REALISTIC RENDERING OF THATCHED GRASS BASED ROOVES

NARONG CHAIWUT

MASTER OF ENGINEERING

IN

COMPUTER ENGINEERING

SCHOOL OF INFORMATION TECHNOLOGY

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ABSTRACT

The physical based modeling and rendering of grass is an interesting topic in computer graphics. They have been used in many applications such as computer games, simulation and animation. Particularly, thatched grass based rooves made from local grass is a wisdom of Asian culture and supports many applications. However, there has been little research about thatched grass based rooves modeling and rendering at present. Also, the normal method is not based on physical characteristics or appearances.

In this thesis, a skeleton-based model was applied to the characteristics of thatched grass. This method created the natural grass look based on grass's physical appearance. A BRDF (Bidirectional Reflectance Distribution Function) was applied on the front side, and a BSSRDF (Bidirectional Scattering Surface Distribution Function) was applied on the back side. Using this method, proved that thatched grass based rooves are based on natural characteristics.

These results showed that this method is more accurate than the previous method basing on physical characteristics and appearance. A questionnaire was used to evaluate the methods with a score from 1-10. The evaluation compared the photographs, the previous methods and the proposed methods. According to the results of the questionnaires, the proposed method appeared to be more realistic than previous methods.

Keywords: BRDF/BSSRDF/Shader Model/Skeleton Based Modeling/Grass/Natural Rendering

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ABBREVIATION AND SYMBOLS

L_0	The summation of surface ‘s radiance
L_e	The self emit radiance
L_r	A surface ‘s radiance
kd	The coefficient of diffuse
ks	The coefficient of specular
$F(w_o,h)$	The Fresnel term
$D(h)$	The Microfacet distribution function
$T(r,d)$	The diffuse transmittance
d	Slap thickness
α'	Reduce albedo
Zr,j	Positive diffusion pole dipole
Zv,j	Negative diffusion pole dipole
Dr,j	The distance from incident surface to light source
Dv,j	The distance form incident surface to virtual light source
σa	Absorption coefficient
σs	Scattering coefficient
n	Refraction index
σtr	The effective transport coefficient
$\sigma' t$	The extinction coefficient
P	Point
N	Normal vector
I	Light vector
V	Camera vector

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Definition

Thatched grass based rooves are a wisdom of Asia. They have been used on many kinds of accommodation and for decoration such as tiled rooves, walls etc. as shown in Figure 1.1, Nowadays, computer graphics are involved in many applications. For example, computer games, VR (Virtual Reality) and simulation. These kinds of applications try to simulate a thatched grass based roof as an aesthetic virtual scene for a user. However, the realistics of thatched grass based rooves were ignored. The characteristics were not based on physical appearance as shown in Figure 1.2. The purpose of this thesis is to create a realistic thatched grass based roof by using a skeleton-based model for the characteristics and use BRDF (Bidirectional Reflectance Distribution Function) and BSSRDF (Bidirectional Scattering Surface Distribution Function) for appearance.

1.2 Objective

1.2.1 Study the physical characteristic and appearance of thatched grass based rooves.

1.2.2 Develop a novel methodology both in modeling and rendering to create a realistic thatched grass based roof.

1.3 Scope

1.3.1 A new modeling method will be based on a skeleton-based model.

1.3.2 A shading model for appearance will be a modification of BRDF and BSSRDF.

1.3.3 Evaluate the proposed method with photographs and conventional methods.

1.3.4 The proposed method eligible for grass and other kinds of organics should be modified based on their characteristics.

1.4 Procedure

1.4.1 Study attributes of both physical characteristics and appearances of thatched grass based rooves.

1.4.2 Model each grass blade based on the skeleton-based model. This method proposes that each grass blade has a primary vein from bottom to top. Create a thin slap to describe a grass's leaf that is attached to a primary vein at its center. In addition, secondary veins occur on both sides of the grass's leaf that are described by a displacement map.

1.4.3 Simulate an appearance by using a BRDF (Bidirectional Reflectance Distribution Function) on the front side and using a BSSRDF (Bidirectional Scattering Surface Distribution Function) on the back side.

1.4.4 Create a scar texture and apply it on the surface of a grass's blade for reducing a repeat pattern of its surface.

1.4.5 Attach each grass blade to a bamboo rod to create a thatched grass based roof.

1.4.6 Evaluate the proposed method with photographs and previous methods.

1.5 Outline of the Thesis

This thesis is structured as follows: literature review involved with thatched grass based roof characteristics and appearance, modeling methods and shading models. The next chapter is a methodology for creating a thatched grass based roof. After that, results and evaluation is in a chapter that discusses the rendered images of grass blades and thatched grass based rooves with different modeling methods and shading models for evaluation. The final chapter is the conclusion and a discussion.

From Imm-Sukk. (2006). **Ban pha moob.** Retrieved August 28, 2011, from http://uc.exteenblog.com/seasave/images/Pamoob/Pamoob11.JPG

Figure 1.1 A Photograph of a Thatched Grass Based Roof used Instead of a Tiled Roof.

Note. However, the realism was ignored and aliasing occured at the border.

From ABT. (2008). **nVidia 400 series image quality analysis.** Retrieved August 25, 2011, from http://alienbabeltech.com/main/wp-content/uploads/2010/10/Far-Cry-32x.png

Figure 1.2 This Picture Renders a Thatched Grass Based Roof with a Plane Polygon.

CHAPTER 2

LITERATURE REVIEW

Mainly, this thesis consists of two components. The first is modeling which is the process used to create objects in 3D. It is composed of a series of vertex connected together. This is called polygon. In addition, the object can use mathematic functions such as curves, Bezier, points etc. to represent the object. The second is rendering which is the process of translating 3D included geometry, surface reflection, lighting or other physical phenomenon into 2D image. Many techniques are used to accelerate speed and realism. For example, raytracing, path tracing, photon mapping etc. In this chapter, previous methods for modeling and a shading model of grass are reviewed.

2.1 Grass Characteristics and Appearance

Thatched grass uses dried grass for making roof tiles. Grass has its primary vein in the middle of itself. It divides its leaf into left and right with almost perfect symmetry. Each leaf (both left and right), has secondary veins parallel with the primary vein. The primary vein and secondary veins join at a single point on the apex.

(Qingkeleqiqige, Xiao, Guo & Wen, 2011) proposed that secondary veins were cylindrical. On the contrary, when we cut a grass leaf in half, we saw that the secondary veins are not cylindrical. They look like a curry surface that’s shown in figure 2.2

Figure 2.1 Living Grass used to Make a Thatched Grass Based Roof.

Note. It clearly shows that the primary vein is not cylindrical.

Figure 2.2 A Cross Section of a Grass Blade when Cut in Half.

When grass is cut and dried, its color changes. It changes to a brown color that depends on how long it has been cut. Each grass blade will be attached to a bamboo rod to make a thatched grass based roof.

Note. It composed of many grass blades.

Figure 2.3 An Image of a Thatched Grass Based Roof.

Grass also has another interesting characteristic. Its surface has a different characteristic on the front side and the back side. On the front side, dry grass's surface is mainly shinny. When we hold it up to the light, we will see a highlight occuring on its surface. In contrast, the back side is mainly composed of a diffuse surface and a scattered phenomenon. It will have fewer highlights than the front side. (Cope, Corney, Clark, Remagnino & Wilkin, 2012).

Note. It reflects when held up to light.

Figure 2.4 The Front Side of Grass.

Note. It shows the translucency phenomenon.

Figure 2.5 The Back Side of Grass.

2.2 Grass Modeling Method

For creating grass, there are many methods and techniques. It depends on, what the usage is for. For example, if it is used in an interactive system, it's better to use a technique that reduces the time for computing. Otherwise, the batch render system should be used. This thesis decided to create a realism of grass. According to the research, types of modeling grass can be categorized by.

2.2.1 Geometry Modeling

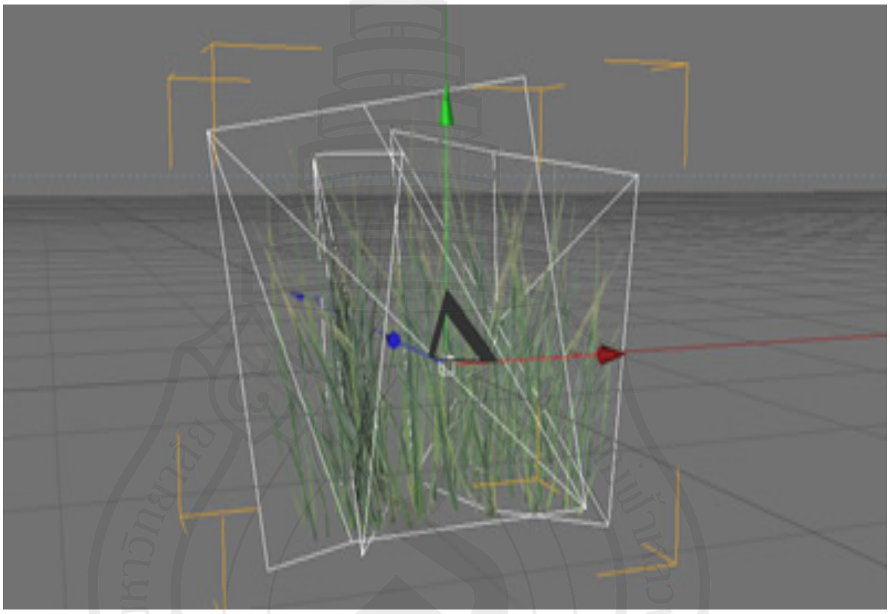
This is a traditional and tedious method for modeling because each grass geometry will be modeled by hand (Chen & Johan, 2010). However, this results in a high quality grass. Moreover, time and memory assumption are significant with this method. Figure 2.6, shows a picture using the geometry modeling method.

