Color Map and Polynomial Coefficient Map Mapping

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***Abstract*—In computer graphics, texture mapping is an important means to enhance the realism of model. Traditional texture image always was captured under special light condition. If the lighting in virtual environment is different from the texture image, the result of rendering will be incorrect and unrealistic. This paper proposes an image-based method to fit the reflection mode by a quadratic multinomial. The coefficients of quadratic multinomial will be gained from BTFs and are stored for every texel as polynomial coefficient maps. A picture is taken under well-proportioned environment light as a color map, which the chromaticity is saved. The method can interpolate light effective under varying virtual lighting conditions by color map and coefficient maps and represent the variation of luminance and color for each texel independently. Color map and polynomial coefficient map make texture mapping become more realistic, simple and dynamic.**

***Index Terms*—color map, polynomial coefficient map, iamge-based , texture mapping**

I. INTRODUCTION

In the reality scene, there are three basic structures in the geometry, namely macrostructure, mesostructure and microstructure. The macrostructure with the certain geometry shape can be seen by the eyes, such as building, furniture shape etc. Mesostructure with quite small geometry shape still can be seen, for instance orange's skin. Microstructure is the micro unit of surface can't be seen. The Microstructure affects optical quality such as light scattering. The mesostructure causes visual effect [1] like roughness, self-shadows, occlusions, inter-reflection and subsurface scatting etc., which is an important factor that we get the realistic object surface with rich detail [2]. Mesostructures are typically rendered using techniques such as bump mapping [3], horizon mapping [4] or displacement mapping [5]. Mesostructure and microstructure decide the optical quality and the detail visual quality of object surface.

Using traditional texture, for example a realistic image, may realistically increase the model's geometry detail by mapping texture to the surface of object. However, because the texture is generally get by taking photographs under some special viewpoint position and specific lighting condition. When this texture is mapped to the 3-D object surface, the lighting condition in the virtual scene is not considered. If the lighting in the virtual environment is consistent with the lighting which the texture was captured under, the reality is the most strong. Contrarily, the result of rendering will appear incorrect and unrealistic. Bump mapping provides basic shading, which perturbs mesh normals to match those of the fine geometric detail, but not shadowing, occlusion, and silhouettes. Introducing variations in the surface normals causes the lighting method to render the surface as though it had local surface variations instead of just a smooth surface. Bump maps can be either hand modeled or, more typically, calculated procedurally. But it is still difficult to create a bump map base on real pictures.

This paper proposes an image-based method for representing various lighting effect, which is suitable for the diffuse and specular reflection object. The pictures are captured under fixed viewpoint and under kinds of illuminations condition. We choose a polynomial model to describe the variation of each texel's luminance. The polynomial coefficients can be stored as polynomial coefficient maps. A picture is taken under well-proportioned environment light as a color map. The color map and polynomial coefficient maps can be mapped to the object simultaneously. This method can reconstruct the texture's luminance and color under varying virtual lighting conditions.

II. TEXTURE LUMINANCE FITTING

A. Related work

Many studies have contributed much to rendering real-world objects in virtual space in high quality. An important problem is acquisition of reflection properties

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and geometric detail of surface. Geometry and reflection properties as textures mapped to the surface of 3D model can realistically reproduce an appearance of real world object.

Reflection model-based methods

BRDFs(Bidirectional Reflectance Distribution Function) were introduced by Nicodemus [6] which characterizes the color of a surface as a function of incident light and exitant view directions. There have been a large number of techniques developed to accurately and compactly represent the 4D BRDF. These include linear basis functions such as spherical harmonics [7], [8], [9], physically based analytic models [10], [11],and empirical models [12], [13]. Parametric-based methods emphasize the use of physically-based or empirical parametric reflectance models, which are effective abstraction for describing how the light is reflected from a surface. Often to fit reflection models based on a sparser set of samples. A number of researchers have described methods for fitting reflection models to measured sample data [14] [15] [13] [16] [17] [18] [19]. Of these methods, the ones by Ward Larson [18] and Lafortune et al. [13] do not consider spatial variations. Sato et al.[17] fit a Torrance-Sparrow model [20] to the data, and consider high-frequency variations for the diffuse part but only per-triangle variations for the specular part. This is also the case for the work by Yu et al. [19][21], which also takes indirect illumination into account. Boivin and Gagalowicz[22] reconstruct arbitrary reflection properties for whole patches in a scene using just one image. McAllister [16] fits a spatially varying Lafortune model to very densely sampled planar materials. The achieved results are impressive but the technique requires flat surfaces and an automated setup to get a dense sampling of the reflection properties. In [23] and [24] inverse rendering algorithms are proposed that reconstruct the reflection properties and the incident light field at the same time. Ramamoorthi and Hanrahan [23] as well as Westin et al. [25] project BRDF data into a spherical harmonics basis instead of fitting an explicit reflection model.

