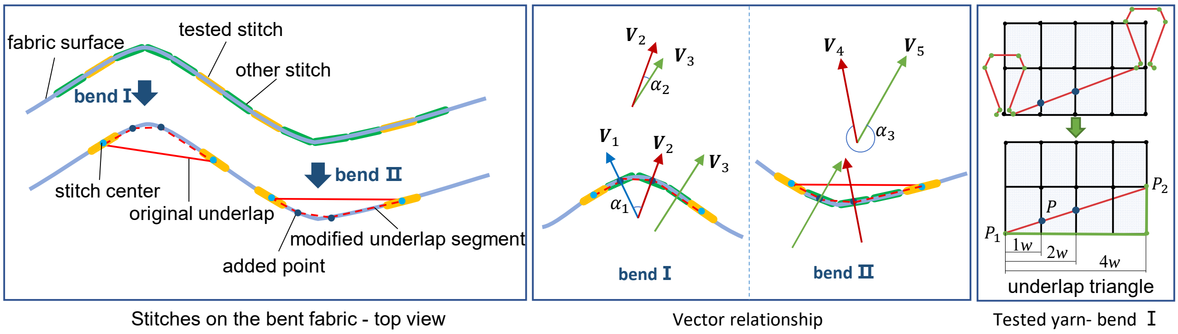


Figure 4. The modified stitch models on the bent fabric.

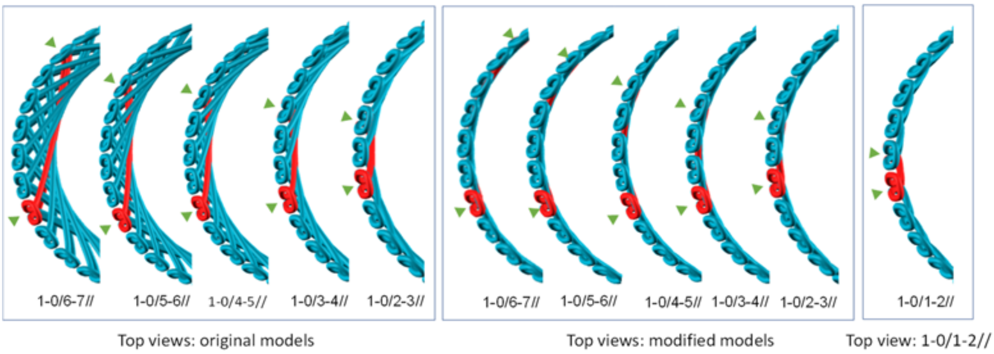
RESULTS AND DISCUSSION

Tubes

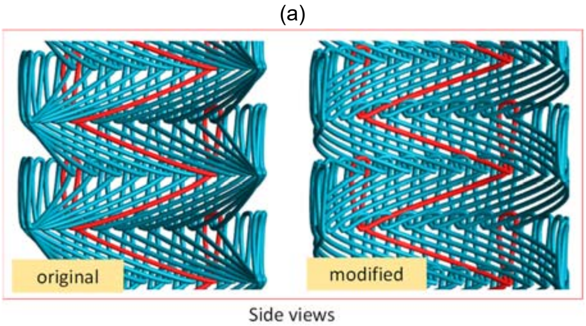
Figure 5 shows some simulation results for different underlaps on the same curvature of the regular tubes. The structure 1-0/1-2// is special because there is no added point on the underlap. The green triangles mark the red stitch position in the tested yarns. The maximum vertical distances from underlaps to stitches are listed in Table 1. This measurement size for the modified group is the average of each underlap segments. The modified models seem thinner than the original ones, which means underlaps are closer to the surface. Each structure saves 48~79% distance. The longer the underlap, the more efficient improvement the modified model shows. For a fabric in the size of 15 wales × 10 courses (150 stitches), the time efficiency is recorded in Table 1. Although underlaps with added points takes longer calculation time, the differences are within an acceptable range of 10%. From the side view of these tubes in Figure 5, they look similar for one single yarn. But yarns in the modified simulation result are more neatly arranged.

Table 1. Size and time efficiency comparison for the tube models.

