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ANALYSIS OF MICROFACET AND WAVE APPROACHES TO THE FORMATION OF REALISTIC IMAGES OF ANISOTROPIC SURFACES

Chan A., Romanyuk O. N.

Розглянуто особливості мікрофасетного та хвильового підходу до рендерингу візуально реалістичних зображень фізичних об'єктів на прикладі дистрибутивних функцій відбивної здатності та визначенні коефіцієнта шорсткості анізотропної поверхні за допомогою довжини хвилі світла.

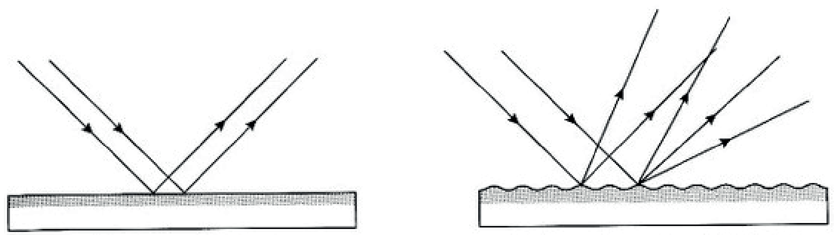
Peculiarities of microphase and wave approach to rendering visually realistic images of physical objects on the example of distributive functions of reflectivity and determination of the roughness coefficient of an anisotropic surface using the wavelength of light are considered.

One of the important tasks of computer graphics today is to render images from existing digital models of physical objects. In most cases, the leading role is played by the correspondence to a certain level of photorealism, which allows to achieve a smaller difference between the image and the real object [1].

One of such situations is the process of visually realistic reproduction of anisotropic surfaces, which takes place in various information technology areas with computer graphics application — medicine (for example, to reproduce the surface of human skin), social security, game industry, cinema, design, visualization objects in various scientific studies, etc. Today, there are many methods for modelling rough inhomogeneous surfaces with different approaches according to the field of application. However, many of them remain imperfect for a variety of reasons: the problem of real-time implementation; the complexity of calculations, which causes a high cost of resources, and, accordingly, increases the cost of the modelling process and so on. Therefore, in order to further address this type of shortcomings, it is important to study and compare existing methods of visually realistic reproduction of anisotropic surfaces using computer graphics.

When creating a visually realistic image of an object with a rough surface, you need to build a geometric model based on the reflectivity of the surface, which plays a leading role in photorealism. The directional reflectance distribution function of the surface is characterized by physical models built on the basis of algorithms for calculating the total illumination and of the incident light reflection. Accordingly, the reflective properties of any surface can be described by calculating the bidirectional reflectance distribution function (BRDF) [2].

Most of the existing models of BRDF today are not universal in relation to the surfaces for which they are used for modelling. A specific model of BRDF may be better for determining the reflective properties of one surface and worse for others. This is due in particular to different approaches to the formation of surface illumination depending on the type of surface material. For the formation of rough surfaces, we can distinguish two approaches to the construction of the model BRDF — microfacet and wave. The first considers a rough surface as a set of microscopic flat planes at different angles relative to each other. The light wavelength is ignored and transferred to the RGB colour model. The second is based on the wave nature of light and determines the roughness coefficient of the anisotropic surface taking into account the light wavelength.



a) b)

Fig. 1. Reflection of light on a homogeneous (a) and rough (b) surface

Consider in more detail the microfaceted approach. In the early stages of the development of computer graphics technology, Phong, Schlick, and Blinn models were used to form a model for illuminating various objects, each of which initially did not take into account the surface roughness factor. Such calculations are better suited for isotropic smooth surfaces on which incident light propagates without interference.

The Phong model is based on the calculation of the total illuminance of the surface at each point, which takes into account the sum of specular, diffuse and ambient light components, as well as the reflection coefficient of a smooth surface (depending on the surface properties) and a set of vectors (Fig. 2).

