

Multispectral Photometric Stereo for Spatially-Varying Spectral Reflectances: A well posed problem?

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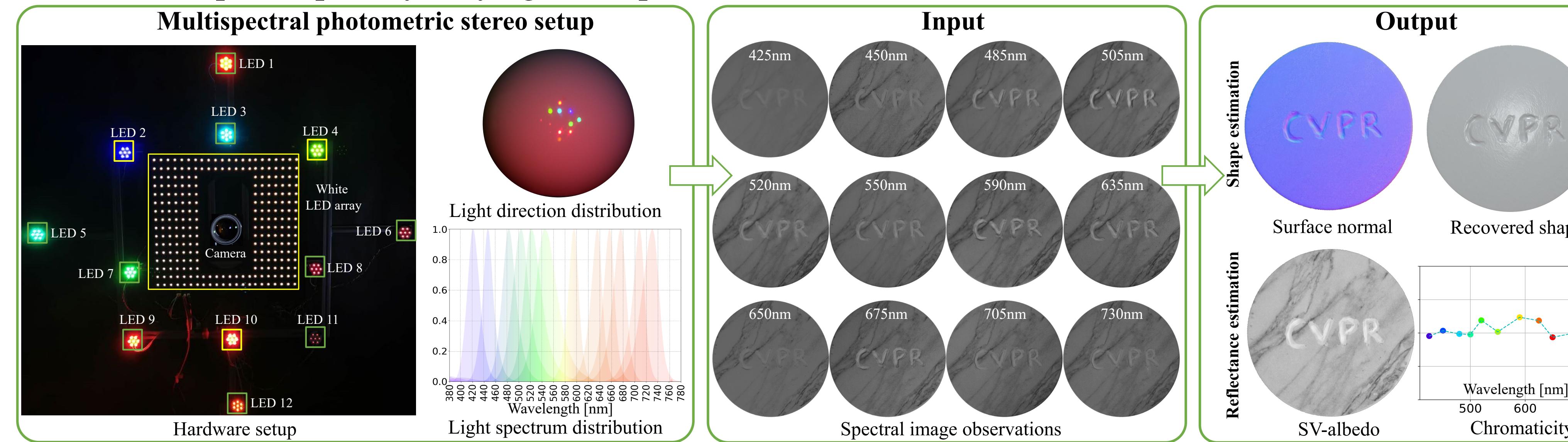
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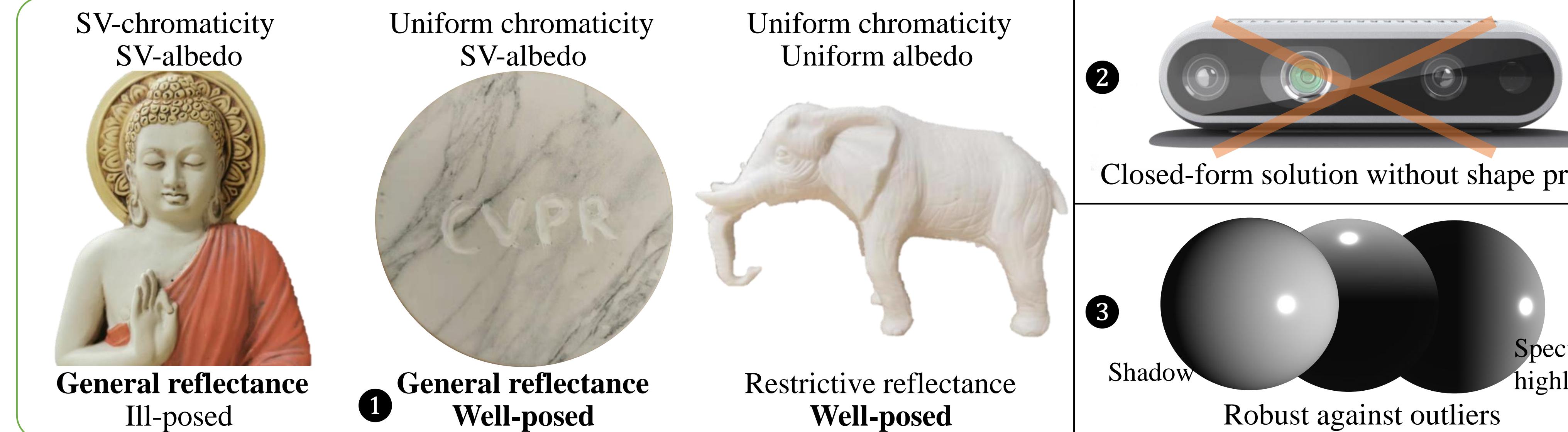


