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GPU-BASED FACE RENDERING VIA THE PHYSICAL MODEL OF LIGHT INTERACTION WITH HUMAN SKIN

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Abstract. *Skin has always been difficult to render: it has many subtle visual characteristics, and human viewers are acutely sensitive to the face appearance in particular. In this paper, we design a physical model of light interaction with human skin which includes surface reflection simulation and diffuse reflection simulation, and implement a fast rendering via GPU (Graphics Processing Unit) rendering pipeline. Surface reflection is typically approximated with a physically based model of micro-facet distribution, which simulates the complex interaction between incoming light and skin bump surface. Diffusion reflection is effectively approximated via weighted Gaussian blurs and the fast computation is achieved via Gaussian convolution characteristics. The results show that we can achieve comparable rendering quality such as color-bleed and soft shadow with faster speed.*
Keywords: Light interaction, Human skin, Surface reflection, Diffuse reflection, GPU

1. **Introduction.** Human skin has always been one of the most difficult materials to render. We as humans are very sensitive to the appearance of skin, and even close approximations will look very wrong to most people until they are very realistic. On the surface, skin has thousands of small pores and wrinkles, which are noticeable immediately if missing. Light is scattered under the surface of the skin in different amounts for different wavelengths of light, giving it a very smooth look. Therefore, more advanced surface and diffuse reflection models are needed and realized.

Many methods for realistic rendering of human skin have been presented in the past. Simple empirical surface models, such as the familiar Blinn-Phong model [1] long supported by OpenGL and Direct3D, do not accurately approximate the surface reflectance of skin. As a result, if we need realistic rendering of human skin, we have to take physically based surface model into account [2]. A realistic skin shader must model this scattering process otherwise the result appears hard and dry. Krishnaswamy and Baronoski [3] use a complex optical model comprising five layers; however, for most practical purposes, a two layered model [4] can meet requirement of realistic rendering. The milestone to render skin is that NVIDIA Corporation [5] realizes the texture space rendering to give a more realistic rendering of human skin based on physical skin structure. Then Jimenez et al. [6] provide the screen space rendering compared to [5] and give a feasible solution to simulate subsurface scattering (SSS) at interactive frame rates. Recently, considering influence of environment illuminating to face appearance, Yang and Wang [7, 8] have implemented dynamic environment illuminating to face appearance and give a realistic rendering in real time, which can meet requirement of some applications in practical scenes. Typically Englund [9] evaluates skin rendering via ultrasound medical data acquisition methods such as CT (Computed Tomography) and MR (Magnetic Resonance), and Kim et al. [10] simulate the realistic fetus skin color based on ultrasound volume rendering. Especially the technical report [11] catches our attention that it provides a description and comparison of classical and improved diffusion theory as used for rendering subsurface scattering, and proves diffusion profile as priority selection to realistic rendering. Considering that the area of human skin rendering is one which holds a lot of relevance in the present consumer driven industry of 3D games and animation. We differ in that we achieve comparable quality with faster speed of rendering via the state of the art GPU technique for this purpose. In this paper, we simulate the surface reflection of human skin via a physically based model of micro-facet distribution, and approximate the diffusion profile via weighted Gaussian sums. Combining surface reflection with diffusion reflection, we obtain a realistic rendering of human skin with faster speed.

The rest of this paper is organized as follows. Surface reflection simulation via efficient micro-facet method is given in Section 2. Diffusion reflection simulation via weighted Gaussian sums is deduced in Section 3. At last, experimental results are discussed in Section 4, and finally conclusions are given in Section 5.

2. **Surface Reflection Simulation via Micro-facet Method.** BSSRDF (Bidirectional Surface Scattering Reflectance Distribution Function) is an eight dimensional function (two positions and two directions) as shown in Equation (1) and is hard to be captured in the general case, so it is impractical to be realized in practice.

$$S(x_o, \omega_o, x_i, \omega_i) = \frac{dL(x_o, \theta_o)}{dE(x_i, \theta_i)} \tag{1}$$

where x_o and ω_o are outgoing point and outgoing direction respectively. x_i and ω_i are incoming point and incoming direction respectively. θ_i and θ_o are incoming angle and outgoing angle respectively. L is the outgoing energy. E is the irradiance energy.

