MP-PG.3

Diffuse-Specular Separation of Multi-View Images under Varying Illumination

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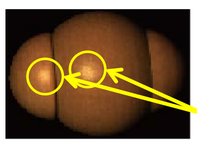
Objective

Separating **diffuse** and **specular** reflection components for **photometric stereo** based on **light fields**

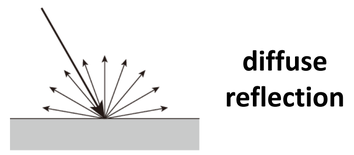
- Input images
  - multi-view images taken under varying lighting directions
- Specular reflection components
  - conventional PS: noise
  - uncalibrated PS: useful for resolving the GBR ambiguity



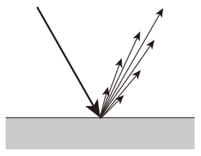
specular reflection components

Key Idea

Integrating two complement clues based on **varying viewing directions** and **varying lighting directions**



diffuse reflection

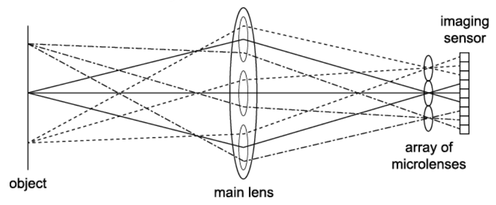


specular reflection

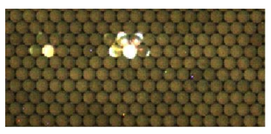
- Varying viewing directions
  - diffuse reflection components: **viewpoint-invariant**
  - specular reflection components: viewpoint-dependent
- Varying lighting directions
  - diffuse reflection components: **low-dimensional** (3D subspace)

Proposed Method

- Assumption
  - microlens-based light field camera
  - focus on an object of interest

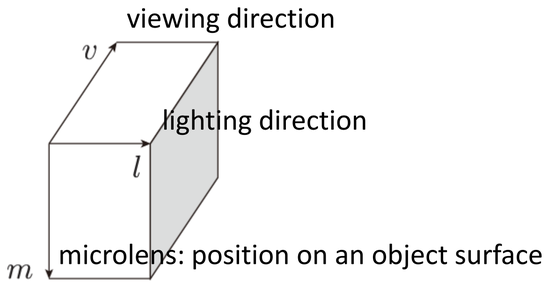


observe the **same** point from **different** viewing directions

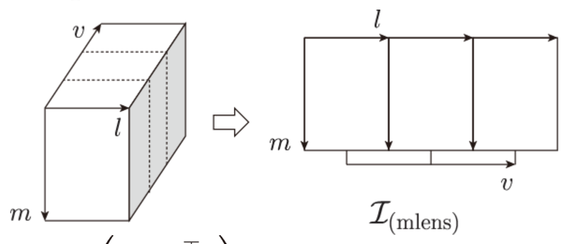


close-up of a raw light field image

- Representation
  - a set of raw images = **3rd order tensor**



- Structure of 3rd order tensor
  - unfolding w.r.t. **microlens axis**



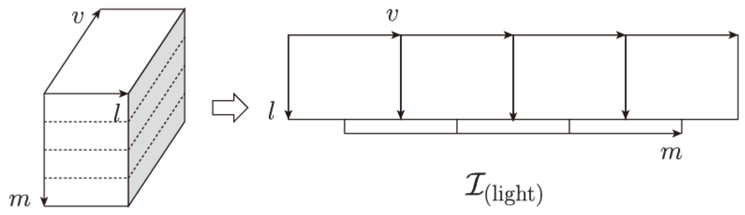
$$\mathcal{I}_{(\mathrm{mlens})}$$

$$\begin{pmatrix} \rho_1 \boldsymbol{n}_1^\top \\ \vdots \\ \rho_M \boldsymbol{n}_M^\top \end{pmatrix} \boldsymbol{s}_l$$