Problem Definition and Contribution

Multispectral Photometric Stereo (MPS): Taking a multispectral image observation as input, estimating both surface normal map and spatially-varying (SV) spectral reflectance.



Contributions:



Problem Formulation

Image Formation Model: Given a Lambertian surface point with normal $\mathbf{n} \in S^2 \subset \mathbb{R}^3$ being illuminated by f incoming spectral lights with directions $\mathbf{L} \in \mathbb{R}^{f \times 3}$, the image formation model can be expressed as

$$\mathbf{m} = \text{diag}(\mathbf{r})\mathbf{L}\mathbf{n}, \quad \mathbf{r} = \mathbf{v}\rho$$

\mathbf{m} : Measured intensity $\mathbf{r} \in \mathbb{R}_+^f$: Spectral reflectance $\mathbf{v} \in \mathbb{R}_+^f$: Chromaticity $\rho \in \mathbb{R}_+$: Albedo

Ill-posedness: Given f knowns \mathbf{m} , estimate $f + 2$ unknowns (f for the reflectance \mathbf{r} , 2 for the surface normal \mathbf{n})

Method

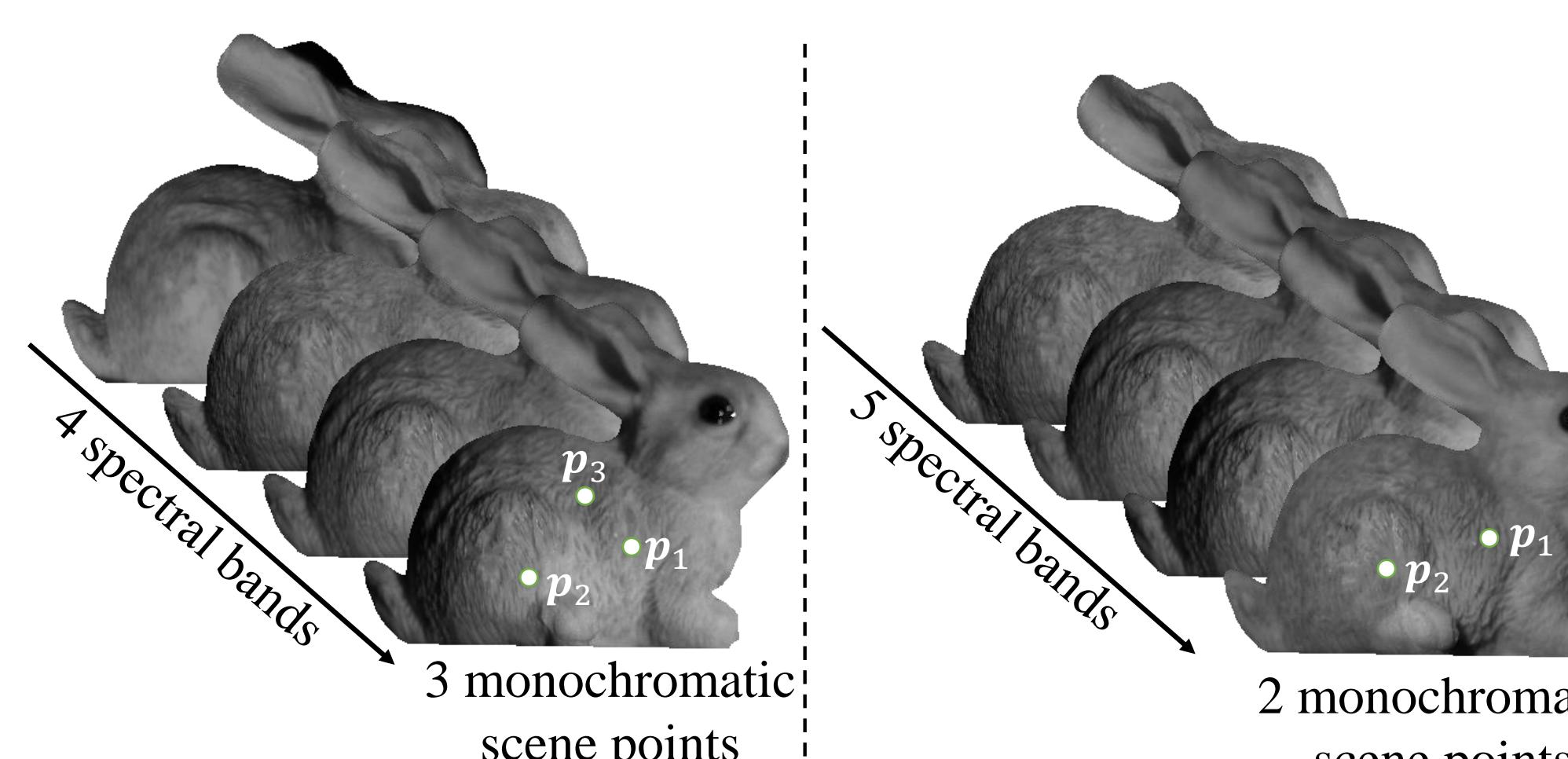
Reflectance assumption: All the scene points share uniform chromaticity $\tilde{\mathbf{v}}$ but spatially-varying albedos.

Closed-form solution:

$$\{\mathbf{V}^*, \mathbf{B}^*\} = \underset{\mathbf{V}, \mathbf{B}}{\text{argmin}} \|\mathbf{M} - \mathbf{V}\mathbf{LB}^\top\|_F^2$$

$$\underbrace{[-\mathbf{I}_p \otimes \mathbf{L} | [\text{diag}(\mathbf{m}_1) \cdots | \text{diag}(\mathbf{m}_p)]^\top]}_{\mathbf{D} \in \mathbb{R}^{pf \times (3p+f)}} \underbrace{\begin{bmatrix} \text{vec}(\mathbf{B}^\top) \\ \mathbf{V}^{-1}\mathbf{1} \end{bmatrix}}_{\mathbf{x} \in \mathbb{R}^{3p+f}} = \mathbf{0}$$

