

A Layered Method for Realistic Rendering of Towels and Carpets

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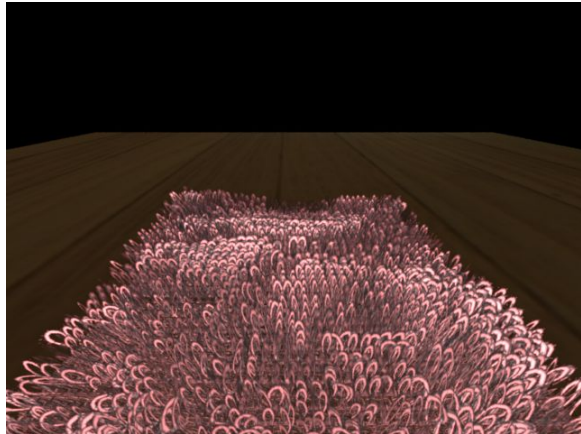


Figure 1: Result3, 240*280 yarns

Abstract

We present a balanced method for realistic rendering of towels and carpets from a normal viewing distance. Since the yarn loops on the surface of a towel contribute more to the appearance of a towel than the underneath skeleton yarns do, we model yarn loops with more accurate geometry and lighting models. To show the randomness in the shape of a yarn loop, we control the shape of yarn loops by bilinear patches. To keep the continuity between the shapes of neighboring yarn loops, we determine the vertices of a bilinear patch by both the underneath towel stitch pattern and a turbulence function. We also present a reasonably simplified method to ray trace the a yarn loop volume. In our ray-tracing method, only one intersection point needs to be calculated for each incident ray. Both our lighting model and geometry model can also be applied to other layered objects (e.g. fur and grasses).

1 Introduction

Cloth simulation is used in many areas: Animation, CAD and Games etc. In the past twenty years, a lot of cloth modeling and rendering techniques have been invented. Some methods [Xu *et al.*, 2001] [E.Groller *et al.*, 1995] [Adabala *et al.*, 2003] [Baraff & Witkin, 1998] [Bridson *et al.*, 2003] generated highly realistic pictures. But for complex woven products, like towels and carpets, little work was done. We can apply some knitwear or fur rendering methods [Xu *et al.*, 2001] [Kajiya & Kay, 1989] to render towels, but there are two unsolved problems. One is that none of these methods can depict the continuous randomness feature of yarn loops on towels. The other is the inherently long computation time, which limits their application into commercial use. In this paper, we explore a computationally fast model for photorealistic rendering of layered cloth objects like towels and carpets. For

succinctness, we use the word "towel" instead of "layered cloth object" in the rest of this paper.

Based on the observation that the yarn loops on the surface of a towel contribute more to the appearance of a towel than the underneath skeleton yarns do, we model yarn loops and skeleton yarns with different method. For yarn loops, we represent them with more accurate geometry and lighting models and put more rendering time on them. For the underneath skeleton, since most part of them are in the shadow of yarn loops, we use simplified geometry and lighting model.

We organize the rest of this paper as follows. We give an overview of related work on rendering varieties of cloth and fur in Section 2, and discuss their limitations to effectively rendering of towels. In Section 3, we introduce our general approach and explain why it is effective by analyzing the substructure of towels. We then discuss the geometry models for towel skeleton and yarn loops in Section 4, and the lighting models for towel skeleton and yarn loops in Section 5. In Section 6 we introduce our algorithm to combine the above four models. Subsequently, results are exhibited in Section 7, and future works are discussed in Section 8.

2 Related Work

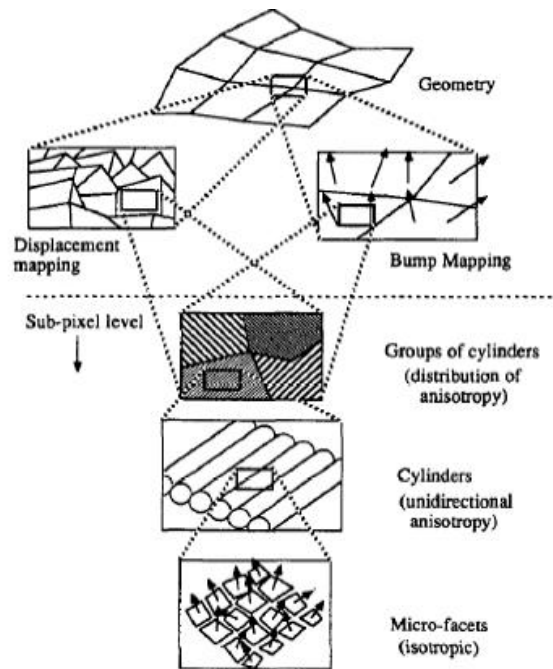


Figure 2: Levels in models of a surface [Fournier & Lalonde, 2000].

