

## Three-dimensionally Simulated Monofilament Fabrics with Changes in Warp/Filling Yarn Diameter

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### Abstract

The purpose of this work is to present three-dimensional models of plain fabrics having various warp and filling yarn diameters. In order to simulate a woven fabric, a 3-dimensional CAD software with NURBS modeling capability was used. Final rendering was performed on the fabric model. It was demonstrated that the changes in yarn diameter could be three-dimensionally modeled through the use of fabric geometry and the 3D CAD. A short RhinoScript program was composed to implement the data importing and model building on the 3D CAD.

**Key Words :** 3-dimensional CAD, Yarn Diameter, Rendering, Warp/filling yarns

### I. Introduction

One of the general purposes of CAD systems in the sectors of textiles or apparel manufacturing is to provide easy and accurate designing and realistic simulation of the structures of the objects on a screen in order for the designers or manufacturers to evaluate their designs before weaving, knitting or other related processes.

Clothing is of prime importance in both live action and three-dimensionally generated characters in computer graphics sectors. The relationship among tailoring, body composition and material selection are equally important for either medium as these qualities make each

garment unique to every individual, real or fictional. Clothing folds, wrinkles and stretches to conform to its wearer. It also sticks to itself and other layers of clothing. The appearance of a piece of clothing comes primarily from responses to these conditions. Thus it is essential for clothing created using computer graphics to model considering all the possible combinations of wearing conditions and physical properties of the fabrics. A discreet selection of cloth model is consequential both to obtain the desired look and feel of the cloth, and to obtain simulation results within a reasonable time frame.<sup>1)</sup>

Due to the complex folds or creases formed, textiles are difficult to simulate. White

et al.<sup>2)</sup> suggested a method that can recover high resolution measurements of the shape of actual cloth, using multiple cameras, cloth with special pattern imprinted, and high shutter speeds to capture fast motions, for instance, people's jumping about, which often generate dramatic shapes of folds that are unlikely to appear in static scenes. The interaction between applied force and the force of inertia would be difficult to model without real data. The study also demonstrated reconstruction quality using both static and dynamic scenes and results that would be challenging to get from a laser scanner that does not produce a parameterization, or no strain constraints, and cannot act quickly enough to capture fast motion.

Huang et al.<sup>3)</sup> proposed an objective fabric modeling systems that convey not only the visual but also the haptic and audio sensory feedbacks to remote/internet users via an audio-haptic interface, by developing a fabric surface property modeling system consisting of a stylus based fabric characteristic sound modeling and an audio-haptic interface. With the developed system, PhilaU Haptic Device, a combination of force feedback and a tactile display, people can perceive fabric's surface roughness, friction, and softness though not as precise as with their bare fingers.

Yasuda et al. reported a shading model for clothes exhibiting interaction of light with individual threads of the cloth.<sup>4)</sup>

Daubert et al.<sup>5)</sup> presented an efficient cloth modeling and rendering techniques, which are applicable especially for coarse woven fabric and knitted fabric. In this case, the threads occupy a volume and the shadowed regions of the milli-geometry have a significant contribution to the BRDF(Bi-directional Reflectance Distribution

Function) of the material, using NURBS(Non-Ashikhmin et al.<sup>6)</sup> developed a micro-facet based techniques for modeling light interaction with surfaces and applied them to simulate the velvet and satin fabric appearance.

Adabala et al.<sup>7)</sup> have presented an algorithm that utilizes the weave pattern to create a global illumination model for cloth. They approached the weave pattern as a WIF (Weave Information File) format, which is parsed to obtain the weave pattern being used to generate color maps. As the fabric can be observed from different distances, a level of detail representation was created for the weave pattern from the color maps. For distant viewing a mipmapping of the weave pattern was used to define the properties of the fabric that occurs at a pixel and the illumination model was evaluated accordingly. For close-up observation of the construction of the cloth at a particular pixel was identified using the weave pattern representation in their study.

Human mechanoreceptor cells respond to a change in external stimulus such as pressure, temperature, etc. The change in the external stimulus is converted to a voltage pulse across neurons. While the voltage pulses occur immediately after the external stimulus, the pulse rate declines over time and returns to normal level. The rate at which the pulse returns to normal after an external stimulus is called the rate of adaptation. Thus there is a change in signal required even if the quantity is static such as roughness of a surface.