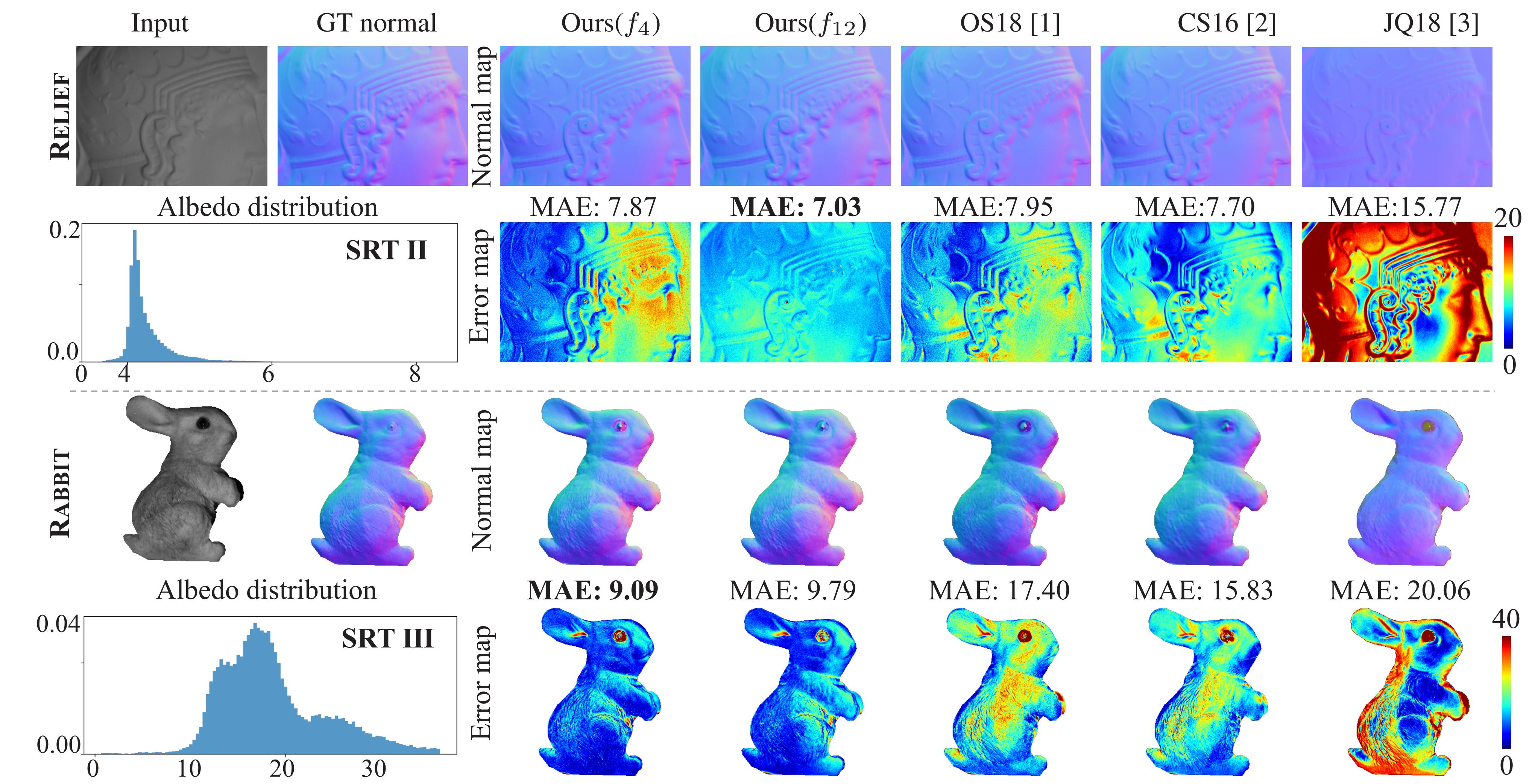
Minimal Solvable Condition:



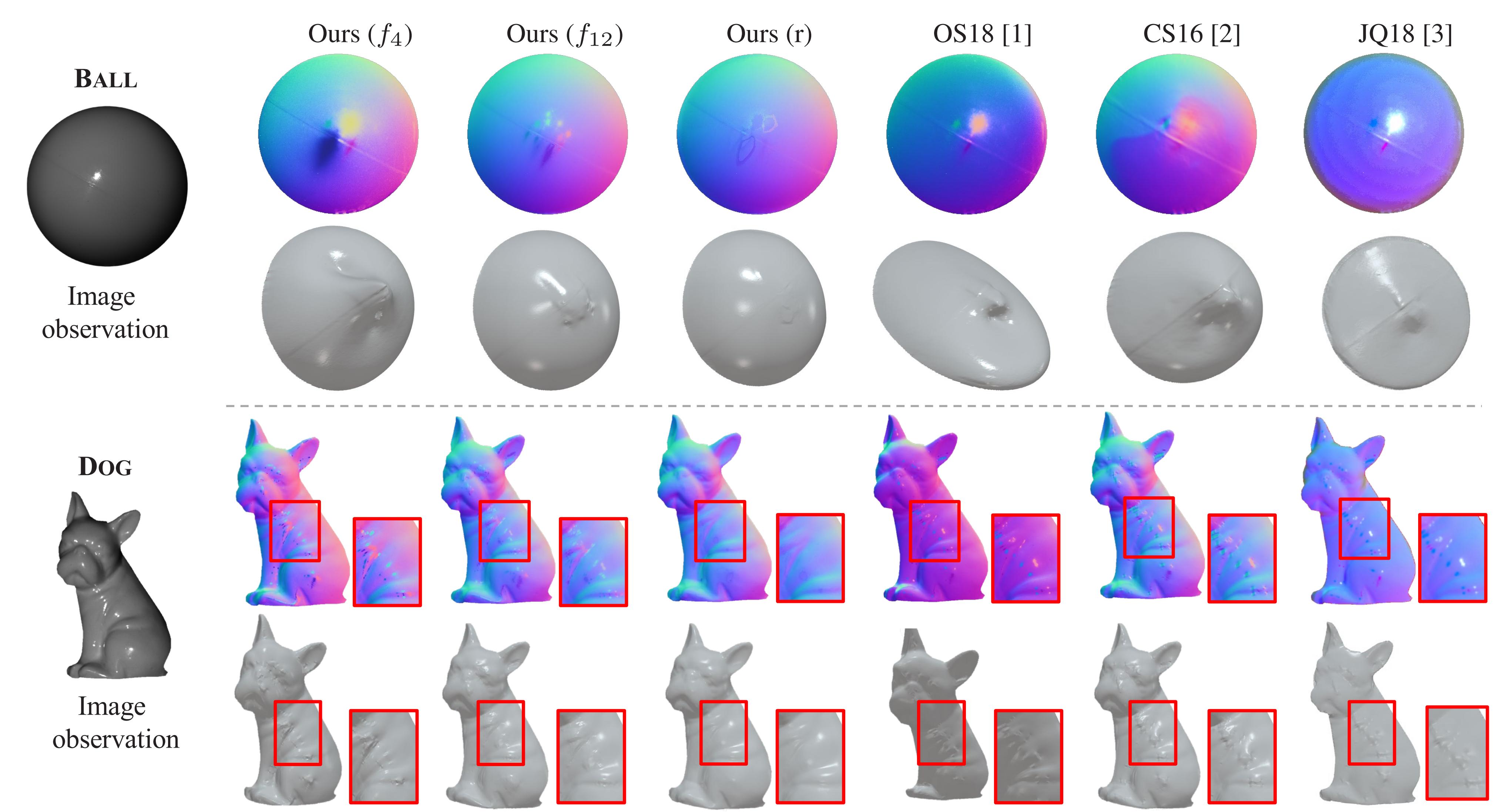
- $\mathbf{M} \in \mathbb{R}^{p \times f}$: Image observations under f lights
- $\mathbf{B} \in \mathbb{R}^{p \times 3}$: Albedo-scaled surface normal
- $\mathbf{V} = \text{diag}(\tilde{\mathbf{v}})$: Diagonalized uniform chromaticity $\tilde{\mathbf{v}}$

Experiments & Results

Quantitative Comparison on Real Captured Data: RELIEF and RABBIT



Robustness Comparison against Outliers



References:

- [1] Ozawa *et al.* Single color image photometric stereo for multi-colored surfaces. (CVIU 2018)
- [2] Ayan *et al.* Single-image RGB photometric stereo with spatially-varying albedo. (3DV 2016).
- [3] Ju *et al.* Demultiplexing colored images for multispectral photometric stereo via deep neural networks. (IEEE Access 2018)