Fast Image-based Separation of Diffuse and Specular Reflections

Bruce Lamond Pieter Peers Paul Debevec
University of Southern California, Institute for Creative Technologies

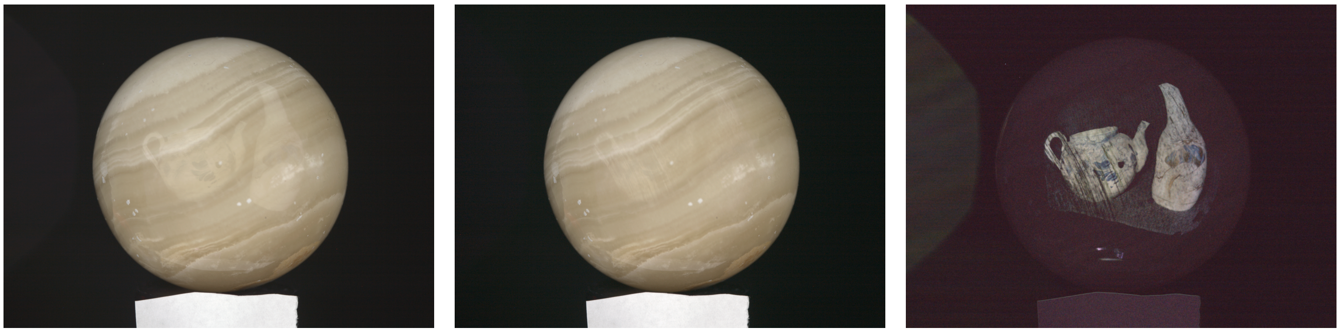

Figure 1: ***Diffuse-specular separation under image-based indirect illumination.*** *(left) A marble ball illuminated by a photograph of a teapot. (middle) The extracted diffuse component under the same illumination. The angular variation of the incident illumination is completely blurred out. (right) The extracted specular component showing all the detail of the incident illumination.*

We present a novel image-based method for separating diffuse and specular reflections of real objects under distant environmental illumination. By illuminating the 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.

Rationale. Our method builds on [Nayar et al. 2006], 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.

Implementation. Similar to Nayar et al., we emit high frequency illumination. We use four binary vertical stripe patterns with fixed frequency, but each with a different phase. We also use a projector to emit these illumination patterns onto the scene, but instead of directly aiming the projector at the scene, we direct the illumination into a reflective hemisphere using a projector equipped with a fisheye lens [Peers et al. 2006]. 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. A key difference from Nayar et al. is that we illuminate the observed scene *indirectly* via the hemisphere rather than directly projecting light onto the scene, allowing to separate the different components for a large range of 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.

Results. In Figure 2 a mirrored sphere and a colored cube are shown: under uniform illumination (left), the separated diffuse component (middle), and the separated specular reflection component (right). A fingerprint intentionally left on the specular ball becomes clearly visible in the diffuse and specular component due to the difference in reflectance behavior. The colored cube shows how the specular reflection is completely colorless, while the diffuse component contains many colors. 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.

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. Figure 1 shows a marble ball illuminated (indirectly) by a photograph of a teapot and a vase (left). The structure of the illumination is not visible in the diffuse component (middle), in contrast to the specular component (right) 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).

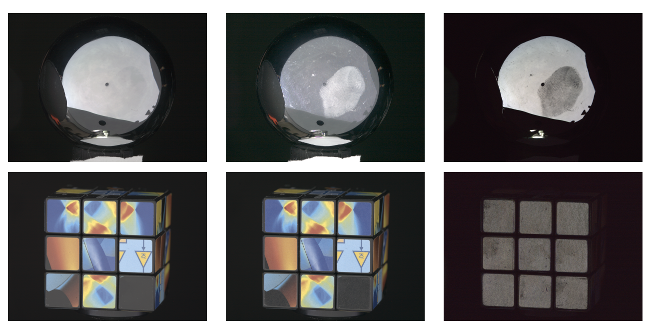

Figure 2: ***Diffuse-specular separation under uniform illumination.*** *The top row shows a mirrored sphere with a greasy fingerprint (left), and its diffuse (middle) and specular (right) reflections. The bottom row shows the same for a colored cube.*

References

NAYAR, S., KRISHNAN, G., GROSSBERG, M. D., AND RASKAR, R. 2006. Fast Separation of Direct and Global Components of a Scene using High Frequency Illumination. *ACM Trans. on Graphics* (Jul).

PEERS, P., HAWKINS, T., AND DEBEVEC, P. 2006. A Reflective Light Stage. Tech. rep., USC, Dec. ICT-TR-04.2006.