Microfacet distribution function for physically based bidirectional reflectance distribution functions

O.N. Romanyuk[a], S.V. Pavlov[a], R.Yu. Dovhaliuk*[a], N.P. Babyuk[a],
M.D. Obidnyk[a], P. Kisala[b], B. Suleimenov[c]
[a]Vinnytsia National Technical University Khmelnutske shose str. 95, Vinnytsia, Ukraine;
[b]Lublin University of Technology, Nadbystrzycka 38A, 20-618 Lublin, Poland;
[c]Kazakh National Technical University after K. I. Satpaev, Satpaeva 22, Almaty, Kazakhstan

ABSTRACT

A microfacet distribution function is presented. This function can be used to calculate the microfacet distribution term in BRDF models. The function differs from other well-known microfacet distribution functions like Blinn or Beckmann distributions in that it doesn`t use special functions like acos, tan, exp, pow and thus has lower computational complexity.

Keywords: microfacet distribution, bidirectional reflectance distribution functions, shading

1. INTRODUCTION

Visual appearance of a surface is determined by its interaction with incident light. To create realistic images it is necessary to know the properties of a surface and their influence on light scattering. In modern computer graphics the reflection properties of a surface are determined using the *bidirectional reflectance distribution function* (BRDF). Using the BRDF models it is possible to calculate the ratio of differential reflected radiance exiting in the direction $\vec{\omega}_o$ to the differential irradiance incident on the point of the surface with normal $\vec{n}$ from direction $\vec{\omega}_i$ such that[1]:

$$L_o(x,\vec{\omega}_o) = \int_{\Omega 2\pi} f_r(\vec{\omega}_o,\vec{\omega}_i)\cdot L_i(x,\vec{\omega}_i)\cdot(\vec{\omega}_i \bullet \vec{n})\, d\vec{\omega}_i, \tag{1}$$

where $f_r(\vec{\omega}_o,\vec{\omega}_i)$ is the BRDF.

Table 1. Important terms used in this paper.

$\vec{\omega}_o$	direction toward the viewer
$\vec{\omega}_i$	direction of incident radiance
$L_o(x,\vec{\omega}_o)$	differential reflected radiance
$L_i(x,\vec{\omega}_i)$	differential incident irradiance
$\vec{h}$	normalized half-vector between the incident radiance direction and direction toward the viewer
$\vec{n}$	normalized surface normal

To simulate a reflectance behavior from a rough surface one need to use special microfacet BRDFs. One of such models is a Cook-Torrance BRDF. The Cook-Torrance BRDF model is represented by three terms as follows[2]:

$$f_r(\vec{\omega}_o,\vec{\omega}_i) = \frac{D(\vec{h})\cdot G(\vec{\omega}_o,\vec{\omega}_i)\cdot F_r(\vec{\omega}_o,\vec{\omega}_i)}{\pi\cdot(\vec{n}\bullet\vec{\omega}_i)\cdot(\vec{n}\bullet\vec{\omega}_o)}, \tag{2}$$

where $F_r(\vec{\omega}_o,\vec{\omega}_i)$ is the Fresnel term, $G(\vec{\omega}_o,\vec{\omega}_i)$ is the shadowing-masking term and $D(\vec{h})$ is the microfacet distribution term which describes the roughness of the surface as the distribution of the slopes of the microfacets.

* rdovgaliuk@yandex.ua; ran12345@mail.ru, psv@vntu.edu.ua

Optical Fibers and Their Applications 2012, edited by Ryszard S. Romaniuk, Waldemar Wójcik,
Proc. of SPIE Vol. 8698, 86980L · © 2013 SPIE · CCC code: 0277-786/13/$18 · doi: 10.1117/12.2019338

The microfacet distribution term *D* is defined using the microfacet distribution functions. Below the equations for some common used distribution functions are presented.
Beckmann distribution with parameter *m*:

$$D(\vec{h}) = \frac{e^{-\left(\frac{\tan(\arccos(\vec{h}\bullet\vec{n}))}{m}\right)^2}}{\pi \cdot m^2 (\vec{h}\bullet\vec{n})^4}, \tag{3}$$

where *m* is the average slope of the microfacet`s normal.

Another distribution based on Gaussian distribution was proposed by **Blinn**[3]:

$$D(\vec{h}) = ce^{-\left(\frac{\arccos(\vec{h}\bullet\vec{n})}{m}\right)^2}, \tag{4}$$

where *c* is a user defined constant used to adjust the distribution.

Both functions (3) and (4) use exponential rising to $\left(\frac{\tan(\arccos(\vec{h}\bullet\vec{n}))}{m}\right)^2$ and $\left(\frac{\arccos(\vec{h}\bullet\vec{n})}{m}\right)^2$ powers respectively. The values of mentioned powers are evaluated in runtime and can be up to 10 000 which leads to performance degradation.

2. DERIVATION OF NEW MICTOFASET DISTRIBUTION FUNCTION

The parameter $e^{-\left(\frac{\tan(\arccos(\vec{h}\bullet\vec{n}))}{m}\right)^2}$ in Beckmann distribution can be closely approximated using the following function:

$$e^{-\left(\frac{\tan(\arccos(\vec{h}\bullet\vec{n}))}{m}\right)^2} \approx (\vec{h}\square\vec{n})^{\frac{2}{m^2}}. \tag{5}$$

Substituting $e^{-\left(\frac{\tan(\arccos(\vec{h}\bullet\vec{n}))}{m}\right)^2}$ parameter for $(\vec{h}\square\vec{n})^{\frac{2}{m^2}}$ in Beckmann distribution, we get:

$$D(\vec{h}) = \frac{(\vec{h}\bullet\vec{n})^{\frac{2}{m^2}}}{\pi \cdot m^2 (\vec{h}\bullet\vec{n})^4} = \frac{1}{\pi \cdot m^2}(\vec{h}\bullet\vec{n})^{\frac{2}{m^2}-4}. \tag{6}$$

