# Relighting with Free-form Polarized Reflectometry in Mixed Reality Space

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**ABSTRACT**

We focus on a challenging trial of a Look-Change mixed reality (MR) space. Look refers to perceived ambience of an image created by illumination and color tone. Regarding the Look-Change, we have been working on a relighting technique which allows MR space to have additional virtual illumination. Furthermore, we demonstrate a photorealistic approach to create photorealistic virtual objects with free-form polarized reflectometry which requires no specialized hardware and is portable, thus making it easy apply to MR.

**KEYWORDS:** Mixed Reality, Relighting, Photometric consistency, Image based lighting, Reflectometry.

**INDEX TERMS:** H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture—Reflectance

## 1 INTRODUCTION

Photometric consistency is one of the most important issues in the research of MR technology. To overcome this issue, a lot of research has tried estimating environmental illumination conditions from real world scenes and by rendering virtual objects. Some of the research has focused on camera lens issues. While such research has focused on photometric consistency itself, we have worked on Look-Change of MR space as an advanced step [1]. In this paper, we demonstrate relighting which is a technique to illuminate real and virtual objects in MR space simultaneously. We also present a photorealistic approach to create photorealistic CG objects. Bidirectional reflectance distribution function (BRDF) models are implemented for creating precise and photorealistic CG objects. In general, estimation of appearance parameters directly from real objects is complicated. To improve the realism of CG models in MR space, we attempted to utilize the free-form polarized reflectometry [2] for acquiring appearance parameters of real objects. This also has the potential to improve illumination effects by synthesizing photorealistic CG objects.

## 2 METHOD

First, the CG objects to be visualized in MR space were prepared and their appearance parameters obtained from a real object with free-form polarized reflectometry. These parameters were fitted to CG objects for rendering and then synthesized in MR space. Finally, real world and CG objects were illuminated simultaneously in real-time with our relighting technique to achieve the desired effects shown in MR (Figure 1).

### 2.1 Free-form Polarized Reflectometry

The appearance parameters described as BRDF have been acquired in many ways. Free-form polarized reflectometry was one of the methods based on Ghosh et al. [3]. Transformations on the captured images allowed the computing surface normals, diffuse albedo, specular albedo and specular roughness to be calculated without requiring explicit fitting of the measurements to analytic BRDF models. This free-form method was portable, manageable and required no specialized hardware and no on-site calibration.

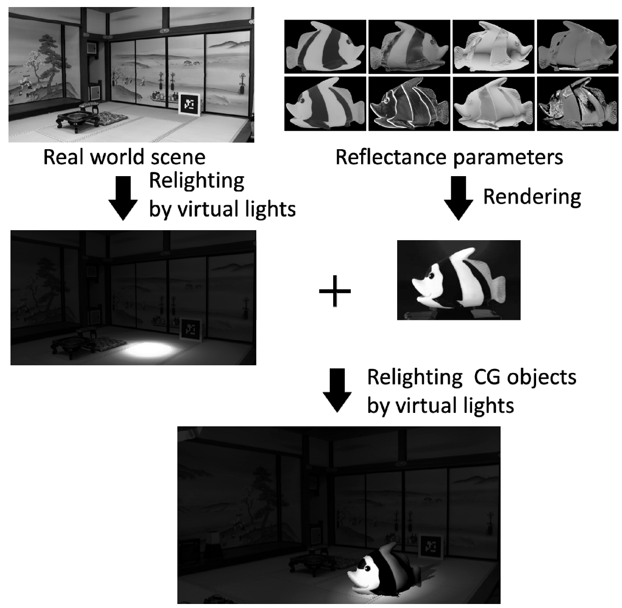


Figure 1. Relighting process

**Data Capture.** LED light, right/left circular polarizers and a digital camera were utilized for shooting image data sets. The object was continuously photographed whilst the light was moved to different illuminating positions (Figure 2). The density of sampling relied on the number of photographs taken. In this experiment, we captured a plastic toy for acquiring appearance parameters. To render a 3D CG model of the plastic toy in MR space, two datasets were captured from the front and back sides. Once we captured the front data as the first data set, we turned the object from front to back and shot another 160 images for the second data set. The edge of textures was made seamless, allowing observers to change their viewpoints in MR space.

**Light Direction.** In the method of [2], diffuse ball or objects' normal were calculated for estimating light directions. To achieve better estimation, a magnetic sensor which is commonly used to setup of MR systems was used and a laser pointer was attached to the hand-held light to point at a target easily.