From Virion. (2006). **Better grass.** Retrieved February 19, 2013, from http://irrlicht. sourceforge.net/forum/viewtopic.php?t=35328

Figure 2.6 Grass Polygon Modeled by Using the Geometry Modeling Method.

2.2.2 Image-Based or Billboard

(Zhang & Teboul, 2007; Wang, Jiang & Ge, 2009; Chen & Johan, 2010; Quan et al., 2010) proposed that Billboard is a square or cross plane that stores a grass image inside itself. This method needs less resources than geometry modeling. It is famous in computer games because it needs less memory. However, this method produces an aliasing at the edge and it seems to be a repeat pattern.

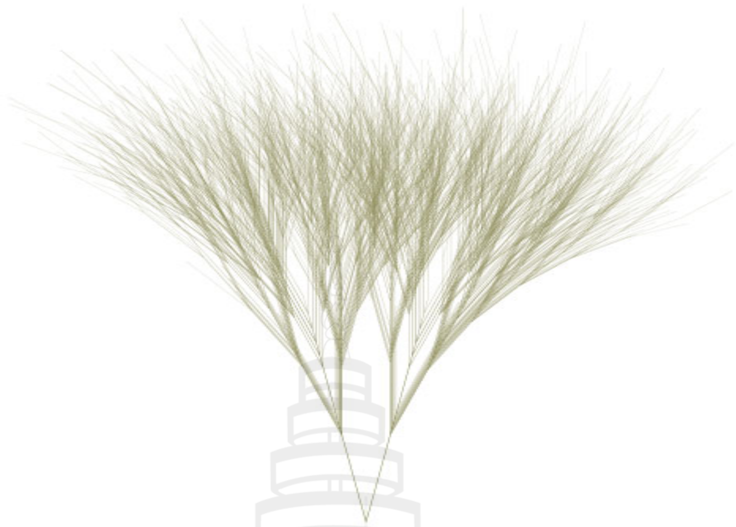


From Unity 3D. (2012). **Terrain tutorial.** Retrieved February 19, 2013, from http://unity3d.com/index.php/Terrain_tutorial

Figure 2.7 Image-Based or Billboard Store a Photograph of Grass Inside it.

2.2.3 The L-system

Firstly, the L-system was introduced by (Lindenmayer, 1968). This method uses a set of rules to model an organic shape. From the work of (Ding, Zhang, Zhu, Cheng & Zhu, 2010). They used parametrics to control the L-system for overall rice. However, they ignored the details of rice leaves. This method requires an understanding of the set of L-system rules.

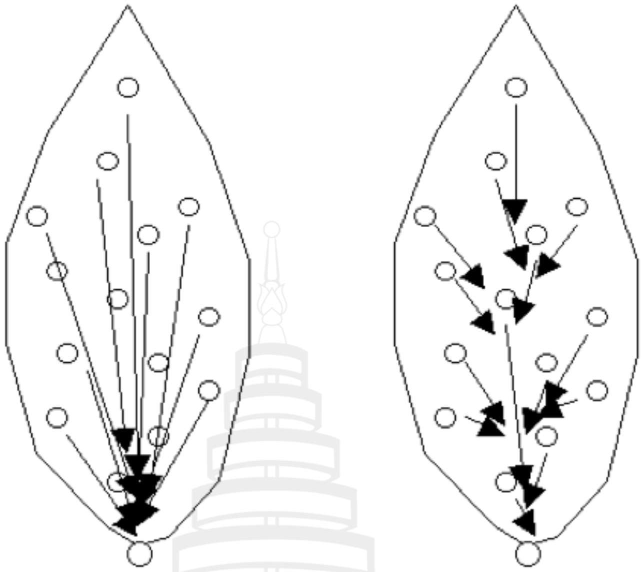


From Meyer, M. (2008). **L-system.** Retrieved February 19, 2013, from http://nodebox.net/code/index.php/Mark_Meyer_%7C_L-system

Figure 2.8 The L-System uses Rules to Construct the Organic Shape.

2.2.4 Particle

This method uses particles for modeling. (Yodthong Rodkaew, Suchada Siripant, Chidchanok Lursinsap & Prabhas Chongstitvatana, 2002) proposed modeling of a leaf by using particles. Initially, particles are placed at the leaf's margin. Then, the particles are moved to the petiole. When they pass other particles. Current particles will combine to the neighborhood. Otherwise, this method simulates only veins of grass or leaves. They need to use image processing to enhance the quality. Moreover, this method is not based on the physical appearance.



From Yodthong Rodkaew, Suchada Siripant, Chidchanok Lursinsap & Prabhas Chongstitvatana. (2002). An algorithm for generating vein images for realistic modeling of a leaf. In **Proceedings of the international conference on computational mathematics and modeling** (pp. 1-9). Bangkok, Thailand.

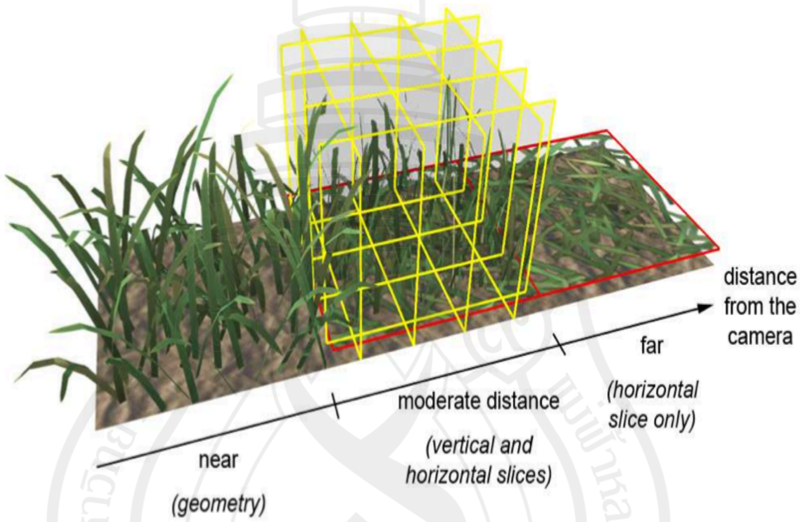
Figure 2.9 A Simulation of Primary and Secondary Veins of a Leaf by Using Particle.

2.2.5 Scanning

The scanning method uses a 3D scanner device to capture the characteristics of grass or leaves and extracts the geometry. (Yongjian, Lichen, Jingli & Gang, 2009; Miao, Zhao, Guo & Lu, 2011) used a 3D scanner to scan a real leaf. The quality and appearance almost looks like the real thing. In contrast, this is not convenient for using because of the price of a scanner and all kinds of physical leaves that they want to use are required to be brought.

2.2.6 Hybrid Modeling

Hybrid Modeling is the combination of several methods applied together. (Chen & Johan, 2010; Shah, Kontinnen & Pattanaik, 2005) used image-based with clusters, or image-based with Level of Detail (LOD). In reality, far away objects have less detail when compared closer. This method reduces the time for computing. However, this method is less realistic when looking closer.



Note. It is composed of grass geometry, image plane and billboard of grass and grass image.

From Shah, M. A., Kontinnen, J. & Pattanaik, S. (2005). Real-time Rendering of Realistic-looking Grass. In **Proceeding GRAPHITE'05 Proceedings of the 3rd international conference on Computer graphics and interactive techniques in Australasia and South East Asia** (pp. 77-82). Dunedin, New Zealand.

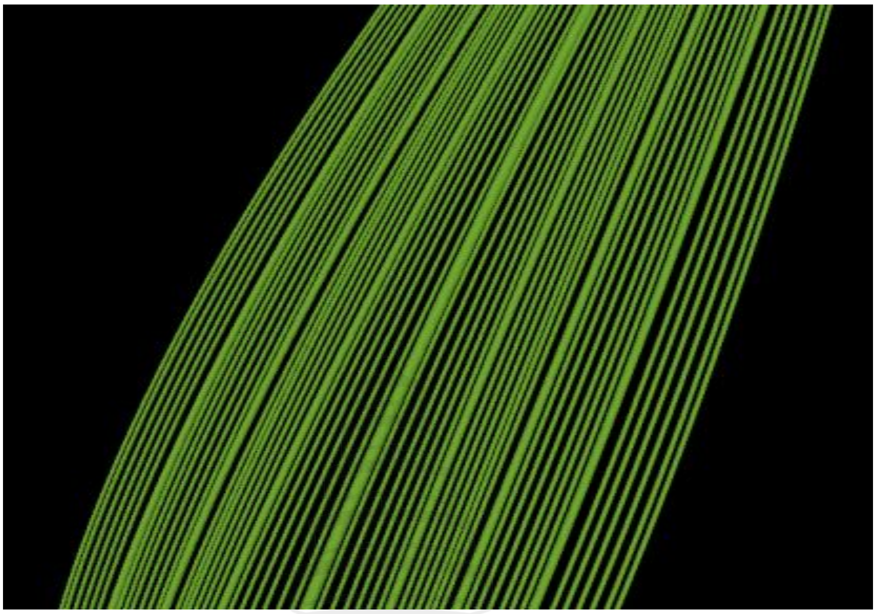
Figure 2.10 The Hybrid System.

