# raytrix

## Light Field Cameras

*for metric 3D measurements*

Dr. Christian Perwass

www.raytrix.de
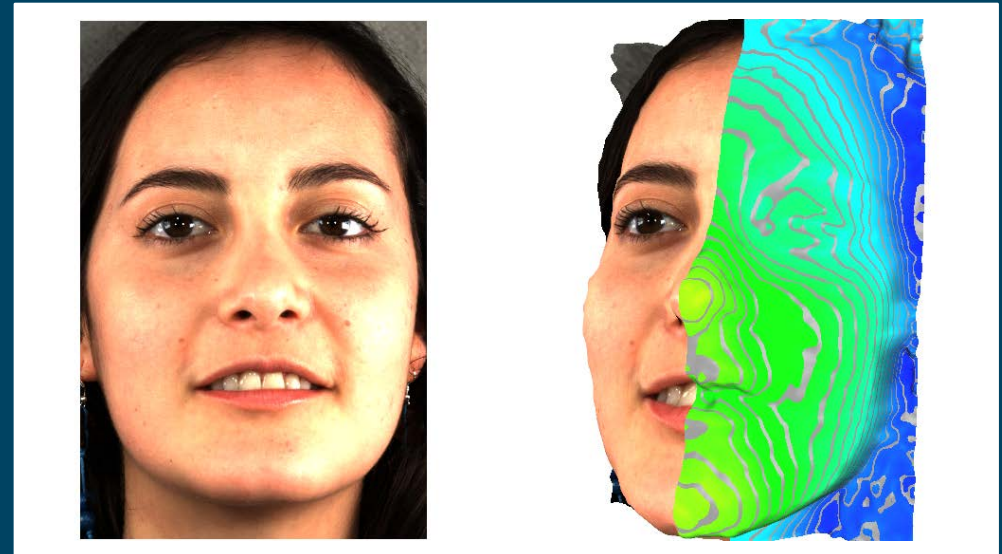
# The Company

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"
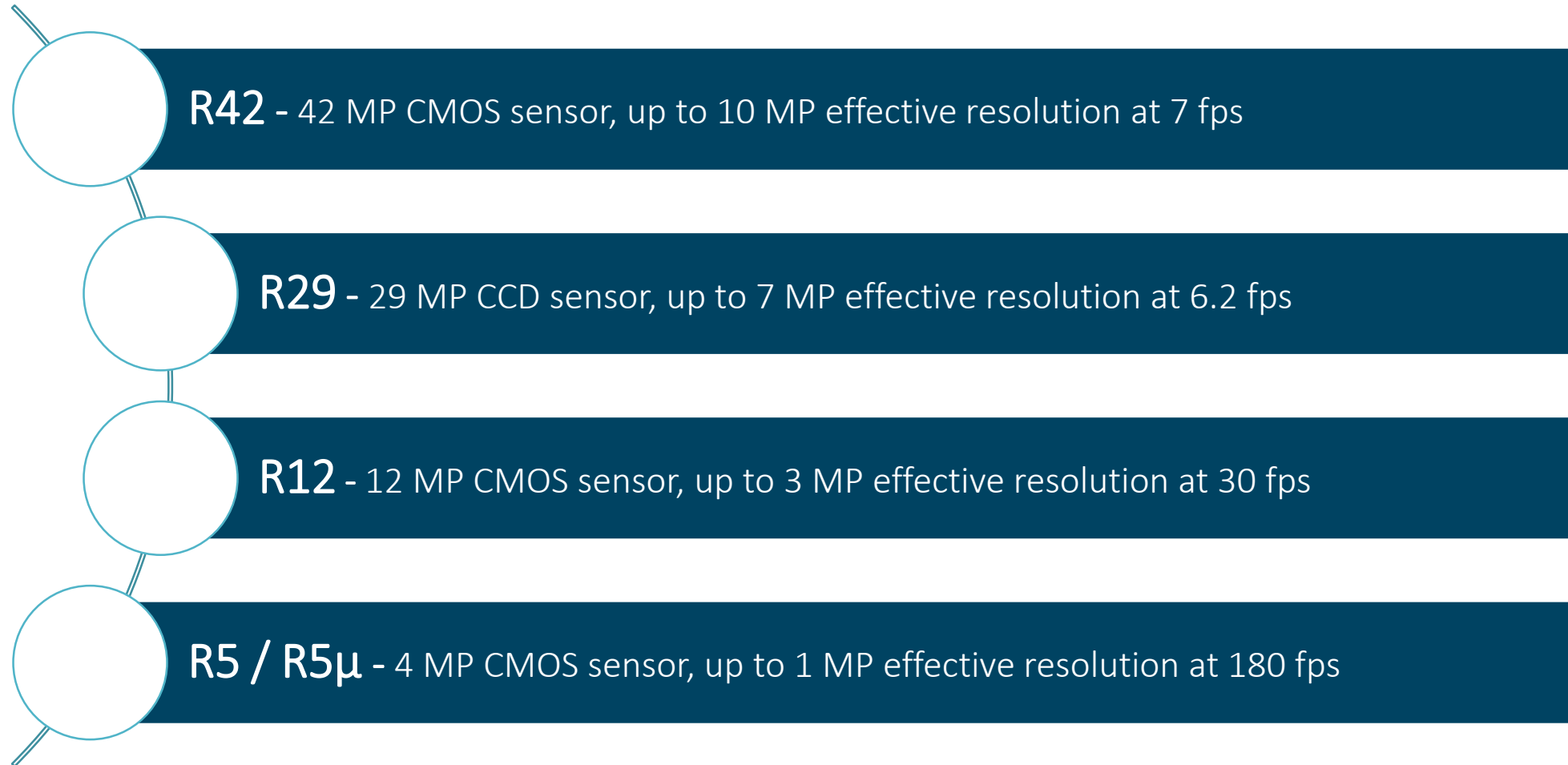
iF Design Award 2014

reddot design award

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# Light Field Cameras

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*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
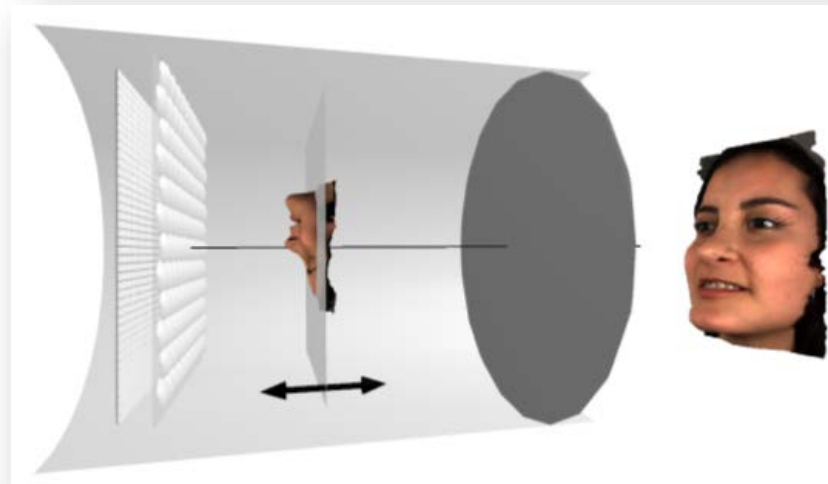
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# Content