The explanation related to this physiological phenomenon could further be explained with the help of physically realistic three-dimensional models of complicated fabrics.

uniform Rational B-Splines) are that they provide the flexibility to design a large variety of shapes, can be evaluated reasonably fast by numerically stable and accurate algorithms, and are invariant under affine as well as perspective transformations. In the computer-aided design and computer graphics, the term spline refers to a piecewise polynomial curve. Splines are popular curves in these sub-sectors because of the simplicity of the construction, ease and accuracy of evaluation and their capacity to approximate complex shapes through curve fitting and design. The purpose of this work is to present three-dimensional models of plain fabrics having differing warp and filling yarn diameter. Using a 3-dimensional CAD program, yarn path was constructed having crimps generated due to the weave structure. Rendering was also performed on the three-dimensional model to allow for visual evaluation.

## II. Experimental

### 1. 3-dimensional yarn model basis

In solid form, NURBS surfaces are used to represent the yarn. Control points are always connected either directly to the curve/surface or act as if they were connected by a rubber-band. By evaluating a NURBS curve at various values of the parameter, the curve can be represented in Cartesian 2- or 3-dimensional space. By evaluating a NURBS surface at various values of the two parameters, the surface can be represented in Cartesian space.

The woven fabrics are generally anisotropic, have poor in-plane shear resistance and have

less modulus than the fiber materials due to the existence of crimp and crimp exchange. Reducing yarn crimp in the loading direction or using high modulus yarns increases fabric modulus. The three main types of single layer weave geometry are plain, twill and satin weave and in each case the warp and the filling yarns are oriented at zero degree and 90 degrees, respectively. Plain weave gives the highest frequency of yarn interlacing, hence the highest level of structural integrity and a greater extensibility to the fabric, due to the high degree of bending or crimp of the fibers and yarns comprising the weave.

The yarn is modeled as a round monofilament yarn in this study. It is assumed to be uniform throughout its length. A plain weave does not necessarily result in a plain surface effect or design in the fabric. Variation of yarn linear densities and/or yarn spacing variations can produce rib effects shown in taffeta, faille, and grosgrain, while the use of color pattern for warp and filling yarns result in color and weave effects.

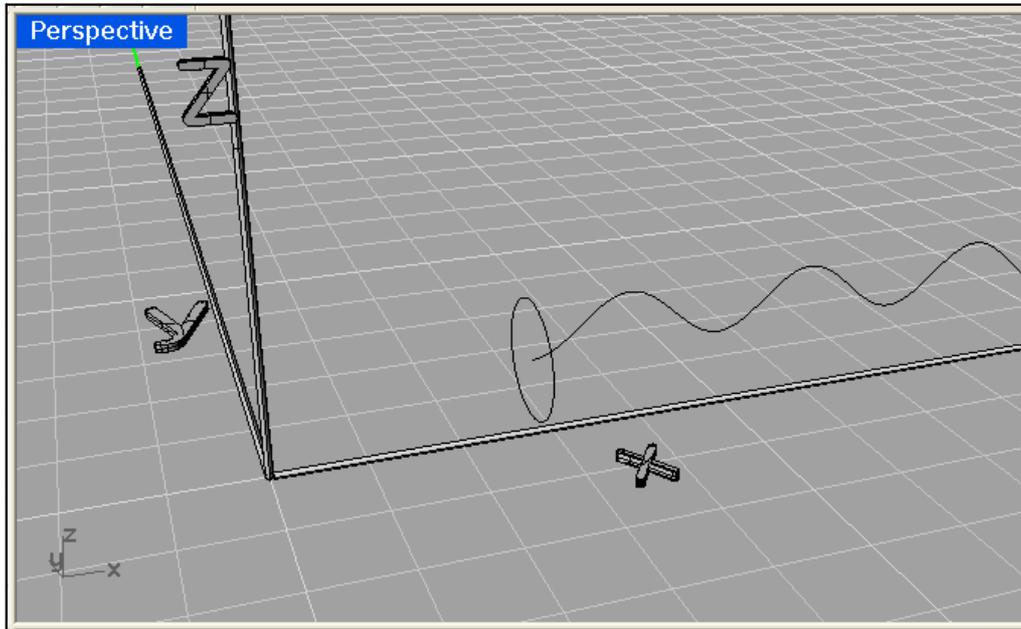
### 2. Modeling and rendering

It is assumed that the plain fabric model yarn follows a sinusoidal crimp, where  $d_w$  or  $d_f$  is the diameter of a warp or filling yarn,  $p$  is the pitch between neighboring two yarns, and

$$p = \sqrt{3} \frac{1}{2} (d_w + d_f) \text{ as shown in <Fig. 1>.$$

In this study, filling yarn diameter was set to 1.0 mm. Warp yarn diameter of each 3-dimensional model fabric was 0.3, 0.5, 0.8, and 1.0 mm, respectively.