2.2.7 Volume (Texel) Modeling

(Jiao, Wu, Heng & Wu, 2012) proposed a volume or Texel that is a method for modeling an object inside a cube. This technique can apply any force to produce grass behavior that constraints the cube such as, wind. (Jiao et al., 2012) proposed a method for modeling grass with the ability to wither. Otherwise, it needs more time to compute.

2.2.8 Skeleton-based Modeling

Skeleton-based modeling is a method that assumes that grass or leaves have primary veins from bottom to top. (Lu, Zhao & Guo, 2009) modeled a plant leaf withering by using skeleton-based modeling. It works well for watermelon and cucumber leaves but not on other kinds of venation base like grass or leaf. (Qingkeleqiqige et al., 2011) modeled a rice leaf based on skeleton but that method is harder to create and isn't based on the physical structure of grass.



From Qingkeleqiqige, Xiao, B., Guo, X. & Wen, W. (2011). Venation Skeleton-based Modeling of Rice Leaf. In **Fourth International Conference on Intelligent Computation Technology and Automation** (pp. 308-311). Shenzhen, China.

Figure 2.11 A Cylindrical of Primary and Secondary Veins Produced by Skeleton-Based Modeling.

In this thesis, the skeleton-based modeling method was used because the thatched grass based roof's characteristics are based on the skeleton-based modeling method. This method is more realistic than other methods.

2.3 Shading Model

Shading model is an equation that describes the reflectance or scattering of an object's surface. Computer graphics researchers have been developing this for a long time. There are so many kinds of appearances: such as, BRDF, BSSRDF and BTDF.

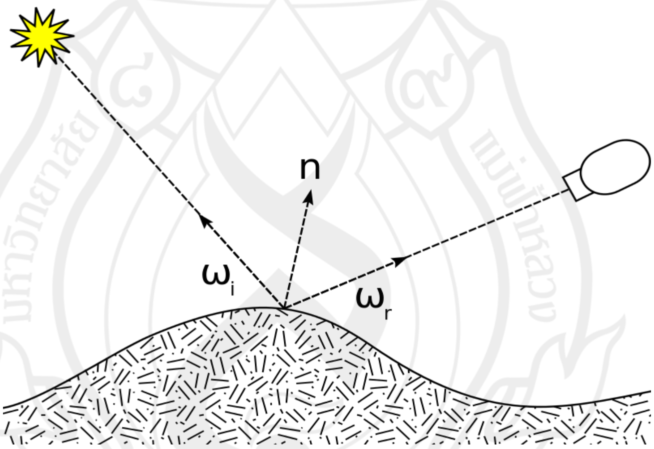
These models are used to describe different objects such as, shinny objects, matte objects etc.

(Kajiya, 1986) proposed a rendering equation. It proposed that a final radiance was equal to a self emit radiance plus a radiance of a surface's reflectance.

$$L_o(x, w_o) = L_e(x, w_o) + L_r(x, w_o) \quad (1)$$

L_r is the function of a surface's reflectance that is described by BRDF, BSSRDF, BTDF and other models.

2.3.1 BRDF's reflectance Model



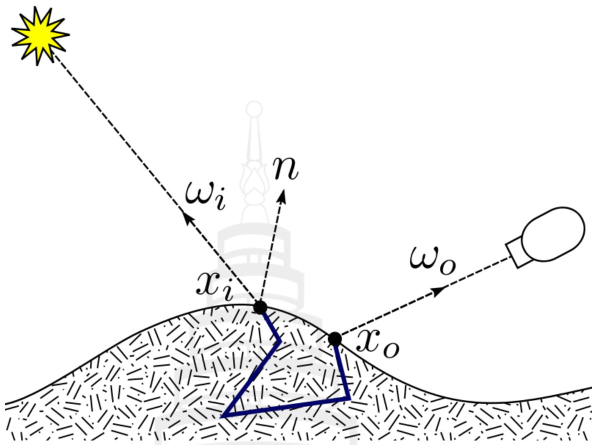
From Thomason, A. (2012). **Bidirectional reflectance distribution function.** Retrieved November 28, 2012, from http://www.andythomason.com/lecture_notes/agp/agp_advanced_rendering.html

Figure 2.12 An Illustration of a BRDF Model.

The BRDF(Bidirectional Reflectance Distribution Function.) is a function that describes the ratio of the differential radiance reflected and the differential irradiance incident at any point on a hemispherical coordinate (Dutre', Bala & Bekaert, 2006). A BRDF itself has many attributes. For example, Helmholtz Reciprocity: the incident and excitant are interchangeable and have an unchanged value of BRDF, or Energy Conservation: the existence radiance is not more than incident radiance. (Torrance & Sparrow, 1967) proposed the first BRDF model based on a Microfacet theory. Otherwise, the model can only be used with an isotropic material. A BRDF model of (Duer, 2005; Ward, 1992) was developed based on the BRDF model of (Cook & Torrance, 1982). However, their shading model is not physically plausible and didn't normalize a Microfacet distribution function. (Ashikhmin & Shirley, 2000) proposed a Microfacet BRDF framework which was further developed by (Ashikhmin, Premoze & Shirley, 2000). However, it is not physically plausible because they ignored the $cos\theta_h$ term. Later, a halfway vector model disk was used in shading modeling by (Edwards, Boulos, Johnson & Shirley, 2006). However, this shading ignores reciprocity. Currently, (Kurt, Szirmay-Kalos & Krivanek, 2010) proposed a Microfacet BRDF model that can be used in both isotropic and anisotropic materials. Their shading model is based on physical plausibility. Equation 2 is a BRDF equation.

$$f_r(x, w_i, w_o) = \frac{dE(x, w_o)}{L(x, w_i)\cos(N, w_i)dw_i} \tag{2}$$

2.3.2 BSSRDF's reflectance model



From Holroyd, M. (2011). **Diagram of the bidirectional scattering surface reflectance distribution function.** Retrieved November 28, 2012, from http://meekohi.com

Figure 2.13 An Illustration of BSSRDF Model.

The BSSRDF (Bidirectional Scattering Surface Distribution Function) is a function used to describe the diffuse and scattering of a slab object. It has been used to describe skin (Jimenez, Whelan, Sundstedt & Gutierrez, 2010), milk, leaves or any translucent material (Franzke & Deussen, 2006). A dipole approximation of light diffusion is used to simulate a subsurface-scattering (SSS). It was firstly introduced by (Jensen, Marschner, Levoy & Hanrahan, 2001). (Donner & Jensen, 2005) and further improved the multipole base on the dipole model of (Jensen et al., 2001). Quantized-Diffusion was introduced by (D'Eon & Irving, 2011). They improved the diffuse theory that bettered the classical diffuse theory. This diffuse theory was used in dipole or multipole modeling. This thesis's proposed method is based on (Habel, Kusternig & Wimmer, 2007). They used the Cook-Torrance model to describe the reflectance term. However, the specular of this model is not based on physical plausibility. Their method needs a 3D scanner for scanning a leaf's shape and many texture maps to define the characteristics of grass. This is not intuitive or suitable. Equation 3 is the BSSRDF equation.

$$s_r(x_o, x_i, w_i, w_o) = \frac{dE(x_o, w_o)}{L_i(x_i, w_i)(N.w_i)dw_i} \tag{3}$$

2.4 Grass or Leaf Shading Model

(Habel et al., 2007) proposed a method for using in a leaf. Their model can capture the natural phenomenon of a leaf. Otherwise, their work used the model of (Cook & Torrance, 1982). (Kurt et al., 2010) claimed that Cook-Torrance has more log square error than his work. A log square error is used to describe a fitting of each shader model with the value of a physical object, which is captured by using a gonioreflectometer. (Ngan, Durand & Matusik, 2005; Kurt et al., 2010).

For the final thatched grass model, a shading model was implemented based on (Habel et al., 2007) on the back side and (Kurt et al., 2010) on the front side. To decide, which sides are front or back, an illuminance function in Renderman Shading Language was used. The front side uses the integral over PI argument. In contrast, the -PI argument is used to denote the back side. (See appendix A for more detail.)

Illuminance (P, Nf, PI)

$$L_o(x, w_o) = L_e(x, w_o) + \int_{\Omega+} f(x, w_i, w_o) L_i(x, w_i)(w_i.n)dw_i \tag{4}$$

Illuminance (P, Nf, -PI)

$$L_o(x, w_o) = L_e(x, w_o) + \int_{\Omega+} s(x_i, w_i, x_o, w_o) L_i(x_i, w_i)(w_i.n)dw_i \tag{5}$$

L_e is the self-emitter radiance. However, L_e was ignored in this thesis because grass itself doesn't have the ability to emit radiance. $s(x_i , \omega_i , x_o , \omega_o)$ is the scattering function (BSSRDF) and $f(x, \omega_i , \omega_o)$ is the reflectance function (BRDF). All of the radiances need to be calculated over the hemisphere coordinate.