The traditional approach to measure reflectance properties is to use specialized devices, that position both a light source and a sensor relative to the material. These devices can only obtain one sample for each pair of light and sensor position and are therefore relatively slow. Image-sampling approaches have been proposed. These methods are able to acquire a large number of samples at once. For example, Ward Larson [18] uses a hemispherical mirror to sample the exitant hemisphere of light with a single image. Instead of using curved mirrors, it is also possible to use curved geometry to obtain a large number of samples with a single image. This approach is taken by Lu et al. [26], who assume a cylindrical surface, and Marschner et al. [27] who obtain the geometry using a range scanner.

Image-Based Methods

Image-based methods create vivid imagery without explicit knowledge of geometry or reflectance properties. Classic image-based rendering (IBR) [28] uses a large amount of 2D images of different views to generate the illusion of 3D scenes. One may traverse the scenes by directly changing, interpolating, or warping between these images. Most of the early stage object movies are based on fixed lighting, which means it is impossible to change lighting conditions. Many attempts have been made to solve this problem, such as [29]. Although they may produce rendering under varying lighting condition, the viewpoint remains fixed. It is possible, though exhausting, to acquire an object movie under various lighting conditions. However, the accompanying tremendous storage need and management problems make it impractical. In the last decade, more IBR representations are proposed. The surface light field (SLF) [30] is a function that outputs appearance color to each viewing direction from a specific surface location. The SLF can well represent the object appearance under complex (but fixed) lighting conditions. There has been a number of approaches ranging from a relatively sparse set of images with a geometric model [31] over the Lumigraph [32] with more images and a coarser model to the light field [33] with no geometry and a dense image database. Recently surface light fields [34] [35] have become popular, which feature both a dense sampling of the directional information and a detailed geometry. The polynomial texture map (PTM) [36] is a special case of image-based representation. A PTM approximates the sequence of input images which are captured under varying lighting condition using biquadratic polynomials, so only the fitted polynomial parameters are stored in PTM. The BTF proposed by Dana et al. [37] is a pioneering work in representing complex surface appearance under various lighting conditions and viewpoints in a manner similar to traditional texture map. Due to the high dimensionality of BTF, it requires huge memory space for storage. Therefore, how to efficiently manipulate BTFs becomes an issue. Methods such as principle component analysis (PCA), factorization or vector quantization are frequently adopted to preprocess the data for better run-time efficiency. Compared to Reflection model-based approaches, which require much fewer images (mainly for the fitting process), image-based methods need up to hundreds of images.

With very simple geometries, texture and bump mapping yield good results for simple materials, but for more complex materials we will need the ability to change the appearance for varying light and view conditions. Early approaches simulated a single BRDF for the whole material [38]). Kautz and McCool [39] approximated the BRDF by two functions, whose results are stored in textures and were combined by the graphics hardware. These methods where improved by [40], [41] and [42] to BRDFs, lit by prefiltered environment maps, but their models are currently not capable for real-time rendering of BTFs. For fixed viewpoint the polynomial texture map by Malzbender et.al. [43] can be suitable for varying light conditions. Huijian Han et.al[44] proved through experiments that quadratic polynomial approximation can simulate diffuse reflection and specular reflection effects.

B. Fitting BTFs data

According to the thinking of Malzbender et.al [29],in order to simplify the BTF model, this paper only considers the situation of fixed viewpoint and keeps the two dimensions in exitant direction constant, namely the reflection field of BTFs is $I=I(x,y,\theta_i,\varphi_i)$. Under the special illumination circumstance, now one picture is a space sampling of two-dimensional, and to each point (x,y), the change of I is only relevant with (θ_i,φ_i).The principle of gaining BTFs sample of fixed viewpoint is described as figure 1.

As done by Malzbender et.al [29] and in the field of photometric stereo in general, multiple images of a static object with a static camera can be collected under varying lighting conditions. Figure 1 shows a device to assist with this process. The first is a simple once subdivided icosahedral template that assists in manually positioning a light source in 40 positions relative to a sample. In this manner multiple registered images are acquired with varying light source direction. Note that since the camera is fixed we avoid the need for any camera calibration or image registration.

