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

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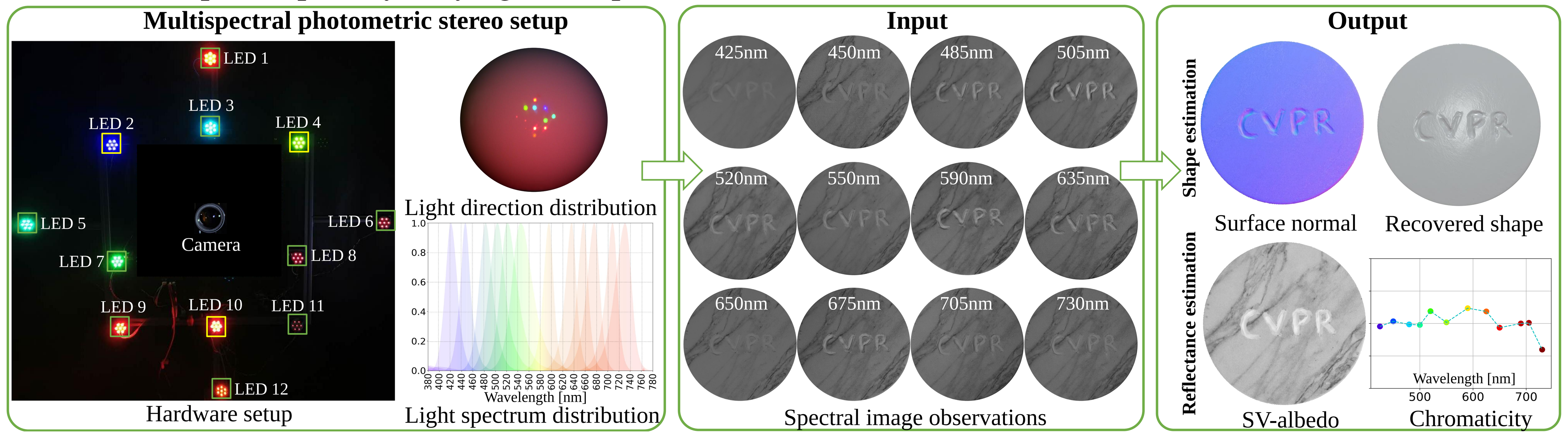
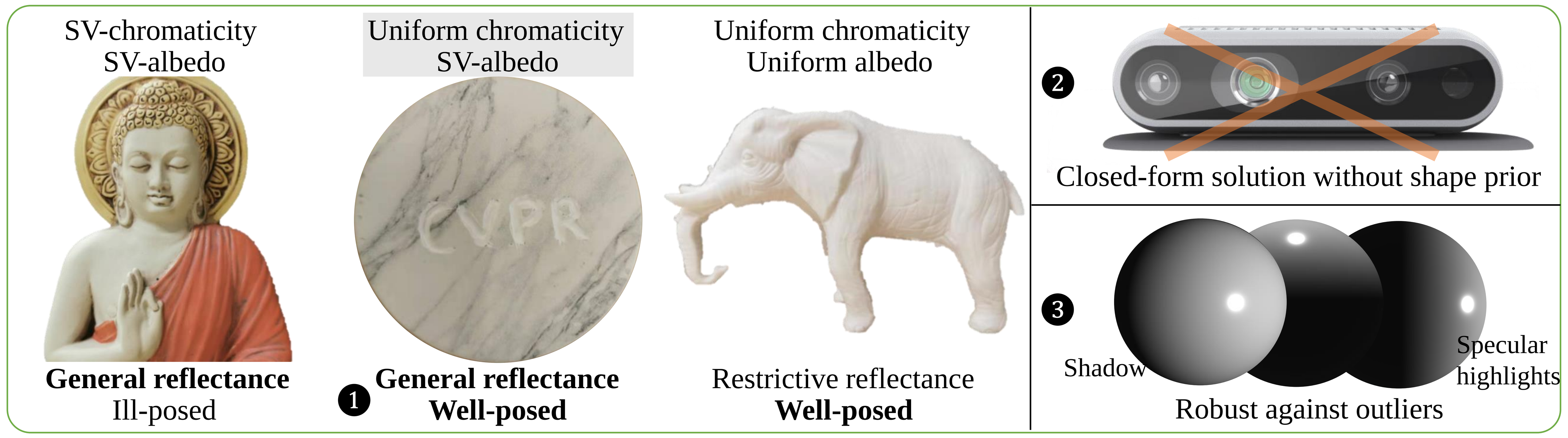
Problem Definition and Contribution

