Variational Uncalibrated Photometric Stereo under General Lighting

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Abstract

Photometric stereo (PS) techniques nowadays remain constrained to an ideal laboratory setup where modeling and calibration of lighting is amenable. This work aims to eliminate such restrictions. To this end, we introduce an efficient principled variational approach to uncalibrated PS under general illumination, which is approximated through a second-order spherical harmonic expansion. The joint recovery of shape, reflectance and illumination is formulated as a variational problem where shape estimation is carried out directly in terms of the underlying perspective depth map, thus implicitly ensuring integrability and bypassing the need for a subsequent normal integration. We provide a tailored numerical scheme to solve the resulting nonconvex problem efficiently and robustly. On a variety of evaluations, our method consistently reduces the mean angular error by a factor of 2–3 *compared to the state-of-the-art.*

A. Further Details on Synthetic Experiments

To provide further insights on the synthetic experiments (in Section 6.1), we visualize the environment lighting ℓ^i, $i = 1 \ldots 25$, used to render each image. Figure 1 shows all 25 environment maps[1]. The impact of each incident lighting ℓ^i, $i = 1 \ldots 25$, is illustrated in Figure 2 showing the Joyful Yell with a White ($\rho \equiv 1$) albedo. Thus, color changes in the images are caused by lighting only, as depicted in model (1) and (7) in the main paper.

Table 1 shows the mean angular error (MAE) of each dataset on the state-of-the-art approaches [1, 2, 3] and our proposed methodology. It can be seen that our approach consistently overcomes [1, 2, 3] by a factor of 2–3. Only the Pattern albedo seems to bias the resulting depth negatively, yet even in this case our approach estimates the geometry more faithfully than the current state-of-the-art.

Two more qualitative results on synthetic data are shown in Figure 3. While [1] gives more meaningful results on Armadillo with Constant albedo, depth deteriorates strongly on Lucy with Hippie albedo. Methods of [2, 3] both result in rather flattened shapes (cf. Lucy). Most accurate results are achieved using the proposed method where fine geometric details, as well as non flattened depth estimates are shown.

B. Further Details on Real-World Results

Supplementary to the real-world experiments (in Section 6.2), Figure 4 shows alternative viewpoints of the real-world results. The estimated albedos, which are mapped onto the surfaces, appear satisfactory.

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[1] All environment maps were downloaded from http://www.hdrlabs.com/sibl/archive.html

References

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Figure 1. All environment maps ℓ^i (360° view) used throughout the synthetic evaluation.

Figure 2. Illustration of the input data. The Joyful Yell dataset with White albedo to show the impact of the different environment maps used throughout the synthetic experimental validation.

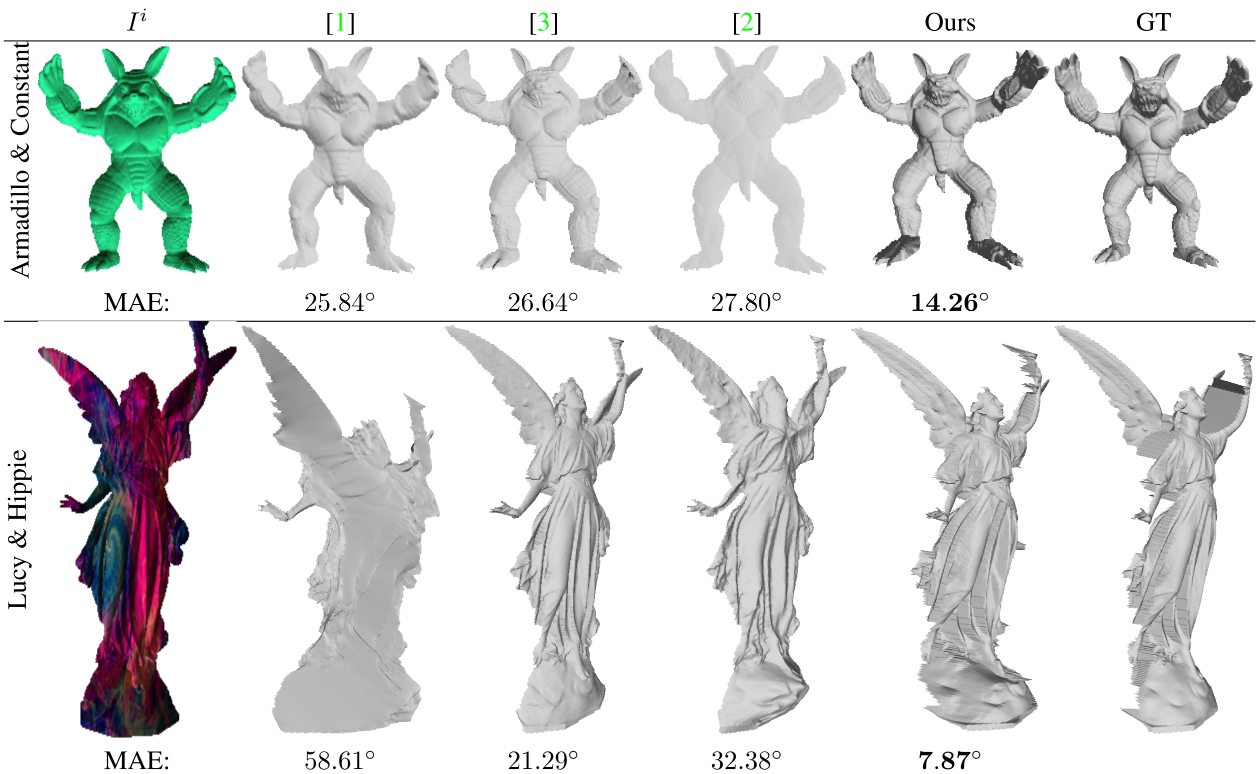

Figure 3. Results of state-of-the-art approaches and our approach on two out of the 36 synthetic datasets. Numbers show the mean angular error (MAE) in degrees.

