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Tabulation of pBRDF Image Measurements

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Introduction

Empirical polarized bidirectional reflectance distribution functions (pBRDFs) can improve simulations of light-matter interaction. However, obtaining comprehensive Mueller matrix (MM) measurements at multiple scattering geometries and wavelengths is resource-intensive. Here, a more efficient method for acquiring and tabulating pBRDFs is demonstrated.

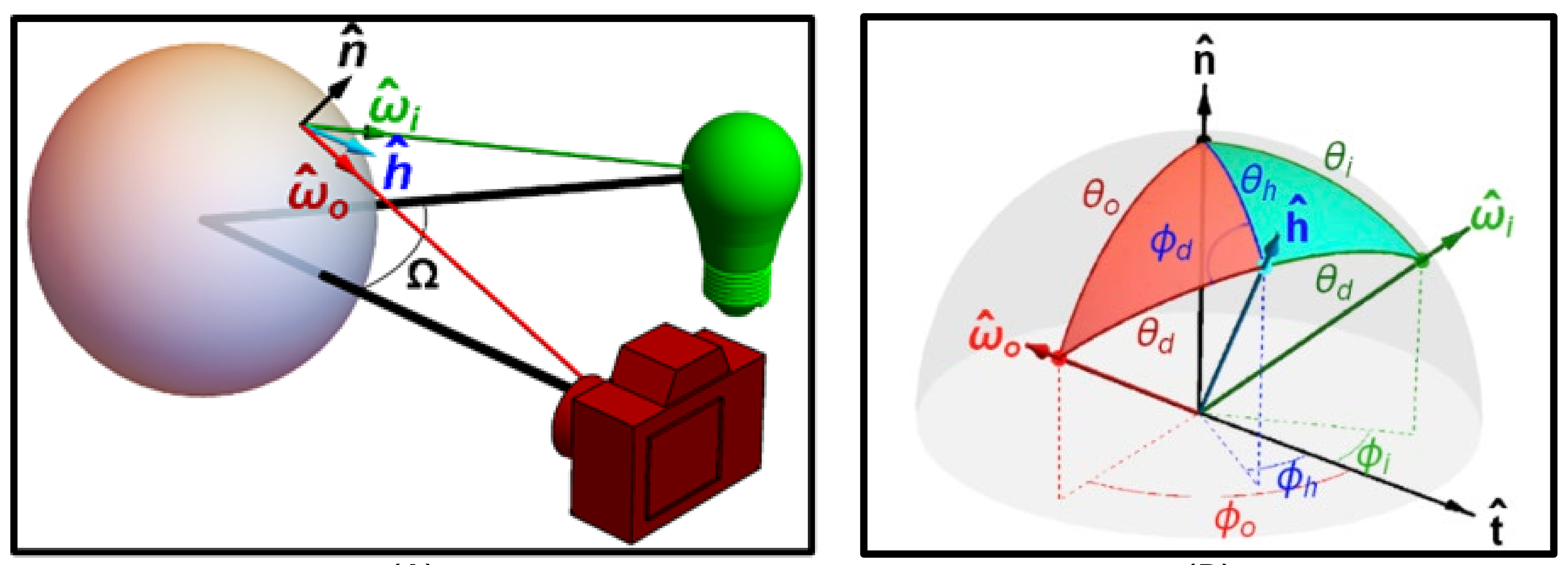

Figure 1: In (A) measurement configuration of a spherical object with a light source and a camera separated by Ω. In (B) scattering geometry in spherical and Rusinkiewicz coordinates, where the green vector $\hat{\omega}_i$ is the incoming ray direction and the red vector $\hat{\omega}_o$ is the scattered ray direction. The surface normal of the object is black $\hat{\mathbf{n}}$.

Polarized and scalar BRDFs BRDFs describe the incoming and scattered ray directions, parameterized in spherical coordinates relative to the surface normal. For reflection geometries, the ray direction zenith angles (θ_i and θ_o) must be less than $\pi/2$. Isotropic surfaces, which are invariant to rotations around the surface normal, reduce the parameterization to three angles: θ_h, θ_d, and ϕ_d. The Rusinkiewicz parameterization uses these angles relative to the microfacet normal $\hat{h}$ [2]. To ensure physically valid ray directions for external reflection, specific conditions for θ_i and θ_o must be met, derived using spherical geometry.

The three Rusinkiewicz angles for isotropic pBRDFs were previously tabulated as Cartesian coordinates. Here, they are interpreted as the radial, azimuthal, and axial coordinates in a cylindrical space. This representation is more compact [1].