**Appearance Parameters.** Ghosh et al. calculated the appearance parameters from images in which objects were illuminated under spherical gradient conditions with special equipment. They setup a system consisting of an LED sphere with a number of individually controllable lights. Alternatively, to acquire appearance parameters from images captured by free-form polarized

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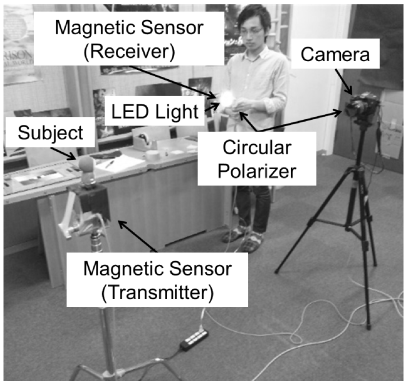


Figure 2. Free-form polarized reflectometry

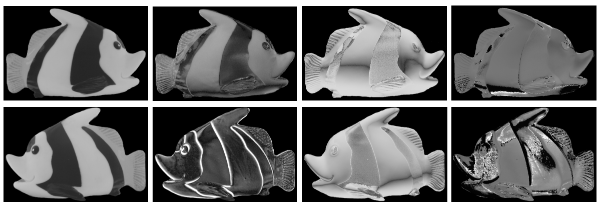

Figure 3. Appearance parameters (from left-hand column:diffuse albedo, specular albedo, normal map, specular roughness)

reflectometry, image based lighting was used for generating images under gradient illumination conditions. To exploit diffuse and specular components from photographs, left/right circular polarizers were utilized for canceling out specular reflection from objects in images. The parameters were applied for rendering.

### 2.2 Relighting

**Relighting Real World Scene.** Using the technique described in [1], we prepared the rough geometry and reflectance properties of the illuminated surface for relighting to real world scene. First, we obtained the relationship between pixel RGB value and illuminance on the surface to approximate the reflectance property. After the virtualization, whole scenes were illuminated by virtual lights. The amount of increased illuminance was calculated for each pixel on the illuminated surface according to the distance from the lamp and the angle of the light axis.

**Relighting CG objects.** CG objects were rendered based on the approximation of real objects' appearance parameters by Torrance-Sparrow model [4]. The rendering and relighting result $B_{lighting}$ at a surface point $P$ by a virtual light $L$ was calculated as equation (1) and (2):

$$i_s = \rho_s \frac{1}{N_{MRspace} \cdot V} \exp\left(-\frac{\alpha^2}{2\sigma^2}\right) \tag{1}$$

$$B_{lighting} = \frac{I(\rho_d \cos\varphi + i_s)}{dist(P,L)^2} \tag{2}$$

where intensity $i_s$ was derived from specular albedo $\rho_s$, normal in a world coordinate system in MR space $N_{MRspace}$, viewpoint $V$, the angle $\alpha$ between specular reflection and viewpoint and specular roughness $\sigma$. The diffuse component included diffuse albedo $\rho_d$ and angle $\varphi$ which was the angle between the surface normal and light source. $I$ was luminous intensity of real lights distribution presented in IES (Illuminating Engineering Society) data. To visualize CG objects in MR space, $N_{MRspace}$ was calculated from the equations (3) and (4). $N_{model}$ was the normal of the local

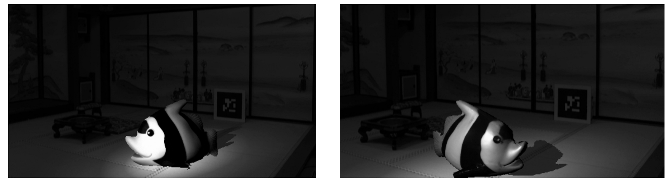

Figure 4. Relighting a CG object and real world scene

coordinate system in MR space and derived from the transformation matrix $W_{img}$ and the estimated normal $N_{img}$ in an image. The normal $N_{model}$ was converted to the world coordinate system of MR space with the transformation matrix $W_{MRspace}$. This technique can be applied to any CG objects even if they do not exist in real world and creating realistic objects.

$$N_{model} = W_{img}^T \cdot N_{img} \tag{3}$$

$$N_{MRspace} = \left(W_{MRspace}^{-1}\right)^T \cdot N_{model} \tag{4}$$

## 3 RESULTS

The system used for shooting was a white LED light, right/left circular polarizers and a Canon EOS 50D. The camera took 160 images. The number of photos was sufficient to ensure sampling. The parameters governing the appearance of object were normal maps, diffuse/specular albedo and specular roughness as shown in Figure 3. These images were used to calculate and render photorealistic CG objects. This system allowed observers to change their viewpoints in MR space (Figure 4).

## 4 CONCLUSION

Synthesis of photorealistic CG objects and relighting techniques in MR systems were successfully demonstrated. This approach improved the realism of the objects in MR space by synthesizing photorealistic CG objects and by illuminating real and virtual objects simultaneously. This implied photometric consistency between real and virtual objects. The color images of this work are available on [5].

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