So we use BRDF (Bidirectional Reflectance Distribution Function) model to simplify and simulate BSSRDF model, which is a four dimensional function written as

$$f_{BRDF} = \frac{dL(x, \theta_o)}{dE(x, \theta_i)} = \frac{dL(x, \theta_o)}{L(x, \theta_i)\cos(n_x, \theta_i)d\omega_{\theta_i}} \tag{2}$$

where n_x is the normal at the point x.

Equation (2) can be further written as

$$dL(x, \theta_o) = f_{BRDF} L(x, \theta_i)\cos(n_x, \theta_i)d\omega_{\theta_i} \tag{3}$$

In fact, the surface of human skin is rough surface which has many fine bump characteristics as shown in Figure 1, so the simulation of interaction between incoming light and the rough surface is very complex.

In order to effectively simulate surface reflection on the bump surface of skin, we use a physically based model of micro-facet distribution called Beckmann distribution function

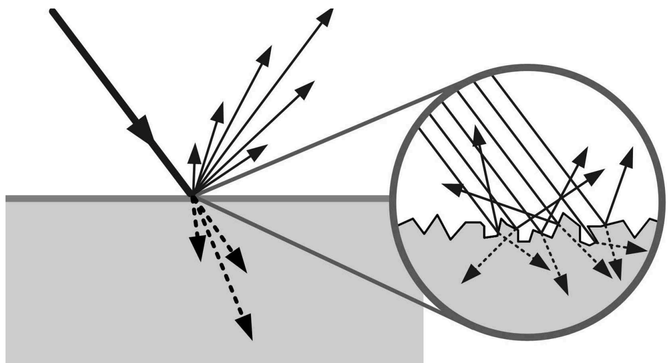

FIGURE 1. Fine bump characteristics of skin surface

which can be defined as

$$f_{BRDF} = \frac{e^{\lambda}}{\pi m^2 \cos^4 \alpha} \tag{4}$$

where N is the normal at the incoming point. H is the half-angle between view direction and incoming light direction. $\alpha = \arccos(N \cdot H)$. m is the RMS (Root Mean Square) slope of the surface micro-facets (the roughness of the material). λ is the wavelength of incoming light which can be written as

$$\lambda = -\frac{\tan^2(\alpha)}{m^2} \tag{5}$$

Finally, by combining light color with shading shadow, surface reflection of incoming light can be simulated as follows

$$L_s = ColorTex \times ShadowTex \times \frac{e^{\lambda}}{\pi m^2 \cos^4 \alpha} \times \cos(n_x, \theta_i) \tag{6}$$

where $ColorTex$ is incoming light color and $ShadowTex$ is shading shadow and both of them can be pre-computed as texture map.

3. **Diffusion Reflection Simulation via Weighted Gaussian Sums.** A diffusion profile provides an approximation for the manner in which light scatters underneath the surface of a highly scattering translucent material such as human skin. When a beam of light is striking the surface, we will see a glow around the center point, because some light is going beneath the surface and returning nearby. The diffusion profile on the surface of a highly scattering translucent material is physically shown in Figure 2.

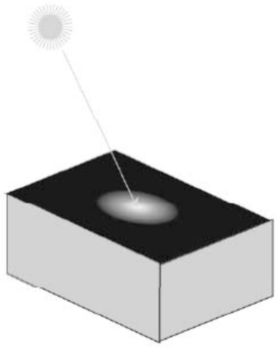

Figure 2. Diffusion profile on the skin surface

As we have observed from Figure 2, part of the light arriving at such adjacent points will penetrate into the object and exit at surrounding points, with the specific attenuation given by the diffusion profile $R(r)$. For this, the following integral needs to be calculated:

$$L_d(x_o, \omega_o) = \int\int E(x_i, \omega_i) R(r) dx d\omega \tag{7}$$

where L_d is the radiant exitance at point P and E is the irradiance which can be simulated by irradiance texture map.