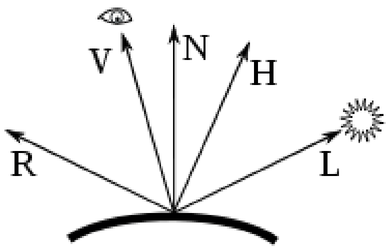
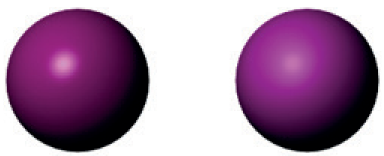


Fig. 2. The main vectors of the Phong model

The vectors in the direction of the observer (V), to the light source (L) and the normal to the surface (N) are taken into account. The vector with the direction of the reflected beam of light is quite difficult to calculate. Therefore, in the Blinn-Phong model, an additional vector H is introduced, which is the median of the angle between the vectors V and L. Thus, a certain simplification of the model is achieved. As a result of the calculation of the illuminance according to Blinn-Phong, the light on the surface is more diffused, compared with the result according to the Phong model (Fig. 3).



a) b)

Fig. 3. Glare formation according to the model of Phong (a) and Blinn (b)

However, under such conditions, the possibilities of realistic reproduction of illumination of many materials are limited — the first models of calculating illuminance are better suited for forming images of smooth, mirror surfaces, but it does not take into account the heterogeneity of surfaces of complex materials. To date, many modifications have been made to existing BRDF, including the Phong lighting model.

One of them was the Ashikhmin-Shirley model, known in 2000 as the anisotropic Phong reflection model, designed to process the agreement between surface and body reflection from the observer's point of view. In this model there are no attempts to model shadows and masking, instead, there is a compromise between diffuse and mirror coefficients [3]. The model is to find the sum of these reflection coefficients and has the form:

$$I_d = \frac{28 R_d}{23\pi}\left(1 - R_s\right)\left(1 - \left(1 - \frac{(n,l)}{2}\right)^5\right)\left(1 - \left(1 - \frac{(n,\nu)}{2}\right)\right)^5;$$

$$I_s = \frac{\left(n_x + 1\right)\left(n_y + 1\right)}{8\pi(h,l)\max\left((n,l),(n,v)\right)}(n,h)^{n_u \cos^2\phi + n_\nu \sin^2\phi} F\left((h,l)\right).$$

$$I_r = I_d + I_s,$$

where n_u and n_ν — coefficients that control the shape of the mirror particle. Different ratios of these coefficients give different results of illumination of the object.

Figure 4 shows the lighting for two bodies according to the Phong and Ashikhmin-Shirley models with the same degree of roughness. As can be seen from the figure, the anisotropic model is more suitable for illuminating rough surfaces, because according to Phong, objects still remain smoother and polished.

The Ashikhmin-Shirley model has a number of specific features, which is due to the realistic reproduction of rough surfaces. This model meets the principles of reciprocity and energy saving; allows to model reflections from anisotropic surfaces; the shape of the reflection function is determined by intuitive parameters; contains the Fresnel coefficient due to which the surface mirror reflectance increases with increasing angle of incidence; has a variable coefficient of diffuse reflection, which reduces the diffuse reflectivity with increasing angle of incidence [4].

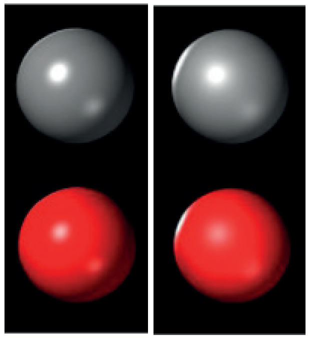
To form the image of rough surfaces, methods of forming maps of coefficients are used, which help to calculate the scattering of incident rays more realistically and closer to how it occurs in nature. One of the distributive functions that implement this approach is the Ward model, which has the following form:

$$I = e^{-k\frac{1-(\vec{h},\vec{n})^2}{(\vec{h},\vec{n})^2}},$$

where $\boldsymbol{I}$ — an integral component of light, which is the result of calculating the relationship between background, diffuse and specular components; $\boldsymbol{n}$ — normal to the surface; $\boldsymbol{h}$ — normal to the surface, the bisector of the vectors from the light source l and the observer v, where:

$$h = \frac{\vec{l}+\vec{v}}{|\vec{l}+\vec{v}|},$$

$\boldsymbol{k}$ — coefficient, which is set according to the surface material.



