Fast Image-based Separation of Diffuse and Specular Reflections

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Abstract

We present a novel image-based method for separating diffuse and specular reflections of real objects under distant environmental illumination. By illuminating a scene with only four high frequency illumination patterns, the specular and diffuse reflections can be separated by computing the maximum and minimum observed pixel values. Furthermore, we show that our method can be extended to separate diffuse and specular components under image-based environmental illumination. Applications range from image-based modeling of reflectance properties to improved normal and geometry acquisition.

1 Introduction

Separating diffuse and specular reflections of real object is an important problem. For example, surface normals can usually be much more accurately estimated when no specular reflections are present.

In this report, we present a novel image-based method for separating diffuse and specular reflections of real objects under distant environmental illumination. Unlike previous methods, our technique does not rely on polarization or colorspace analysis and works for objects of arbitrary color. We illuminate the scene with a small set of high frequency illumination patterns. The specular and diffuse reflections can then be separated by computing the maximum and minimum observed pixel values. Our method is also able to separate the diffuse and specular components under image-based environmental illumination.

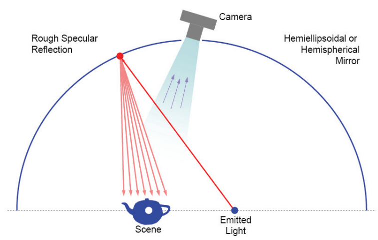
2 Rationale

Our method builds on [3], where it is observed that direct and indirect illumination can be separated by shifting high frequency illumination and computing the minimum and maximum pixel values. In effect, they perform band-pass filtering on the reflectance behavior of the incident illumination on the object: high frequency responses correspond to direct illumination, while low frequency responses correspond to indirect illumination.

We use similar reasoning to separate specular and diffuse reflections under distant environmental illumination. A specular reflection is a high frequency angular response, only reflecting the incident illumination coming from the reflected direction. Diffuse reflection, on the other hand, is a low frequency response, averaging out much of the incident illumination over the complete sphere of incident directions.

3 Implementation

Similar to [3], we emit high frequency illumination. We use four binary vertical stripe patterns with fixed frequency, but each with a different phase (Figure 2, top four images of the left column). We also use a projector to emit these illumination patterns onto the scene, but instead of directly aiming the projector at the scene,



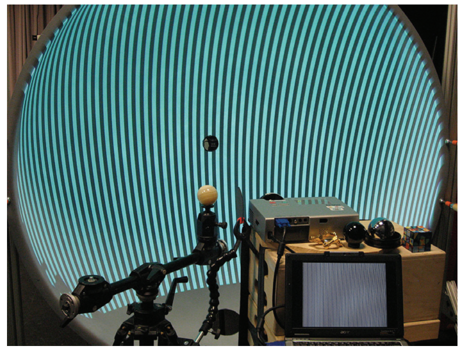


Figure 1: **Experimental setup.** Left: Schematic of Reflective Light Stage. Right: spherical dome and the 180-degree fisheye video projector from Immersive Display Solutions. The projector is emitting one of the four phase-shifted high-frequency stripe patterns. The object (a marble sphere) being photographed is on the left of center and is photographed through the hole at the center of the dome.

we direct the illumination into a reflective hemisphere using a projector equipped with a fish-eye lens [4]. The projector and object are placed at opposing foci near the center of the hemisphere. The camera is positioned at the apex of the dome, recording digital photographs of the object. An illustration and photograph of the setup are shown in Figure 1. A key difference from [3] is that we illuminate the observed scene *indirectly* via the hemisphere rather than directly projecting light onto the scene, allowing to separate diffuse and specular components for a large range of surface normal directions.

Next, we compute for each pixel the minimum and maximum values over the four acquired photographs. The specular reflection corresponds to the maximum pixel value (peak) minus the minimum pixel value (average). The diffuse component can be computed by subtracting the specular reflections from a fully lit image of the scene. This fully lit image can be easily computed by summing all four patterns, and does not require capturing an additional photograph.

Our method can also be extended to separate the specular and diffuse component of an object under image-based illumination (such as an environment map). Instead of just emitting stripe patterns, we modulate the patterns with the desired image-based illumination.

4 Results

In Figure 2 a mirrored sphere and a marble ball are shown. The mirrored sphere is shown under uniform illumination (left column), and both the mirrored sphere and marble ball are shown under image-based illumination of a vase and a teapot (middle and right column). The top four rows show the different illumination patterns used. The fifth row shows the sum of the top four photographs. The lower two rows show, respectively, the extracted diffuse and specular components. A fingerprint intentionally left on the specular ball becomes clearly visible in the diffuse and specular component due to the difference in reflectance behavior. For the marble ball, the structure of the illumination (a photograph of a teapot and a vase) is not visible in the diffuse component, in contrast to the specular component where the overall structure of the incident illumination can be clearly recognized. The marble ball has fine scratches that become visible in the specular component (left side of the teapot). It is interesting to note that the frequency of the patterns determines how narrow the lobe of the object's BRDF can be before it is classified as a specular reflection. Furthermore, also note that the indirect illumination inside the hemispherical dome due to the structured illumination is not taken into account when separating the components, and becomes part of the diffuse component (clearly visible in the mirrored sphere case).