Then, Equation (7) can be written as a two-dimensional convolution which fits GPU evaluation easily.

$$L_d(x_o, \omega_o) = E(x_i, \omega_i) * R(r) \tag{8}$$

Although diffusion profile $R(r)$ is difficult to be measured, through observation to the illumination effect of flat surface, we can use mathematical representation to simulate it as follows

$$R(r) = \sum_{i=1}^{k} \omega_i G(v_i, r) \tag{9}$$

where ω_i and v_i are weight and variance of Gaussian function G respectively.

We choose the following definition for the Gaussian function as in

$$G(v,r) = \frac{1}{2\pi} e^{-\frac{r^2}{2v}} \tag{10}$$

We use a very nice property of convolution: the convolution of an irradiance texture E by a kernel is the same as a weighted sum of irradiance E as follows

$$L_d = E * R(r) = E * \left(\sum_{i=1}^{k} w_i G(v_i, r) \right) = \sum_{i=1}^{k} w_i E * G(v_i, r) \tag{11}$$

Two-dimensional convolutions are still costly for real-time applications such as 3D games. Fortunately, some two-dimensional convolutions are separable and radially symmetric, which means they can be separated into two faster one-dimensional convolutions. Gaussian convolutions are one of these separable convolutions, so the convolution of any two Gaussians is another Gaussian as follows

$$G(v_1) * G(v_2) = G(v_1 + v_2) \tag{12}$$

Finally, we can obtain the approximated result of diffusion reflection by convolving the irradiance texture with the weighted sum of Gaussian functions according to Equation (11).

4. **Results.** In this section we demonstrate the effectiveness of our design technique. All results are generated on the platform as follows, CPU: Intel Core 2 i7, GPU: NVIDIA GeForce GT240 @2G, RAM: 4G, Application language: C++ and OpenGL, Shader language: CG, Programming environment: VS2012. Finally, we give the rendering appearance of human skin and clearly show the realism of results.

Firstly we give the 3D model of human face from IR-LTD (IR-Entertainment Ltd) as our rendering object as shown in Figure 3.

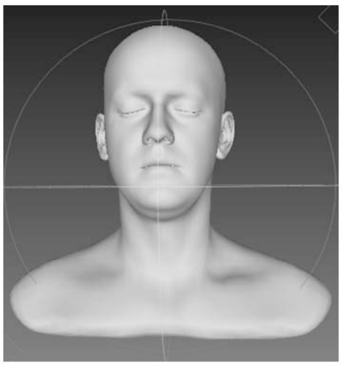

FIGURE 3. Rendering model of human face

Then we implement the simulation of BRDF reflection according to Equation (6) and linear sums of Gaussian blur according to Equation (11), and obtain rendering results of human face in front as shown in Figure 5, which is compared to multi-layered rendering [8] as shown in Figure 4.

In order to highlight the difference between two methods, we give the local face rendering and magnify them to give the comparison clearly.

From Figure 4 to Figure 7, we could acquire more detailed characteristics and illumination effect such as soft shadow. Also our method can show light is scattered under the surface of the skin in different amounts for different wavelengths of light, and give a more smooth look such as color-bleed effect. Therefore, we could get reasonable conclusion that more advanced surface and diffuse reflection models can be simulated by our method.