References

[1] Quinn Jarecki and Meredith Kupinski (2024), "Sampling Optimization and Compact Tabulation of Isotropic Polarized Scattering," Opt. Express 32(18).
[2] S. M. Rusinkiewicz (1998), "A New Change of Variables for Efficient BRDF Representation," Rendering Techniques 11–22.
[3] https://github.com/Polarization-Lab/RGB950

Acknowledgements

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Methods

An efficient pBRDF acquisition captures MM data at as many unique scattering geometries as possible while minimizing the number of angular steps of the goniometer. Discretized scattering geometries can be calculated before image acquisition to compare different protocols for a given object shape. The dual rotating retarder (DRR) Mueller imaging polarimeter called RGB950 was used for pre-acquisition evaluation and optimization of scattering geometries [3].

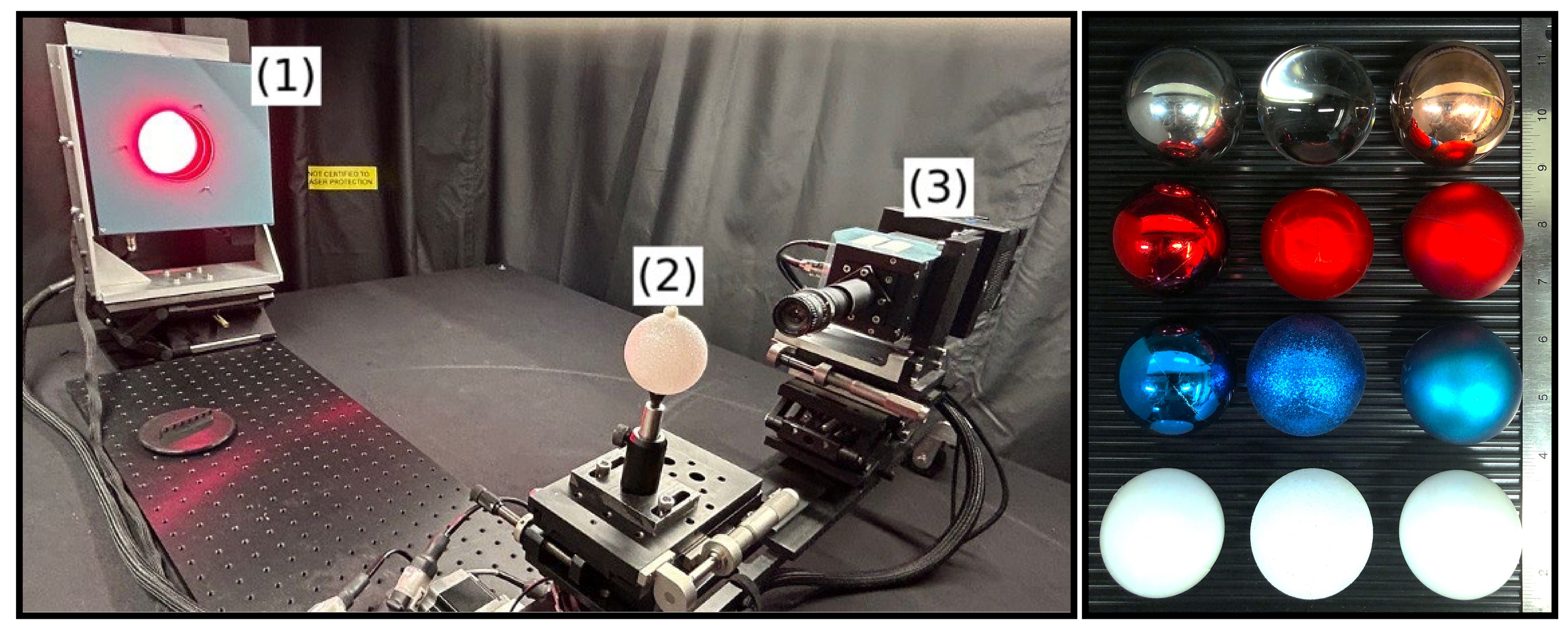

Figure 2: In (A) experimental setup of RGB950 on goniometric stage: (1) PSG, (2) sample space, (3) PSA. In (B) a selection of sample spheres measured in this study. The samples represent a range of materials and surface finishes. Each sample is 2 inches in diameter.

A sphere was used for pBRDF measurements because it includes the greatest number of scattering geometries in one measurement [1]. It is illuminated by a visible light source and evenly sampled at goniometer positions from 20 to 160 degrees between the camera and the source. Utilizing the compact representation, we identified 92 goniometric camera positions that efficiently sample 82% of the physically realizable scattering geometries for a given sphere size and polarimeter parameters [1].