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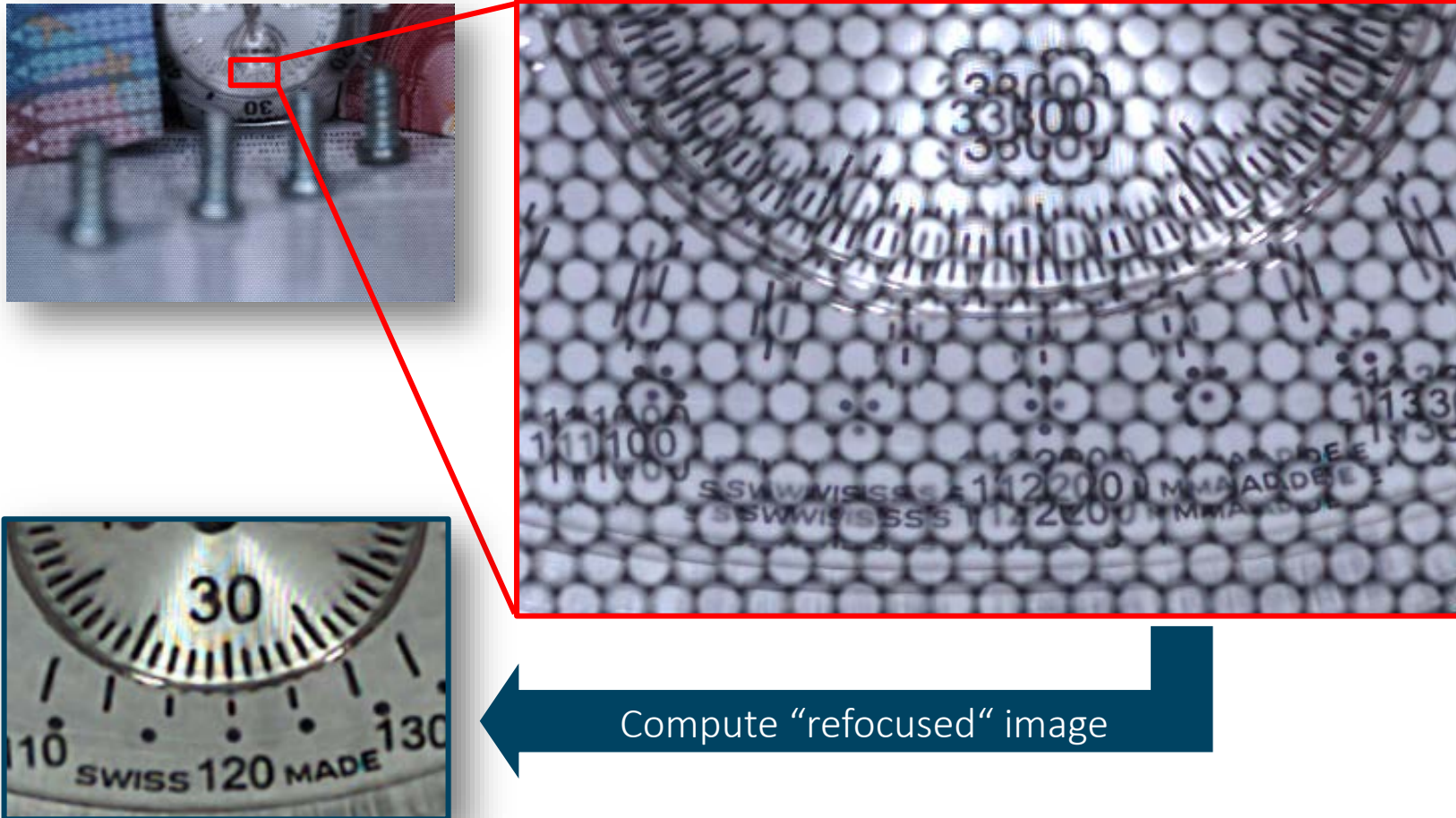### Standard Camera
Main lens focuses directly onto image plane.
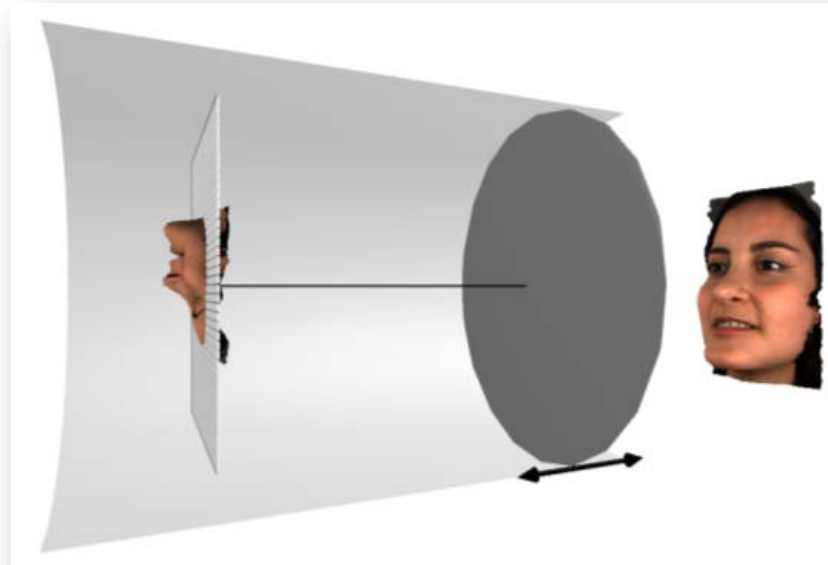


### Lightfield Camera
Main lens generates intermediate image. Microlens array acts as camera array that focuses intermediate image onto image plane.
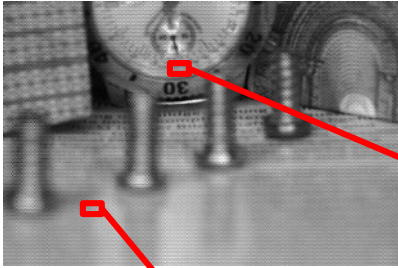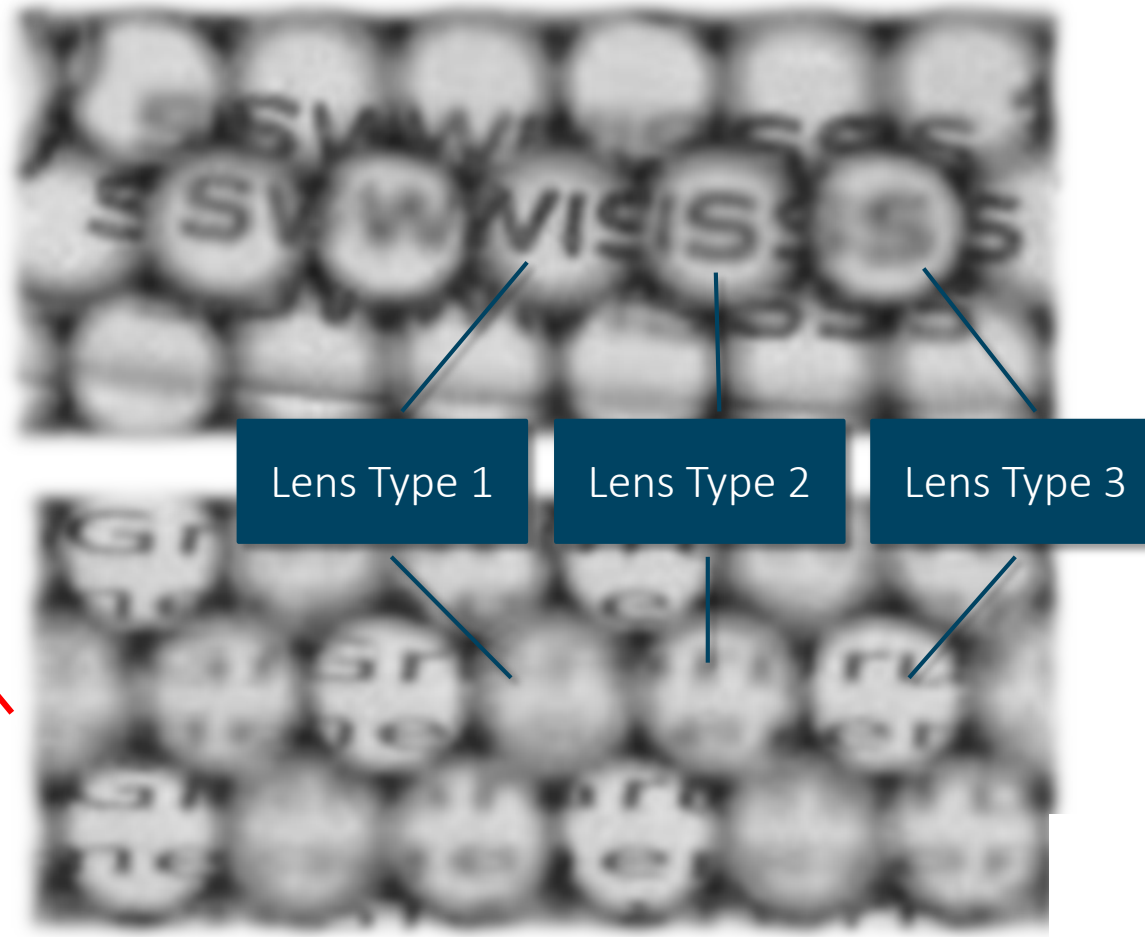


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*Plenoptic Camera Raw Image*



Compute "refocused" image

# Extended Depth-of-Field

Lens Type 1

Lens Type 2

Lens Type 3

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.

