# A Global Illumination and BRDF Solution Applied to Photorealistic Augmented Reality

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**ABSTRACT**

This paper presents a solution for the photorealistic rendering of synthetic objects into dynamic real scenes, in Augmented Reality applications. In order to achieve this goal, an Image Based Lighting approach is proposed, where environment maps with different levels of glossiness are generated for each virtual object in the scene at every frame. Due to this, illumination effects, such as color bleeding and specular reflections, can be simulated for virtual objects in a consistent way, even under the presence of scene changes. A unifying sampling method for the spherical harmonics transformation pass is also used. It is independent of map format and does not need to apply different weights for each sample. The developed technique is combined with an extended version of Lafortune Spatial BRDF, featuring Fresnel effect and an innovative tangent rotation parameterization. The solution is evaluated in various Augmented Reality case studies, where other features like shadowing and lens effects are also exploited.

**KEYWORDS:** Photorealism, global illumination, BRDF, augmented reality.

**INDEX TERMS:** H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism— Color, Shading, Shadowing, and Texture

## 1 INTRODUCTION

This work contributes to global illumination and BRDF modeling in the context of photorealistic AR. An Image Based Lighting (IBL) approach is adopted, where each virtual objects' environment maps are dynamically generated [1]. This approach enables a consistent illumination of virtual objects with regard to changes in their surroundings. The utilization of a different map sampling scheme for the spherical harmonics transformation, used in map generation, is also proposed. It has the advantages of being both simpler and more general. In addition, instead of using a simple Lambertian BRDF, the Lafortune Spatial BRDF (SBRDF) [2] is applied, with extensions to support tangent rotation parameterization and the Fresnel effect. All these features are integrated in an AR solution, which also encompasses functionalities such as shadowing and lens effects. This paper's main contribution lies in extending McAllister's work [2] to support dynamic environments in order to make it suitable for AR applications.

## 2 PROPOSED SOLUTION

Two new features were added in the existent SBRDF representation: *tangent rotation map* and the *Fresnel factor*. A tangent rotation map was conceived as a monochromatic texture where the color stored in a given position represents the angle through which the tangent vector of a point on the object surface should rotate around the normal vector. This approach allows per-pixel tangent variation, expanding the range of materials reproduced by this solution.

The other important extension added to McAllisters's SBRDF was the introduction of a *Fresnel factor* approximation. This attempts to imitate the perfect reflections that arise when incident light occurs at grazing angles. The Fresnel contribution is given by:

$$f(R) = \big(1 - (R \cdot N)\big)^{\left(\frac{1}{\varphi}-1\right)}. \tag{1}$$

The result of Equation (1) is then used to generate new terms for the specular albedo $\rho_s$, the glossiness exponent $n$, and the irradiance falloff $g(R)$, giving respectively:

$$\rho_{s(new)} = \rho_s + (1-\rho_s)f(R), \tag{2}$$

$$n_{(new)} = n + (1-n)f(R), \tag{3}$$

and

$$g(R)_{(new)} = g(R) + \big(1 - g(R)\big)f(R). \tag{4}$$

At the end, replacing the old terms by these new ones will give the final SBRDF expression.

In addition, in the proposed approach, the way that King samples the environment map was changed in order to make easier the spherical harmonic transformation pass. King samples texel by texel, for example, if it is a cubic environment map, then he spends six full screen quad passes to sample the whole map (one for each face). When it is a dual paraboloid map, then King's strategy spends two passes. The main difficulty encountered by such sampling scheme is that each sample will be subtended by a different solid angle, which consequently implies in using a different weight for each sample. Furthermore, samples weights will also vary according to each environment map format, for example, the place with the highest density of samples in a cubic environment map is close to the cube edges, whereas in a latitude longitude environment map it is close to the poles. In order to avoid such difficulties and generalize the sampling operation, a uniform spaced sampling scheme was used [3].

McAllister was able to make Lafortune's BRDF feasible in real-time using GPUs, although environment maps should be static in their nature. Nonetheless, in AR applications, virtual and real objects may move independently, hence virtual objects appearance may also change because of the surrounding scene changes. These changes are usually seen as effects like light bleeding and dynamic specular reflections. In order to support such effects, a new environment map is captured from the center of each virtual object, so each one will have its own environment map. This environment map is acquired by hiding its owner and rendering the surrounding scene from the owner's center. The surrounding scene is composed by the other virtual objects, the phantom objects, and the skybox with the real environment map.

However, this generated environment map can only support the rendering of perfectly reflexive objects, so, in order to extend it some new maps are first generated. Actually, one diffuse and two glossy environment maps are also generated, hence, four

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environment maps will finally be used to illuminate virtual objects. These maps are interpolated in order to simulate a large variety of materials, for example, different levels of glossy materials are simulated using their glossiness exponent as a parameter to weight each generated environment map.

