

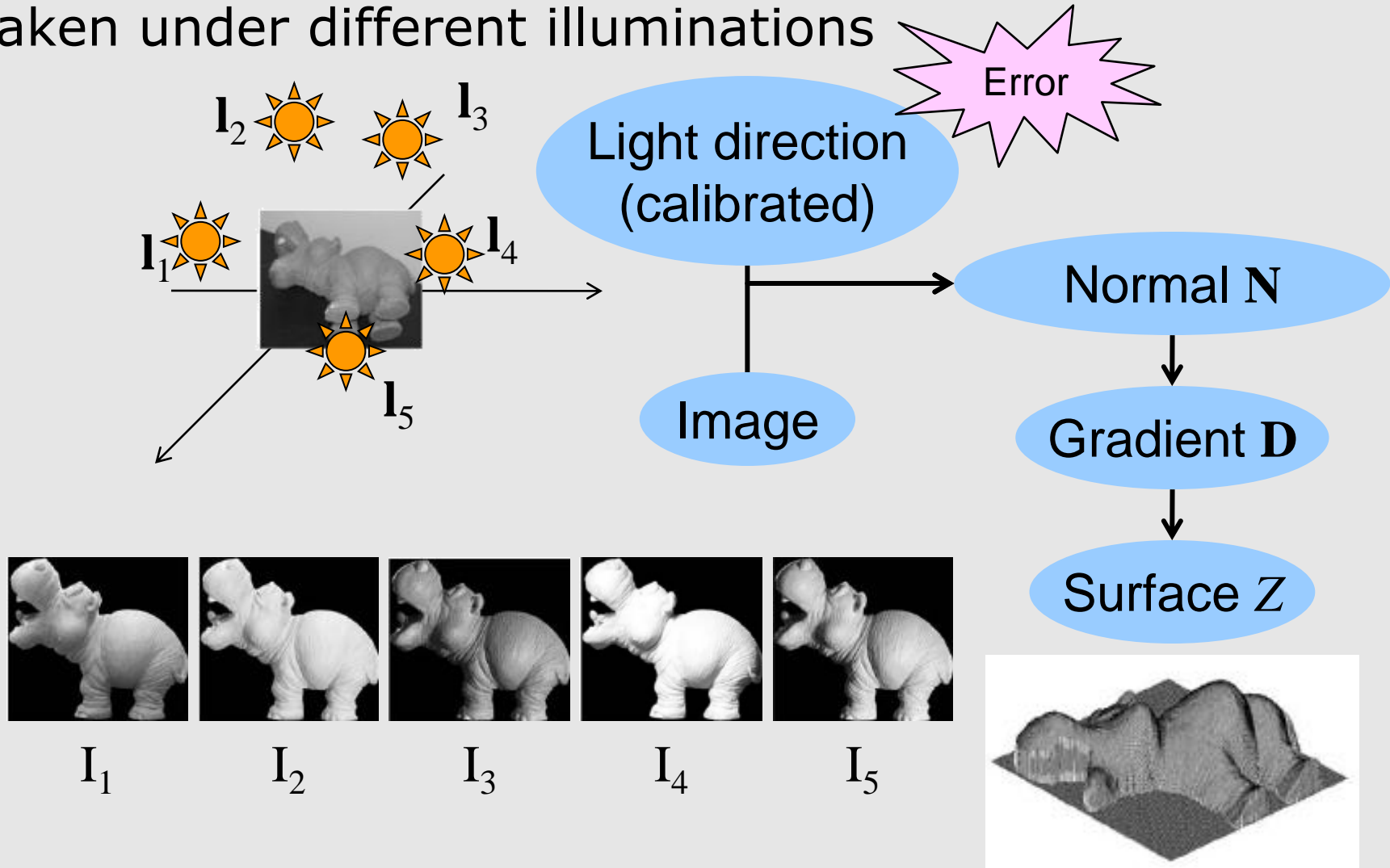
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Surface Reconstruction in Photometric Stereo with Calibration Error

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» Estimates surface orientation (normal) from images taken under different illuminations