*Worldwide Patent*

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# Extended Depth of Field

*Comparison for standard photography*
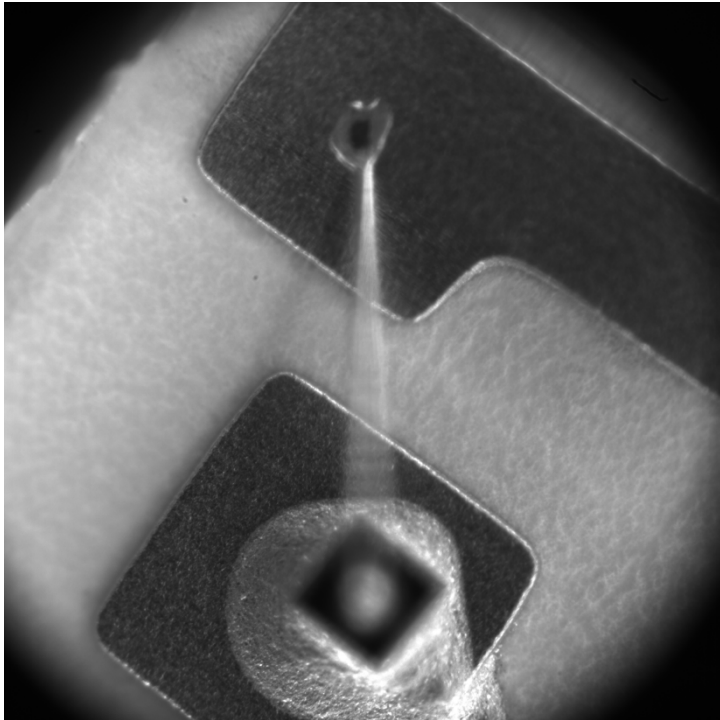
Standard Camera

Raytrix Lightfield Camera



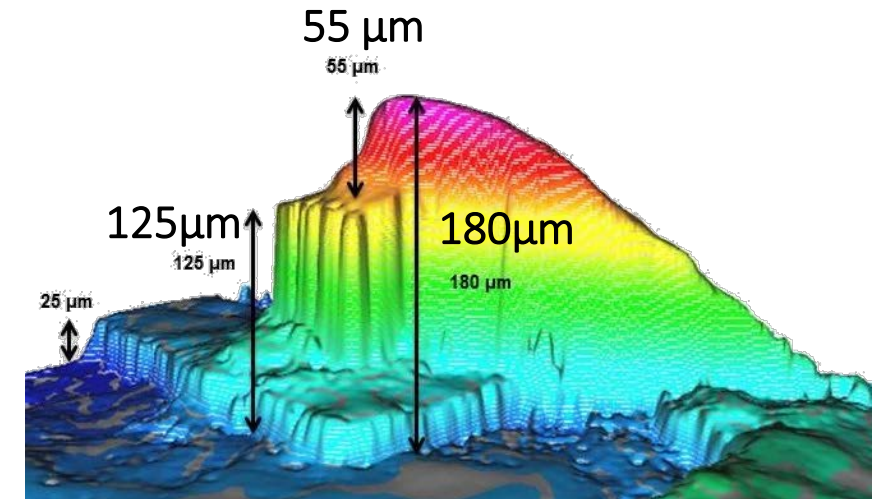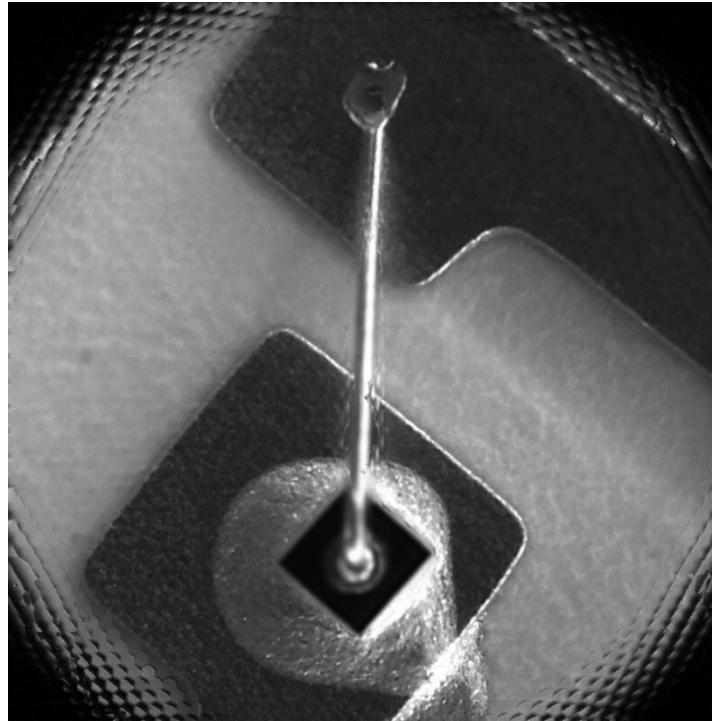Both images were taken with same 11 megapixel sensor, same lens and same aperture.

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# Extended Depth of Field

*Comparison for microscopy*

Standard 4MP Camera

Raytrix Lightfield Camera R5µ



55 µm

125µm

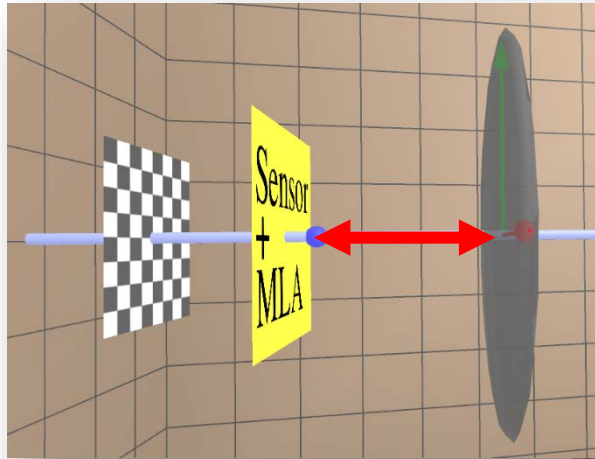180µm

25 µm

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# Content

Introduction

**Technical Details**

Application Examples

Conclusion

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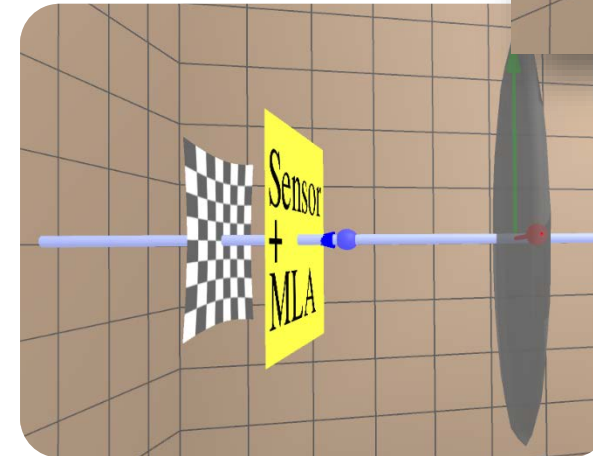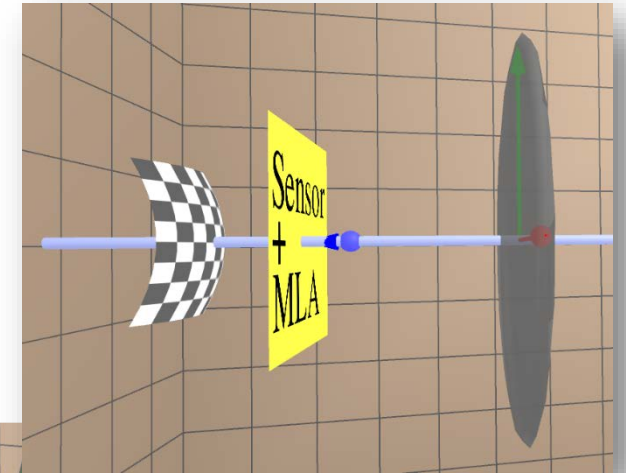∞ **raytrix**