Interpolating these input images to create textures from arbitrary light directions would be very costly both in memory and bandwidth. For each texel in our texture map we would be required to store a color sample for each input light position. One source of redundancy among these images is that the chromaticity of a particular pixel is fairly constant under varying light source direction; it is largely the luminance that varies.

Phong developed a popular illumination model. It is

$$I = I_a k_a + I_p (k_d (\vec{N} \cdot \vec{L}) + k_s (\vec{N} \cdot \vec{H})^n) \quad (1)$$

Let $f(x,y)=I/I_p$. Without considering ambient light, We try to fit Eq.(1) by following Eq.(2) .We choose to model this dependence with the following biquadratic per texel .

$$f(x,y) = k_0 b_x{}^2 + k_1 b_y{}^2 + k_2 b_x b_y + k_3 b_x + k_4 b_y + k_5 \quad (2)$$

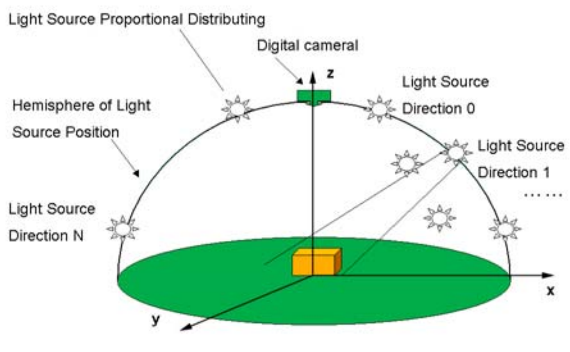

Figure 1. Schematic drawing for sampling BTFs with fixed viewpoint

Where *bx by* are projections of the normalized light vector into the local texture coordinate system (u,v) and *f(x,y)* is the ratio of the surface luminance and light luminance at that coordinate. The local coordinate system is defined per vertex, based on the normal and on the tangent and binormal derived from the local texture coordinates. Coefficients (*k0-k5*) are fit to the photographic data per texel and stored as a spatial map referred to as a Polynomial Texture Map. Given N+1 images, for each pixel we can compute the best fit in the f_i norm using singular value decomposition (SVD) to solve the following system of equations for *k0-k5*.

$$\begin{pmatrix} b_{x0}^2 & b_{y0}^2 & b_{x0}b_{y0} & b_{x0} & b_{y0} & 1 \\ b_{x1}^2 & b_{y1}^2 & b_{x1}b_{y1} & b_{x1} & b_{y1} & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ b_{xN}^2 & b_{yN}^2 & b_{xN}b_{yN} & b_{xN} & b_{yN} & 1 \end{pmatrix} \begin{pmatrix} k_0 \\ k_1 \\ k_2 \\ k_3 \\ k_4 \\ k_5 \end{pmatrix} = \begin{pmatrix} f_0 \\ f_1 \\ \vdots \\ f_N \end{pmatrix} \quad (3)$$

As shown in figure 1, *N+1* photographs are taken under fixed viewpoint and varying lighting conditions. Each photograph corresponds with a light source position. Then every the same position texel in texture space has *N+1* values of brightness and every value corresponds with a known direction of ray. It can be seen that I and bx ,by can be measured. The value of I is expressed from 0 to 255, so realistic brightness of light source Ip is regarded as 255. *f(x,y)* can be computed using luminance of gradation charts. In view of *N+1* samples of each texel, the equation with six unknown coefficients of k_0-k_5 is given by formula (2). The fitting algorithm uses singular value decomposition (*SVD*) to solve the following system of equations, which leads to the minimal least squares error. The *SVD* can be computed once and be applied per texel. Given *N+1* images, for each texel coordinate, we get *N+1* equations and compute the best fit in the *f* to solve the following system of equations for k_0-k_5.

$f_0,\ldots,f_N$ is a rate of energy of outgoing light to incoming light in each texel area, which is measured per texel of varying light directions. b_{x0}, b_{y0} is the projection for the first light-direction to the local texture coordinate system, b_{x1}, b_{y1} the projection of the second and so on.

