Single-shot Monocular RGB-D Imaging using Uneven Double Refraction

CVPR 2020 Oral

Andreas Meuleman†* Seung-Hwan Baek†* Felix Heide§ Min H. Kim†

†KAIST §Princeton University

* Equal contribution
RGB-D Imaging Applications

- **Autonomous vehicles**
  - [Menze and Geiger CVPR15]

- **Robotics**
  - [Zeng et al. RSS19]

- **VR/AR**
  - [Holynski and Kopf TOG18]
RGB-D Cameras

Pulsed ToF
- High cost
- Sparse sampling

Correlation ToF
- Indoor only
- Occlusion issue

Apple

Multi-view camera
- Occlusion issue
- Large form factor
- Synchronization

Dual pixel
- Short depth range

Light-field camera
- Low spatial resolution

Velodyne

Microsoft

[Lytro](https://www.lytro.com)
Goals of Our Monocular RGB-D Imaging

Passive
• Indoor/outdoor

Single shot
• Dynamic scene

Single camera
• Small form factor

Real time
• User feedback
Double Refraction

Birefringent crystal

Ordinary ray

Extraordinary ray

[Baek et al., TOG16]
Depth from Double Refraction

Ordinary ray

Extraordinary ray

Birefringent crystal

Scene

Lens

Sensor

$z$

$f$

$P_s$

$P_o$

$P_e$

$O$

[Baek et al., TOG16]
Depth from Double Refraction

Scene \( \rightarrow \) Lens \( \rightarrow \) Sensor

- Single shot
- Passive
- High spatial resolution

[Baek et al., TOG16]
Even Double Refraction

Even intensity of double refraction

Identification problem of the edges

Double refraction

[Baek et al., TOG16]
Challenges of Depth from Double Refraction

Low computational efficiency
38 sec. @ 2048 x 1500 pixels

Restored color image with deconvolution artifacts
Technical Contributions

- Uneven double refraction
- Joint depth & color reconstruction
- Rectification
Cross Polarization of Double Refraction

Birefringent crystal

Ordinary ray

Extraordinary ray

Linear polarizer

Birefringent material

Linear polarized perpendicular to each other
Uneven Double Refraction
Joint Reconstruction of Depth and Image

Depth samples: \(\{z_1, z_2, \ldots, z_{N-1}, z_N\}\)
Joint Reconstruction of Depth and Image

Depth samples: \( \{z_1, z_2, \ldots, z_{N-1}, z_N\} \)
Rectification

Spatially-varying disparity

Spatially-invariant disparity
Simulation Results: Input
Simulation Results: Estimated Depth
Real-world Results: Input
Real-world Results: Restored Image
Real-world Results: Estimated Depth
Conclusion

- Monocular RGB-D imaging
  - Real-time
  - Single-shot
  - Passive

https://github.com/KAIST-VCLAB/fastbirefstereo

Andreas Meuleman*  Seung-Hwan Baek*
Felix Heide  Min H. Kim

* Equal contribution

Narrated by Mustafa Yaldiz