*Free Parameters*
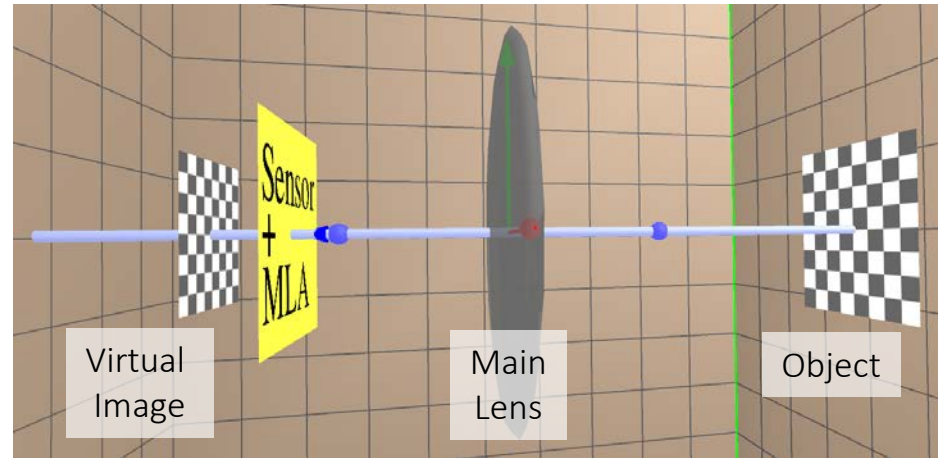


Simplified projection model

Focal Length
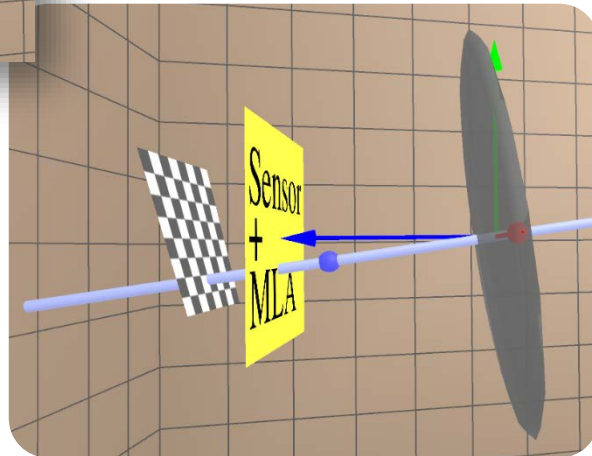
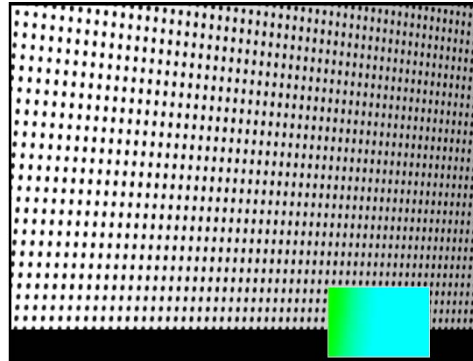Optical Axis

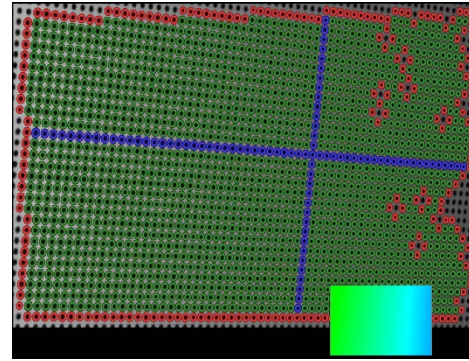Radial Distortion

Depth Distortion

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# Metric Calibration

*Capturing Images for Metric Calibration*

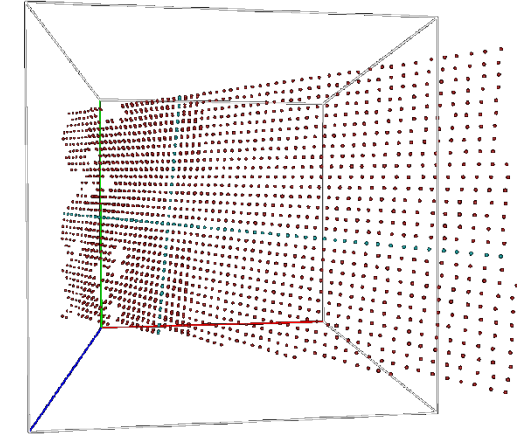First image of a dot target with 1mm dot pitch.

*The small inset image shows the calculated virtual depth distribution.*
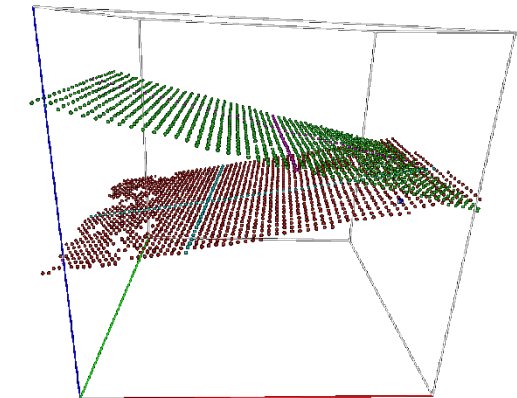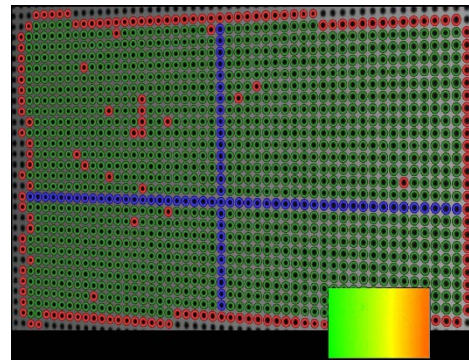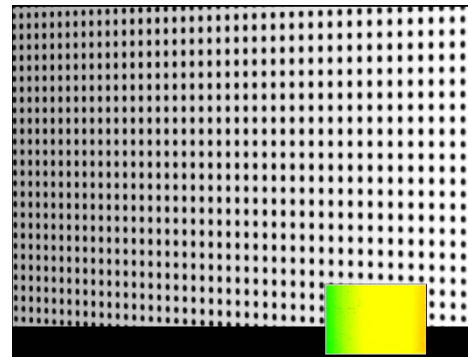


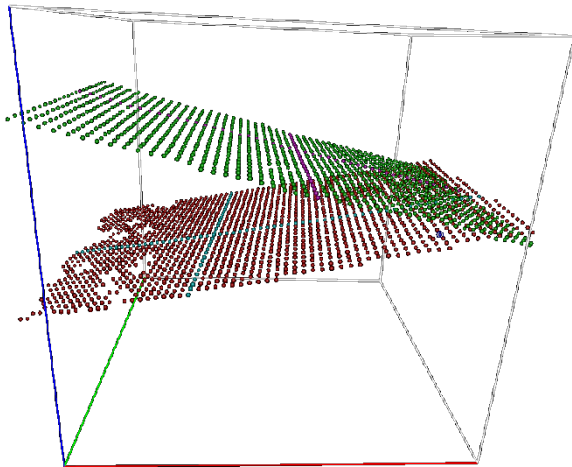Dot target image



Detected dot target



Virtual 3D positions of dots
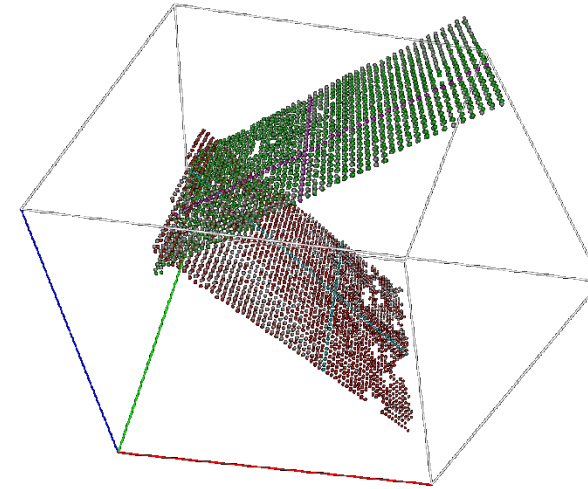
Add a second image of the same dot target.