	Thickness			Calculation time/15 wales ×10 courses		
Structure	Original/*px*	Modified/*px*	Differences/%	Original/ms	Modified/ms	Differences/%
1-0/2-3//	0.257	0.132	48.64	12.867	13.559	5.39
1-0/3-4//	0.366	0.134	63.39	13.856	14.709	6.15
1-0/4-5//	0.413	0.140	66.10	15.560	16.468	5.83
1-0/5-6//	0.525	0.144	72.57	14.636	15.660	7.00
1-0/6-7//	0.703	0.147	79.09	15.474	16.993	9.82



(a)



(b)

Figure 5. Simulation results of the original model and the modified model for regular tubes. (a) from top views; (b) from side views.

Bent fabric

In order to get the specified angle value β, fabrics are bent at certain angles. Figure 6 shows a group of fabrics with the bent angle of 60° before modified. The fabrics are bent at between the 7th and the 8th wales. The fabrics becomes thicker as the underlaps become longer. Both top views and side views of a structure 1-0/4-5// are also shown in Figure 6 as a visual example.

Figure 7(a) is the vertical length (the maximum thickness of the fabric) from the underlaps to the fabric faces at several angles from 0° to 165° with the tested angle step 15°. For the short underlap structures 1-0/1-2// and 1-0/2-3//, the underlap become away from the fabric before the angle 75°. And then the underlap becomes closer to the fabric surface. This decrease is more obvious in the longer underlap structures. But for these structures, the turning angle is 90°. Take the structure 1-0/6-7// for example in Figure 7(b), when the bend angle becomes larger, the underlap triangle becomes smaller, resulting in a shorter distance trend to the fabric. It is because when the bend angle is larger, two fabric pieces get closer to each other. That is why the turning angle exists at 75° and 90°.

The added points can be omitted when the distance short enough. The differences are listed in Table 2 comparing with the flat fabric (0°). Structures are named from 0 to 5, which is relating to the stitch interval number the underlap passes. The differences under 10% are regarded as an acceptable range for the underlap simulation. The underlaps at the angle differences lager than 10% need added points to pull them back. Thus, the specified angle value β is obtained in Table 3.

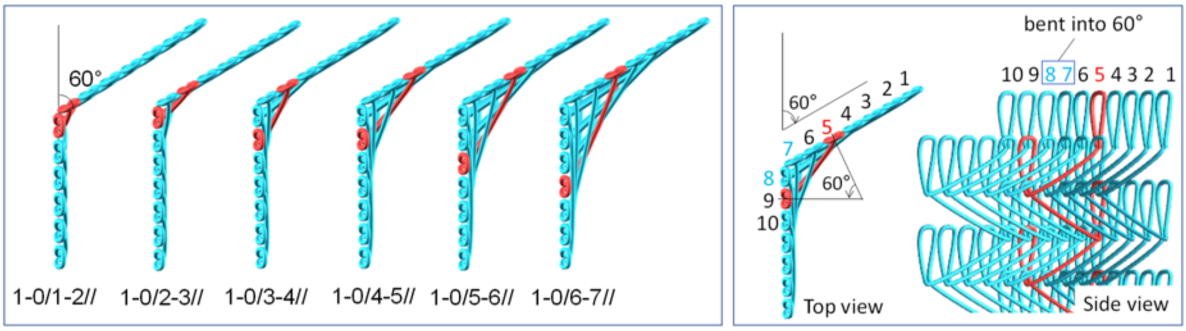


Figure 6. Bent fabrics at 60° before modified.