It is necessary to obtain the tangents to the curve of the central yarn axis to further place the circles that define the yarn cross-section.



<Fig. 1> 3-dimensional interpolated yarn model of a plain weave with round cross-section shape in a Cartesian coordinate system.

Filling yarn axis runs from the origin  $(0,0, Amp)$ , where  $Amp$  represents the amplitude of the central axis of sinusoidal crimped yarn comprising plain weave structure, to the limit position imposed by the input data. In this study, the limit of either warp yarn position or filling yarn position is ca. 30 mm, which is rather small for a fabric swatch from the perspective of commercial basis. However, in order to increase the smoothness of the model yarn, the interpolation steps are 20, which amount to almost 600 discrete data points to cover the 30 mm yarn axis length. The  $x$ ,  $y$ , and  $z$  values of the central yarn axis were imported from the spreadsheets containing calculated data, and the three-dimensional CAD program displayed the interlacing yarn axis with the modified software program presented in the Appendix I.

### III. Results and Discussion

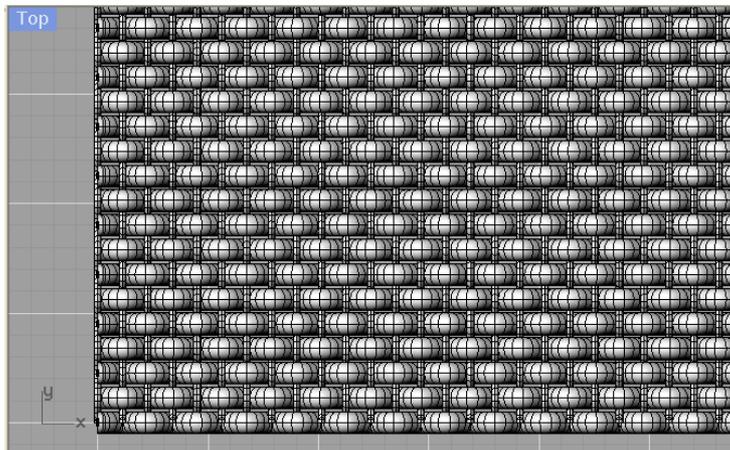
The three-dimensional models of the plain fabric were rendered using RhinoRender, which has the capability of assigning material properties to the model surfaces or solids, such as transparency or reflection characteristics such as plastic or metallic reflection. However, in this study, in order to compare the diameter factors of the comprising yarns, the three-dimensional models were shaded with wire-frame view without colors or transparency factors assigned, and shadow effect was implemented to allow a visual depth cue to the fabric models.

Implementation time of the model building on the 3D CAD program took about 2 minutes, including data reading from the spreadsheets. Rendering of the model, however,

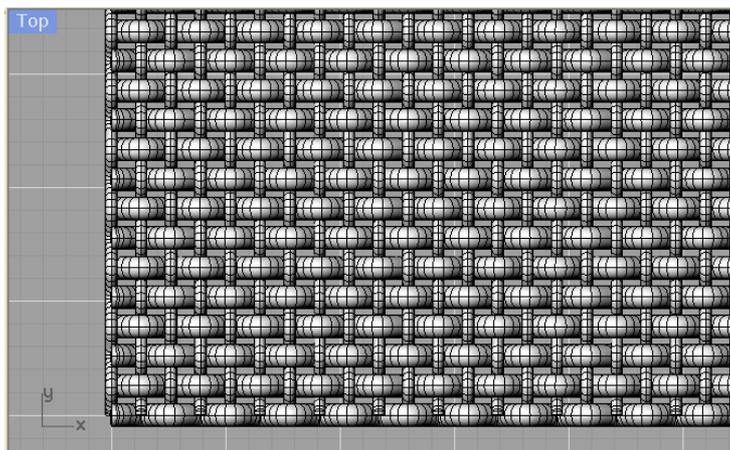
took 5 or 6 minutes depending on the complexity of the models.

<Fig. 2> depicts the top view of the plain weave fabric model having warp diameter of 0.3 mm and filling yarn diameter of 1.0 mm, which would impart strong ribbed surface texture when touched by hand. This type of visual presentation, when further developed, would be helpful in presenting the fine texture of the virtual clothing needed for internet shopping.