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# Metric Calibration



## Calculating Metric Calibration
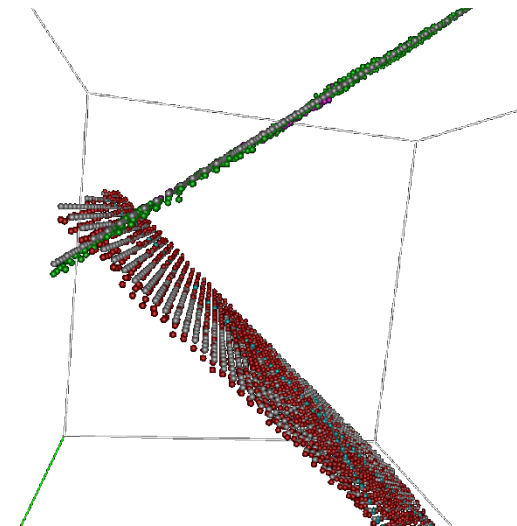
Calibration target points in virtual space

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

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# Metric Calibration
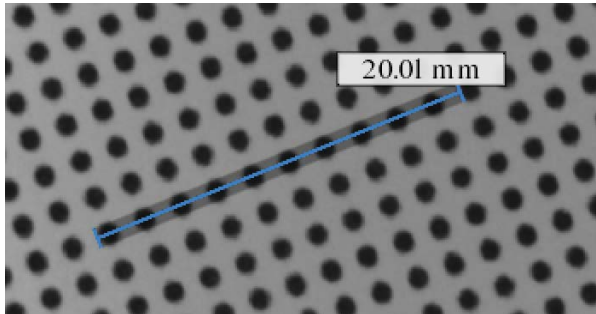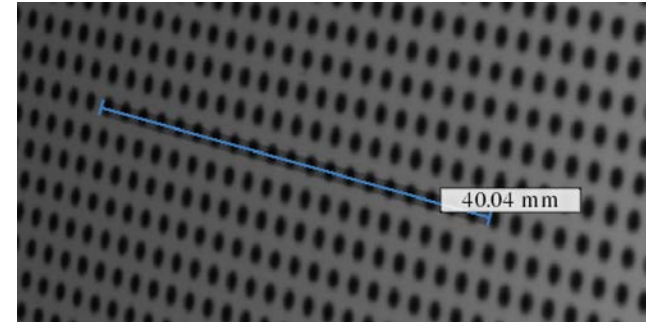
*Measurements on Calibrated Images*

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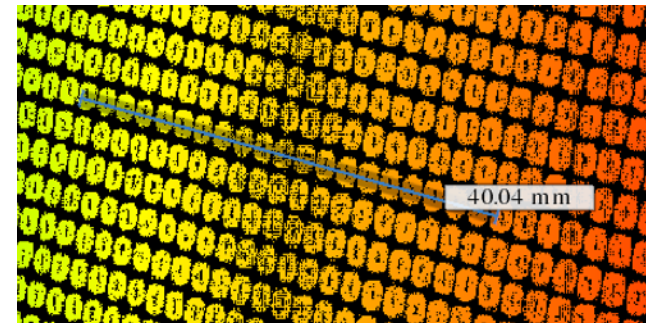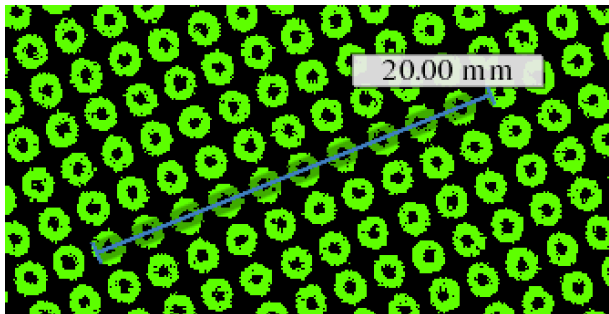Depth precision ~1%, i.e. ~2mm.

Measurement on plane parallel to image sensor

Measurement on tilted plane wrt. to image sensor

Total Focus Image



20.01 mm



40.04 mm

Depth Image
*(not filled)*



20.00 mm



40.04 mm

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# Metric Calibration

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*Comparison with and without metric calibration*

Original

Without Metric Calibration

With Metric Calibration



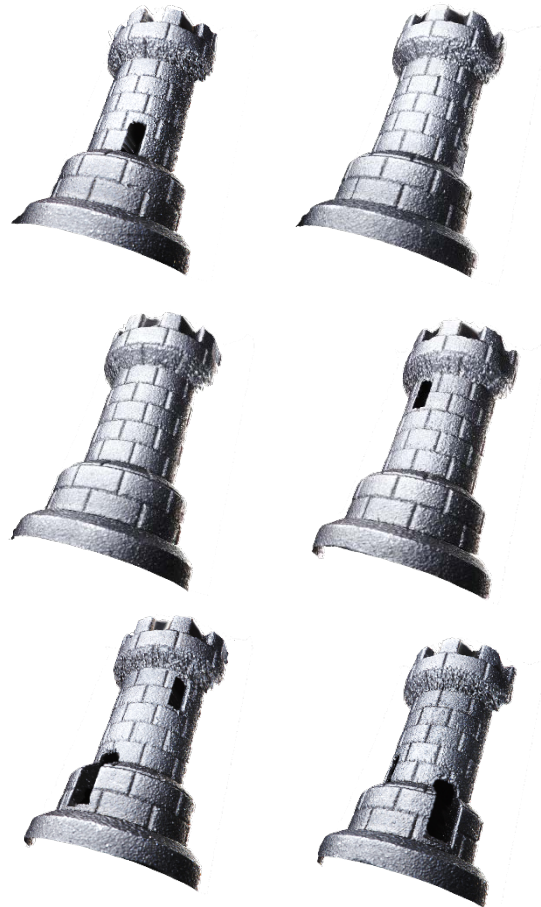Metrically calibrated 3D reconstruction shows correct curvature of tower.

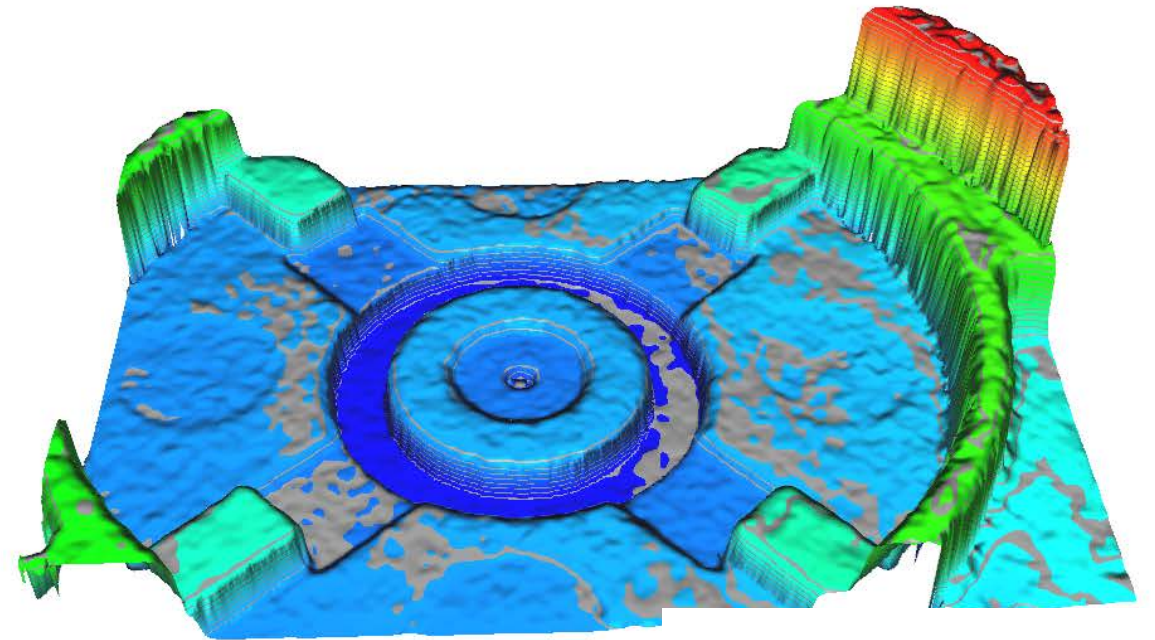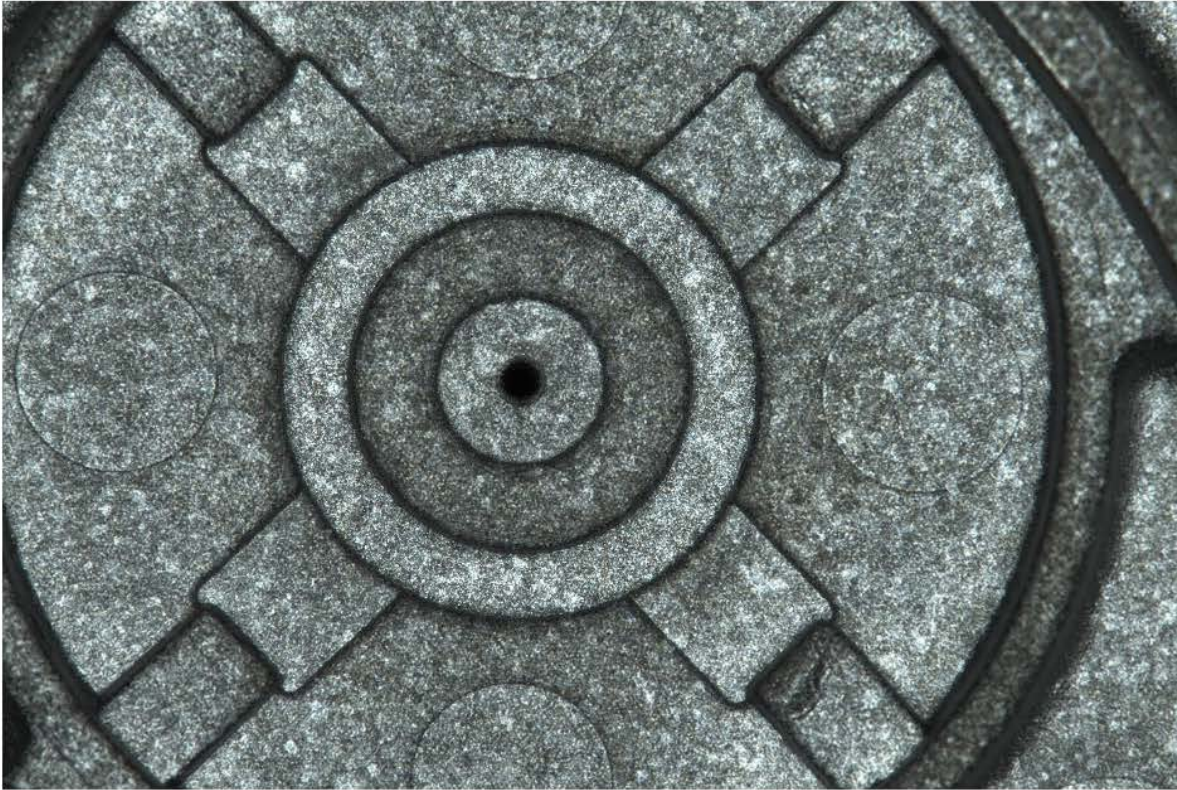## Stitching of 6 Views of Tower