Depending on the viewing distance, cloth shows different levels of detail. These levels of detail may be expressed as geometry models or lighting models. Fournier [Fournier & Lalonde, 2000] classified current modelling and rendering techniques into four different levels (Figure 2).

This level graph can be applied to classify cloth rendering techniques. In order to render a realistic picture, we need to choose a proper model that can depict proper detail for the viewing distance. If more detail is expressed, the model not only takes more computation time but may cause aliasing problems.

The highest level is the geometry model (such as polygons and parametric surfaces), which is suited for distance viewing of a piece of cloth. For example, H. Zhong et al. rendered yarn segments with triangle meshes [H.Zhong *et al.*, 2000]. They used a Phong lighting model and a Gouraud shading model to render the meshes. Their method achieved good effects for a remote view. Due to the simple lighting model they used, their method didn't handle close-up views. However, geometry model is an effective approach to guide the distribution of more detailed models. In this paper, we use a geometry model to determine the position, normal and shape of the volume model for yarn loops on a towel surface.

The second level is mesoscopic level, some techniques affecting the distribution of surface normals, such as displacement maps and bump maps belong to this level. These methods can achieve good effect with relatively low time and space cost. But we can only control the shapes and normals of a surface in a limited scope. In this paper, we adopt displacement map to render the skeleton of our towels.

At the third level, the microscopic level, we usually use a function to express the local reflection models. In recent rendering, this local reflection behavior has been expressed by a Bidirectional Reflectance Distribution (BRDF) Function. BRDF is now a widely used lighting model for photorealistic rendering of cloth [L.R.Waston *et al.*, 1992] [K.J.Dana *et al.*, 1999]. But in most practice use BRDF models are simplified to avoid high cost computation and huge space requirement. In 2003, Neeharika [Adabala *et al.*, 2003] combined a industrial standard of weave pattern representation with BRDF lighting model. The BRDF angle parameters are different for the warps and wefts, so the distribution of reflection is different at different position of the surface. For a close-up view, they further considered the contribution of fibers on the cloth surface into their BRDF model.

BRDF model is a powerful lighting model for local illumination. For a remote viewing distance, a piece of woven cloth can be rendered as a surface with BRDF model. But this is not the case for towels. The lighting scattering and transmission between the yarn loops and the towel skeleton is so obvious that it is more proper to render them by a global illumination model.

Below BRDF model, many lower level models are invented to achieve special effects. In 1990, Poulin and Fournier [Poulin & Fournier, 1990] presented a model for anisotropic reflection, they model the microstructure of surfaces as paralleled cylinders. The reflection mode is determined by the intensity of the cylinders and the height of the floor. This approximation method created realistic visual effect for metals, but haven't been adopted into cloth simulation yet.

Ever since volume rendering technique was introduced into cloth rendering, many volume models have been invented at the microscopic level.

As early as 1989, Kajiya and Key [Kajiya & Kay, 1989] first introduced the original volumetric texture model and applied it on fur simulation. Their first attempt was to use volume density to model surfaces. But they proved this was not a proper way because of the totally different lighting property between surfaces and particles. This attempt is

as instructive as their final result since most researchers will naturally want to model everything, even surfaces, with particles. They used a 3D texture to represent the lighting field of a tiny surface in space. The lighting field was affected by three factors: the density of microspheres, the reflectance function (the material property, they used BRDF function) and the frame (the orientation of the microsphere). The other innovative point was the way they model the bear. They called it "Generative models". By this method, each component of the object, actually a set of 3D polygons are mapped by a function from a 2D rectangle. This method served as a intermediate step between mapping from texture space to world space and greatly simplified texture mapping process. We adopt the 3D texture model to represent a yarn loop volume.