a) b)

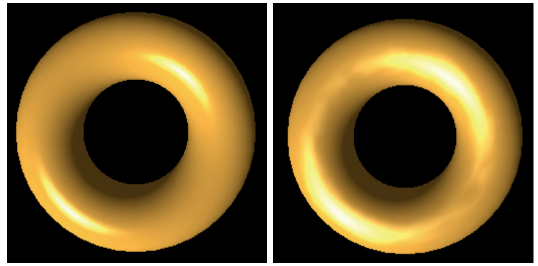
Fig. 4. Lighting of objects according to the model of Phong (a) and Ashikhmin-Shirley (b)

This coefficient is key in the process of creating a realistic image of a complex rough surface, as it is responsible for the shape of the reflection on the X and Y axes. To create images of complex surfaces for each pixel determines its surface coefficient, so we get a map of coefficients for Ward's anisotropic model.

$$k_{spec} = \frac{\rho_s}{\sqrt{(\vec{n}\cdot\vec{l})(\vec{n}\cdot\vec{v})}} \frac{\vec{n}\cdot\vec{l}}{4\pi\alpha_x\alpha_y} e\left[-2\frac{\left(\frac{\vec{h}\cdot x}{\alpha_x}\right)^2+\left(\frac{\vec{h}\cdot y}{\alpha_y}\right)^2}{1+(\vec{h}\cdot\vec{n})}\right].$$

The coefficients α_x i α_y are used to adjust the anisotropic properties. The glare on the surface is formed elongated. This glare is characteristic of metal surfaces. Therefore, the anisotropic model of Ward lighting is the most effective in the application of the reproduction of metal surfaces [5].

As an example, Figure 5 shows the formation of a metal torus surface using the Phong model, which is more efficient for the formation of isotropic simple surfaces, and the Ward model with the formation of a map of the reflection coefficients.



a) b)

Fig. 5. Reproduction of the metal surface of the torus model Fong (a); Ward with a map of the reflection coefficients (b)

It is worth noting that taking into account the geometric component of the surface is also effective for rendering rough surfaces. The Cook-Torrance model describes its use in calculating the reflectivity to take into account the darkening and shielding of the microfaces of the facet surface.

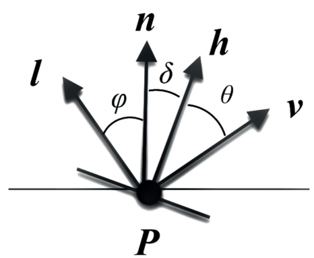


Fig. 6. Basic vectors and angles in the Cook-Torrance model

The root mean square slope of a microface is described by the angle δ between this microface and the normal to the surface:

$$h = \frac{l+v}{\|l+v\|} \quad \delta = (\theta - \varphi)/2 .$$

That part of the microfaces lying at an angle δ to the surface is determined by the Beckman distribution:

$$D(\delta) = \frac{1}{4m^2 \cos^4(\delta)} \cdot e^{-\left[tg(\delta)/m^2\right]} .$$

The surface roughness coefficient *m* usually varies in values [0.2; 0.6]. If the angle δ increases, the distribution of the orientation of the microfaces (Beckman distribution) will decrease.

The geometric component due to the shielding and darkening of the micro faces determines the intensity of the glare, which is formed from unshielded and undocked light. The latter is calculated by the following formulas:

$$G_m = \frac{2\cdot(n\cdot h)\cdot(n\cdot v)}{(h\cdot n)}, \quad G_s = \frac{2\cdot(n\cdot h)\cdot(n\cdot l)}{(h\cdot n)} .$$

The total geometric component is defined as the minimum value in a set consisting of three values — 1, G_m, G_s:

$$G = \min(1, G_m, G_s) .$$

Given that microfaces are not perfectly mirrored parts of the surface, they are not able to reflect the incident rays of light completely. The reflected part of the light is defined as the Fresnel coefficient:

$$F(\varphi,\theta) = \frac{1}{2}\cdot\frac{(g-c)^2}{(g+c)^2}\left[1+\left(\frac{c\cdot(g+c)-1}{c\cdot(g-c)+1}\right)^2\right].$$