Original

6 reconstructed views

Stitching Result

*Good reconstruction of sharp 3D-edges*
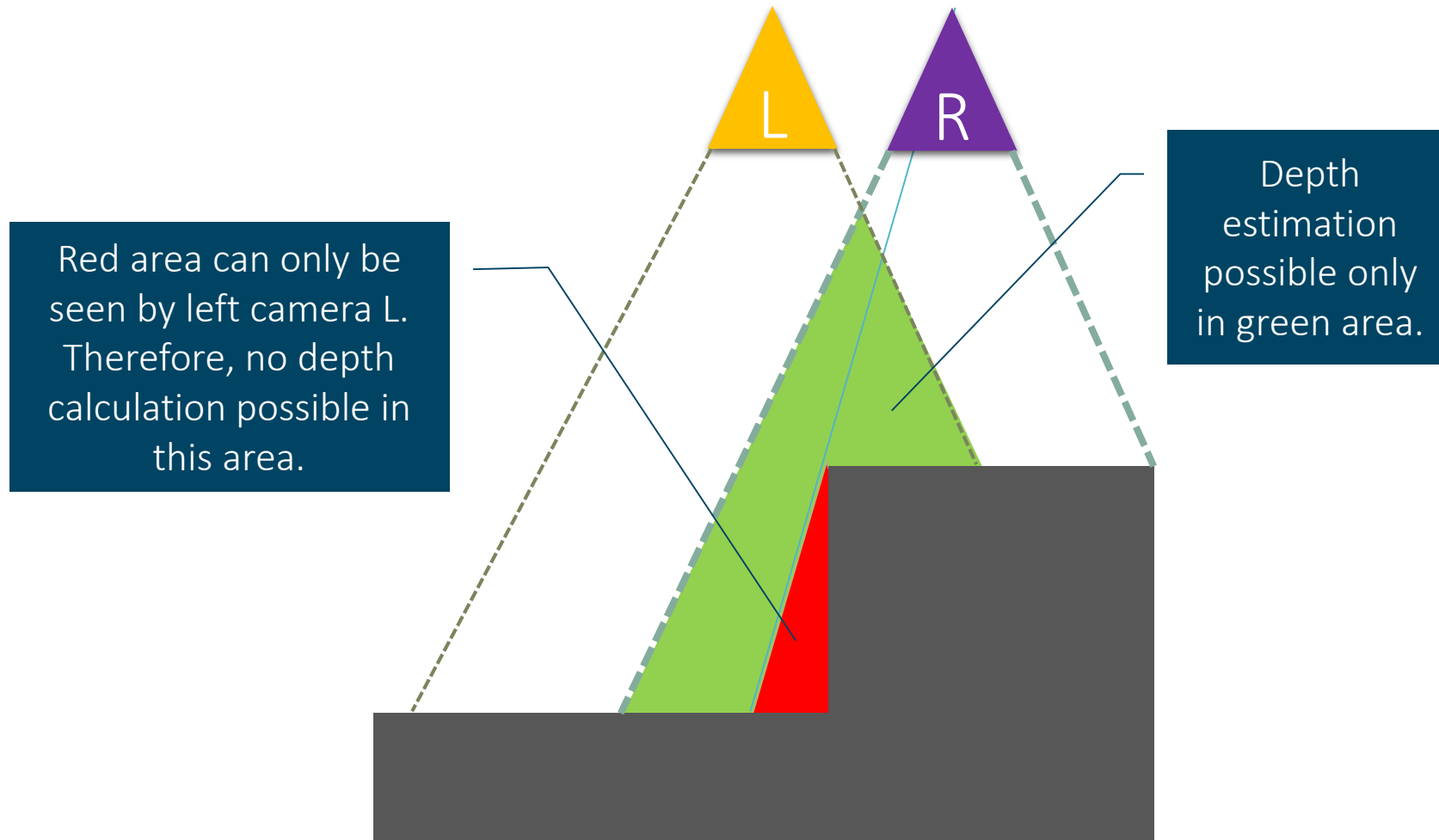


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*Picture taken with Raytrix R29M camera*

## with Stereo Camera System



**L** **R**

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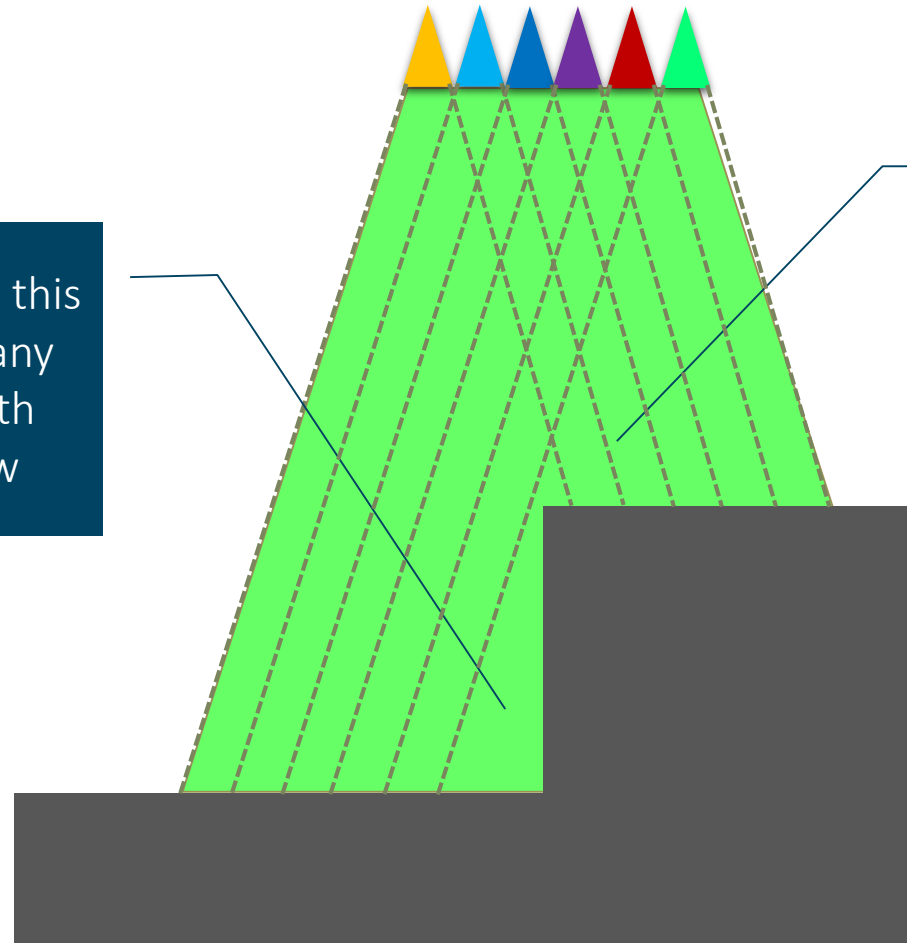
Depth estimation possible only in green area.