rank = 3

light source vector = 3D

  - unfolding w.r.t. **lighting direction**



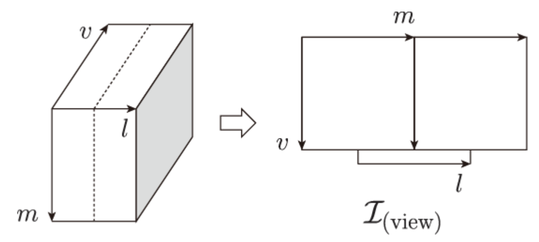
$$\mathcal{I}_{(\mathrm{light})}$$

$$\begin{pmatrix} \boldsymbol{s}_1^\top \\ \vdots \\ \boldsymbol{s}_L^\top \end{pmatrix} \rho_m \boldsymbol{n}_m$$

rank = 3

surface normal vector = 3D

  - unfolding w.r.t. **viewing direction**



$$\mathcal{I}_{(\mathrm{view})}$$

diffuse reflection components: viewpoint-invariant

rank = 1

- Low-rank approximation
  - **higher-order SVD** [Vasilescu 2002]

$$\hat{\mathcal{I}}_{(\mathrm{mlens})} = \hat{U}_{(\mathrm{mlens})} \hat{\Sigma}_{(\mathrm{mlens})} \hat{V}_{(\mathrm{mlens})}^\top$$

low-rank approximation of unfolded matrices

$$\hat{\mathcal{I}} = \hat{\mathcal{Z}} \times_1 \hat{U}_{(\mathrm{mlens})} \times_2 \hat{U}_{(\mathrm{light})} \times_3 \hat{U}_{(\mathrm{view})}$$

product of unfolded and low-ranked matrices

  - SVD with missing data [Shum 1995]

robust against outliers such as specular reflection components and shadows

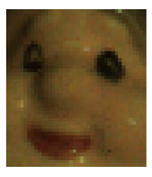
Experiments

- Setup
  - input: 10 images captured by **LYTRO ILLUM**
  - objects: ceramic dwarf & wood bread
- Qualitative comparison

input image

proposed method

proposed method w/o outlier removal



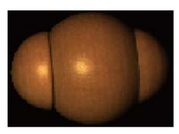
varying viewing direction

varying lighting direction

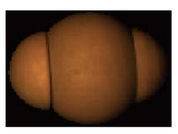
polarization

- Application to **uncalibrated PS**
  - diffuse only: up to the GBR ambiguity
  - diffuse + specular: unique shape

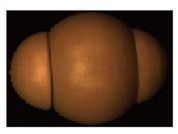
- Quantitative comparison
  - ground truth: polarization + averaging
  - evaluate RMSE of pixel values



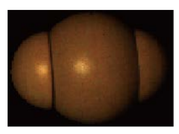
input image



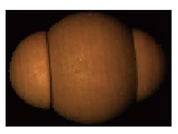
RMSE: 3.67
proposed method



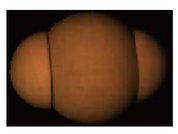
RMSE: 7.49
proposed method w/o outlier removal



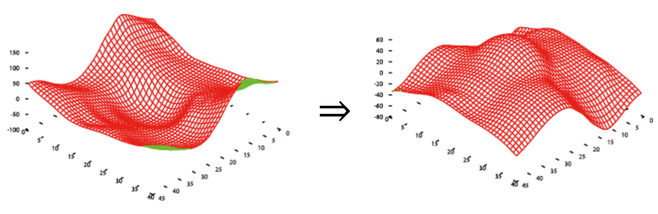
RMSE: 9.24
varying viewing direction



RMSE: 4.91
varying lighting direction



ground truth: polarization + averaging



diffuse only ⇒ diffuse + specular

Conclusion

- Main contribution

Separating **diffuse** and **specular** reflection components for **photometric stereo** based on **light fields**

  - reveal the **low-rank structure** of multi-view images under varying lighting directions
  - achieve diffuse-specular separation via **low-rank approximation** of 3rd order tensor
  - show the effectiveness of integrating two clues based on **varying viewing directions** and **varying lighting directions**
- Future work
  - scenes with **non-negligible parallaxes**
  - non-Lambertian diffuse reflection
- Acknowledgements

JSPS KAKENHI Grant Numbers JP16H01676 and JP17H01766