CHAPTER 3

METHODOLOGY

In this section, there is a proposed method for modeling and creating shading of thatched grass based rooves. According to Figure 3.1, the image shows that the proposed method consists of 3 main parts. Firstly, the modeling part, which is on the upper left. This part describes how each grass blade is made. It consists of a subsequent method: creating a circle and curve path to simulate the primary vein, creating a thin slab polygon for a grass leaf and altering the surface with a displacement map. Secondly, a shader part which is represented on the upper right. This part is used to describe the reflectance and translucent of a grass blade's surface. In addition, a scar texture was applied to a grass surface to reduce the repeat surface pattern. Finally, all of the grass blades were attached to a bamboo rod to create a thatched grass based roof.

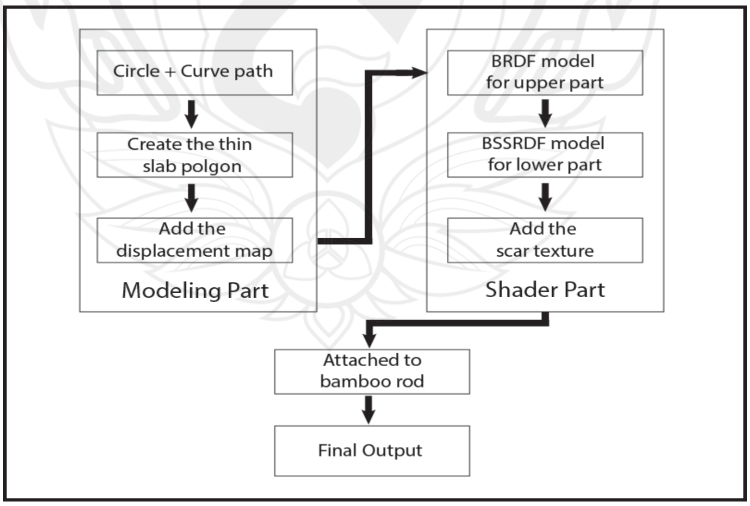
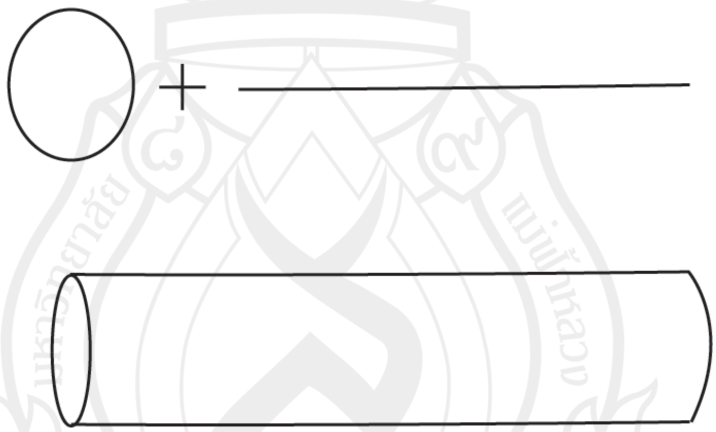


Figure 3.1 Over View of the Proposed Method of Modeling, Surface Shadering and Final Output.

3.1 Thatched Grass Blade Skeleton-Based Modeling

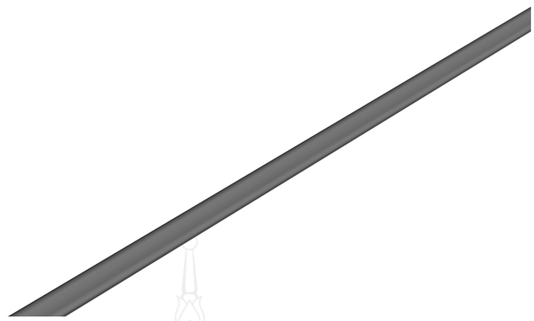
3.1.1 Creating a primary vein

Modeling a primary vein by using a circle curve and a curve path. A primary vein extends geometry along a curve path. A circle curve is used to control the diameter of the primary vein that has the ability to make it bigger or smaller. A curve path is used to guide how long a grass's blade is. From the research, a primary vein of thatched grass is not circular. It looks like a U shape or horseshoe. To manipulate this phenomenon, the vertexes need to be pushed down at the upper part of the primary vein.



Note. By creating the primary vein with a circle and curve path, then modeling it along the curve paths, the diameter can be controlled.

Figure 3.2 The Primary Vein Framework.

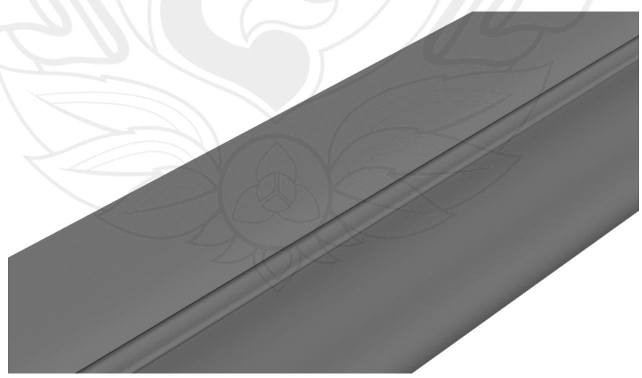


Note. It needs to push the top down until it looks like a U shape or horseshoe.

Figure 3.3 The Primary Vein of a Thatched Grass Blade.

3.1.2 Creating a thin slab for a thatched grass leaf

After getting the primary vein, a leaf of thatched grass was created by using plane geometry and increasing its thickness by around 5 millimeters. This thin slab starts at approximately 12 inches from the root of the grass. Then, expanding to an inch on each side and keeping it parallel until it joins at the top. In addition, the leaf will connect to a primary vein in the middle.



Note. It used for creating the thatched grass leaf.

Figure 3.4 The Thin Slab Geometry.

3.1.3 Controlling the width and the height with a displacement map

According to a research, secondary veins are not composed cylindrically. In this process, a displacement map is used to alter a leaf's surface. The displacement mapping will change the surface of the geometry by using texture or procedural texture. This texture can be created with any third party program: photoshop, gimp etc. This thesis, used procedural texture of (Cortes & Raghavachary, 2008) by implementing in Renderman Shading Language. It can control the width and the height of thatched grass leaves. The algorithm of the procedural texture follows as below;

Algorithm 3.1 : Displacement map algorithm.

```
Displacement stripes (float value, frequency;)
{
        float c = mod (t * frequency,1);
        float d = (smoothstep (0.2,0.25,c) – smoothstep (0.75,0.8,c));
        P += value * d * normalize (N);
        N = calculatenormal (P);
}
```

This algorithm, can create and change the secondary vein on a leaf easily and also can be applied on a primary vein.

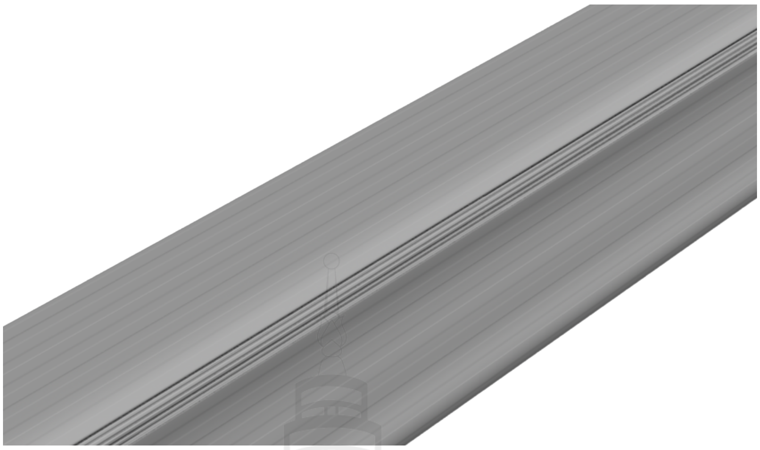
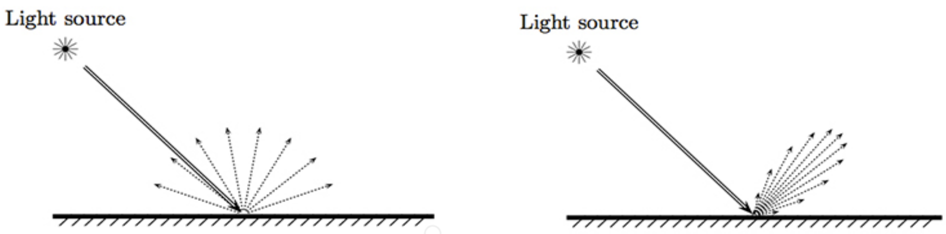


Figure 3.5 Thatched Grass Blade with Displacement Mapping.

3.2 Thatched Grass Shading Model

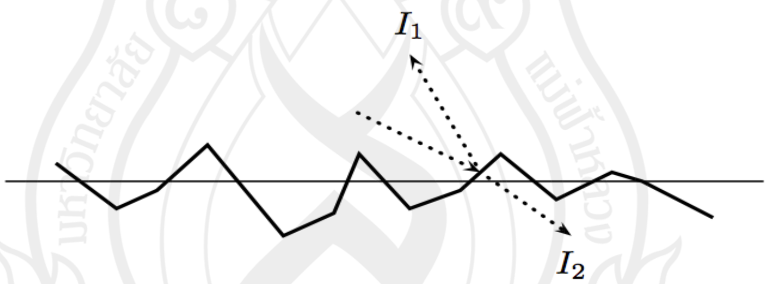
3.2.1 The front side using BRDF

For the front side, (Kurt et al., 2010)'s BRDF equation 6 was used. Mainly, it is composed of 2 parts: diffuse term and specular term. The diffuse term is the phenomenon that light scatters equally in all directions when it reflects. The pure Lambert term is used that can be calculated by diffuse coefficient divided by *Pi*. The other term is specular term. It calculates the amount of reflection of light. It depends on the incident angle. Specular of Kurt is based on the Microfacet theory. This theory assumes that all material's surfaces are not smooth. They are rough with small facets on the entire surface. It is also proposed that a specular reflection loses its energy when it goes further. It's calculated by the Fresnel equation. Figure 3.6 shows the difference between diffuse and specular term.