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 $\boldsymbol{n} \in S^2 \subset \mathbb{R}^3$ 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

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

$\mathbf{m}$: 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.

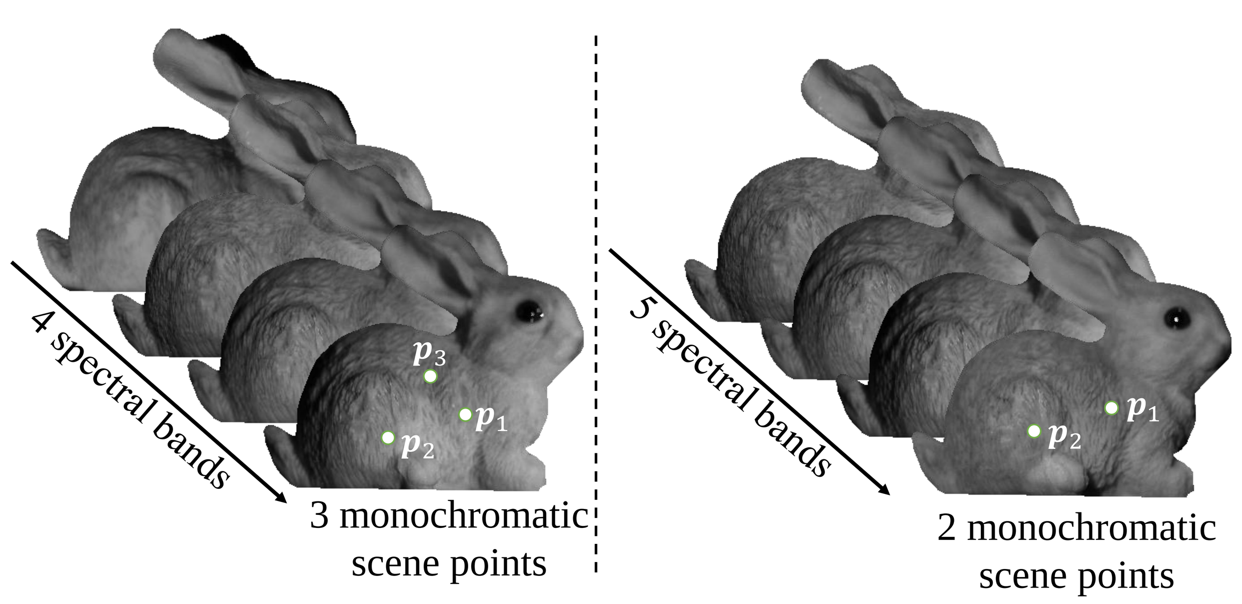
Closed-form solution:

$$\{\mathbf{V}^*, \mathbf{B}^*\} = \operatorname*{argmin}_{\mathbf{V},\mathbf{B}} \left\|\mathbf{M} - \mathbf{V}\mathbf{L}\mathbf{B}^\top\right\|_F^2$$