» Reconstruct surface Z from gradient \mathbf{D}

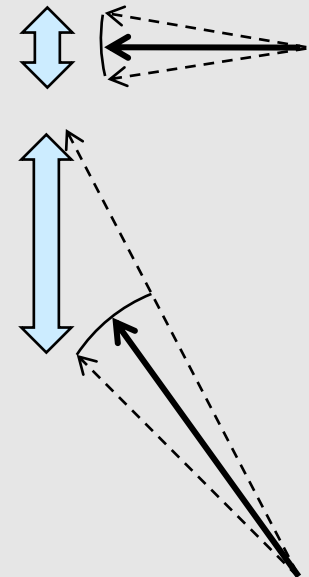
- > Error function

$$E = \int \left\{ \left(\frac{\partial Z}{\partial x} - D_x \right)^2 + \left(\frac{\partial Z}{\partial y} - D_y \right)^2 \right\} dx dy$$

2D Gaussian noise

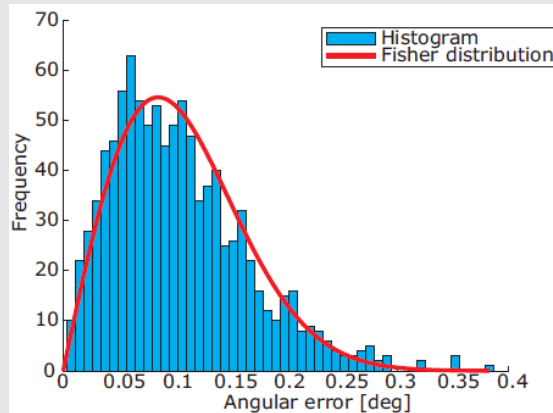
» Problem of reconstruction from gradient

- > Empirical assumption of noise
 - > Angular deviation results differently according to the true orientation
- ## » *What is the origin of errors in PS?*
- > Calibration errors of light directions



» Simulate calibration errors

- > Mirror ball images with image and quantization noise

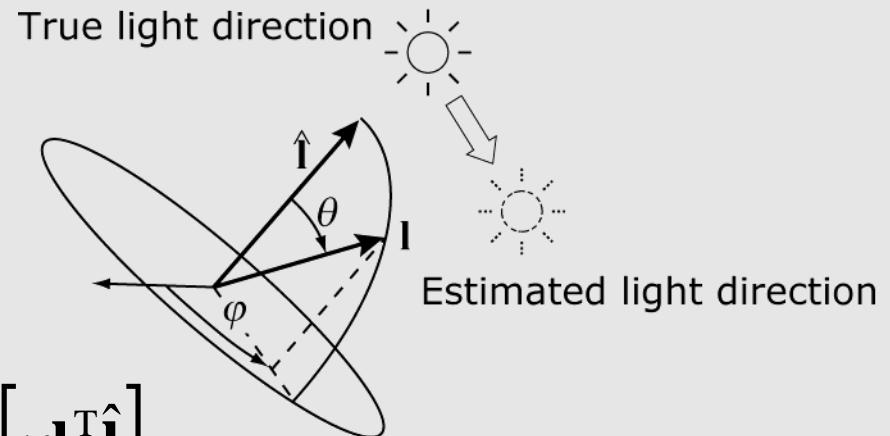


» Fisher distribution

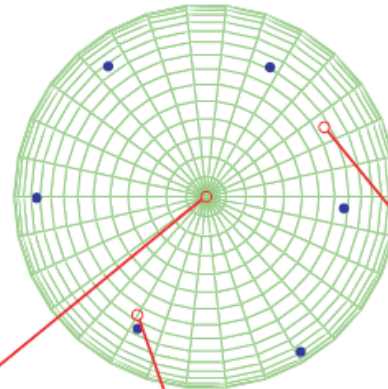
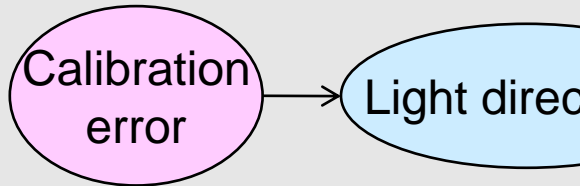
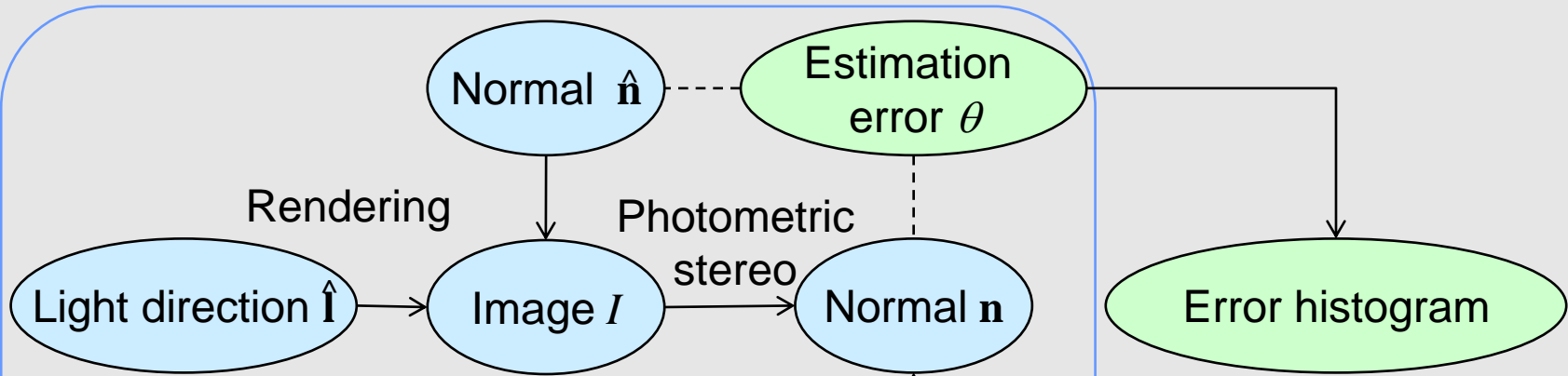
- > Angular error of unit vectors

