High Quality Shape from a RGB-D Camera using Photometric Stereo

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PROBLEM STATEMENT
Depth images from RGB-D cameras:
- Noisy
- No fine details
- Missing areas
Goal: Improve the quality of depths

CONTRIBUTIONS
- Propose a novel RGB ratio model to solve the nonlinearity and achieve similar accuracy to the previous methods.
- Introduce a robust multi-light method which outperforms the state-of-the-art approaches without any regularization term.
- First depth super-resolution method based on photometric stereo.

REFLECTANCE MODEL
Lambertian Reflectance Model

Intensity \( I \) [1]  
Albedo \( \rho \)  
Shading \( S \)

\( I = \rho S = \rho I^\top n \)

\( I \): light direction, \( n \): surface normal.
1st-order Spherical Harmonics (SH)

\( I = \rho (I^\top n + \varphi) = \rho s^\top n \)

\( \varphi \): ambient light parameter. SH model accounts for 87.5% real-world illumination.
Surface Normal

\[ n = \frac{1}{\sqrt{\nabla z^2 + 1}} \begin{pmatrix} \nabla z \\ -1 \end{pmatrix} \]

Our goal is to acquire \( z \) from the SH model.

OVERALL ENERGY

\( E(s, \rho, z) = E_{data}(z) + E_{shading}(s, \rho, z) + E_{regu} \)

\( E_{data}(z) = \lambda_z \| z - z_0 \|^2 \) depth data term

\( E_{shading}(s, \rho, z) \) varies from methods

\( E_{regu} \) regularization imposed on \( \rho \) or \( z \)

REFERENCE


RGBD-FUSION LIKE METHOD
Modification of RGBD-Fusion method [2].

\[ E_{shading} = \| I - \rho s^\top n \|^2 \]

\[ E_{regu} = \lambda_s \| \sum_{k \in N} \omega_k (\rho - \rho_k) \|^2 + \lambda_z \| \Delta z \|^2 \]

Input depth [3]  Pre-processing  Refined depth

MULTI-LIGHT METHOD

Red and Green channel:

\[ \frac{I_R - \rho R \varphi_R}{I_G - \rho G \varphi_G} = \frac{\rho R l_R^\top n}{\rho G l_G^\top n} \]

Nonlinearity has been resolved.

\[ \rho_R (I_R - \rho R \varphi_R) l_R^\top n - \rho_R (I_G - \rho G \varphi_G) l_G^\top n = 0 \]

\[ \rho_G (I_G - \rho G \varphi_G) l_G^\top n - \rho_G (I_R - \rho R \varphi_R) l_R^\top n = 0 \]

\[ \Rightarrow R(\rho, z) = 0 \text{ (RGB ratio model)} \]

RESULTS

SYNTHETIC DATA

RMSE 2.87, MAE 17.22  RMSE 2.88, MAE 17.73  RMSE 2.89, MAE 19.64

REAL DATA

RMSE 3.33, MAE 16.30

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