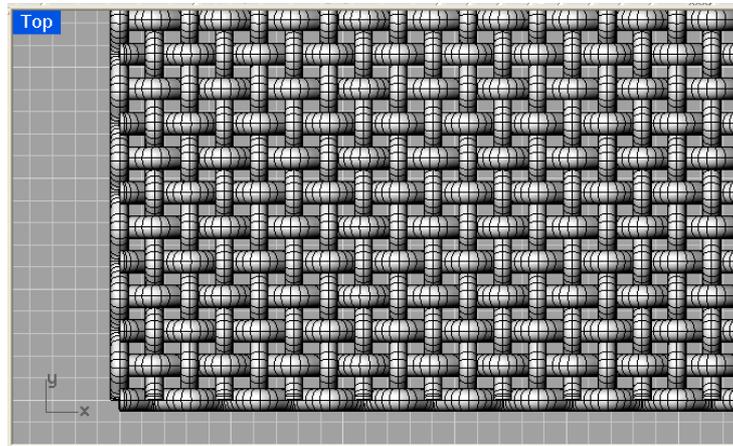
<Fig. 3> and <Fig. 4> show the models of intermediate warp yarn diameter values, which are becoming more balanced look by visual examination. The changes in the height values of the warp and filling yarn crimps are already reflected for the model building. Therefore, the texture difference may be easily translated into the touch-simulation system, such as PhilaU Haptic Device.<sup>3)</sup> Since the device is a combination of force feedback and a tactile



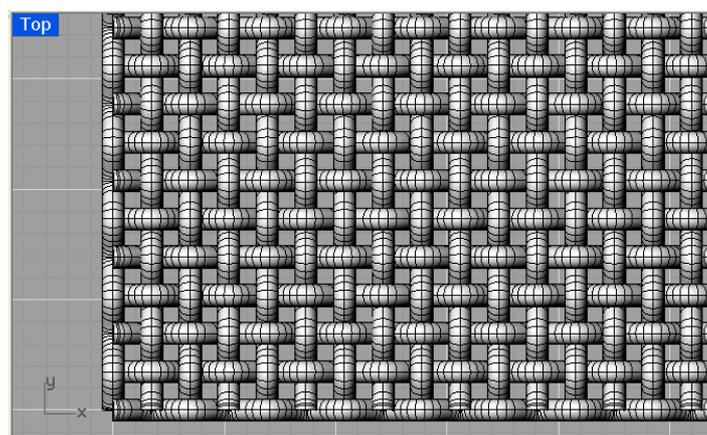
<Fig. 2> Rendered fabric model, warp 0.3mm, filling 1.0mm.



<Fig. 3> Rendered fabric model, warp 0.5mm, filling 1.0mm.



<Fig. 4> Rendered fabric model, warp 0.8mm, filling 1.0mm.



<Fig. 5> Rendered fabric model, warp 1.0 mm, filling 1.0mm.

display, consumers or designers of the textile fabrics may perceive fabric's surface roughness, friction, and softness though not as precise as with their bare fingers, even though they are in a remote place from the fabric or the representing models, which would play a pivotal role in the internet shopping or e-commerce of textile products.

<Fig. 5> shows the model of warp yarn diameter of 1.0 mm and filling yarn diameter

of 1.0 mm, which is a well balanced plain weave fabric.

Another possibilities of the application of the developed model in this study are: visual examination of yarn to yarn spacing or cover factor calculation, and visual observation of the underlying fabrics in a multi-layer fabric or clothing system due to the actual presence of the interstices in this fabric model. Surface roughness or geometrical roughness of the

designed woven fabric may be predicted from the 3-dimensional model fabric by calculating the z-values, or height values of the fabric models. A possible application in this area is briefly demonstrated in <Fig. A> of Appendix II, which compares the difference of the three-dimensional profiles of the selected two rendered fabric models shown in <Figs. 2 and 5>, for inferring the geometric fabric surface roughness or surface texture from the cut-away view. Even a visual comparison of the rendering results of sectioned models of warp/filling yarns higher than a plane of selected height would give some visual clues to the surface contours of the models or texture related information.

Yarn thickness/mass variance, usually measured as U% or CV%, either along the single yarn length, or among the yarns, due to some disturbances in the process may be visualized in the model fabric by further incorporation of variance factors in yarn cross-section modeling.

The model developed in this work may be used to present a more realistic model for visualization purposes, for instance, by introducing smoother crimped yarns, differently colored yarns, transparent or translucent yarns, multi-filament yarns with or without twists, or modified cross-section yarns such as trilobal, multilobal, multichannel, or hollow, etc.

#### IV. Conclusions

It was demonstrated that the application of the different warp/filling yarn diameter to the plain weave fabric with the aid of 3-D CAD program, for instance, in the area of

geometrical roughness comparison, was possible. The rendered view also gave visually plausible effect, which further could be developed into sophisticated models having different shades for realistic visual effects, different cross-sections of filaments, or multi-filament yarns.