Xu's paper in 2001 [Xu *et al.*, 2001] presented a well-balanced method for photorealistic knitwear rendering. They actually combined several techniques in a creative way. They invented a primitive called "lumislice" to represent the lighting field of the cross-section of the yarn. The illumination values on the lumislice is pre-computed according to a BRDF model. They also considered multiple scattering between voxels when calculating input lighting for a voxel. Their experiment result is highly realistic and they mentioned that their rendering method can be used to render carpets.

Just as mentioned before, we can apply the above methods on towel rendering. But none of the current methods can depict the continuous randomness feature of yarn loops on towels. The running time is inherently long in current realistic rendering approaches. In this paper, we try to solve these two problems with the cost of acceptable image quality depression.

3 General Approach

A towel typically contains three layers. The middle layer is constructed from sparsely woven cloth. The two surface layers are made up of arrays of yarn loops. Since the yarn loops on the surface of a towel contribute more to the appearance of a towel than the underneath skeleton yarns do, we model yarn loops with more accurate geometry and lighting models.

(1) Model yarn loops with explicit geometry, model towel skeleton with displacement map. Yarns loops grow in the third direction other than the underneath skeleton. Even for a remote viewing position, we can't render towels well without considering the reflection of yarn loops and the lighting scattering and transmission between yarn loops and the underneath skeleton .

(2) Combine yarn loops and towel skeleton by stitch pattern. Towels belong to woven fabrics. The woven fabric is composed of interlaced yarns(warps and wefts).Yarns are interlaced in a pattern called a weave structure or stitch pattern. A yarn loop is actually a continuous segment of the warp thread. Figure 3 shows how yarn loops combines with the underneath skeleton.

As an approximation to the real world, we plant the yarn loops to the towel surface according to the stitch pattern. The shape of yarn loops is not totally controlled by the skeleton where the loops are planted. They are distorted by some randomness. Neighboring loops have continuous distortion.

(3) Model the lighting effect of yarn loops by volume, model skeleton yarns by cheap lighting models. Just as mentioned before, we need a global illumination model to render



Figure 3: A yarn loop is actually a segment of warp thread

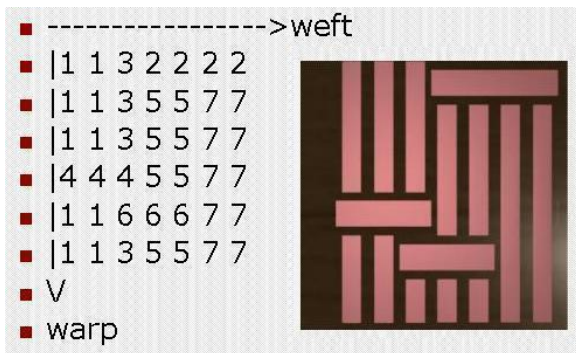
yarn loops. Volume illumination has been proved to be an effective way to render both knitwear yarns and fur. So we use volume model to render yarn loops. On the other hand, since the towel skeleton is mostly hidden by yarn loops, it contributes little to the final radiosity. Using simple lighting model (e.g. Lambertian model) for it, we can achieve significant performance enhancement with the cost of a very little quality depression.

Another observation further enforced the above conclusion. Fibers are twisted together to form yarns, but some fibers dissociate from the yarn. These free fibers give cloth a fuzzy appearance. We calculate the fuzzy appearance of yarn loops by ray tracing volume data. Since skeleton yarns are tightly constrained by nearby yarns, less free fibers dissociate from the yarn body. Since simple lighting models can hardly capture the fuzzy effect of free fibers, this fact decreases the error of our skeleton lighting model.

4 Geometry Models for Towel Skeleton and Yarn Loops

4.1 Geometry Models for Towel Skeleton

Different towels have different stitch pattern. We represent a stitch pattern with a 2D array. Figure 4 shows a typical stitch pattern:



A typical stitch pattern. Yarn loops are planted where the array value is 7.

Figure 4: A typical stitch pattern

We use displacement map to change the surface position and normal according to the stitch pattern. The geometry

model for warps and wefts of the towel skeleton is a winding cylinder. In order to show the interlacement of the yarns, we modulate the cylinder position with a sine wave along the thread direction.