From Yu, T. (2010). **Color and lighting.** Retrieved February 14, 2013, from http://cse.csusb.edu/tong/courses/cs621/notes/color.php

Figure 3.6 The Left Image is the Diffuse Term. The Right Image is the Specular Term.



From Yu, T. (2010). **Color and lighting.** Retrieved February 14, 2013, from http://cse.csusb.edu/tong/courses/cs621/notes/color.php

Figure 3.7 All of the Surface's Material is not Smooth. This Can be Calculated by the Microfacet Theory.

$$f_r(x, w_i, w_o) = \frac{kd}{\pi} + \frac{k_s F(w_o.h)D(h)}{4(w_o.h)((w_i.h)(w_o.n))^{\alpha}} \quad (6)$$

The Fresnel term is an equation that is used to calculate the behavior of light when moving between media. The approximation was proposed by (Schlick, 1994).

$$F(w_o.h) = R + (1 - R)(1 - w_o.h)^5 \tag{7}$$

R is a specular coefficient. The value is ranked from 0-1. This approximation is fast and accurate and the Microfacet distribution function is calculated by equation 8. A Microfacet has the ability to capture shelf shadow.

$$D(h) = \frac{1}{\pi m^2 \cos^4 \theta_h} e^{-\frac{\tan^2 \theta_h}{m^2}} \tag{8}$$

Table 3.1 The Definition of a BRDF Model.

Symbol	Meaning
kd	The coefficient of diffuse
ks	The coefficient of specular
$F(w_o.h)$	The Fresnel term
D(h)	A Microfacet distribution function

A thatched grass blade was assumed to be an isotropic material. After that, the implementation of (Kurt et al., 2010) was used which is an algorithm 2. The color over all of the grass blades was gained by a sampling color technique. This technique creates a color by sampling one pixel color and using a sampling color value. The overall thatched grass blade color was [0.447059 0.392157 0.294118] which is normal for RGB color space.

Algorithm 3.2 : BRDF based on (Kurt et al., 2010)

```
Surfacekurt (float kd, ks, rough, m, alpha; color diffuse, specular)
{
        normalNf = faceforward (normalize (N), I);
        vector V = -normalize (I);
        vector H = normalize (I+E);
        color final;
                illuminance (P, Nf, PI){
                floatschlick = calculate by equation 7;
                floatmicrofacet = calculate by equation 8;
                final = diffuse * diffuse term in equation 6 + specular *
                specular term in equation 6;
                }
        return final;
}
```

Figure 3.8 The Front Side of a Thatched Grass Blade by Using BRDF.

3.2.2 The back side using BSSRDF

The back side is composed of diffuse and scattering. Otherwise, it won't contain the specular term like the upper part (Habel et al., 2007). This phenomenon can be calculated with BSSRDF or BTDF. However, the BTDF is more efficient in memory consumption and rendering speed. This thesis used a BSSRDF based on (Habel et al., 2007). A BSSRDF includes diffuse term and scattering term that can be calculated by equation 9.

$$S(x_i, w_i, x_o, w_o) = S_d(x_i, w_i, x_o, w_o) + S^{(1)}(x_i, w_i, x_o, w_o) \quad (9)$$

The scattering term is

$$S^{(1)}(x_i, w_i, x_o, w_o) = \rho_t(x_i, w_i) T(r, d) \rho_t(x_o, w_o) \quad (10)$$

The *T(r,d)* is diffuse transmittance at non-facing lit surface. Which can be calculated by equation11.

$$T(r,d) = \sum_{j=-n}^{n} \frac{\alpha'}{4\pi} \left(\frac{(d - z_{r,j})(1 + \sigma_{tr} d_{r,j} e^{-\sigma_{tr} d_{r,j}})}{d_{r,j}^3} - \frac{(d - z_{v,j})(1 + \sigma_{tr} d_{r,j} e^{-\sigma_{tr} d_{v,j}})}{d_{v,j}^3} \right) \quad (11)$$

Equation 12 and 13 are positive and negative pole dipole.

$$Z_{r,j} = 2j(d + 2_{Zb}) + l \quad (12)$$

$$Z_{v,j} = 2j(d + 2_{Zb}) - l - 2_{Zb} \quad (13)$$

In this thesis, the absorption coefficient is the color in RGB color space that equals 0.447059, 0.392157 and 0.294118 and the scattering coefficient is 0.0021, 0.0041 and 0.0071, by using the sampling value method. Those 2 coefficients were implemented in the extinction coefficient and the effective transport coefficient in equation14, 15, respectively.

$$\sigma_t' = \sigma + (1 - g)\sigma_s \tag{14}$$

$$\sigma_{tr} = \sqrt{3\sigma_a \sigma_t'} \tag{15}$$

Equations 16 and 17 show the distance from the incident surface to the light source and the virtual light source.

$$d_{v,j} = |x_o - x_{v,j}| \tag{16}$$

$$d_{r,j} = |x_o - x_{r,j}| \tag{17}$$

Table 3.2 The Definition of BSSRDF Terms.

Symbol	Meaning
$T(r,d)$	The diffuse transmittance
d	Slap thickness
α'	Reduce albedo
$Z_{r,j}$	Positive diffusion pole dipole
$Z_{v,j}$	Negative diffusion pole dipole
$d_{r,j}$	The distance from incident surface to light source
$d_{v,j}$	The distance from incident surface to virtual light source.
σ_a	Absorption coefficient
σ_s	Scattering coefficient
n	Refraction index (1.2-1.7)
σ_{tr}	The effective transport coefficient
σ'_t	The extinction coefficient

An index of refraction was equal to 1.3 using a BSSRDF shader followed by this algorithm.

Algorithm 3.3 : BSSRDF based on (Habel at el., 2007).

```
Surface BSSRDF (color diffuse, absorption; float refection index;)
{
        normalNf = faceforward (normalize (N), I);
        vector V = -normalize (I);
        color final;
                illuminance (P, Nf, -PI)
                {
                        color transport = calculate by equation 14,15;
                        final  = calculate by equation 11;
                }
        return final;
}
```

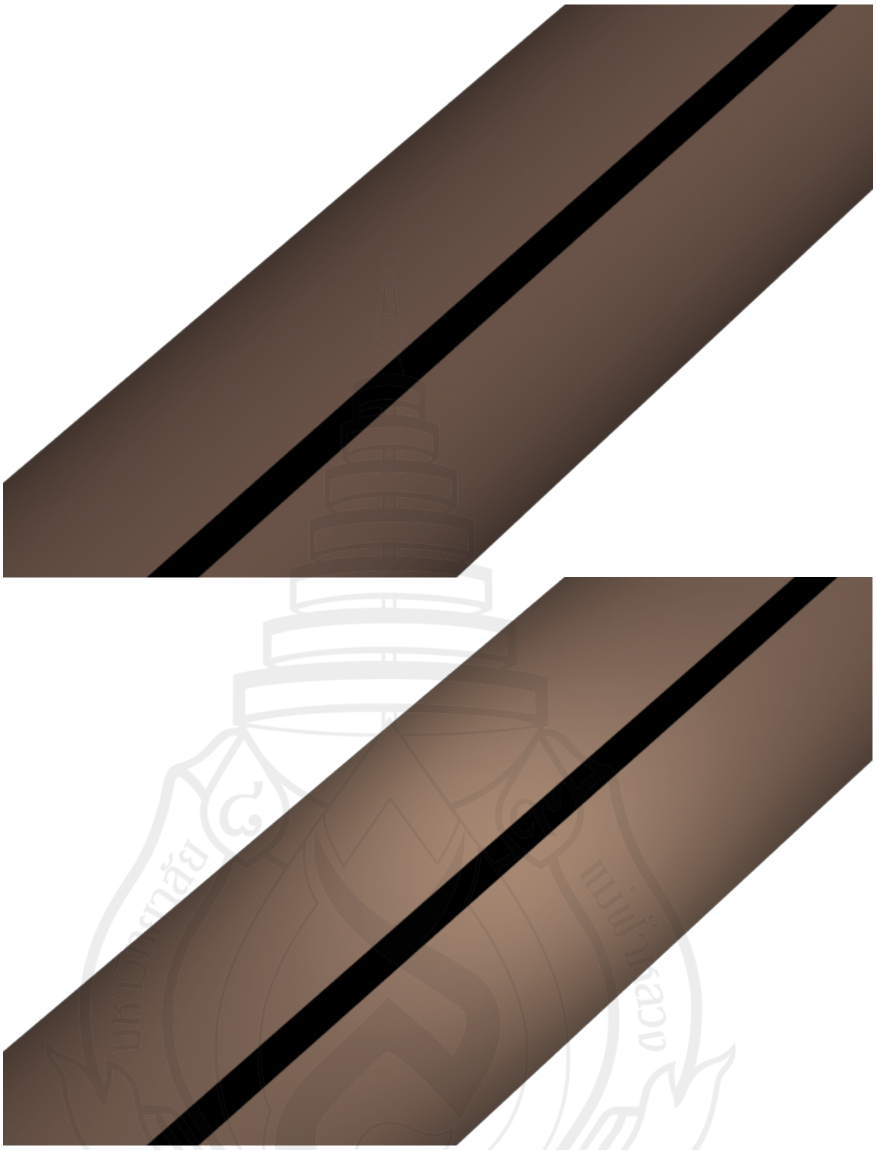


Figure 3.9 Upper : The Back Side of a Thatched Grass Blade by Using BSSRDF.
Lower : Add Point Light in Front of a Thatched Grass Blade.