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

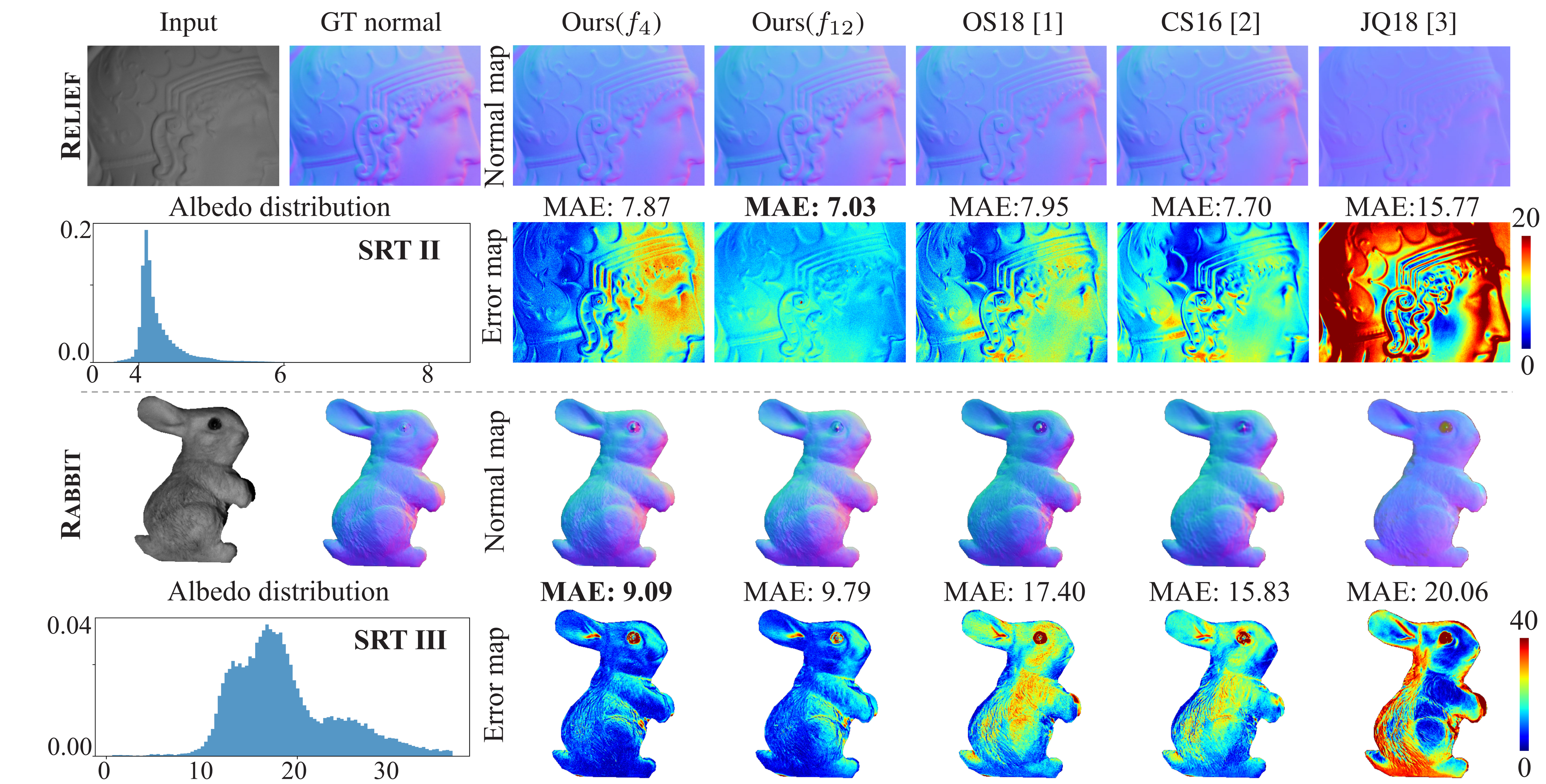
- $\mathbf{M} \in \mathbb{R}^{p\times f}$: Image observations under f lights
- $\mathbf{B} \in \mathbb{R}^{p\times 3}$: Albedo-scaled surface normal
- $\mathbf{V} = \mathrm{diag}(\tilde{\mathbf{v}})$: Diagonalized uniform chromaticity $\tilde{\mathbf{v}}$

Minimal Solvable Condition:

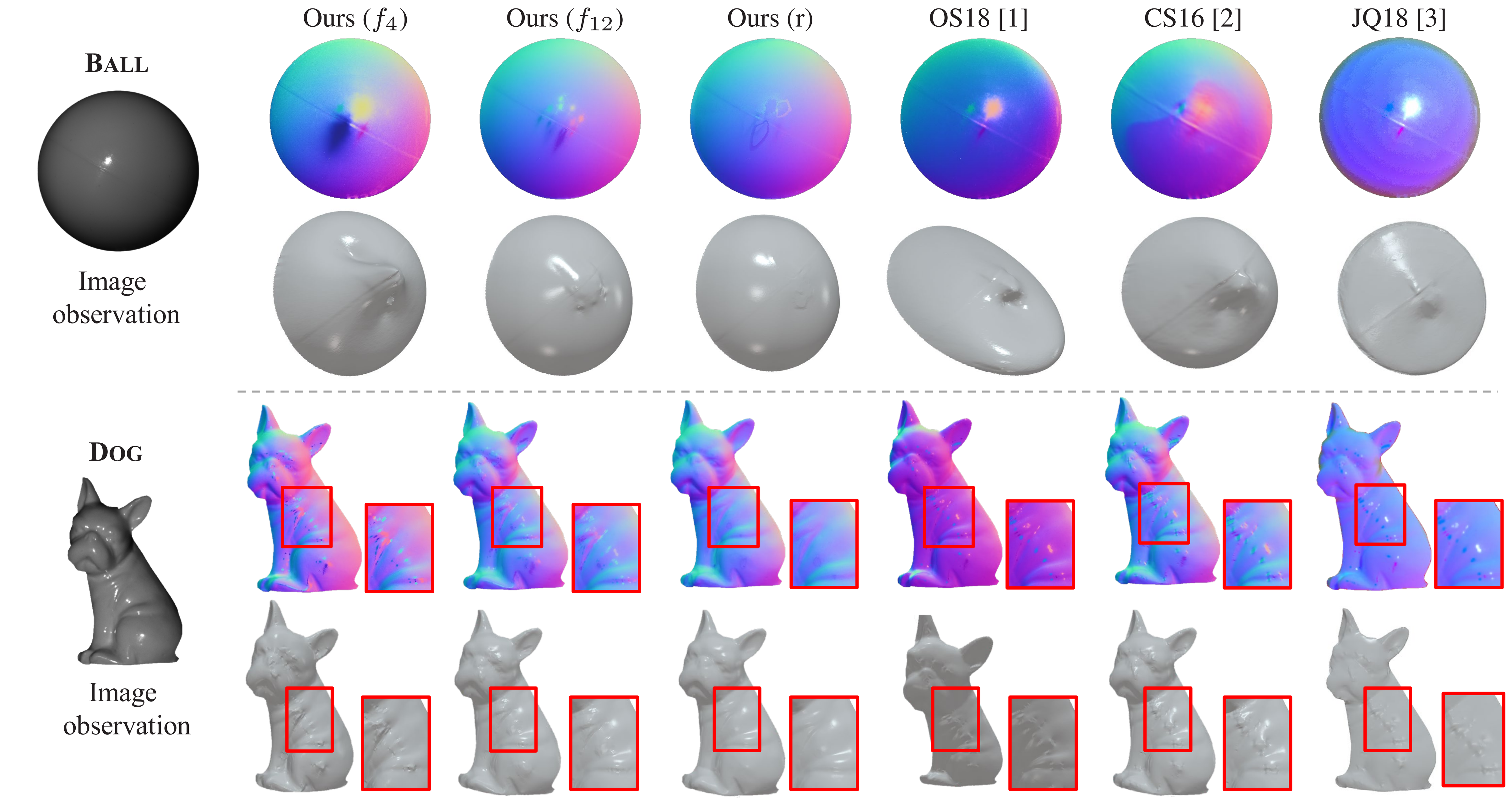


Experiments & Results

Quantitative Comparison on Real Captured Data: RELIEF and RABBIT



Robustness 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)