

Self-calibrating Deep Photometric Stereo Networks

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Problem Definition and Contribution

Goal: Estimating the normal map of a non-Lambertian surface with unknown isotropic reflectances observed under unknown varying light directions.

Motivations:

- Traditional methods for uncalibrated photometric stereo often assume a simplified reflectance model.
- Recent learning based methods for photometric stereo often assume known light directions.
- The performance of the existing learning based method for uncalibrated photometric stereo (*i.e.*, the single-stage method UPS-FCN [1]) lags far behind the calibrated methods.

Problem Formulation

Image Formation Model: Consider a non-Lambertian surface whose appearance is described by a general isotropic BRDF ρ . Given a surface point with normal $n \in \mathbb{R}^3$ being illuminated by the j -th incoming lighting with direction $l_j \in \mathbb{R}^3$ and intensity $e_j \in \mathbb{R}$, the image formation model can be expressed as

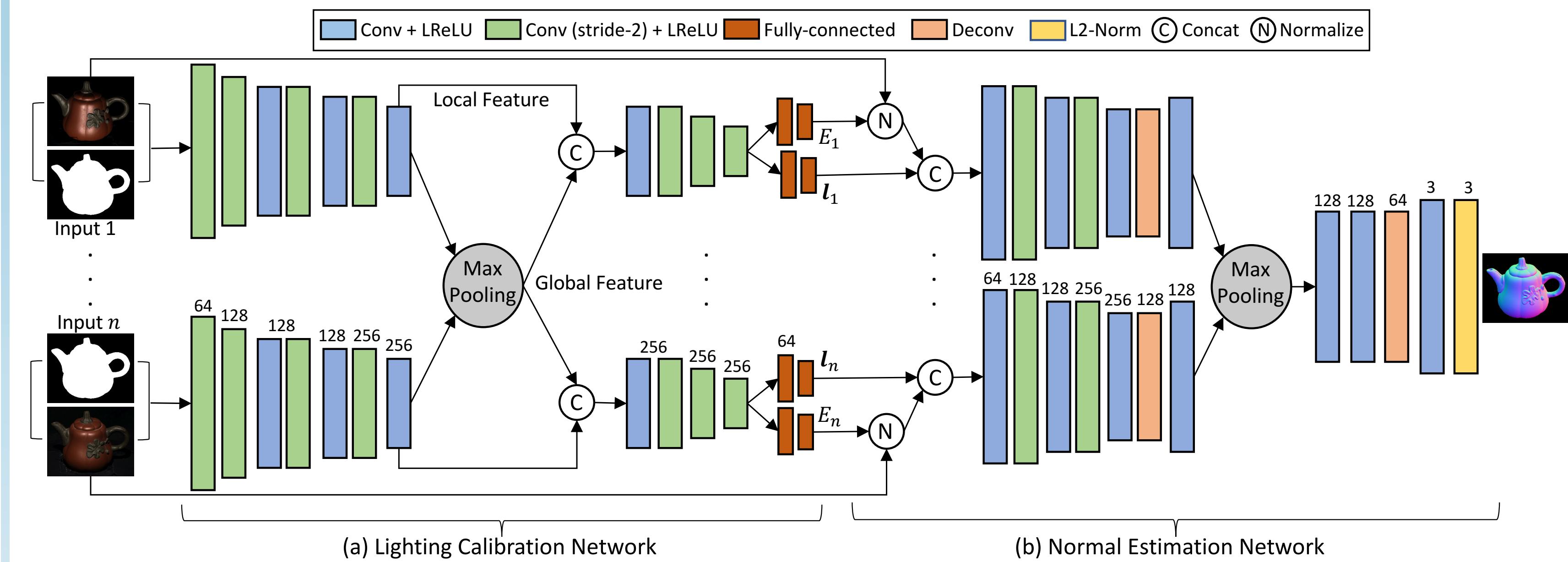
$$m_j = e_j \rho(n, l_j) \max(n^\top l_j, 0) + \epsilon_j,$$

where m represents the measured intensity, $\max(\cdot, 0)$ accounts for attached shadows, and ϵ accounts for the global illumination effects and noise.