3.2.3 Add scar to surface

To enhance the realism of this method, a texture of scar was added over the surface. A scar texture is an ordinary picture that contains dots spread over its area. It needs to be transformed into Renderman compliant format, first. In this thesis, 3DELight was implemented. Generally, there is a program called “tdlmake.exe” and also addition-blending algorithm was applied to the surface.

Algorithm 3.4 : Scar color

```
color output (color base; over; float opacity;)
{
    return base + (over * opacity);
}
```

Note. The scar texture image was applied to the thatched grass blade surface to reduce the repeat pattern.

Figure 3.10 The Scar Texture.

Figure 3.11 A Blending of Scar Texture and Surface Made Surface Less Pattern.

3.3 Combining to A Bamboo Rod

Finally, each thatched grass blade was attached to a bamboo rod by bending each blade in half. After that, a shader was applied to it. Figure 3.12 and figure 3.13 show the final thatched grass blade roof.

Figure 3.12 The Final Thatched Grass Based Roof.

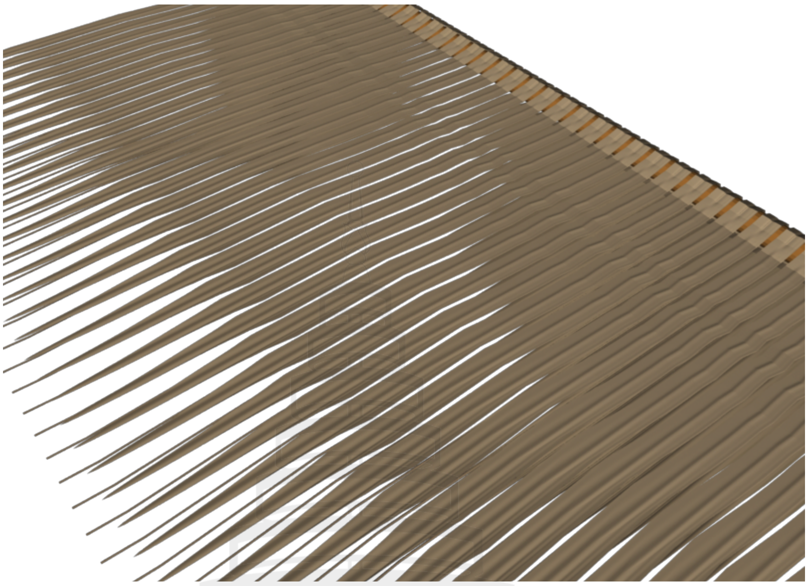


Figure 3.13 The Final Thatched Grass Based Roof from a Different Angle.

CHAPTER 4

RESULTS

4.1 Realistic Evaluation

The purpose for evaluation was to determine which method is the most practical for making thatched grass based rooves between the proposed method and the previous method. So, the author decided to make a questionnaire: comparing the proposed method and the previous method. The reason why the evaluation used a questionnaire was because this thesis is based on qualitative research. The questionnaire was set up and handed out to random people who had not been involved in 3D computer graphics. The questionnaire was about background knowledge in computer graphics, genre, age, and the comparison of the photographs, the previous method and the proposed method. Each picture could be rated from 1-10 points. A lower score meant it is less practical and a higher score more practical. The indicator of this evaluation was determined by which picture got a higher average score (See appendix B). According to the evaluation of the photographs, the proposed method and the previous method were the highest to the lowest, respectively.

4.2 Experiment Environment

4.2.1 Roof Scene

The experiment of a thatched grass based roof was done on a PC with a 3.6 GHz Pentium i7 processor and a Redeon HD4670 graphics card. A roof scene that was used for evaluation is a close up shot. This set up will reveal more detail than a whole roof. A render scene was set up with the same geometry, light and camera position. Otherwise, the difference was model method and shading. The previous method used a skeleton-based model based on (Qingkeleqiqige et al., 2011) and used Phong shading. The proposed method used a modification of both a skeleton-based model, a BRDF and a BSSRDF.

4.2.2 Rendering Parameter

The rendering was set up as follows by the parameter in Table 4.1. These parameters are the values that are used to create a thatched grass based roof.

Table 4.1 The Rendering Parameters

Values	Meaning
0.447059 0.392157 0.294118	Diffuse color and absorption coefficient
1.00 1.001.00	Specular color
3	Diffuse coefficient
2	Specular coefficient
0.05	The Kurt's BRDF m value
0.25	The Kurt's BRDF alpha value
0.3	Surface roughness
1.3	Index of refraction
0.0021 0.0041 0.0071	Scattering coefficient
0.0008	Displacement height
15	Displacement frequency
3	Diffuse coefficient
2	Specular coefficient

4.2.3 Rendered Scene

Rendering was developed in Renderman Shading Language and 3Delight. Figure 4.1 shows the result of the rendering of a thatched grass blade that was magnified on each component. Figure 4.2 is the close up picture of a thatched grass blade. It can capture all the characteristics of thatched grass, included scar, primary vein and secondary veins. The result can capture a light reflection in various incoming light angles that are shown in Figure 4.3. Figure 4.4 shows the front side and the back side of a thatched grass blade. Figure 4.5 is the whole thatched grass based roof.

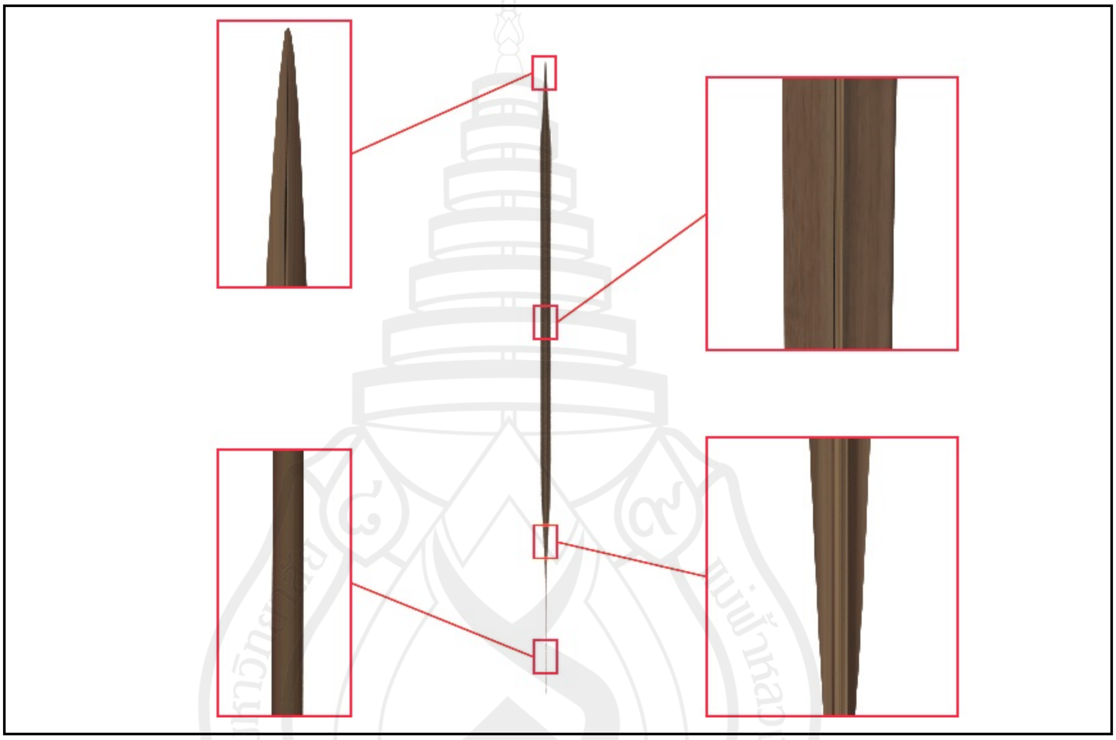


Figure 4.1 Each Part of a Thatched Grass Blade.

Figure 4.2 Close Up of a Thatched Grass Blade.