Figure 3 shows a Rubik's cube and a tennis ball under uniform illumination (top row), and their separated diffuse (middle) and specular (bottom) reflections. The colored cube shows how the specular reflection is completely colorless, while the diffuse component contains many colors. The tennis ball contains almost no specular component, illustrating that our method also works in such an extreme case.

5 Conclusion

We have presented a straightforward image-based method to separate the diffuse and specular components of real objects under environmental illumination. Our method only requires four photographs of the object under high-frequency illumination to successfully separate the components.

In future work, our method could be used to estimate an object's surface normal map from just its specular component, even if the object has both sharp specular and diffuse or subsurface reflection components. To do this, a set of one or more image-based lighting environments should be chosen so that the pixel values of the specular component under the set of environments reveal the angle of the environment that is reflected by the pixel. As shown in this work, each environment would be sliced into a set of phase-shifted patterns. The environments could resemble the structured illumination patterns of [5], the real-time color ramp of [1], or the spherical gradient patterns of [2].

References

[1] Yung-Yu Chuang, Douglas E. Zongker, Joel Hindorff, Brian Curless, David H. Salesin, and Richard Szeliski. Environment matting extensions: Towards higher accuracy and real-time capture. In *Proceedings of SIGGRAPH 2000*, pages 121–130, 2000.

[2] Wan-Chun Ma, Tim Hawkins, Pieter Peers, Charles-Felix Chabert, Malte Weiss, and Paul Debevec. Rapid acquisition of specular and diffuse normal maps from polarized spherical gradient illumination. In *Rendering Techniques 2007: 18th Eurographics Workshop on Rendering*, June 2007.

[3] S.K. Nayar, G. Krishnan, M. D. Grossberg, and R. Raskar. Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination. *ACM Trans. on Graphics*, Jul 2006.

[4] Pieter Peers, Tim Hawkins, and Paul Debevec. A Reflective Light Stage. Technical report, USC, Dec 2006. ICT-TR-04.2006.

[5] Marco Tarini, Hendrik P. A. Lensch, Michael Goesele, and Hans-Peter Seidel. 3D acquisition of mirroring objects using striped patterns. *Graphical Models*, 67(4):233–259, 2005.