The coefficients *c* and *g* are determined as follows:

$$c = \cos(\varphi) = (n\cdot l), \quad g^2 = \eta^2 + c^2 - 1 .$$

The calculation of the total amount of reflected light according to the Cook-Torrance model also takes into account the regulation of the intensity of incident light. To do this, the product is calculated in the denominator of the general formula $(v \cdot n)$ [6]. Thus, the general formula of the Cook-Torrance reflection model has the form:

$$K = \frac{F\cdot G\cdot D}{(v\cdot n)(l\cdot n)} .$$

Figure 7 shows an example of the formation of an anisotropic surface using the Cook-Torrance model.

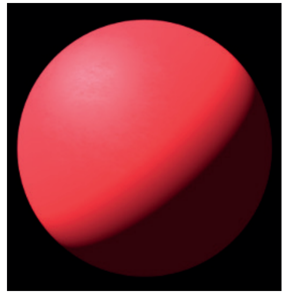


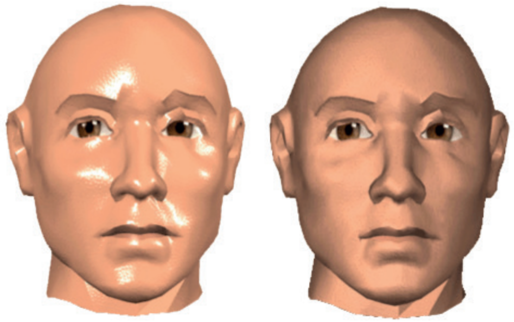
Fig. 7. Image of a sphere with an anisotropic surface using the Cook-Torrance model

Another common method of forming rough surfaces is the Monte-Carlo method. This method is presented as a numerical algorithm, which in turn uses a generator of pseudo-random variables and uses them in the process of solving problems by modelling and calculating the probabilistic characteristics of the obtained samples [7].

In practice, the Monte-Carlo method is most often used to render human skin, because when forming this type of rough surface it is necessary to take into account not only the coefficients of the glare of the upper layer but also to calculate behaviours — absorption and scattering of light rays entering the inner layers of skin.

The Monte-Carlo method was first used in cancer research to model human skin. To do this, a model of stable light propagation in multilayer skin tissue was developed. To simplify the calculations, the model applied only to perpendicularly incident rays. To increase the physical correctness of the construction and thus increase the realism of the image, such simplifications are discarded.

This model is based on the fact that the incident light, falling on the surface, is partially reflected, and the rest is absorbed. In this case, the reflected light is regulated by the Fresnel equation, and the absorbed light is scattered in random directions. Particles of light scatter and weaken. Scattered photons propagate in different directions and contribute to the diffuse distribution of light in the tissue. In this case, random directions of light particle propagation are calculated using a pseudo-random number generator. As a result, it becomes possible to create a realistic reflection and propagation of light from the skin. This distribution is as close as possible to a similar natural phenomenon [7]. For comparison, Figure 4 shows an example of modelling a human face using the Fong distribution function and the Monte-Carlo method.



a) b)

Fig. 8. Modelling of the human face: a) by the Phong BRDF; b) by the Monte-Carlo method

Due to the implementation of the generator of pseudo-random variables, their probabilistic calculation and analysis as models of the directions of motion of the photons of incident light absorbed by the inner layers of the skin tissue, the Monte-Carlo method is quite expensive and nonefficient in resources consumption. This makes this method difficult to implement real-time simulation. For this purpose, certain simplifications through which sometimes it is necessary to sacrifice realism are used.

As a result of the analysis of features of the described models of the formation of rough surfaces, it is possible to come to a conclusion that at a choice of an effective method of the image rendering it is necessary to pay attention to features of a surface, material, the resulting form of reflection which this or that physical model considers. By approximating the existing models, their modification, it becomes possible to reduce resource costs and hardware requirements, increase realism by taking into account additional physical features of the surface.