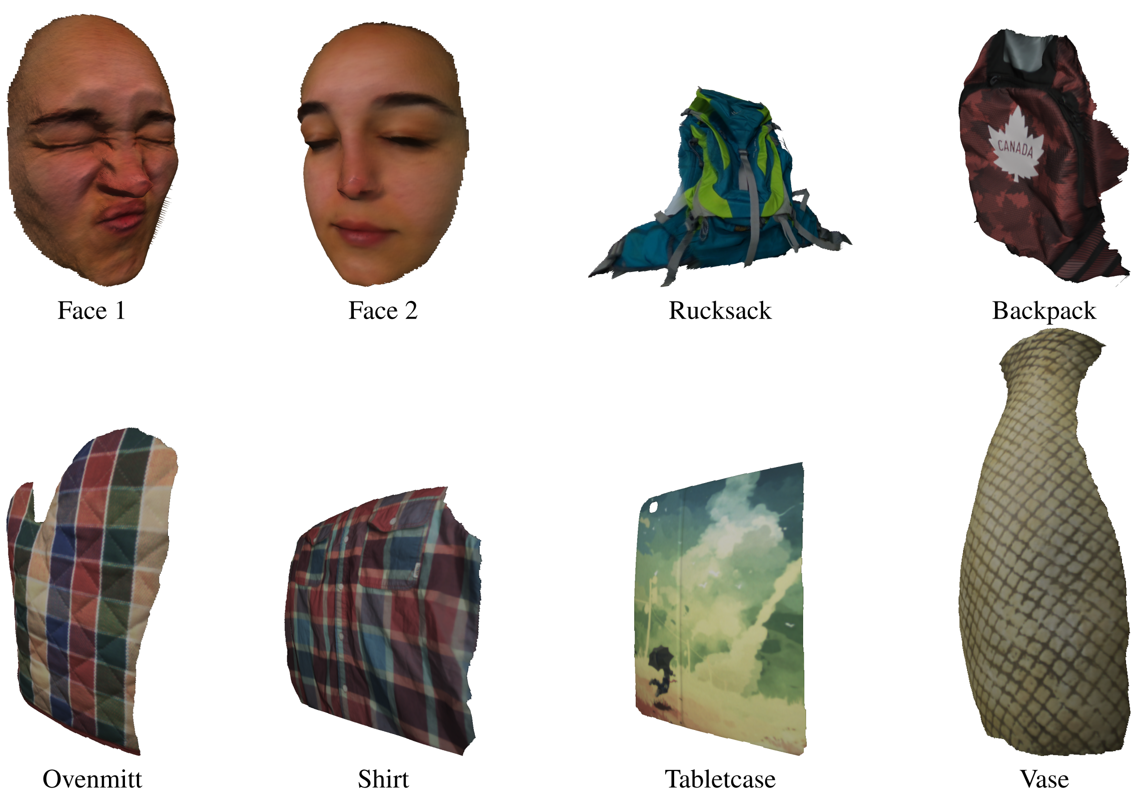

Figure 4. Estimated results (with albedo mapped onto the surface) from real-world data under alternative viewpoints.

Dataset		[1]	[3]	[2]	Ours
Shape	Albedo				
Armadillo	Bars	26.22	27.84	36.91	**16.78**
	Constant	25.84	26.64	36.87	**13.97**
	Ebsd	25.34	26.88	27.80	**14.26**
	Hippie	28.21	27.30	25.82	**14.52**
	Lena	27.07	27.33	28.36	**14.78**
	Pattern	45.87	26.82	24.01	**19.06**
	Rectcircle	26.97	26.71	36.23	**14.06**
	Voronoi	25.62	26.91	50.70	**14.07**
	White	26.19	26.64	52.04	**14.13**
Joyful Yell	Bars	21.84	16.26	31.80	**8.69**
	Constant	23.95	14.93	33.47	**5.96**
	Ebsd	26.08	15.63	15.91	**7.28**
	Hippie	28.67	16.23	22.96	**7.49**
	Lena	21.33	16.33	19.70	**9.21**
	Pattern	26.07	18.76	26.67	**16.97**
	Rectcircle	35.27	15.19	52.41	**7.34**
	Voronoi	22.27	16.42	45.74	**6.57**
	White	27.12	14.32	33.06	**6.20**
Lucy	Bars	49.13	21.90	36.51	**8.16**
	Constant	54.98	19.89	36.57	**8.71**
	Ebsd	62.33	20.81	23.56	**9.61**
	Hippie	58.61	21.29	32.38	**7.87**
	Lena	64.01	22.24	30.93	**9.56**
	Pattern	48.83	22.25	32.68	**17.78**
	Rectcircle	24.68	20.99	43.13	**8.98**
	Voronoi	61.53	22.10	48.14	**7.59**
	White	64.43	19.33	44.76	**8.76**
Thai Statue	Bars	25.53	21.91	66.17	**8.55**
	Constant	27.20	18.91	38.47	**9.58**
	Ebsd	27.85	20.22	34.11	**9.47**
	Hippie	21.91	21.86	30.62	**8.83**
	Lena	33.53	19.66	34.00	**9.19**
	Pattern	26.77	22.06	28.81	**15.27**
	Rectcircle	29.36	19.92	43.86	**8.84**
	Voronoi	30.65	21.56	36.58	**8.69**
	White	28.02	18.64	37.31	**9.16**
Median		27.16	21.14	34.06	**9.17**
Mean		34.15	21.18	35.53	**10.72**

Table 1. Quantitative comparison between our method and other state-of-the-art methods on multiple challenging synthetic datasets.