The displacement for each point on the warps of the cloth skeleton surface can be expressed by the following equation:

$$A = \sqrt[2]{\text{Radius} - (P - \text{YarnCenter}) * (P - \text{YarnCenter})} \quad (1)$$

$$P+ = N * A * \sin(2\pi * (P\%Step) + d) \quad (2)$$

In the above equation:

P: the position of any point on the warps of the cloth skeleton surface

N: the surface normal at this position

A: the displacement along the yarn cross section

d: phase displacement because of the stitch pattern

Step: warps or wefts per stitch pattern

Radius: radius of yarn cylinder model

YarnCenter: axis of yarn cylinder model

The wavelength of the sine wave is the same as the width of a stitch pattern. Figure 5 shows the towel skeleton appearance after modulated by sine waves and cylinders.

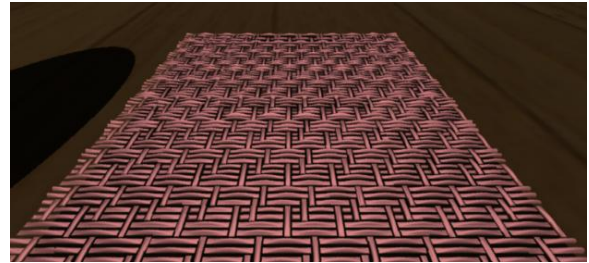


Figure 5: Displacement map: sine waves along the thread, cylinders for cross section

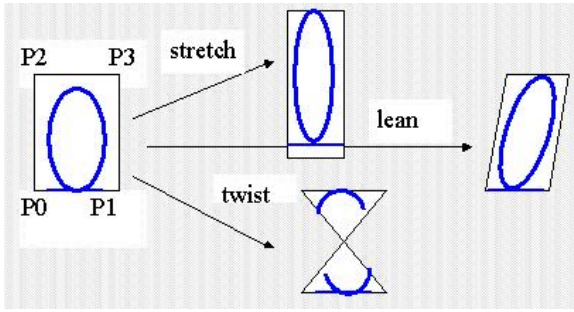
4.2 Geometry Models for Yarn Loops

Our geometry model for a yarn loop is a 3D volume with the shape and position defined by the "Yarn Loop Frame". A yarn loop frame is a bilinear patch defined by four control points. We calculate the four control points according to the underneath stitch patterns, chart images and some noise functions.

The stitch patterns control the position and the density of yarn loops. The two control points (as points P0 and P1 shown in Figure 6) at the bottom of the yarn frame are totally determined by the stitch pattern. For example, in Figure 4 yarn loops are planted where the array element value is 7.

The chart image controls the color, the shading property and the length of yarn loops. In this way, any picture can be modulated onto the towel. The relationship between the yarn loop length and the texel in the char image can be defined by different ways. One simple way is to let the yarn loop length proportional to the texel gray scale. A more flexible way is to map the texel color into a lookup table. The shading property of yarn loops represents the material of the yarn. Texel values are considered as parameters for the shading model.

The noise function stretches, tilts and twists yarn loops (See Figure 6) by displacing the two control points at the top of the yarn loop frame. To keep the continuity between



A yarn loop frame can be stretched, tilted or twisted by changing the position of point P2 and P3

Figure 6: A yarn loop frame.

the shapes of neighboring yarn loops, we use a smooth turbulence function. To further smooth it, we can also filter the turbulence function with a box filter or gaussian filter.

Figure 7 shows varieties of the yarn loop frame shapes generated according to the stitch pattern and a turbulence function.

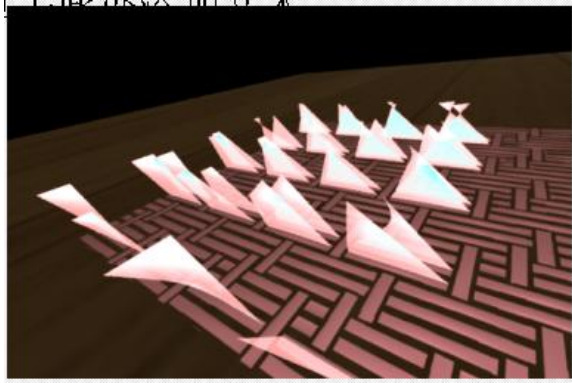


Figure 7: The yarn frames controlled by stitch pattern and a turbulence function

5 Lighting Models for Towel Skeleton and Yarn Loops

5.1 Lighting Model for Towel Skeleton

Since the geometry model for skeleton layer is a surface, we can choose from a variety of existing surface shading models. Simple and fast ones include Lambertian and Phong model. Since a yarn is formed by twisted sub yarns, we can calculate the lighting effect more accurately with Pierre Poulin and Alain Fournier's anisotropic reflection model [Poulin & Fournier, 1990].

