Light Field Cameras

for metric 3D measurements

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www.raytrix.de
The Company

Founded 2009 – 15 employees in 2015

Light field cameras for industry and research

Patented MLA design for optimal depth-of-field and effective resolution combination

Image Engineering Innovation Award 2013
CHIP Awards 2012 „Innovation of the Year”
iF Design Award 2014
red dot design award
Light Field Cameras

Some of the currently available Raytrix cameras

- **R42** - 42 MP CMOS sensor, up to 10 MP effective resolution at 7 fps
- **R29** - 29 MP CCD sensor, up to 7 MP effective resolution at 6.2 fps
- **R12** - 12 MP CMOS sensor, up to 3 MP effective resolution at 30 fps
- **R5 / R5μ** - 4 MP CMOS sensor, up to 1 MP effective resolution at 180 fps
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**Standard Camera**
Main lens focuses directly onto image plane.

**Lightfield Camera**
Main lens generates intermediate image. Microlens array acts as camera array that focuses intermediate image onto image plane.
Example

Plenoptic Camera Raw Image

Compute “refocused” image
Raytrix cameras use micro lens arrays with different micro lens types which differ in their focal length. This extends the depth-of-field of the camera.
Extended Depth of Field

**Comparison for standard photography**

Both images were taken with same 11 megapixel sensor, same lens and same aperture.
Extended Depth of Field

Comparison for microscopy

Standard 4MP Camera

Raytrix Lightfield Camera R5µ
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Metric Calibration Model

Free Parameters

Simplified projection model

- Focal Length
- Optical Axis
- Radial Distortion
- Depth Distortion
Metric Calibration

Capturing Images for Metric Calibration

First image of a dot target with 1mm dot pitch.

The small inset image shows the calculated virtual depth distribution.

Add a second image of the same dot target.
Metric Calibration

Calculating Metric Calibration

Calibration target points in virtual space

Calculate projection model parameters by projecting points from virtual space to object space and calculating residuals to best fitting metric dot target models.

White points show ideal dot target models.

RMS calibration error ~0.5mm.

Total calibration volume ~100x70x200mm
Metric Calibration

Measurements on Calibrated Images

Total working volume 100 x 70 x 200 mm (WxHxD).
Depth precision ~1%, i.e. ~2mm.

Measurement on plane parallel to image sensor

Measurement on tilted plane wrt. to image sensor

Total Focus Image

Depth Image (not filled)
Metric Calibration

Comparison with and without metric calibration

Original

Without Metric Calibration

With Metric Calibration

Metrically calibrated 3D reconstruction shows correct curvature of tower.
Metric Calibration

Stitching of 6 Views of Tower

Original

6 reconstructed views

Stitching Result
Sharp 3D-Edges

Good reconstruction of sharp 3D-edges

Picture taken with Raytrix R29M camera
Occlusion

with Stereo Camera System

Red area can only be seen by left camera L. Therefore, no depth calculation possible in this area.

Depth estimation possible only in green area.
Occlusion

with Light Field Camera

No occlusion area in this example due to many micro cameras with small field of view.

Depth estimation possible in green area.
The light projection envelopes for virtual image points behind the image plane at different positions create non-overlapping sets of micro images.

The original light projection envelope can be reconstructed.
The closer an object is to the camera, the further away the virtual image is from the image plane and the more micro lenses see the same point.

The effective resolution is a combination of the number of micro images a point is projected to and the micro lenses' depth-of-field.
Effective resolution ratio for one image dimension per lens type with respect to virtual image position. Objects projected onto total covering plane are those furthest away that can still be refocused. As objects get closer to camera, the effective resolution is reduced.
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Overview

The following slides show the effect of using lenses with different focal lengths with a R29C Raytrix multi-focus plenoptic camera. It can be seen that the shorter the focal length, the closer objects have to be to the camera to be depth resolved.

The R29C has a 29 megapixel Kodak CCD sensor and offers a maximal effective resolution of 7 megapixels. Images in similar quality can be shot with a 25 megapixel sensor at 30 fps.
35mm Main Lens on R29C

Total Focus Image

Most of the 3D resolution is close to the camera. The background is more or less at one depth.

3D Rendering
50mm Main Lens on R29C

Total Focus Image

3D Rendering
Total Focus Image

3D Rendering

There is more depth resolution at the trees in the background.
100mm Main Lens on R29C

Total Focus Image

3D Rendering
100mm Main Lens on R29C

The grass plane to the trees in the background is better resolved. The person in the foreground is flat.

Total Focus Image

3D Rendering
35mm Main Lens on R29C

Refocus

Focus onto the blossom close to the camera.

3D Rendering
Refocus

Focus onto the background far from the camera.

3D Rendering
Darken everything depending on its distance from the focus plane.
3D-Face Capture

Picture taken with Raytrix R11C camera
3D-Face Capture
3D Lightfield Microscope

- Microscope Setup
- FoV ~ 1x1mm
- Total Focus
- 3D Reconstruction

Camera used is R5 with 4MP CMOSIS sensor.
Bonding Wire – Raytrix Camera
Particle Tracking Velocimetry

Single Camera Volumetric PTV

- Measure 3D flow of particles in water.
- Single light field camera.
- Simple metric calibration.
- In a typical measuring volume of 72x48x40mm we have a depth resolution < 0.4mm with an R29.
Particle Tracking Velocimetry

Calculated 3D flow from light field data
3D Capture of Paintings

LIGHT FIELD CAMERAS - RAYTRIX GMBH - 2014
Inspection Tasks

Picture taken with Raytrix R29M camera
Quality Inspection

Connector

Picture taken with Raytrix R5M camera.
Plant Growth Analysis

Picture taken with Raytrix R11C camera
One Shot – Many Outputs

**Single shot**
- One raw image
- Video possible
- Makro and Tele lenses
- Arbitrary object sizes and distances
- High effective resolution

**Depth Map**
- No metric 3D-calibration needed but possible
- Depth can only be calculated at structured areas

**3D-View**
- Variable base line
- Variable image orientation
- Multi-View for auto-stereoscopic displays

**All-In-Focus**
- Selective per-pixel focus
- Variable view point horizontally and vertically
- Variable 3D-zoom effect

**Image Processing**
- No metric 3D-calibration needed but possible
- Depth can only be calculated at structured areas

**3D-Data**
- One raw image
- Video possible
- Makro and Tele lenses
- Arbitrary object sizes and distances
- High effective resolution

**Light Field Cameras - Raytrix GmbH - 2014**
Download the free **TrixViewer** for Windows® and MacOS® and **raw light field data** from [www.raytrix.de](http://www.raytrix.de)