$$f_{\text{cart}}(\mathbf{l}; \hat{\mathbf{l}}, \kappa) = \frac{\kappa}{4\pi \sinh \kappa} \exp[\kappa \mathbf{l}^T \hat{\mathbf{l}}]$$

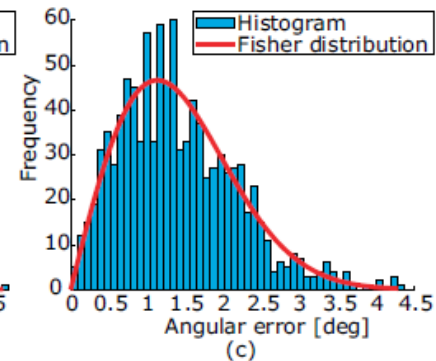
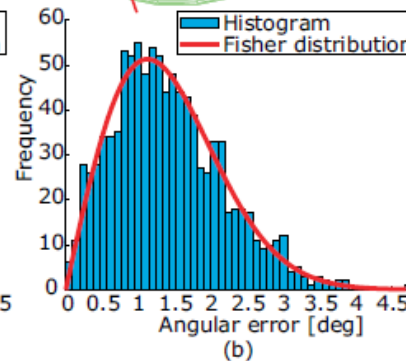
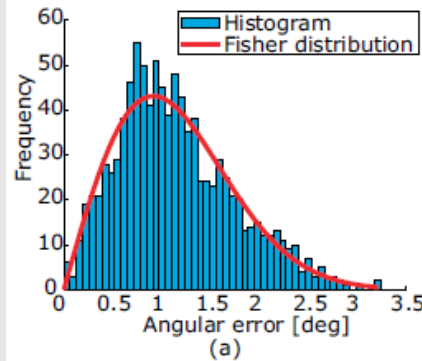
Precision parameter



Error distribution of surface normals



Angular error of surface normal:
↓
Fisher distribution



» Likelihood of surface normal

- > Assumes uniform angular noise κ

$$f_{\text{cart}}(\mathbf{l}; \hat{\mathbf{l}}, \kappa) = \frac{\kappa}{4\pi \sinh \kappa} \exp[\kappa \mathbf{l}^T \hat{\mathbf{l}}]$$

Estimated by photometric stereo

$$P(N | Z) \propto \prod_i \exp[\mathbf{N}_i^T \hat{\mathbf{N}}_i]$$

Calculated from conditioned Z

$$\hat{\mathbf{N}} = \frac{1}{\sqrt{Z_x^2 + Z_y^2 + 1}} \begin{bmatrix} -Z_x \\ -Z_y \\ 1 \end{bmatrix}$$