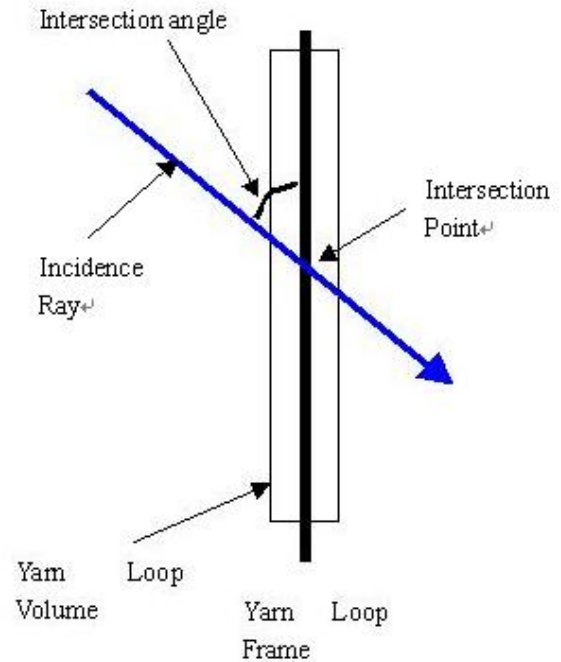
5.2 Lighting Model for Yarn Loops

The lighting model for a yarn loop is based on Kajiya's microsurface volume model for realistic fur rendering [Kajiya & Kay, 1989]. A yarn loop is defined by an 3D array of microspheres. Each microsphere has its own density, normal, transmission and reflection property. When we ray trace a volume, the intensity of the incident ray is given by the following formula:

$$B = \sum_{t=t_{near}}^{t_{far}} e^{-\tau \sum_{u=t_{near}}^t \rho(x(u), y(u), z(u))} \times \left[\sum_i I_i(x(t), y(t), z(t)) \Psi(x(t), y(t), z(t), \theta, \phi, \rho) \right] \times \rho(x(t), y(t), z(t))$$

Figure 8: Ray tracing formula [Kajiya & Kay, 1989].

Kajiya's 3D texture ray tracing method represented the lighting characteristic of fur precisely. The boundary surfaces of the volume can be represented by equation: $P=A*u*v + B*u + C*v + D$. Define the ray by $R=a*t+b$, we can calculate the intersections with the six bounding surfaces of a yarn loop volume by solving an equation array described in Kajiya's paper. But this method is computationally expensive. Based on the observation that the deformation in the yarn cross section is much smaller than the deformation in the other two directions, we suppose the thickness of a yarn loop is fixed. So we only calculate the intersection position and angle between the ray and the yarn loop frame (a bilinear patch) as shown in Figure 9. Theoretically we achieve six times speedup.



Simplified method to ray tracing yarn loop volume. This figure shows a side view of the yarn loop volume.

Figure 9: Ray tracing yarn loop volume.

For simplification, all the microspheres can be defined to be perpendicular to the surface normal of the yarn loop frame. We can also use a Lambertian model for these microspheres. The transmission factor is one minus the intensity value.

6 Algorithm Description

The whole algorithm can be divided into 6 steps: 1.Create a skeleton: create a stitch pattern; store the knot of weft and warp into 2D array, with u and v as index. Each array element includes: position, Normal, weft direction. 2.Calculate yarn loop frames according to towel skeleton, chart image and turbulence function. For each tracing ray do the following: 3.Calculate reflection of yarn loop according to: ray intersections with yarn loop frames, yarn loop volume model. Notice that each ray can intersect with more than one yarn loop frame . 4.Calculate transmission ray intensity from yarn loop according to yarn loop volume. 5.Calculate reflection of the towel skeleton layer and the yarn loop layer on the other side of the skeleton. Yarns in the skeleton layer will be modeled as anisotropic cylinders or volumes. 6. Sum up the reflection of yarn loop volume and the towel skeleton surface.

7 Result

Figure 10 shows a layer of the yarn loop volume. In our following experiment each yarn loop volume contains five layers, each of which has 32×32 voxels. Image resolution is 512×512 pixels.

Figure 12 shows a pictures of yarn loops with 120×140 yarns in skeleton and modulated by a turbulence function shown as the left image Figure 11. The running time is 6 seconds.