C. Color Map

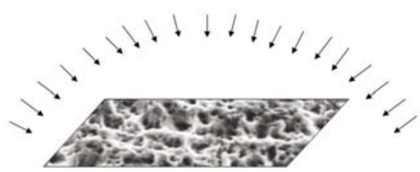

Figure 2. Getting Color Map

In real world, the color of object not only depends on the material itself but also relates to the light source, the color of environment etc. The influence factors are quite complex. When the object is only irradiated by white light, the color of object is decided by reflection characteristic of itself. In general, no matter where the ray comes from , the chromaticity of a particular texel is fairly constant under varying light source, namely the proportion among R,G and B is invariable, and only varying value is the emerge of reflex light (Luminance). In computer, the every value of RGB expresses luminance of each color channel. Under varying light source every component's value of RGB synchronously changes. We can assume, that the color will be constant under varying light directions and fit only the BRDF(*f(x,y)*)'s luminance value and modulate base-color with it. As shown in figure 2, if a picture is taken under well-proportioned environment light, we can get the color of sample point on eyeable surface of object and at the same time the chromaticity is saved. Where, the color $R_B G_B B_B$ that obtained under well-proportioned environment light are named base-color in this paper. The base-color $R_B G_B B_B$ of all texels constitute color map. The base-color $R_B G_B B_B$ are described as Eq.(4).

$$\begin{pmatrix} R_B \\ G_B \\ B_B \end{pmatrix} = \begin{pmatrix} R_p \\ G_p \\ B_p \end{pmatrix} * k_a + \max\{ \begin{pmatrix} R_p \\ G_p \\ B_p \end{pmatrix} k_d (\vec{N} \cdot \vec{L}) \} \tag{4}$$

D. Polynomial Coefficient Map

The coefficients of system of equations (3) k0-k5 will be gained from BTFs and are stored for per texel. To facilitate the storage, the maximum and minimum values of { k0-k5} are obtained and k0-k5 will be mapped to the numerical range 0-255. Then the coefficients can be stored into RGB channels of empty images. The images are named polynomial coefficient maps. Six coefficients can be stored into two maps.

E. Applications of Maps

Figure 3 describes the principle of the application of color map and coefficient maps. In the computer simulation, may designate R_p=G_p=B_p =255. If the picture is captured in the real environment, RBGBBB are color picture's luminance under well-proportioned environment light. Color map applying in luminance-model means that it re-computes the color value (*R(x,y),G(x,y),B(x,y)*) of current each texel under arbitrary incident ray. See formula (5).

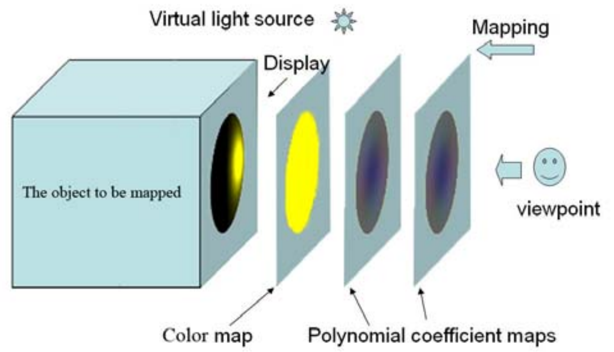

Figure 3. Schematic map of texture mapping with color map and polynomial coefficient map

$$\begin{aligned} R(x,y) &= k * R_B * f(x,y) \\ G(x,y) &= k * G_B * f(x,y) \\ B(x,y) &= k * B_B * f(x,y) \end{aligned} \tag{5}$$

k is a coefficient to adjust brightness of texture image. It is an empirical value that enables recreating more real texture within the range of possibilities. In general, *k=1*. In Eq.(5), $R_B G_B B_B$ from the color map, *f(x,y)* is calculated by coefficients from the coefficient maps.

III. Experiments and Conclusions

A. Experiments

Choose to use computer simulation experiments of slippery object and bump object. To observe the simulation results of specular and diffuse object under virtual light, and to compare with the practical effect. The maximum and minimum values of $\{k_0\text{-}k_5\}$ are between -2 and 3. The coefficients are mapped to the numerical range 0-255. Figure 4 and 7 describe six coefficient maps that every coefficient is stored in a map. Figure 5 and 8 describe three combinations of coefficients that every three coefficients are stored in a map. Six coefficients can be stored into two maps. Experiment is to choose the first combination. Figure 3 is color maps of slippery object and bump object that is taken under well-proportioned environment light and the chromaticity is saved. Figure 6 and 9 describe comparing between the actual results and this paper's simulation result of slippery object and bump object under four different light source positions.

B. Conclusions

This paper proposes an image-based method that requires color map and coefficient maps to interpolate light effective. This method uses a quadratic multinomial to fit the reflection model. The coefficients of quadratic multinomial will be gained from BTFs and are stored for per texel as polynomial coefficient maps. A picture is taken under well-proportioned environment light as a color map, which gets the color of sample point on eyeable surface of object and the chromaticity is saved. The method can reconstruct the surface color and luminance under varying lighting conditions and represent the variation in surface color for each texel independently.

