Depth estimation using light fields and photometric stereo with a multi-line-scan framework

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Content

- Motivation
- Light fields
- Photometric stereo
- Combination of both
- Quantitative results using synthetic data
- Experimental results using AIT multi-line-scan system
- Conclusions
Synthesis of Light fields & Photometric Stereo

Combine advantages of light fields and photometric stereo by a systematic combination

- Fine depth measurements
- Good absolute depth measurements
- 3D reconstruction of homogeneous surfaces
- 3D reconstruction of highly reflective surfaces
Light Field Cameras

AIT multi-line-scan system

Industrial acquisition setup
Light Field Cameras

Lytro

Lytro Illum

Xapt Eye-sect XA

Pelican PiCam

AIT multi-line-scan system
Light-Field Concepts

- Varying viewing perspectives

Plenoptic camera

Matrix camera

Multi-line-scan setup

| e.g. Lytro | e.g. Xapt | AIT |

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Light-field Depth Estimation

\[ \alpha^*(x, y) = \arg \min_\alpha \sum_{i=1}^{n} |I_i(x_\alpha, y_\alpha) - I_0(x, y)| \]

**Skewed stack**

**Reference frame**

**Pros / Cons**
- **Good absolute** depth accuracy
- **Poor relative** depth accuracy

EPI [2]
Photometric Stereo Concepts

- Varying illumination

Light dome

Multi-line-scan setup

Line 1 ... Line n

← Transport direction
Photometry Depth Estimation

\[ I = \rho \cdot L \cdot N \]

- \( I \) ... pixel intensity vector
- \( \rho \) ... albedo
- \( L \) ... illumination vector
- \( N \) ... normal unit vector

**Pros / Cons**
- **Good relative** depth accuracy
- **Poor absolute** depth accuracy

Implemented with Frankot and Chelappa [3]
Synthesis of Light fields & Photometric Stereo

Lightfield (varying observation)

Photometric Stereo (varying illumination)

Lightfield depth

Fusion

Lightfield + Photometric Stereo depth
Combination of Light fields & Photometric Stereo

\[ D = \lambda_{lf} \cdot D_{lf} \ast f_{lo}(u, v) + \lambda_{ps} \cdot D_{ps} \ast f_{hi}(u, v) \]

**Pros / Cons**

- Preserve coarse depth information (low frequencies) from light-field depth estimations and fine details (high frequencies) from photometric stereo depth estimations
Quantitative Results Using Synthetic Data

MSE of disparity w.r.t. GT
- Light field only: **4.7372**
- Light field + Photometric stereo: **0.1808**
AIT Multi-Line-Scan System [1]

- Each sensor line observes the conveyor belt in a different viewing angle
- During acquisition, object moves under the sensor
AIT Multi-Line-Scan System
Experimental Results Using AIT Multi-Line-Scan System

Texture | LF only | LF+PS
Experimental Results Using AIT Multi-Line-Scan System

Texture  
LF only  
LF+PS
Conclusions

Light fields (pros / cons)
- **Good absolute** depth accuracy
- **Poor relative** depth accuracy

Photometry (pros / cons)
- **Absolute** depth offset
- **Good relative** depth accuracy

Combination
- **Improved** depth map
- **Fine surface structures**
- **Good absolute** depth accuracy
- **In-line and real-time** with multi-line-scan setup

Experimental results
- Synthetic rendered data
- Multi-line-scan setup coins

Quantitative results
- Significant improvement of accuracy

Future Work
- Further quantitative evaluation
- Combination through energy minimization
References


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