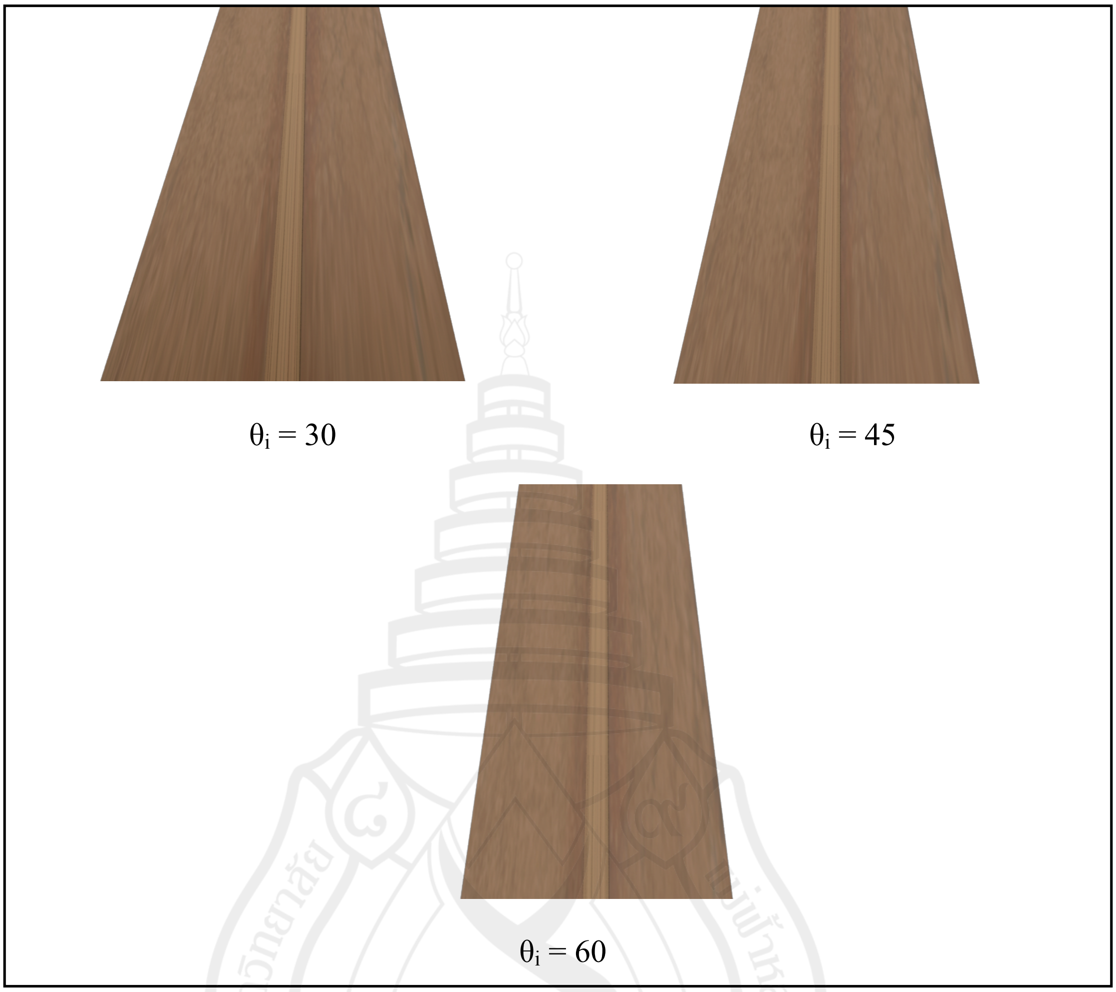


Figure 4.3 The Front Side of a Thatched Grass Blade from Different Angles.

Figure 4.4 The Front and Back Side of Thatched Grass Blade.

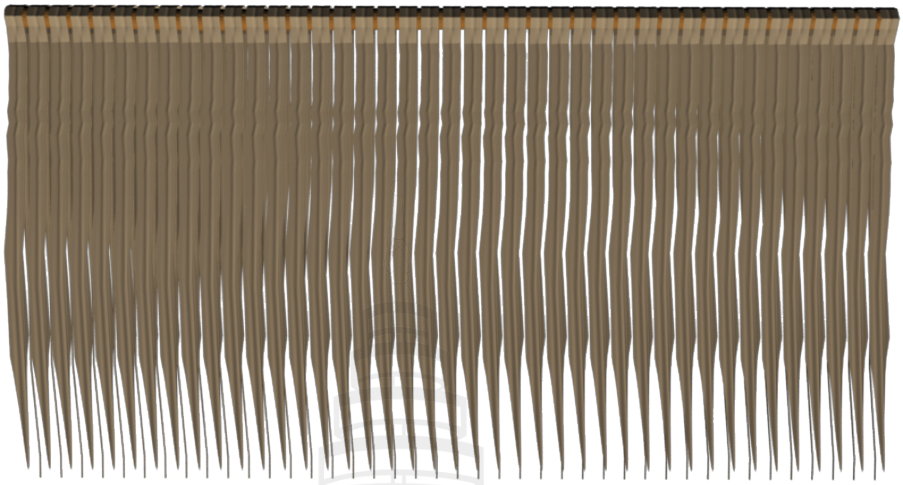


Figure 4.5 An Image of Thatched Grass Based Roof.

4.2.4 Realistic Test Result

The questionnaire surveyed around 30 people (See appendix B) which are students and employees in Mae Fah Luang University. The genre is equally divided among population. Ages were between 20-40 years old. Almost 90 percent hadn't been involved in the computer graphics field. Modeling, rendering and computer graphics were denied when investigated. Table 4.2 shows the average score of each method. The result of each method shows in Table 4.3 that the first row is the front and the back side of a thatched grass blade. The second row is the previous method and the last row is the proposed method.

Table 4.2 The Average Score of Each Method from the Questionnaire.

Method	Average Score
Photograph	10
Previous Method	5
Purposed Method	7

The evaluation, concluded that a skeleton-based model with the proposed method looked more natural and practical than the previous method. In addition, the time for rendering was not so different between the proposed method and the previous method: it took around 6.80-7.10 seconds for the whole thatched grass based roof.

Table 4.3 The Comparison of Each Method: Photograph, Previous Method with Phong Shader and the Proposed Method.

	A front side (BRDF)	**A back side (BSSRDF)**
Photograph		
Previous Method		
Purposed Method		

CHAPTER 5

CONCLUSION AND DISCUSSION

5.1 Conclusion

Thatched grass based rooves have been incorporated in many computer graphic applications. This proposed method can capture their physical appearance and characteristics with the ability to control the primary vein, the leaf's width and height and the width of the secondary veins.

The modeling method of thatched grass blade used skeleton-based modeling. The primary vein used a circle and curve to control its diameter and length. A thin slab was used to simulate a leaf. A displacement map was used to control the width and the height of the primary and secondary veins.

The shading model was implemented in Renderman Shading Language. This shading model can capture all the physical appearances of grass blades. A BRDF model based on (Kurt et al., 2010) was applied on the front side to calculate the reflectance of thatched grass blades. In addition, the back side used a multipole BSSRDF based on (Habel et al., 2002) to capture the diffuse and translucency of thatched grass. A scar on each blade used texture mapping. This enhanced the rendered image to look more natural and realistic.

5.2 Discussion

This proposed method is easier to model than the previous method. When comparing the qualitative nature of this proposed method with the photographs and the previous method, it looks more natural and is based on the physical appearance of the grass blade. However, when attaching each grass blade to a bamboo rod, a whole roof has a repetition of grass blades. Because of that, it's unable to control each grass blade (Figure 5.1). In addition, a further development of this limitation needs to be corrected in the future.

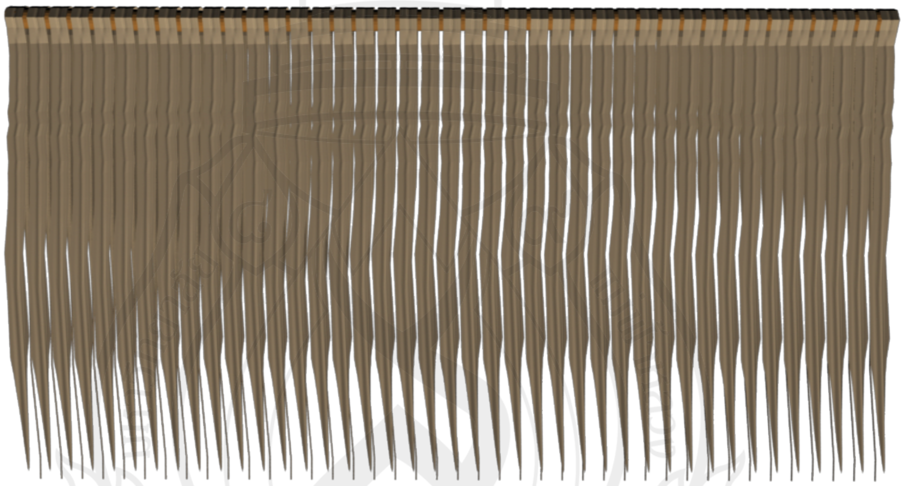


Figure 5.1 A Repeat Pattern of Each Grass Blade After Being Combined to a Bamboo Rod.

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APPENDICES

APPENDIX A

RENDERMAN

In this section, there was a brief introduction of RenderMan. RenderMan was firstly introduced in the 1970's in Lucas Computer Graphic department. RenderMan uses on algorithm called REYES (Render Everything You Ever See). The language itself is similar to C style. The advantages of RenderMan consist of speed, a capability to handle large amounts of data, memory efficiency and motion blur. Mainly, RenderMan consists of 2 parts: First, is RenderMan Interface Bytestream (RIB). It has the ability to describe scenes, such as image resolution, camera and object transformation, etc. Second, the RenderMan Shading Language can be used to describe the surface appearance. Mainly, it is composed of 5 shader types: Imager, Displacement, Surface, Lights and Volume (Atmosphere, Interior, and Exterior).