To lower the computational complexity of equation (6) we need to approximate the $(\vec{h}\bullet\vec{n})^{\frac{2}{m^2}-4}$ term. Such approximation is equal to the approximation of the $\cos^n(x)$ function. To approximate the $\cos^n(x)$ function we need a cosine-based function which equals 1 at $x = 0$. In[4] Romanyk *et al.* describe an approximation of the $\cos^n(x)$ function:

$$\cos^n(x) \approx \left(\frac{n}{16}\cdot(\cos(x)-1)+1\right)^{16}. \tag{7}$$

Using this approximation we can simplify $(\vec{h}\bullet\vec{n})^{\frac{2}{m^2}-4}$ term such that:

$$(\vec{h}\bullet\vec{n})^{\frac{2}{m^2}-4} \approx \left(\frac{\frac{2}{m^2}-4}{16}\cdot((\vec{h}\bullet\vec{n})-1)+1\right)^{16}. \tag{8}$$

If we combine equation (8) with (6) we get:

$$D(\vec{h}) = \frac{1}{\pi \cdot m^2}(\vec{h} \bullet \vec{n})^{\frac{2}{m^2}-4} \approx \left[\frac{\frac{2}{m^2}-4}{16} \cdot ((\vec{h} \bullet \vec{n}) - 1) + 1 \right]^{16}. \quad (9)$$

The resulting microfacet distribution is:

$$D(\vec{h}) = \frac{1}{\pi \cdot m^2}\left[(\frac{1}{8m^2} - \frac{1}{4}) \cdot ((\vec{h} \bullet \vec{n}) - 1) + 1 \right]^{16}. \quad (10)$$

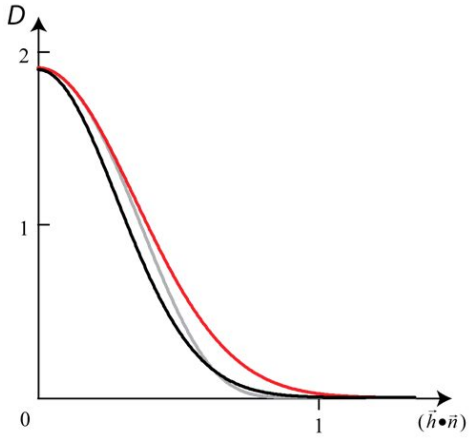


Figure 1. Beckmann (gray), Blinn (black) and proposed (red) distribution functions $D(\vec{h})$ with m = 4.0 and c = 1.9.

3. PERFORMANCE EVALUATION OF MICROFACET DISTRIBUTION FUNCTIONS

The computation complexity of distribution function affects the performance of bidirectional reflectance distribution function calculation and, in turn, determines the speed of scene rendering. Thus the computational complexity of distribution function should be as lower as possible.

To evaluate the performance of Beckmann, Blinn and proposed distribution functions we have used the AMD GPU ShaderAnalyzer software to determine the estimated cycles count required to execute the pixel shader with implemented Cook-Torrance BRDF. Our pixel shader uses Schlick`s approximation of the Fresnel term. The table 2 describes the main settings of AMD GPU ShaderAnalyzer used during performance evaluation.

Table 2. Important terms used in this paper.

Graphics Adapter	Radeon HD6670
Target	ps_3_0
Optimization	Level 3

The results of performance evaluation are described in table 3.

Table 3. Results of performance measurements of microfacet distribution functions.

Distribution function	Estimated cycles count
Blinn	1.67
Beckmann	3.67
Proposed	1.34

The received results show that computation of pixel shader without computation of distribution parameter D ($D = const$) lasts for 8.83 cycles. In turn, computation of Blinn, Beckmann and proposed distributions requires additional 1.67, 3.67 and 1.34 cycles respectively. The implementation of Blinn and Beckmann distributions using a HLSL language requires usage of specific functions like acos, tan, exp, pow. This leads to lower computational performance than in case of proposed distribution which uses only pow specific function.

In proposed distribution an operand $\left(\frac{1}{8m^2}-\frac{1}{4}\right)\cdot((\vec{h}\bullet\vec{n})-1)+1$ is raised to 16 power. A value of a power does not change dynamically and is not evaluated during the runtime. This gives a possibility to lower the computational complexity of the proposed distribution function by substituting the operation of rising to 16 power for 4 multiplications. After applying this optimization the estimated cycles count has lowered to 1.0. Table 4 contains updated results of microfacet distribution functions performance measurement.

Table 4. Results of performance measurements of microfacet distribution functions.

Distribution function	Estimated cycles count
Blinn	1.67
Beckmann	3.67
Proposed	1.34
Proposed (Optimized)	1.0

4. CONCLUSION

In this paper we present a new microfacet distribution function. Developed function doesn't use any specific functions like acos, tan, exp, pow and thus has lower computational complexity than Blinn and Beckmann distribution functions.

REFERENCES

[1] Akenine-Moller, T. and Hoffman, N., [Real-Time Rendering, Third Edition] (2008).
[2] Cook, R.L. and Torrance, K.E., "A reflectance model for computer graphics," Computer Graphics, 15, 3, 307-316 (1981).
[3] Dempski, K. and Viale E., [Advanced Lighting and Materials with Shaders] (2004).
[4] Romanyuk, A.N., Lyashenko, Y.L., Melnik, A.V. and Goncharuk, A.P., "Effective Models for the Specular Color Constituent Computing," Journal of Computer Science and Engineering, Vol. 2, Issue 2, 25-29 (2010).