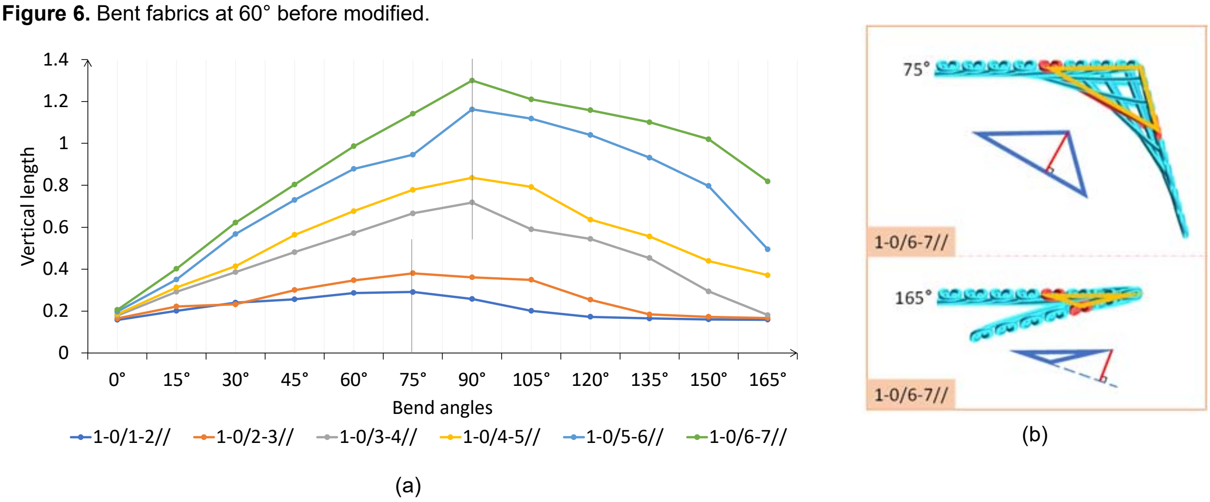


Figure 7. Vertical length measurement results. Vertical length of bent fabrics at different angles.

Table 2. Vertical distance differences comparing with the flat fabric.

Stitch interval number	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
0	27.22	51.90	62.03	81.01	84.18	63.29	27.22	9.49	4.43	1.27	0.63
1	34.55	40.61	81.82	110.30	130.30	118.79	111.52	53.94	11.52	4.85	1.21
2	64.04	116.85	170.22	221.35	274.16	303.37	231.46	205.62	154.49	65.17	1.69
3	69.19	123.78	204.86	265.95	320.54	351.89	328.11	243.78	200.54	137.30	100.54
4	78.17	188.32	270.56	345.69	380.20	489.85	467.51	427.92	373.10	304.57	151.27
5	95.15	201.94	290.29	378.64	453.88	531.07	487.38	462.14	434.47	395.15	297.57

Table 3. *β* ranges.

Stitch interval number	***β***
0	$\begin{cases} \beta = 0° \text{ or } \beta > 120°, \text{no added pointss} \\ \text{else, added points} \end{cases}$
1	$\begin{cases} \beta = 0° \text{ or } \beta > 150°, \text{no added pointss} \\ \text{else, added points} \end{cases}$
2	$\begin{cases} \beta = 0° \text{ or } \beta > 165°, \text{no added pointss} \\ \text{else, added points} \end{cases}$
3	$\begin{cases} \beta = 0°, \text{no added pointss} \\ \text{else, added points} \end{cases}$
4	
5	

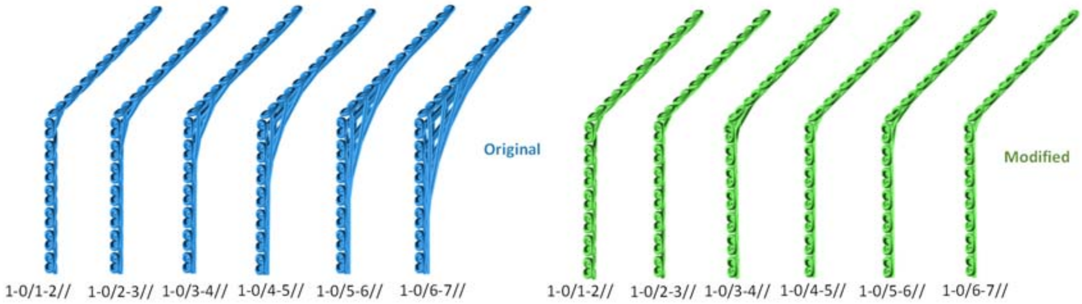


Figure 8. Comparison between original models and modified models at the bend angle of 45°.

Figure 8 shows another example of the bent fabric at the bend angle of 45°. The added points are calculated according to the above regulars. All underlaps are pulled closer to the fabrics after modifying the models, which proves the method proposed in this paper is effective for a better visualization.

CONCLUSIONS

During our 3D simulation for warp knitted fabrics, a pattern related issues with underlaps on deformed surface is discussed. The longer the underlap will get an inaccurate simulation result. Thus, the vertical vectors of stitch grids on the deformed surface are analyzed. And the original stitch model is modified with additional control points on the underlaps. For the tube fabric, points are added at each wale that the underlaps pass. For the bent fabric, the points are added according to the vertical normal vector angles of stitches. Fabrics with several angles of normal vectors are analyzed. Relationships between points and stitch interval number are established and demarcation angles β are obtained. The size comparison results declare that underlaps are pulled back to the fabric well. The results show this method has a positive effectiveness in visualization.

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