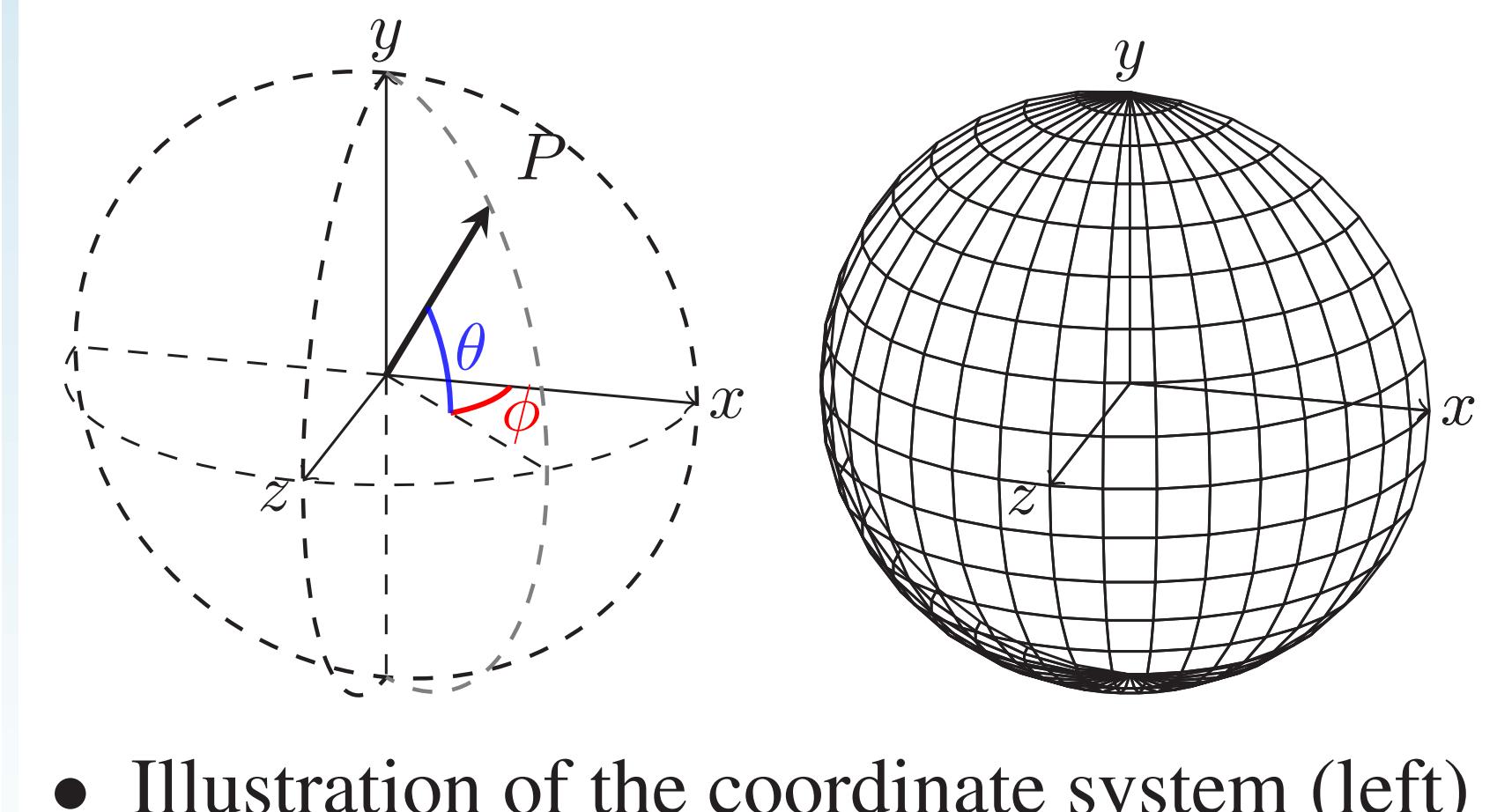
Main Idea: We first estimate lightings from the measured intensities, and then solve for the surface normals using the estimated lightings and measured intensities.