The model is simple but capable of approximating diffuse materials and specular materials. As we are using images to fit the model, effects like self-shadowing, sub-surface scattering and inter-reflections will be preserved as the reflection characteristics of the material. One main implementation of this method is to be used to approximately compute the luminance of each texel, keeping the chromaticity constant. The method can be used in texture mapping, which texture may properly reproduce the variational effects under the different virtual light condition. Application of coefficient map and color map, texture mapping has become dynamic, simple, and realistic. Although approximate, this representation is compact and allows fast color reconstruction during rendering.

C. Future Work

This work suggests an number of areas for future research:

The conversion between polynomial coefficient map and normal map:

Normal mapping is sometimes referred to as "Dot3 bump mapping" . normal mapping has been utilized successfully and extensively on both the PC and gaming consoles. By Phong Lighting equation， study the approximate transformation relationship between polynomial coefficient and normal vector . The existing normal map may be directly translate to polynomial coefficients map.

Polynomial coefficient map filtering:

When the display resolution is greater than or less than the Color map and Polynomial coefficient map,how to interpolate is one content of the study. According to mipmap filtering theory of texture mapping, study polynomial coefficient map applicating mipmap filtering problem.

Coordinate transformation:

Polynomial coefficient map is calculated in a particular coordinate system . When polynomial coefficient map is mapped to the geometric model of the surface, the light source coordinate system should be consistent to the coordinate system of polynomial coefficient map . Only in this way the correct calculation can be ensured. How to calculate lighting effects for each surface patches by polynomial coefficient map need to study how to rapidly translate the coordinate system.

Compression of polynomial coefficient map and color map:

Study using the JPEG method or other methods to compress and decompress the Color map and Polynomial coefficient map.

Rendering with viewpoint variety:

Polynomial coefficient map and color map are captured in fixed viewpoint. Study the rendering method of polynomial coefficient map and color map when viewpoint changes.

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Prof. Han is a member of Chinese Association for System Simulation, Computer Society of Shandong Province, and Academic Committee of Shandong Prov. Key Lab of Digital Media Technology. Prof. Han received third prize of Shandong Province Natural Science Award in 2005, received first prize of Science and Technology Progress Award of People's Republic of China Ministry of Education in 2007 and received Outstanding Contribution Award from the Shandong Provincial Science and Technology Association in 2008.

Caiming Zhang, doctor, professor of Computer Science and technical Department of Shandong Economic University, doctor tutor, president of computer applied technical institute. He has been devoted to digital media, GAGD, CG, science computer visualization, and so on. From 1991 to 1995, he made an academic visit to Tokyo Industrial University and studied for the doctor degree there, and his research field is GAGD, Graphics, and image processing. From 1997 to 1999, he made an academic visit to Kentucky University and did research on the car exterior designing for Ford Motor Corp. as a postdoctoral.

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Figure 4. Color maps of slippery object and bump object