The three-dimensional model woven fabrics provide geometrically realistic models. The model developed in this work may be used to present a more realistic model for visualization purposes, for example by introducing smoother crimped yarns, differently colored yarns of striking contrast for use in union fabrics, transparent or translucent yarns, multi-filament yarns with or without twists, or modified cross-section yarns such as trilobal, multilobal, multichannel, mixed shapes, or hollow, etc. Combining the capabilities of some raytracing programs or other software packages would widen the usages of the three-dimensional models of fabrics.

The developed models may provide a basis from which a sophisticated and adaptable model of a 3D fabric can be developed, leading to the design of various colored fabrics or trendy fabrics for many applications suitable for fabrics used in textile and fashion business.

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**Appendix I. Program for the plain weave model (written in RhinoScript)**

```
' Subroutine: ImportCurveFromExcel
' Credit goes to the Rhino Development Team
  for this original curve importation section.
  Last part of the program was written for
  handling warp and filling yarn replication
  of plain weave.
' Purpose:   Create an interpolated curve
from 3D point coordinates read
'           from a Microsoft Excel
spreadsheet.
'           The spreadsheet must contain
x-coordinate values in column A,
'           Y-coordinate values in column
B, and Z-coordinate values in
'           column C beginning in row 1.
There is no limit on the number
'           of 3D points (rows) that can
be processed.
-----

Sub ImportCurveFromExcel()

' Declare variables and constants
Const xIDown = -4121

Dim sFileName, aPoints(), x, y, z
Dim bPoints(), znegative, dist_1
Dim oExcel, oSheet, nRow, nRowCount
Dim xm, ym

' Get the name of the file to import

' ===== deleted middle section of the
subroutine =====
'

Rhino.Command "_Zoom _All _Extents"
Rhino.Print "Curve from " &
CStr(nRowCount-1) & " points created."

End If

'----- Plain Weave, Warp and
Filling Threads positioning section -----
```

```
Rhino.Command "selLast"
Rhino.Command "enter"

' Replication of warp or filling yarns
For F_copy=1 To 12

arrObjects = Rhino.SelectedObjects

If IsArray(arrObjects) Then

arrStart = Array(0,0,0)

If IsArray(arrStart) Then

arrEnd =
Array(xm*(F_copy*2),ym*(F_copy*2),0)

If IsArray(arrStart) Then

Rhino.CopyObjects arrObjects, arrStart, arrEnd
'Rhino.Command "SelNone"
End If

End If

End If

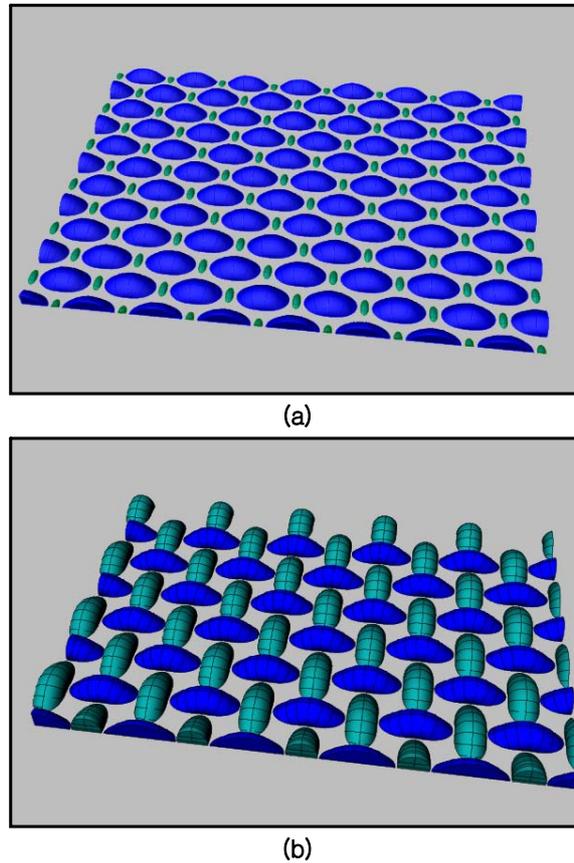
End If

Next

End Sub

ImportCurveFromExcel
```

Appendix II. Three-dimensional Surface Profiling for Inferring Fabric Surface Roughness or Surface Texture



<Fig. A> Rendering of Sectioned Warp/Filling Model Yarns Higher than a Plane of 0.4mm Z-axis Height, (a) Warp 0.3mm, (b) Warp 1.0mm.