First, an example of RIB files.

```
##RenderMan RIB
version 3.03
Format 800 600 1
Orientation "rh"
Sides 2
PixelSamples 3 3
ObjectBegin 1
NuPatch 8 4 [0 0 0 0 0.053472 1 1.04565 2 3 3 3 3] 0 3 11 4 [-2 -2 -1
0 1 2 3 4 5 6 7 8 9 10 10] 0 8 "Pw" [0.0586328 0.0463161 0.00235155 1
0.0586328 0.0457119 -1.01028 1 0.0586328 0.0344125 -19.948 1 0.0851833
0.0244925 -22.0107 1
0.109752 0.0712063 -30.1447 1 0.0586328 0.172107 -77.8806 1 0.0586328 -
```

0.247471 -112.805 1

0.00143558 -0.519351 -130.674 1 -9.46011e-018 0.0706026 0.00233706 1 -9.46011e-018 0.0699984 -1.0103 1

-9.46011e-018 0.058699 -19.948 1 -1.37439e-017 0.0487789 -22.0106 1 -1.77079e-017 0.116925 -30.1447 1

-9.46011e-018 0.196394 -77.8806 1 -9.46011e-018 -0.223186 -112.805 1 -2.31624e-019 -0.518757 -130.674 1

-0.0586328 0.0463161 0.00235155 1 -0.0586328 0.0457119 -1.01028 1 -0.0586328 0.0344125 -19.948 1

-0.0851833 0.0244925 -22.0107 1 -0.109752 0.0712063 -30.1447 1 -0.0586328 0.172107 -77.8806 1

-0.0586328 -0.247471 -112.805 1 -0.00143558 -0.519351 -130.674 1 -0.0829194 -0.0123168 0.00238653 1

-0.0829194 -0.012921 -1.01025 1 -0.0829194 -0.0242203 -19.9479 1 -0.120467 -0.0341401 -22.0108 1

-0.155213 0.0128609 -30.1448 1 -0.0829194 0.113475 -77.8804 1 -0.0829194 -0.306099 -112.804 1

-0.00203022 -0.520787 -130.674 1 -0.0586328 -0.0709496 0.00242152 1 -0.0586328 -0.0715538 -1.01021 1

-0.0586328 -0.0828531 -19.9479 1 -0.0851833 -0.0927727 -22.0109 1 -0.109752 -0.0288086 -30.1449 1

-0.0586328 0.0548422 -77.8803 1 -0.0586328 -0.364728 -112.804 1 -0.00143558 -0.522222 -130.674 1

-2.49852e-017 -0.119389 0.00243601 1 -2.49852e-017 -0.119993 -1.0102 1 -2.49852e-017 -0.131292 -19.9479 1

-3.62992e-017 -0.213951 -22.0109 1 -4.67687e-017 0.0961623 -30.145 1 -2.49852e-017 0.00640303 -77.8803 1

-2.49852e-017 -0.311664 -112.803 1 -6.11746e-019 -0.546969 -130.674 1 0.0586328 -0.0709496 0.00242152 1

0.0586328 -0.0715538 -1.01021 1 0.0586328 -0.0828531 -19.9479 1 0.0851833 -0.0927727 -22.0109 1

0.109752 -0.0288086 -30.1449 1 0.0586328 0.0548422 -77.8803 1 0.0586328 -

0.364728 -112.804 1
0.00143558 -0.522222 -130.674 1 0.0829194 -0.0123168 0.00238653 1 0.0829194 -0.012921 -1.01025 1
0.0829194 -0.0242203 -19.9479 1 0.120467 -0.0341401 -22.0108 1 0.155213 0.0128609 -30.1448 1
0.0829194 0.113475 -77.8804 1 0.0829194 -0.306099 -112.804 1 0.00203022 -0.520787 -130.674 1
0.0586328 0.0463161 0.00235155 1 0.0586328 0.0457119 -1.01028 1 0.0586328 0.0344125 -19.948 1
0.0851833 0.0244925 -22.0107 1 0.109752 0.0712063 -30.1447 1 0.0586328 0.172107 -77.8806 1
0.0586328 -0.247471 -112.805 1 0.00143558 -0.519351 -130.674 1 -9.46011e-018 0.0706026 0.00233706 1
-9.46011e-018 0.0699984 -1.0103 1 -9.46011e-018 0.058699 -19.948 1 -1.37439e-017 0.0487789 -22.0106 1
-1.77079e-017 0.116925 -30.1447 1 -9.46011e-018 0.196394 -77.8806 1 -9.46011e-018 -0.223186 -112.805 1
-2.31624e-019 -0.518757 -130.674 1 -0.0586328 0.0463161 0.00235155 1 -0.0586328 0.0457119 -1.01028 1
-0.0586328 0.0344125 -19.948 1 -0.0851833 0.0244925 -22.0107 1 -0.109752 0.0712063 -30.1447 1
-0.0586328 0.172107 -77.8806 1 -0.0586328 -0.247471 -112.805 1 -0.00143558 -0.519351 -130.674 1]
ObjectEnd
FrameBegin 1
Display "persp_blade.tif" "framebuffer" "rgba"
Format 800 600 1
Projection "perspective" "fov" [42.1847]
Clipping 0.1 100000
Transform [-0.64011 0.703695 0.308339 0 5.55112e-017 -0.401335 0.915931 0 -0.768284 -0.586297 -0.256898 0 -47.7621 -36.8084 -11.6496 1]
WorldBegin

```
   LightSource "distantlight" 1 "intensity" [1]"lightcolor" [1 1 1]"from" [0 -18.0056 0]"to" [0.409898 -17.4259 -0.704218]
   Surface "plastic"
        AttributeBegin
                Attribute "identifier" "name" ["extrudedSurface1"]
                ConcatTransform [1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1]
                        AttributeBegin
                                Attribute "identifier" "name" ["extrudedSurfaceShape1"]
                                Displacement "stripes" "float Km" 0.005 "float textFreq" [2]
                                Attribute "bound" "displacement" 0.005
                                Surface "kurt" "color diff_color" [0.447059 0.392157 0.294118] "float kd" [3] "float ks" [0.1]
                                ObjectInstance 1
                        AttributeEnd
        AttributeEnd
WorldEnd
FrameEnd
```

Second, an example of (Kurt et al, 2010) implements in RenderMan Shading Language.

```
color colorAdd (color BaseMap; color Layer; float Opacity;)
{
        return BaseMap + (Layer * Opacity);
}

float fresnel (vector v , h; float ks;)
{
        return ks+((1-ks)*pow((1-v.h),5));
}
surface kurt (float kd = 0.5, ks = 0.5, rough = 0.3, m = 0.05, alpha = 0.25;
```

```
color diff_color = (0,1,0), spec_color = (1,1,1);)
{
        string tex = "scar_texture.tdl";
        color tex_color = texture(tex,s,t);
        color final_color = colorAdd(tex_color,diff_color,0.65);
        normal Nf = faceforward(normalize(N),I);
        vector V = -normalize(I);
        vector H = normal(I+E);
        float cos_theta = I.H;
        color c = 0;

                illuminance( P, Nf, PI ) {
                        float micro = (1/(PI*pow(m,m)*pow(cos_theta,4)))*exp(-
pow(1/cos_theta,2)-1*1/m*m);
                        float frac = 4*(V.H)*pow((I.N)*(V.N),alpha);
                        vector Ln = normalize(L);
                        c +=  kd/PI * final_color * Cs * Cl * Ln.Nf + ks * spec_color *
fresnel(V,H,ks)*micro/frac;
                }
        Oi = Os;
        Ci = c;
}
```

APPENDIX B

QUESTIONNAIRE

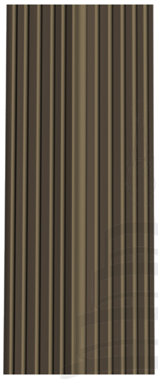
เพศ	☐ ชาย	☐ หญิง		
อายุ	☐ 20-25 ปี			
	☐ 26-30 ปี			
	☐ 31-35 ปี			
	☐ 36 ปีขึ้นไป			

คุณเคยได้ยินคำเหล่านี้เหรอไม่

การเรนเดอร์	☐ เคย	☐ ไม่เคย
การขึ้นโมเดล	☐ เคย	☐ ไม่เคย
คอมพิวเตอร์กราฟฟิก	☐ เคย	☐ ไม่เคย

หากให้คะแนนความเหมือนจริงตั้งแต่ 0 -10 คะแนน คุณให้คะแนนภาพเหล่านี้เท่าไหร่

ภาพที่ 1.



2.

คะแนน ....คะแนน ....คะแนน

ภาพที่ 3.

4.

คะแนน ....คะแนน ....คะแนน

ภาพที่ 5.

6.

คะแนน ....คะแนน ....คะแนน

CURRICULUM VITAE

CURRICULUM VITAE

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PUBLICATION

Narong Chaiwut & Roungsan Chaisricharoen. (2012). Skeleton-based modeling of thatched grass blade. **International journal of information technology & computer science (IJITCS), 5**(1), 69-73.

Narong Chaiwut & Roungsan Chaisricharoen. (2012). Shading model of thatched grass blade. In **The 1st Mae fah luang university international conference**. Chiangrai, Thailand.