# 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.

# Image Formation
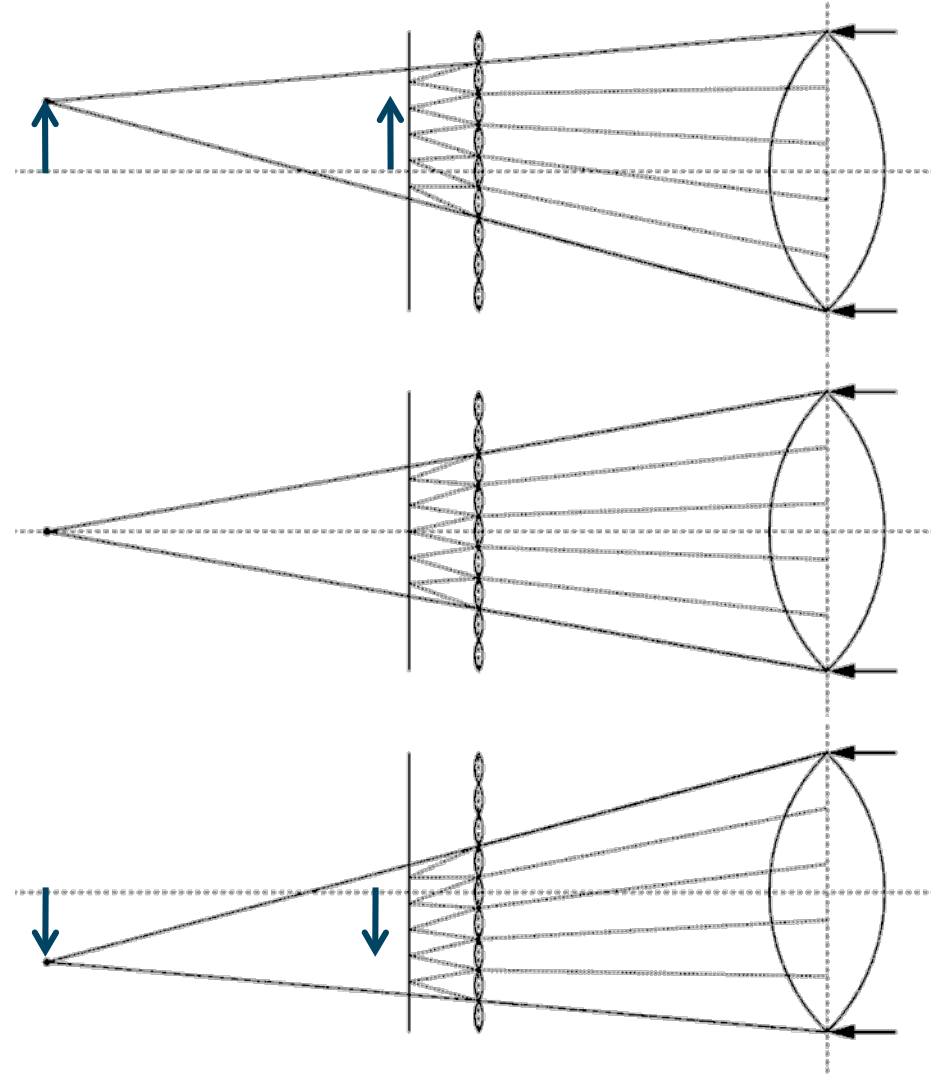
The closer an object is to the camera, the further away the virtual image is from the image plane and the more micro lenses see the same point.

The effective resolution is a combination of the number of micro images a point is projected to and the micro lenses' depth-of-field.

Object further away

Virtual image

Initial object position

Virtual image

Object closer

Virtual image

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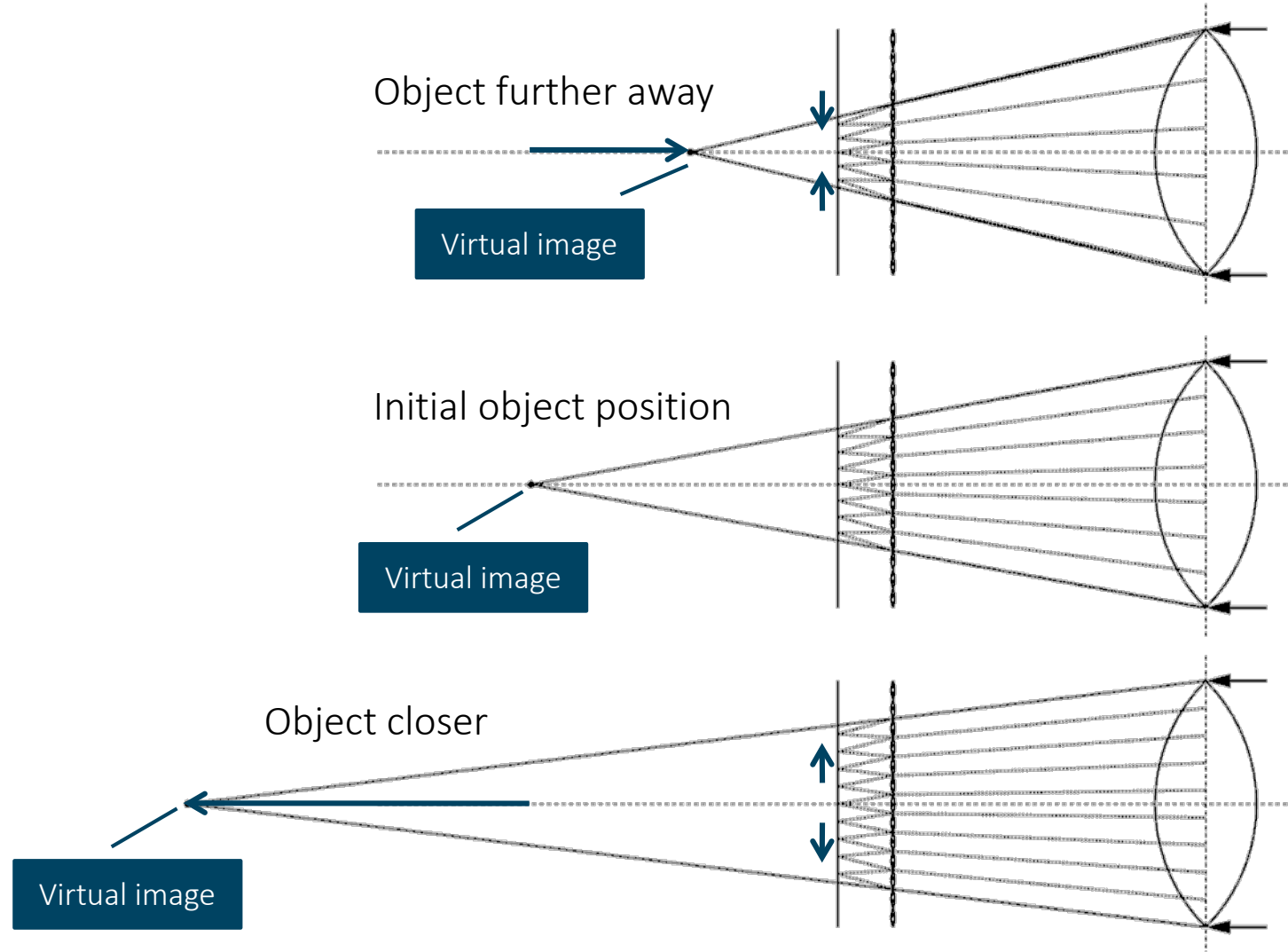
## Multi Focus