Figure 4. Whole face via multi-layered rendering

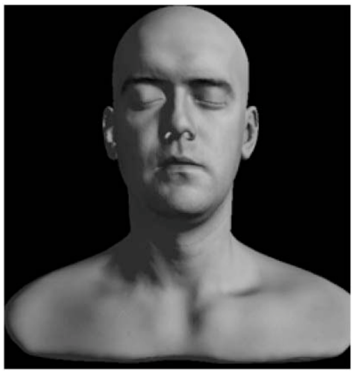

Figure 5. Whole face via our method

Figure 6. Local face via multi-layered rendering

Figure 7. Local face via our method

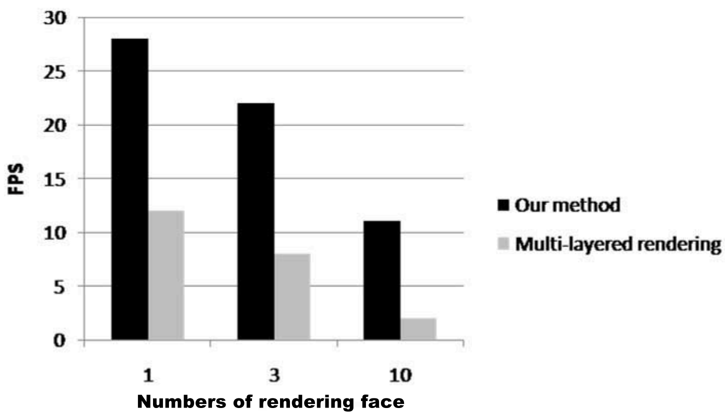

Figure 8. FPS comparison between our method and multi-layered rendering

In the performance of rendering speed, using GPU and fast blur computation we have achieved about 28 frames per second (FPS) when rendering one human face; however, the classic rendering methods such as multi-layered rendering [8] only acquire 12 FPS. The reason we can realize the fast computation is that two-dimensional convolutions of Gaussians in our paper can be separated into two faster one-dimensional convolutions based on the separable and radially symmetric characteristics. When increasing the numbers of human faces, the rendering time between our method and multi-layered rendering [8] is more obvious as shown in Figure 8, which shows that we are able to achieve comparable quality with faster speed.

5. **Conclusions.** We have implemented the fast rendering of human skin based on efficient simulation of surface reflection and diffuse reflection. Surface reflection is simulated by a physically based model of micro-facet distribution and diffuse reflection is approximated by weighted Gaussian sums. Combining surface reflection with diffusion reflection, we obtain a realistic rendering of human skin with faster speed. The results show that we could acquire more detailed characteristics and give a more smooth look in effects such as color-bleed and soft shadow.

Although we have realized the fast realistic rendering, the price is still high in that many passes of Gaussian blurring are very computationally heavy and how the rendering process is simplified is an interesting direction which we are currently working on.

REFERENCES

[1] A. Ngan, F. Durand and W. Matusik, Experimental analysis of BRDF models, *Eurographics Symposium on Rendering*, 2005.
[2] M. Pharr and G. Humphreys, *Physically Based Rendering: From Theory to Implementation*, Morgan Kaufmann Publishers, pp.97-107, 2004.
[3] A. Krishnaswamy and G. V. G. Baranoski, A biophysically-based spectral model of light interaction with human skin, *Computer Graphics Forum*, pp.331-340, 2004.
[4] C. Donner and H. W. Jensen, Light diffusion in multi-layered translucent materials, *ACM Trans. Graphics*, vol.24, no.3, pp.1032-1039, 2005.
[5] E. D'Eon and D. Luebke, Advanced techniques for realistic real-time skin rendering, *GPU Gems 3*, pp.293-347, 2007.
[6] J. Jimenez, V. Sundstedt and D. Gutierrez, Screen-space perceptual rendering of human skin, *ACM Trans. Applied Perception*, vol.23, no.6, pp.293-347, 2009.
[7] M. Yang and K. Wang, Texture space rendering for human face via dynamic environment illuminating, *ICIC Express Letters, Part B: Applications*, vol.4, no.6, pp.1665-1670, 2013.
[8] M. Yang and K. Wang, Real-time rendering for multi-layered translucent materials such as human skin under dynamic environment lighting, *Applied Mechanics & Materials*, vol.274, pp.423-426, 2013.
[9] R. Englund, *Ultrasound Surface Extraction for Advanced Skin Rendering*, Ph.D. Thesis, Linkoping University, pp.1-10, 2013.
[10] Y. T. Kim, K. Kim and S. C. Park, Realistic fetus skin color processing for ultrasound volume rendering, *SPIE Electronic Imaging*, pp.1504-1514, 2014.
[11] R. Habel, P. H. Christensen and W. Jarosz, Classical and improved diffusion theory for subsurface scattering, *Tech. Report, Disney Research Zürich*, pp.1-6, 2013.