Intrinsic3D: High-Quality 3D Reconstruction by Joint Appearance and Geometry Optimization with Spatially-Varying Lighting

Robert Maier¹ ²  Kihwan Kim¹  Daniel Cremers²  Jan Kautz¹  Matthias Nießner² ³

Motivation: RGB-D based 3D Reconstruction

Baseline: over-smoothed geometry bad colors

Goal: high-quality reconstruction of geometry and appearance

Spatially-Varying Lighting Estimation

Spherical Harmonics (SH)
- Lighting approximation using only 9 SH basis functions \( h_n \) (2nd order)
- Shortcoming of single global SH basis: purely directional
does not represent complex scene lighting for all surface points simultaneously

Idea: Spatially-varying Spherical Harmonics (SVSH)
- Partition SDF volume into subvolumes
- Estimate independent SH coefficients for each subvolume
- Per-voxel SH coefficients: tri-linear interp.

Joint Optimization
Estimate SVSH coefficients for all K subvolumes jointly:

\[ L(k; I_1, \ldots, I_K) = \frac{1}{K} \sum_{k=1}^{K} \frac{I_k - I_k^0}{(I_k - I_k^0)^2} \] smooth illumination changes

\[ \sum_{k=1}^{K} \sum_{v \in V_k} (I_k - I_k^0)^2 \] Laplacian regularization

Shading-based Refinement

Intuition: high-frequency changes in surface geometry → shading cues in input images

1) Estimate lighting given surface and albedo (intrinsic material properties)
2) Estimate surface and albedo given the lighting; minimize difference between estimated shading and input luminance

Shading-based SDF Optimization

Joint geometry of optimization: geometry, albedo and image formation model (camera poses/intrinsics):

\[ E_{\text{opt}}(X) = \sum_{v \in V_k} w_v \delta_k + \lambda_a E_a + \lambda_s E_s + \lambda_l E_l \]

Gradient-based shading constraint \( E_s \)

Shading allows for optimization of surface and albedo

Surface stabilization constraint \( E_s \)

Stay close to initial distance values

Shading: Global SH vs. SVSH

Quantitative Surface Evaluation

Quality Colors (Zhou and Koltun [3])

Real Fusion (Zollhöfer et al. [2])

Appearance: Depth

Lighting: Global SH vs. SVSH

Accuracy: 20.14% more accurate

References