## 3 RESULTS

Figure 1 illustrates the results of the application of a tangent map to the object's mesh, in this case, a metallic table.

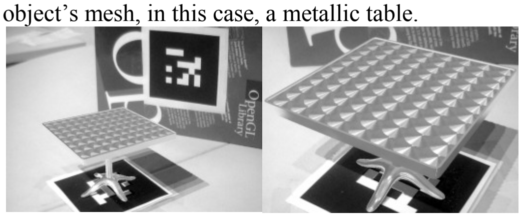

Figure 1. Virtual table inserted into the real world (left) and surface details showing the tangent rotation (right)

In addition, as a subtle improvement, the Fresnel factor helps the object to blend realistically with the scene background. As one can see in Figure 2, the object specularity increases at grazing angles, reflecting the box on the top of the teapot and the table beneath its bottom part.

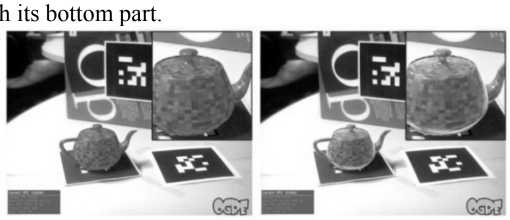

Figure 2. Virtual object without the Fresnel term (left) and with the Fresnel term (right)

In addition to these new features, some effects from third parties completed the range of objects that can be represented by this solution. Some of these effects, however, have a special appeal to them when used in the AR context, e.g., transparency, as seen in Figure 3. Another feature implemented in this solution is a normal mapping technique (as also shown in Figure 3), which increases the object's level of detail without needing any additional geometry.

Figure 3. Transparent object with normal map disabled (left) and enabled (right)

A subtle effect that is usually observed in the real world happens when color bleeds from objects to others. Figure 4 illustrates this effect, where the real box bleeds its color over the virtual statue model.

Figure 4. Color bleeding example

In addition to color bleeding, realistic mirror-like reflections and occlusion were also simulated (see Figure 5). In the reflection case, the virtual teapot reflected real objects surrounding it, such as the box and the table where objects were placed. In the occlusion case the virtual statue and its shadows are occluded by the box. In both cases a phantom of each real object was used.

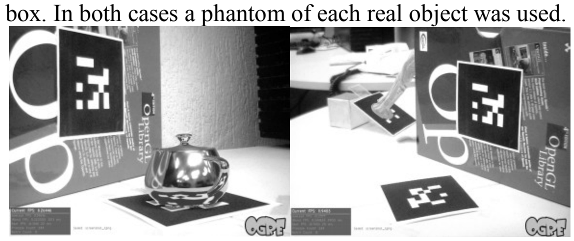

Figure 5. Interactive reflection (left) and occlusion (right)

A more complex virtual object is shown in Figure 6. It exhibits a bigger variety of material, like chrome metal (front up wire), brushed metal (rims), glass, plastic (front down wire), rubber (tires), polished (painting), and emissive material (headlights). Glare and Bloom are exhibited in the car headlights since a HDR texture with high texel values was mapped onto it. The car mesh has 9319 triangular faces, 10795 vertices and the application executed at around 14 fps.

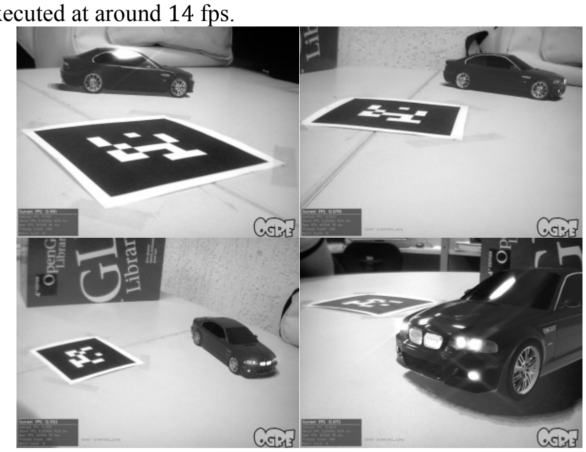

Figure 6. A more complex example of virtual object inserted into a real scene

## 4 CONCLUSIONS

The implemented AR solution for photorealistic rendering allows the use of dynamic scenes and sophisticated materials. In addition, features such as lens effects and shadowing are also supported, contributing to a richer final result. The visual aspect of the generated scenes was satisfactory, as well as the frame rates achieved, which were suitable for AR applications.

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