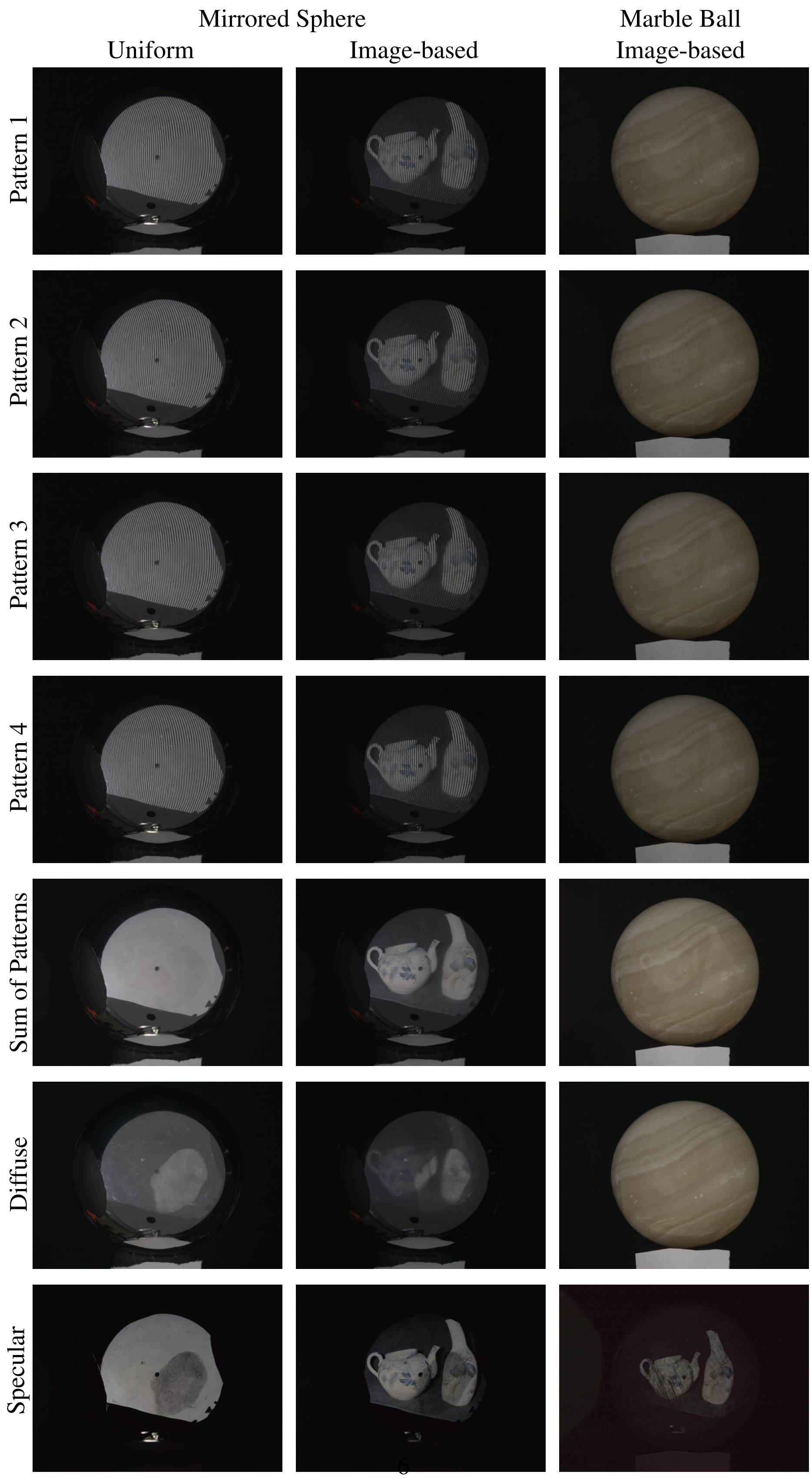


Figure 2: **Full results.** Reflective sphere (left and middle columns) and marble sphere (right column) showing constituent stripe patterns (first 4 rows), sum of the stripe pattern (row 5), diffuse (row 6) and specular components (bottom row). The specular component has been brightened for visualization purposes.

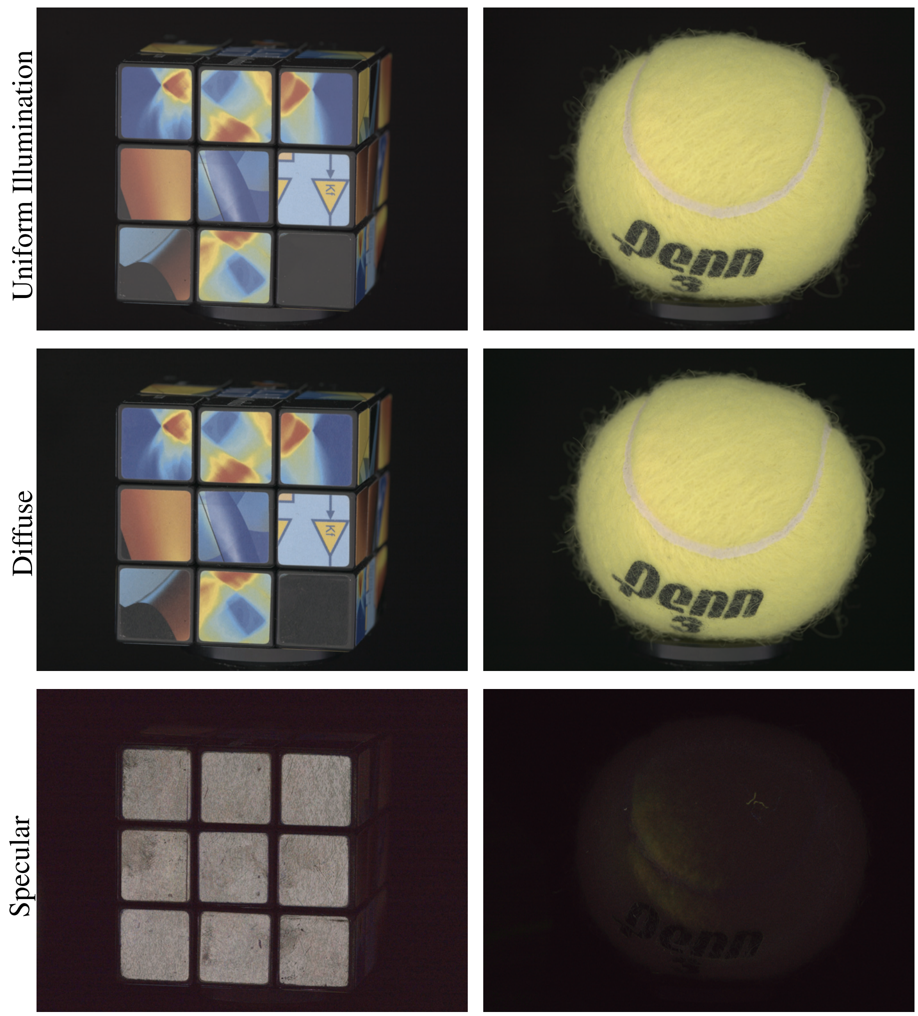


Figure 3: **Other results.** Tennis ball and Rubik's Cube uniform illumination (top), diffuse component (middle), and specular component (bottom). The specular component has been brightened for visualization.