$$Z^* = \arg \min_Z (-\ln P(N | Z))$$

$$= \arg \min_Z \left(-\sum_i \mathbf{N}_i^T \hat{\mathbf{N}}_i \right)$$

Nonlinear optimization

» 3 synthetic scenes

- > Sphere
- > Vase
- > Penny

» 2 real scenes

- > Plaster sphere
- > Plaster statue

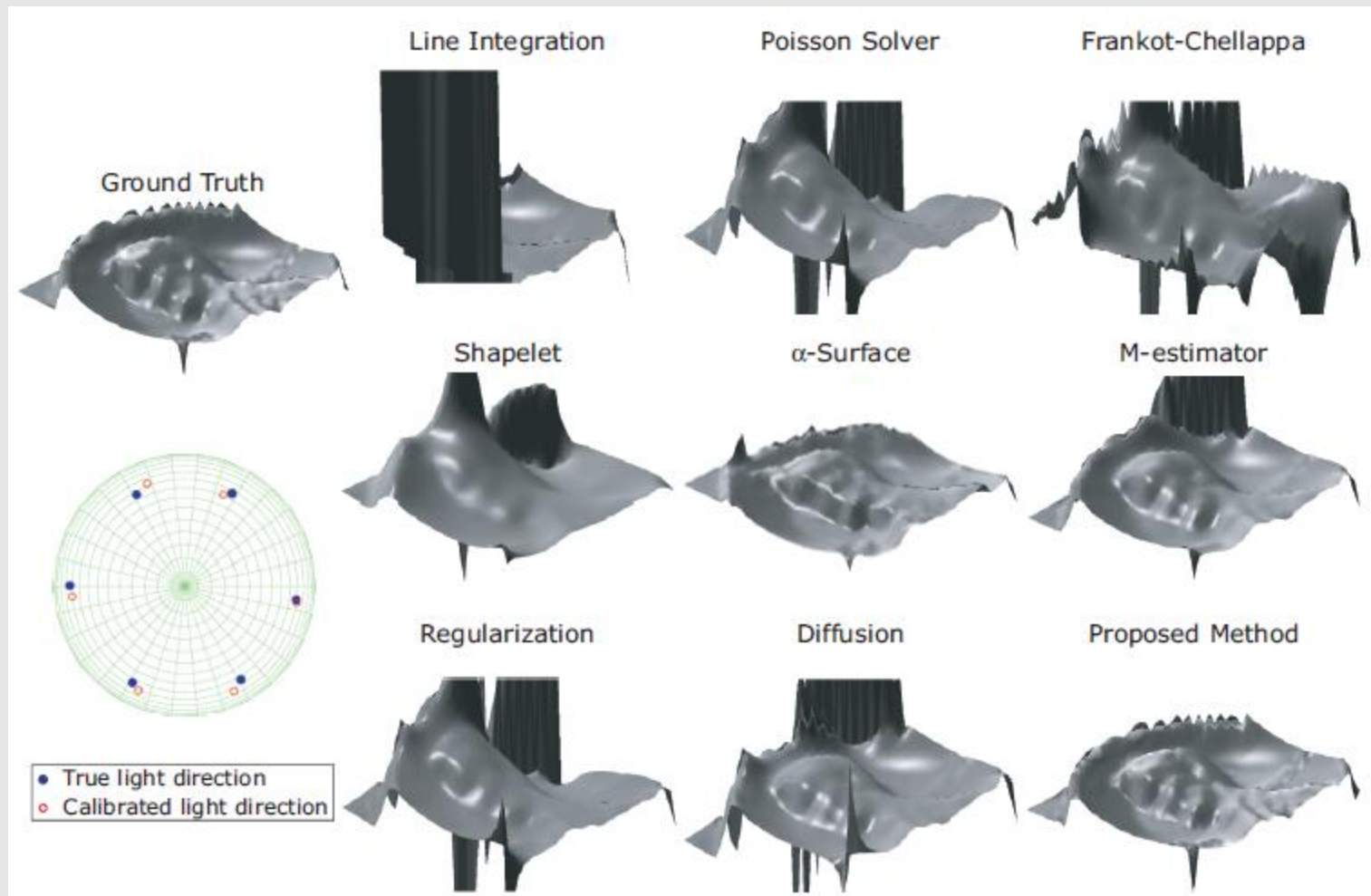
» Compared with 8 existing methods

Gaussian noise model

Compared methods

| Category | Method |
|------------------------------|-------------------|
| 1D integration | Line integration |
| Generalized Poisson equation | Poisson equation |
| | α -surface |
| | M-estimator |
| | Regularization |
| | Affine Diffusion |
| Basis functions | Frankot-Chellappa |
| | Shapelet |
| Fisher noise model | Proposed method |

Results of Penny scene



» Surface reconstruction algorithm incorporating calibration error

- › Noise model for calibration error in photometric stereo
- › Reconstruction by maximum likelihood estimation

» Future work includes...

- › Faster computation
(approx. 100 secs for 25×25 pixels by current implementation)
- › Avoiding local minima
- › Extension to non-uniform/anisotropic noise distribution