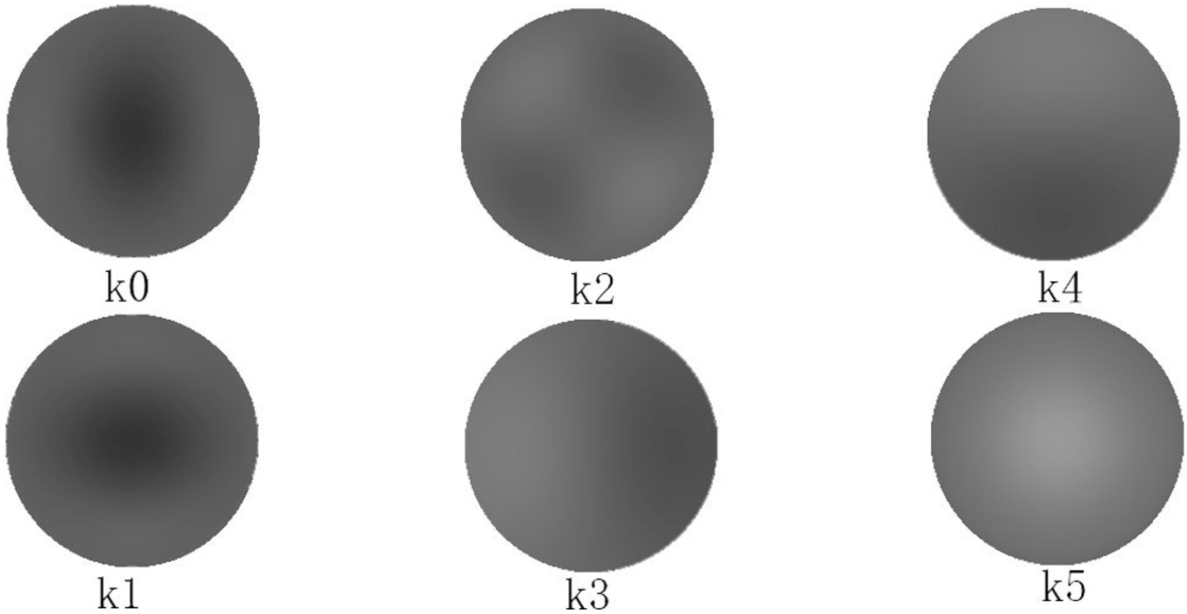


Figure 5. Single coefficient map of slippery object

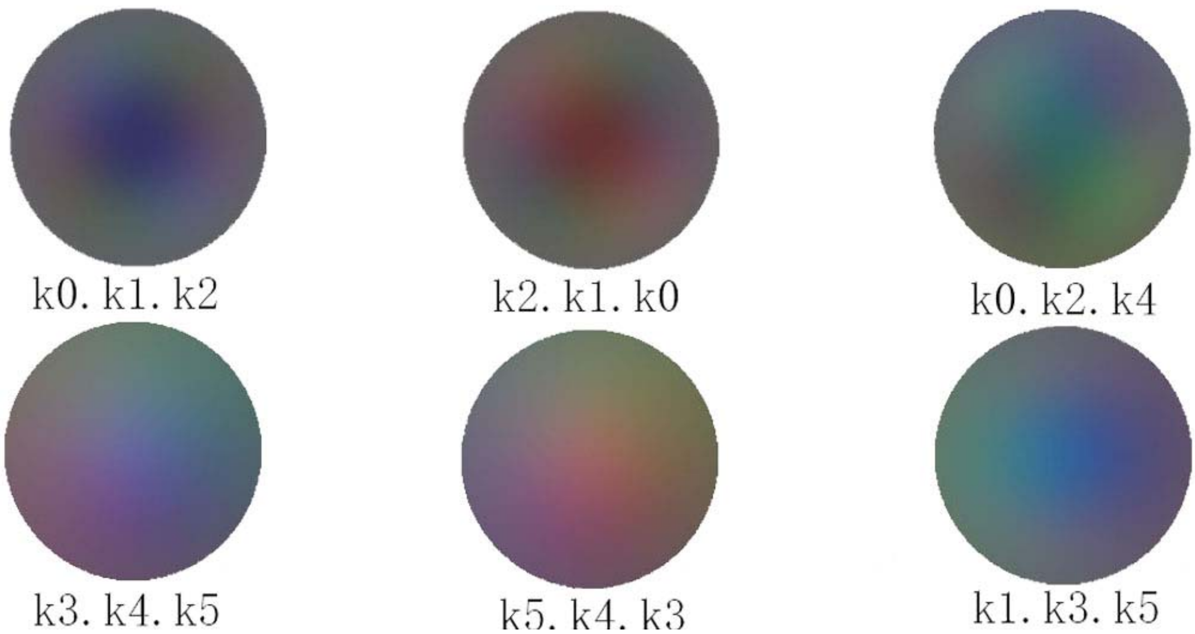
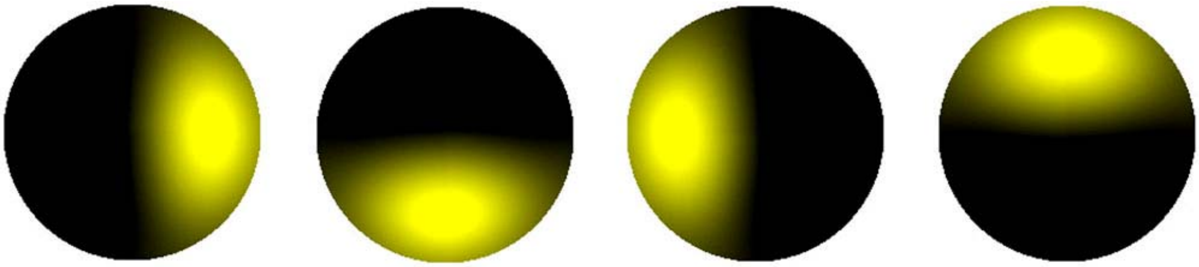
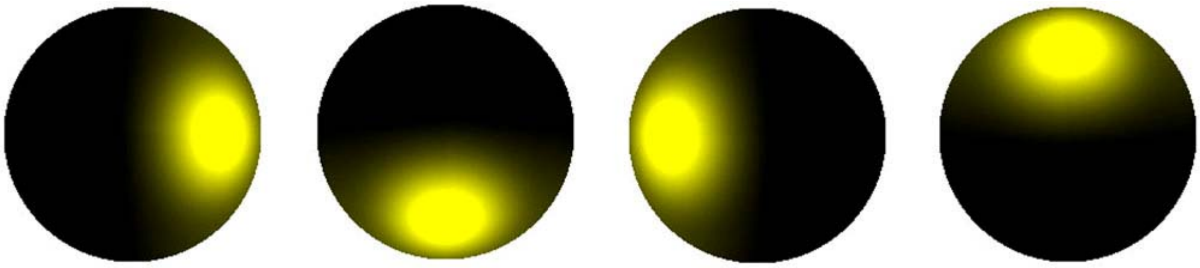