However, in contrast to the formation of the image of the surface by analysing it as a set of shiny microfaces and the corresponding calculation of the integral component of light, there is another approach.

An alternative to the microfacet approach is the use of wave optics models, which are also obtained by physical modelling, but including the dependence of the wavelength and surface properties. They are the result of a scalar solution of Maxwell's equations, assuming a relatively high frequency. The results are more widely available than microfaceted models.

However, the obtained expressions are much more complex both in the calculation and in implementation, which becomes a certain disadvantage of this approach. The two surface parameters commonly used in these models are the surface height σ_s and the correlation length l_c. If it is assumed that the surface is anisotropic and changes the height and distance in different parts, these parameters statistically describe the layout of such irregularities. The height of the surface describes how high these irregularities are on average. The correlation length is a measure of how far on average these inequalities are [8].

The final result of the lighting model, which takes into account the length of light λ and the roughness coefficient g is the Krywonos Modified Beckmann-Kirchhoff model (KMBK), which looks like this:

$$f_{KMBK} = \frac{KQ\pi l_c^2}{2\lambda^2}\exp(-g)\sum_{m=1}^{\infty}\frac{g^m}{m!m}\exp\left(-\frac{\nu_{xy}^2 l_c^2}{4m}\right).$$

The figure 9 shows the result of image formation by the wave method of building a lighting model.

It can be concluded that the approach of wave optics gives no less qualitative results, and in some cases may have an advantage over geometric due to its accuracy and detailed consideration of the features of anisotropic surfaces.

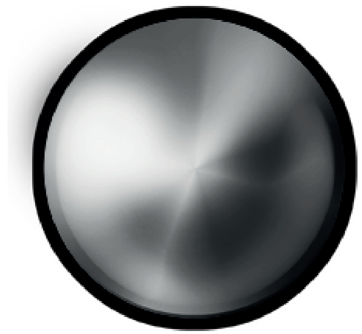


Fig. 9. Image of a rough metal surface according to the Ashikhmin-Shirley model

Conclusions: As a result of the analysis of all the above models for the formation of a photorealistic image of anisotropic, complex surfaces of objects, more commonly used are those models of reflectivity that consider the surface as a set of microfaces, due to a simpler approach.

a) b)

Fig. 10. Microfacet (a) and wave (b) image formation

However, some surfaces are sometimes easier to reproduce with a rendering approach that takes into account the wave nature of light. The resulting images of both approaches are quite realistic, which is the purpose of their study (Fig. 10).

When choosing an approach to image formation of an anisotropic surface should take into account not only its ability to reflect light incident on it but also its ability to absorb, scatter in the inner layers and re-release a certain part of it on the upper layer. There are separate lighting models for this.

Each method can be used in different areas of human activity, depending on the task. Accordingly, when solving some problems, the speed of calculations can be neglected (if the problem is not based on the formation of images in real-time), when solving others, the detailed accuracy of calculations may be irrelevant — simplifications become permissible when the accurate calculation of specific details is not required.

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ІГРОВИЙ ШТУЧНИЙ ІНТЕЛЕКТ В ІГРАХ ЖАНРУ RPG

Шестопалов С. В., Григорюк Д. К.

Показана важливість ігор жанру role-playing game (RPG) на сьогоднішній день. Відзначена важлива роль ігрового штучного інтелекту (ІШІ) в цьому жанрі. Представлене поняття ігрового штучного інтелекту. Проаналізовані недоліки ІШІ в кращих іграх жанру RPG. Наведено невдалі дії ІШІ в сучасних AAA проектах. Показано історію становлення ІШІ від початкового етапу (на основі правил) до сучасного — адаптивного. Розглянуто основні методи реалізації ІШІ. Запропоновано найкращі методи реалізації ІШІ для ігор жанру RPG. Зазначено, що гарно спроектований ІШІ дозволяє неігровим персонажам вести себе більш реалістично, що робить більш цікавим геймплей та занурює гравця в гру.

The importance of role-playing games (RPG) today is shown. The important role of game artificial intelligence (GAI) in this genre is noted. The concept of game artificial intelligence is presented. Analyzed game artificial intelligence in the best

Наукове видання

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