Calibrating Photometric Stereo by Holistic Reflectance Symmetry Analysis

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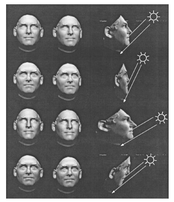
Motivation

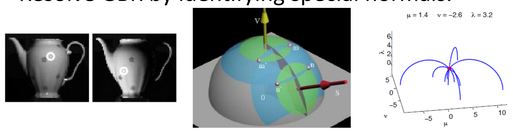
The generalized bas-relief(GBR) ambiguity [1]



$$G = \begin{pmatrix} 1 & 0 & \mu \\ 0 & 1 & \nu \\ 0 & 0 & \lambda \end{pmatrix}$$

$$\hat{\boldsymbol{n}} = \frac{G\boldsymbol{n}}{\|G\boldsymbol{n}\|}, \hat{\boldsymbol{s}} = \frac{G^{-T}\boldsymbol{s}}{\|G^{-T}\boldsymbol{s}\|}$$

Resolve GBR by identifying special normals.



specular spike [2] | isotropic & reciprocal pairs [3] | diffuse maxima[4]

Disadvantages of these methods:

- Rely on the identification of special points
- Do not use all available information

Solve GBR in a global approach?

References

[1] P. Belhumeur, D. Kriegman, and A. Yuille. The basrelief Ambiguity. *IJCV*, 1999

[2] O. Drbohlav and M. Chaniler. Can two specular pixels calibrate photometric stereo? *ICCV,* 2005

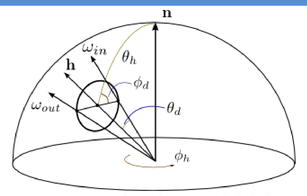
[3] P. Tan, L. Quan, and T. Zickler. The geometry of reflectance symmetries. *TPAMI,* 2011

[4] P. Favaro and T. Papadhimitri. A closed-form solution to uncalibrated photometric stereo via diffuse maxima. *CVPR,* 2012

[5] N. Alldrin, S. Mallick, and D. Kriegman. Resolving the generalized bas-relief ambiguity by entropy minimization. *CVPR*, 2007

[6] B. Shi, Y. Matsushita, Y. Wei, C. Xu, and P. Tan. Selfcalibrating photometric stereo. *CVPR*, 2010

Theory

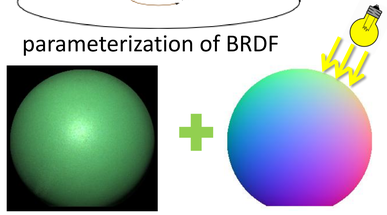


parameterization of BRDF

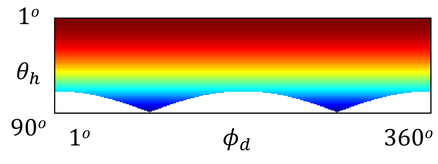
Key Assumption (bi-variant BRDF)

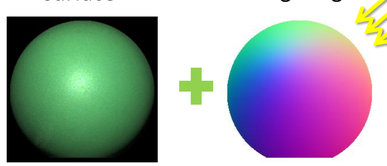
General case: $f(\boldsymbol{\omega}_{in}, \boldsymbol{\omega}_{out}) = f(\theta_h, \phi_h, \theta_d, \phi_d)$

Isotropy + Half-vector symmetry: $f(\boldsymbol{\omega}_{in}, \boldsymbol{\omega}_{out}) = f(\theta_h, \theta_d)$