Figure 13 shows a pictures of yarn loops with 120×140 yarns in skeleton and modulated by a more smooth turbulence function shown as the right image of Figure 11. The running time is 6 seconds.

Figure 1 shows a pictures of yarn loops with 240×280 yarns in skeleton. The running time is 35 seconds.

The running time depends heavily on the density of stitch pattern, image resolution and volume layer number.

Our test machine has a Pentium 4 processor, 512M main memory and a ATI Radeon 7500 video card. For a middle distance view (each yarn loop occupies several or tens of pixels) , 512×512 pixel image takes 0.1-1 minutes. This speed is not far away from the performance requirement of realtime applications.

8 Future Work

Currently we have not implement all the designs. Future work includes:

- (1) Implement a proper lighting model for yarn loops microspheres and towel skeleton.
- (2) Smooth the intersection part of yarn loops with underneath skeleton.
- (3) Use a 3D free form skeleton model to replace the simple square.
- (4) Use soft shadow to enhance image reality.
- (5) Use chart image to control the length, color and even geometry and lighting model of yanloops.



Figure 10: A typical yarn loop volume layer. Defined by a 32×32 pixel image.

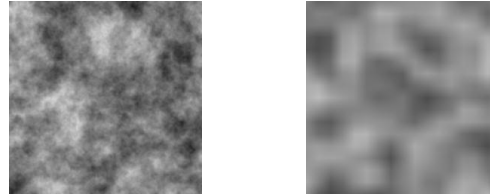


Figure 11: Turbulence Textures

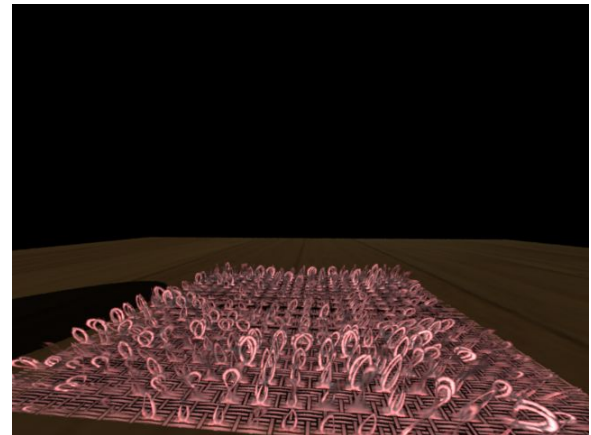


Figure 12: result1, 120×140 yarns, using turbulence Texture1

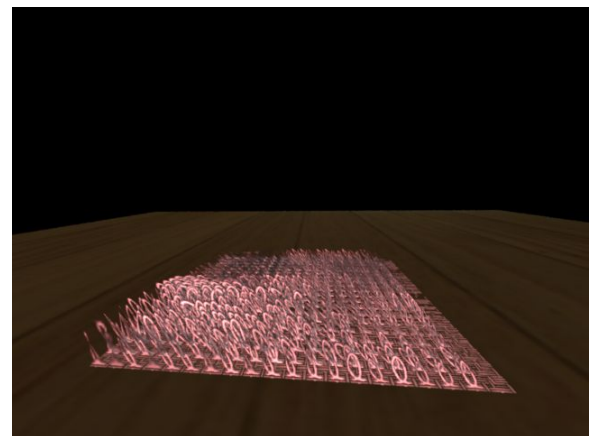


Figure 13: result2, 120×140 yarns, using Turbulence Texture2

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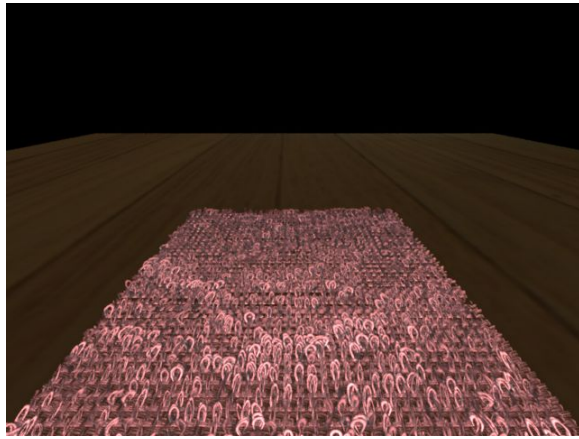


Figure 14: result4, 240*280 yarns

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