Estimating Specular Normals from Spherical Stokes Reflectance Fields

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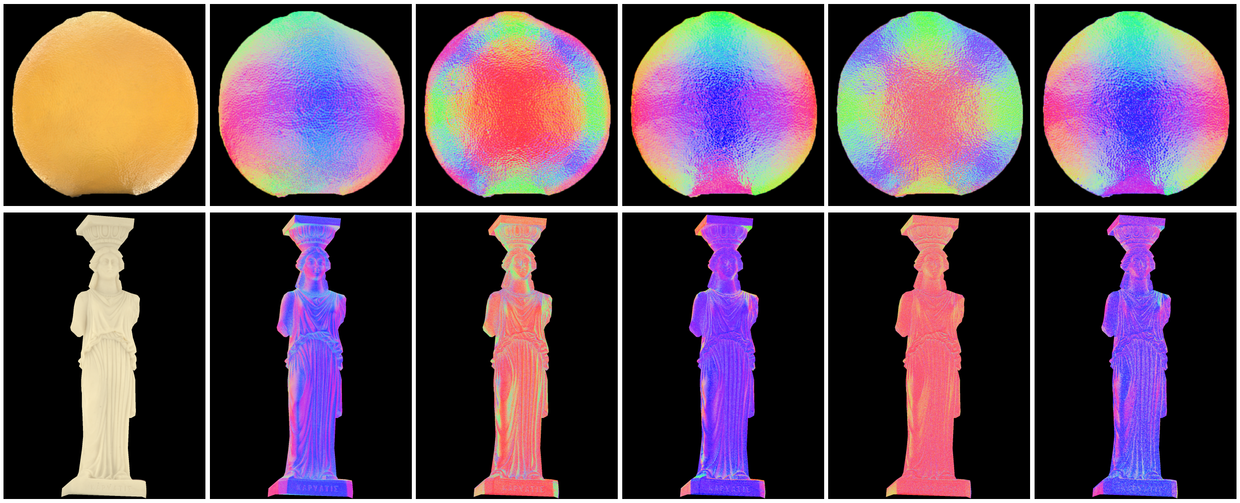
(a) Subject (b) Specular normals (c) Circular Stokes (C.S.) (d) Normals from C.S. (e) Unpol. Stokes (U.S.) (f) Normals from U.S.

Figure 1: *Estimating specular normals from Stokes parameters of incident spherical illumination. Specular normals inferred from circularly polarized illumination (c-d), and unpolarized illumination (e-f), compared to measurement with polarized spherical gradients (b). Top-row: Plastic orange. Bottom-row: Marble statue.*

Introduction. Despite being at the focal point of intense research in both computer graphics as well as in computer vision, accurately reproducing the shape and appearance of real-world scenes remains a challenging problem, especially under uncontrolled conditions. One cue that has been used to separate diffuse and specular reflectance is polarization. Recent work in computer graphics has explored polarization of incident illumination in conjunction with spherical gradient illumination to infer high quality diffuse-specular separation of both albedo as well as photometric normal information [Ma et al. 2007]. Ghosh et al. [2010] improved upon this by removing the view-dependence of the polarization scheme of Ma et al. by analyzing the Stokes reflectance field under incident circularly polarized spherical gradient illumination, and recover more detailed specular reflectance information including index of refraction as well as specular roughness.

Contribution. In this work we analyze the view-independent symmetric Stokes reflectance field under *constant* incident spherical illumination that is either circularly polarized (Fig. 1,c-d), or unpolarized (Fig. 1, e-f). We demonstrate that both types of incident lighting can be used to reliably estimate specular normals, and show how this theory can be applied to normal estimation under uncontrolled outdoor illumination.

Normal Computation. We capture four photographs of the target object under uniform spherical illumination (either circularly polarized or unpolarized) with different polarizers in front of the camera as in Ghosh et al. [2010] (i.e., three linear polarizers (P_0, P_{45}, P_{90}) and a (left) circular polarizer $(P_\circ)$), and compute the four Stokes parameters of reflected light (s_0, s_1, s_2, s_3) per pixel. Without loss of generality, we assume that the camera is looking down the -Z axis. It can be shown that in this case, $\bar{s_3} = s_3/\sqrt{s_1^2 + s_2^2 + s_3^2}$ relates to $\theta = \arccos(\hat{n} \cdot Z)$, where $\hat{n}$ is the specular normal. Furthermore, the *normalized* linear components (s'_1, s'_2), with $s'_i = s_i/\sqrt{s_1^2 + s_2^2}, i \in \{1, 2\}$, relates to the angle $\phi = \arccos(\hat{n} \cdot X)$. However, the mapping from (s'_1, s'_2) to ϕ suffers from a rotational ambiguity: ϕ and $\phi + \pi$ map to the same (s'_1, s'_2). We propose two solutions to solve for this ambiguity:

1. An **additional measurement** under a gradient illumination orthogonal to the camera viewing axis (i.e., X or Y gradient) breaks the ambiguity. However, this reduces the view-independence of the normal computations.
2. For convex objects, we can **grow the normals in from the silhouette**, assuming that the normals at the silhouette are orthogonal to silhouette edge and the view direction.

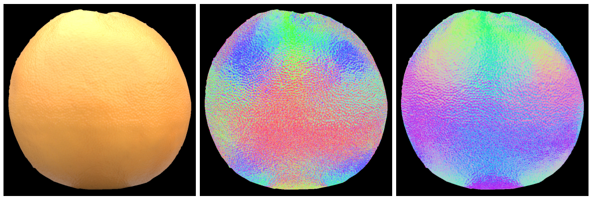
(a) Plastic orange (b) Unpol. Stokes (U.S.) (c) Normals from U.S.

Figure 2: *Estimated specular normals from Stokes parameters of diffuse outdoor illumination.*

Outdoor Illumination. We note that instead of using constant illumination, we can also observe the subject under a Y gradient. In this case, the incident lighting already provides the additional cue to break the rotational ambiguity for computation of ϕ. Interestingly, outdoor illumination on a cloudy day, is approximately similar to unpolarized Y-gradient illumination. We employ this observation to compute the normals under such outdoor lighting condition in Figure 2.

References

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