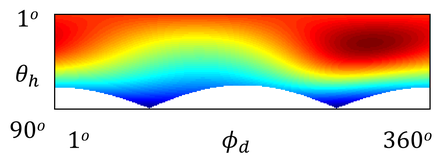


A curved homogeneous surface + True normals + lighting → Estimated 2D BRDF slice



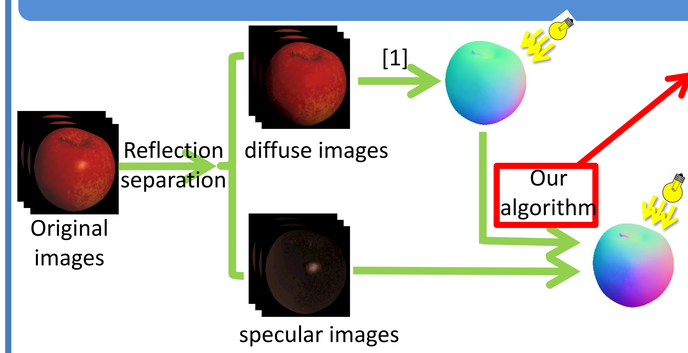


GBR-distorted normals + lighting → Estimated 2D BRDF slice



The GBR ambiguity is uniquely determined by restoring the 'low-rank' structure of BRDF slices estimated from at least two images! (see the paper for proofs)

Auto-calibration Method



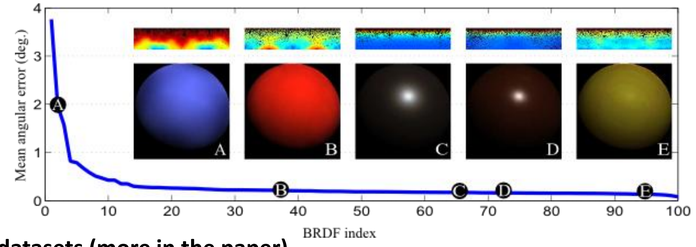
Optimization Problem:
Penalize the variation along each row of BRDF slices.

$$min_G \sum_{i=0}^{N-1} \sum_{\theta_h=1}^{20} \frac{k_{i,\theta_h}}{\sum_{\theta=1}^{20} k_{i,\theta}} \frac{Var[f_i(\theta_h, \phi_d)]}{Mean^2[f_i(\theta_h, \phi_d)]}$$

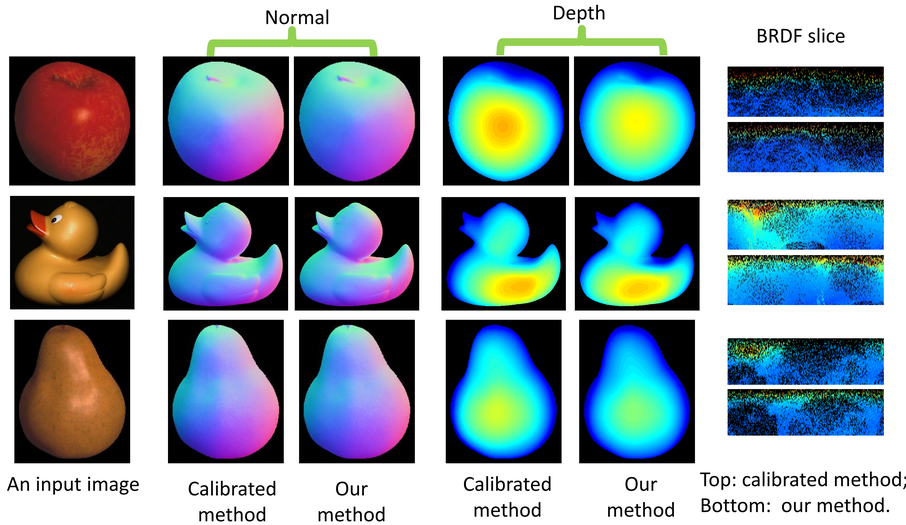
Solve by coarse-to-fine search in a bounded interval of GBR parameters.

Experimental Results

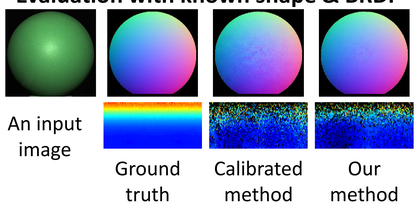
Synthetic data results on the MERL BRDF database



Real datasets (more in the paper)



Evaluation with known shape & BRDF



Methods	BRDF error
Calibrated	0.091
Ours	0.071

Comparison on mean normal error (deg)

Method	Apple	Duck	Pear	Pear2
[5]	9.0	7.5	9.7	23.8
[6]	8.9	6.6	24.9	23.7
[2]	8.7	7.7	4.6	13.8
[3]	9.8	7.3	N/A	N/A
[4]	**7.0**	7.4	7.3	**9.2**
ours	7.8	**5.7**	**4.4**	11.7

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