Figure 6. Several combine of coefficients map of slippery object



Reconstructing result of slippery object applying color map and coefficient maps.



Actual results of slippery object in Phong's model (n=12)

Figure 7. Comparing between the actual results and reconstructing result of slippery object under four different light source position. (ka /kd / ks is 0.0/0.4/0.6; n=12)

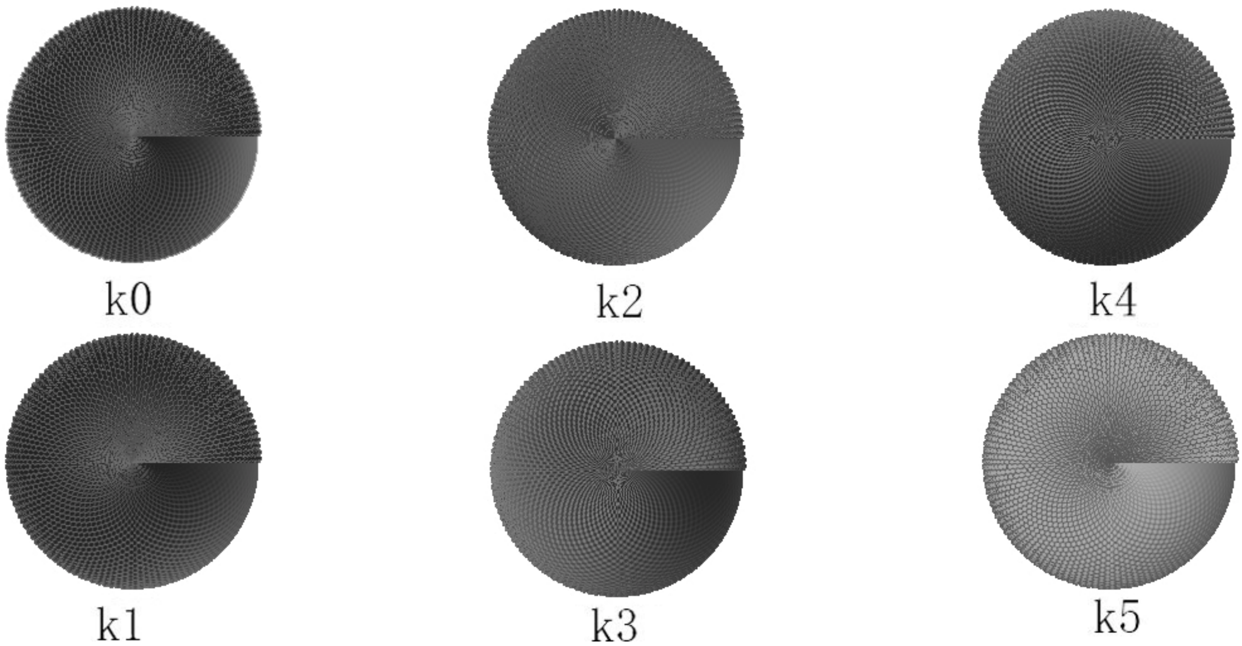


Figure 8. Single coefficient map of bump object