Method

Network Architecture:



Discretization of Lighting Space:



Loss Function for Lighting Estimation:

$$\mathcal{L}_{\text{Light}} = \lambda_{l_a} \mathcal{L}_{l_a} + \lambda_{l_e} \mathcal{L}_{l_e} + \lambda_e \mathcal{L}_e$$

- \mathcal{L}_{l_a} : azimuth classification loss
- \mathcal{L}_{l_e} : elevation classification loss
- \mathcal{L}_e : light intensity classification loss

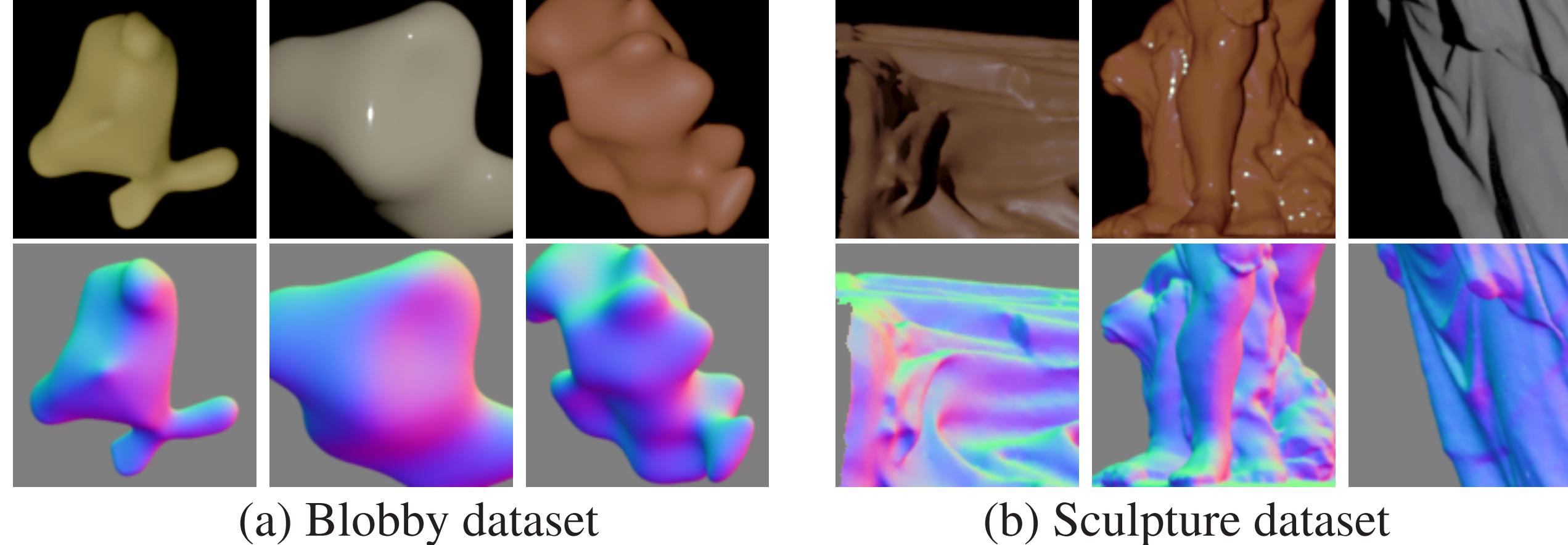
Loss function for Normal Estimation:

$$\mathcal{L}_{\text{Normal}} = \frac{1}{hw} \sum_i (1 - n_i^\top \tilde{n}_i)$$

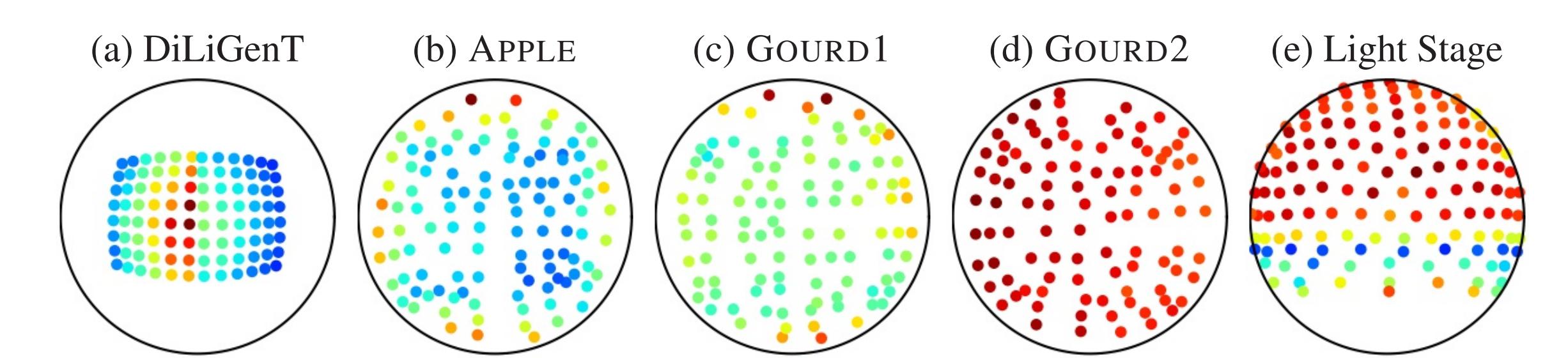
- Cosine similarity loss

Experiments & Results

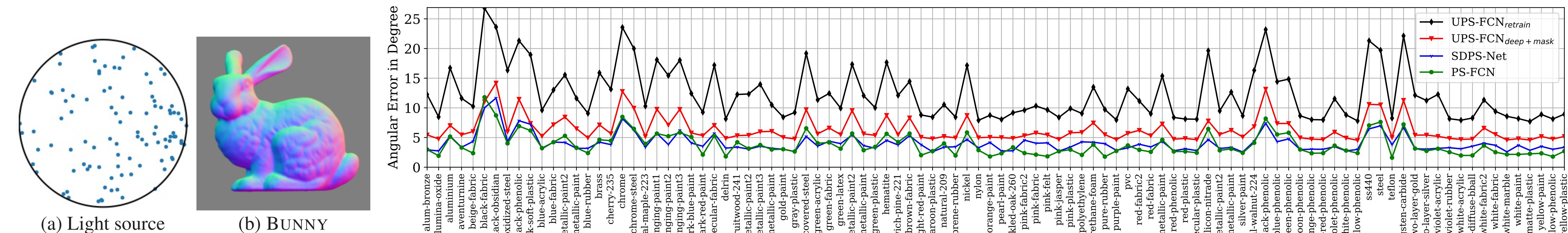
Synthetic Training Datasets:



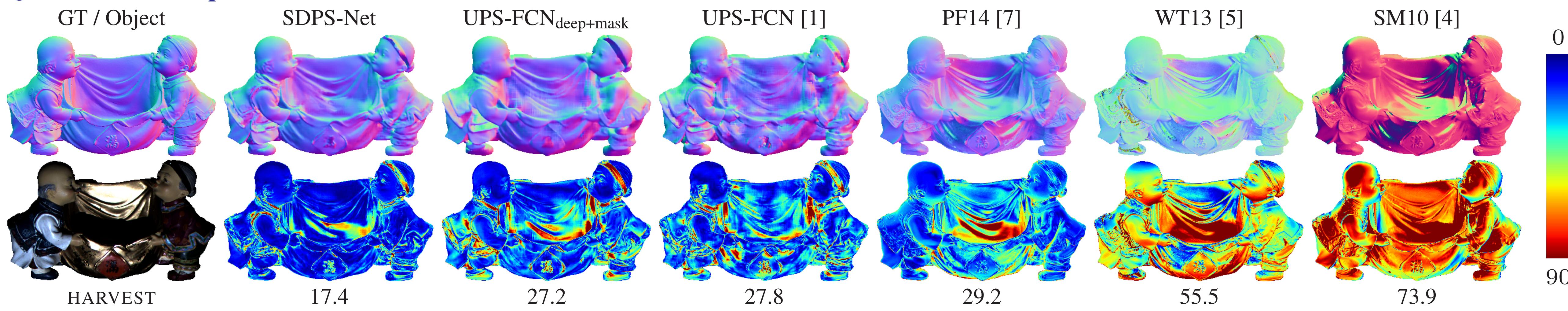
Lighting Distribution of Real Datasets:



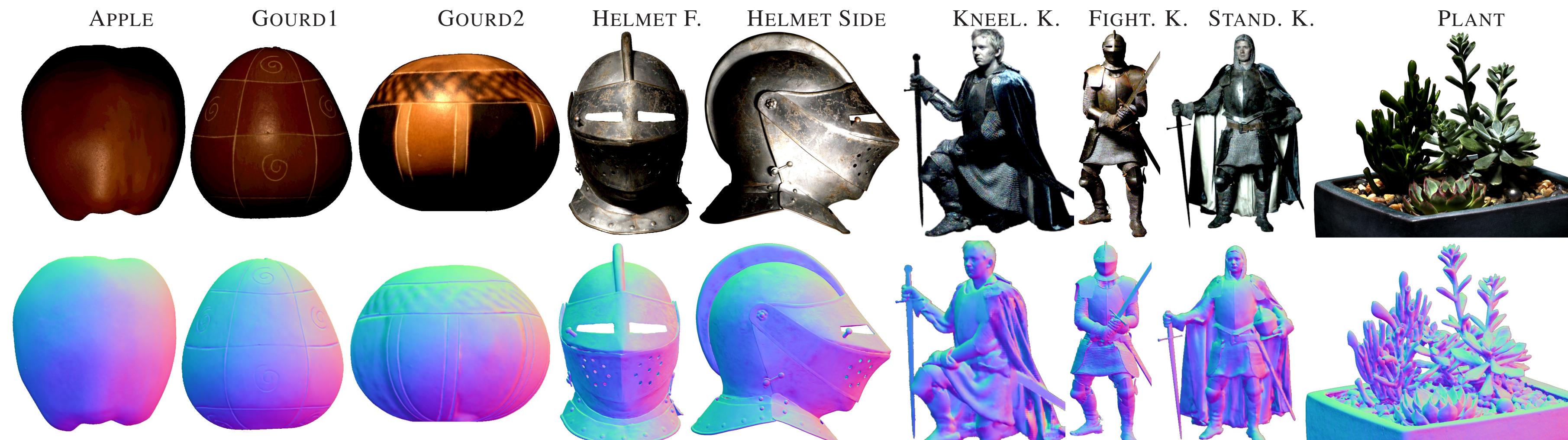
Quantitative Results on BUNNY Rendered with 100 MERL BRDFs:



Quantitative Comparison on HARVEST in DiLiGenT Benchmark:



Qualitative Results on Gourd&Apple Dataset [11] and Light Stage Data Gallery [12]:



References:

- [1] UPS-FCN [Chen et al., ECCV8]
- [2] DiLiGenT [Shi et al., TPAMI19]
- [3] AM07 [Alldrin et al., ICCV07]
- [4] SM10 [Shi et al., CVPR10]
- [5] WT13 [Wu and Tan, CVPR13]
- [6] LM13 [Lu et al., CVPR13]
- [7] PF14 [Papadimitri and Favaro, IJCV14]
- [8] LC18 [Lu et al., TPAMI18]
- [9] L2 [Woodham, OE1980]
- [10] IS18 [Ikehata, ECCV18]
- [11] Gourd&Apple [Alldrin et al., CVPR08]
- [12] Light Stage [Einarsson et al., EGSR06]