Tabulation Process

Load 92 MM images and define discrete sampling bins

↓

Convert lookup table values from Rusinkiewicz angles to bin indices

↓

Apply mask to data based on where sphere is illuminated

↓

Sort pixelated images into discrete bins

↓

Remove empty bins and non-physical MMs

Results

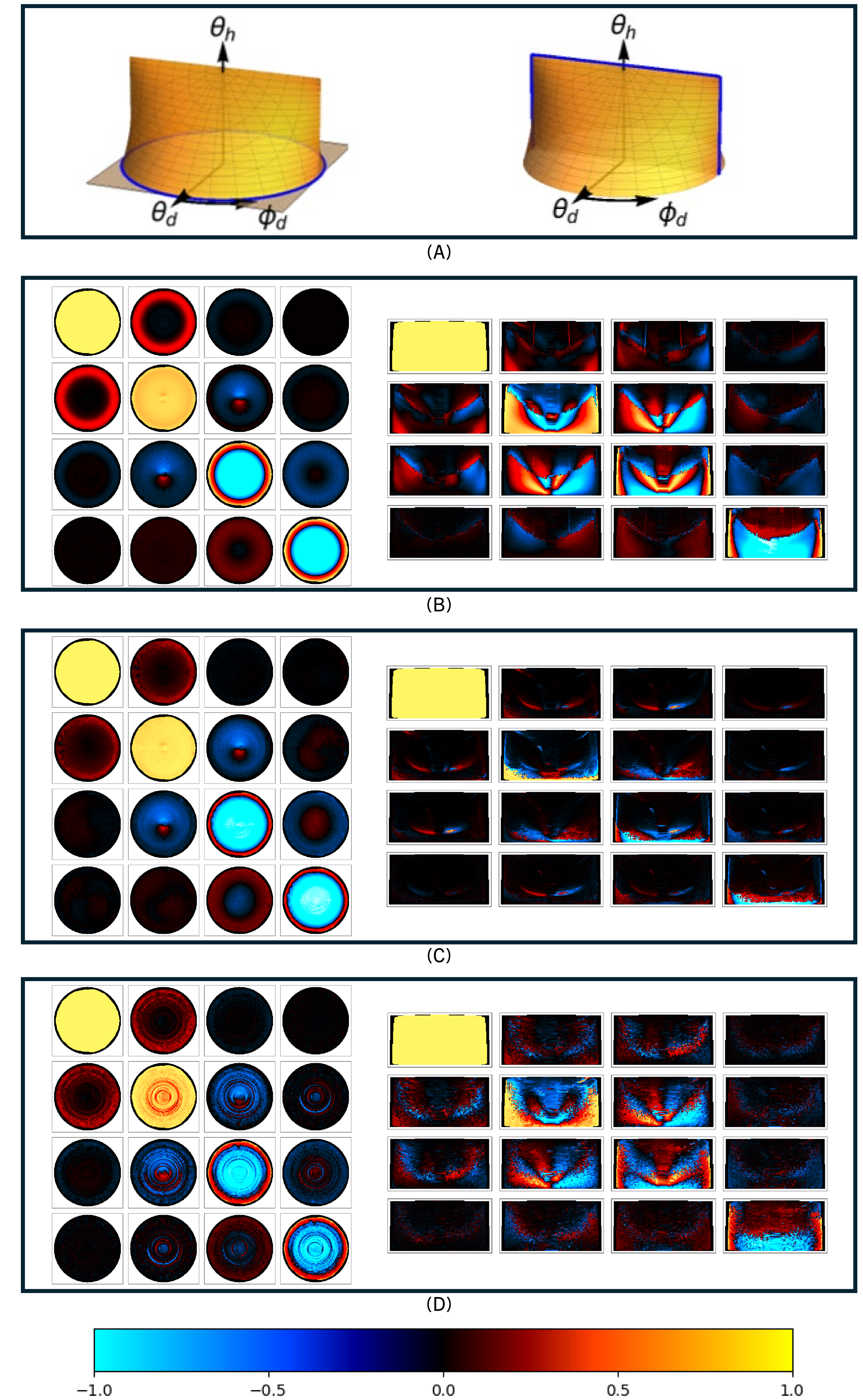

Figure 3: In (A) the tabulated pBRDF is shown in cross sections of the scattering geometries: left column is horizontal and right column is vertical. The measured 451 nm Mueller matrices of the blue spheres pictured in Figure 2B with (B) diffuse, (C) reflective, and (D) sparkle finishes.

Conclusion

A new approach to measuring and tabulating empirical pBRDFs using cylindrical coordinates rather than Cartesian coordinates was presented. The database includes a total of 14 spheres each measured at three wavelengths. A typical file size of a measurement is over 5GB; after tabulation, it is reduced to less than 70MB. This method of tabulation decreases measurement acquisition time and storage cost.