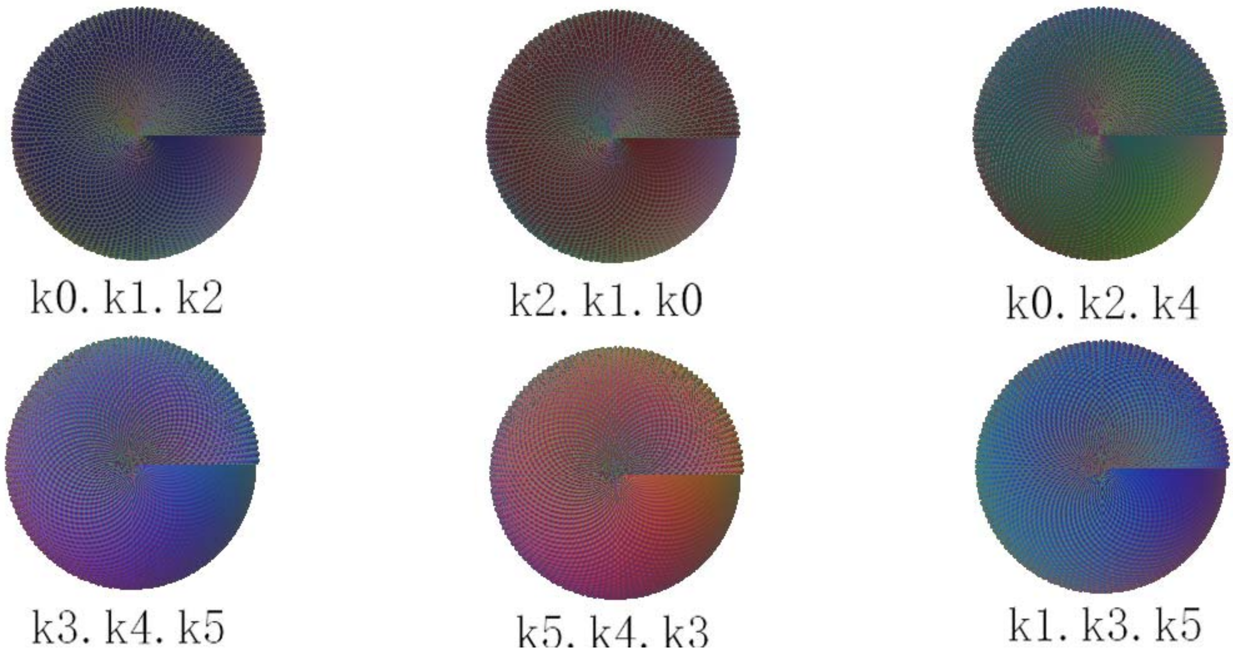
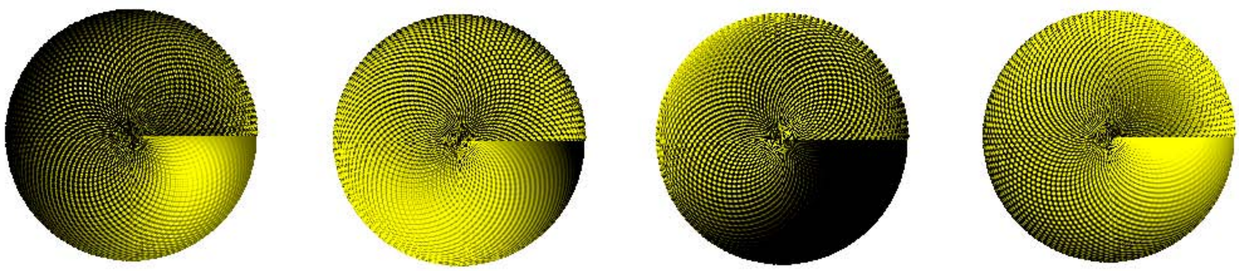
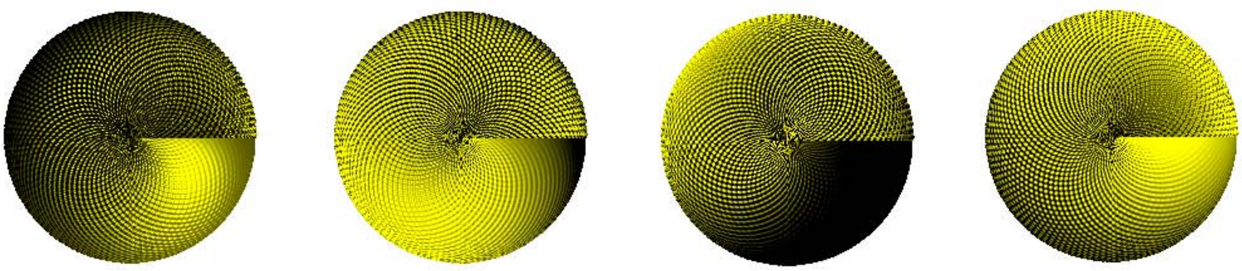


Figure 9. Several combine of coefficients map of bump object



Reconstructing result of bump object applying color map and coefficient maps.



Actual results of bump object in Phong's model

Figure 10. Comparing between the actual results and reconstructing result of bump object under four different light source position.