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.
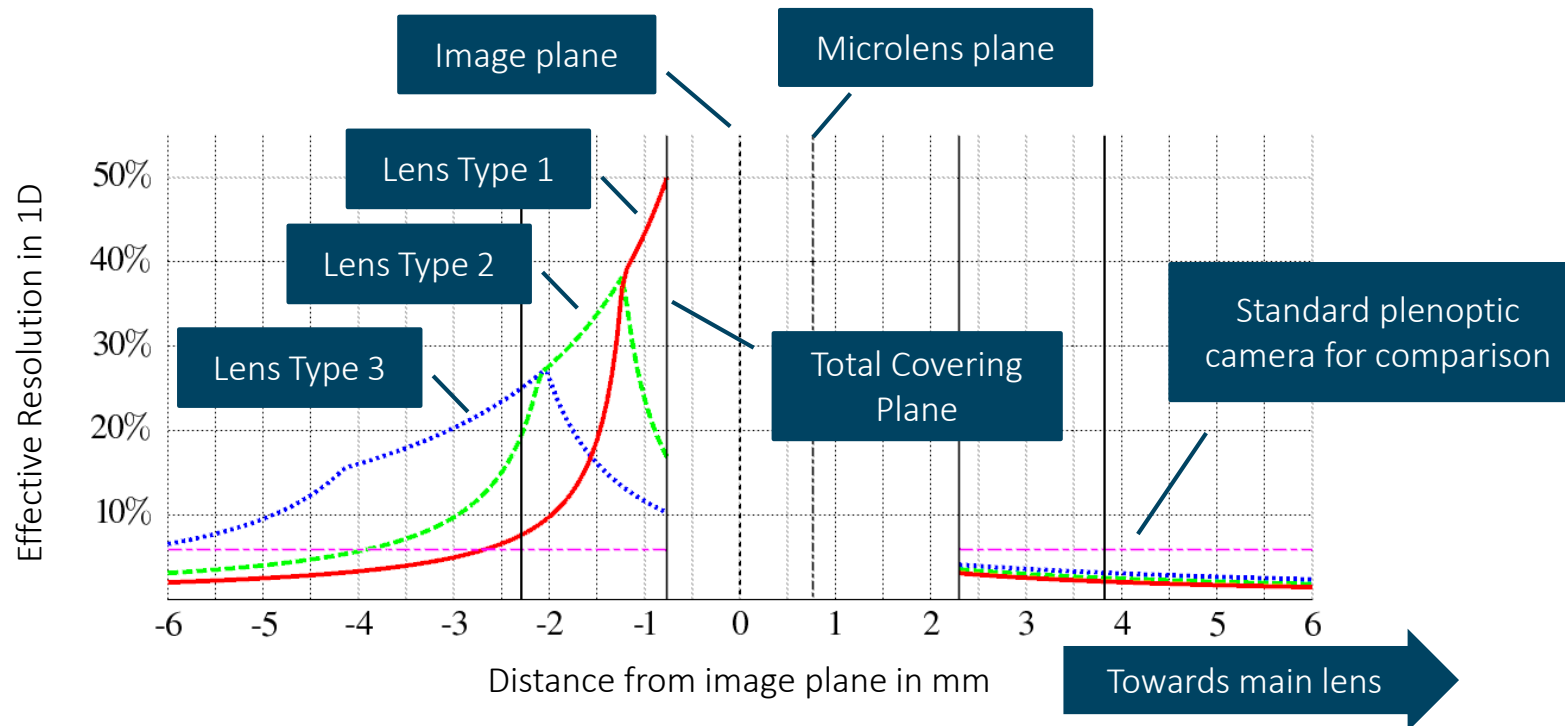
# Content

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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.
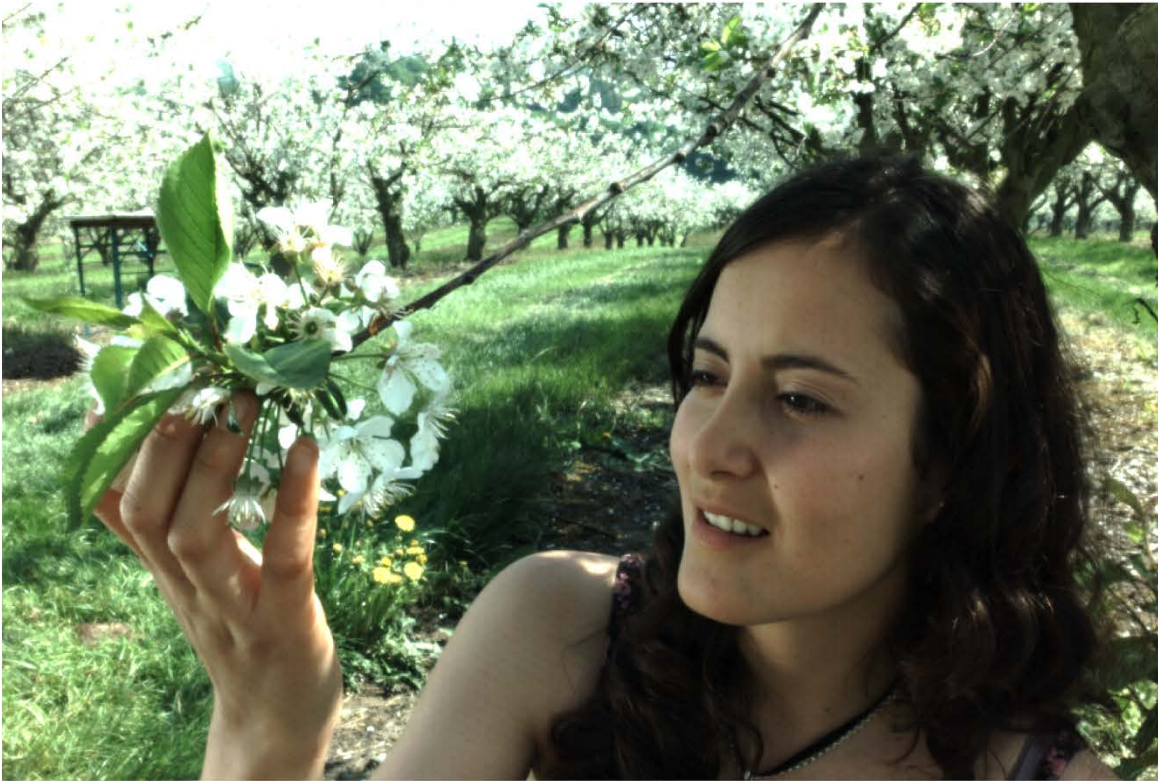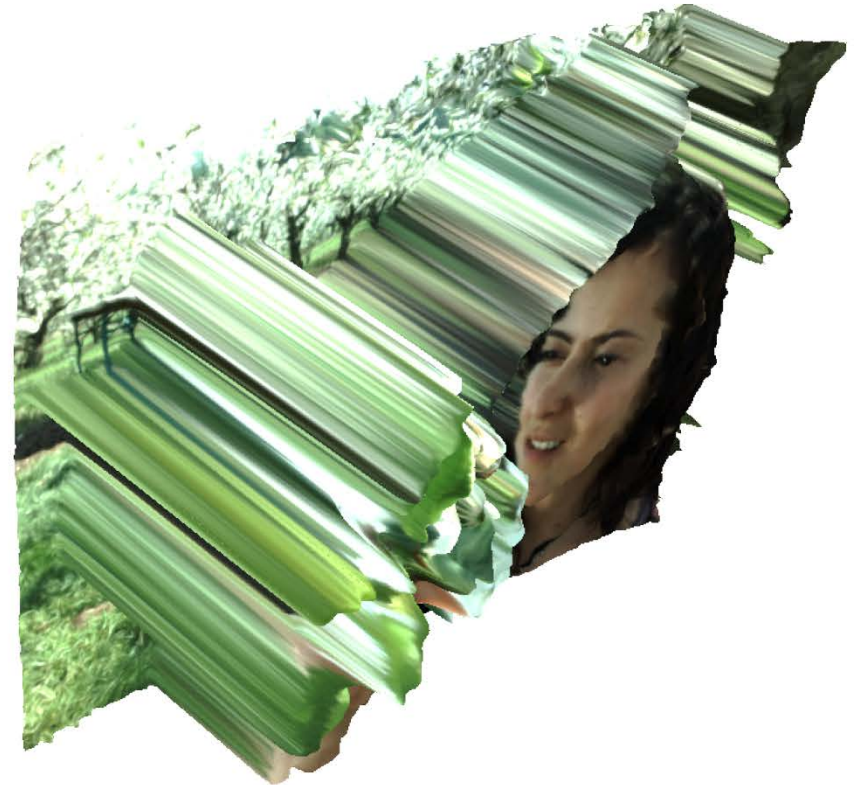
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Total Focus Image

3D Rendering

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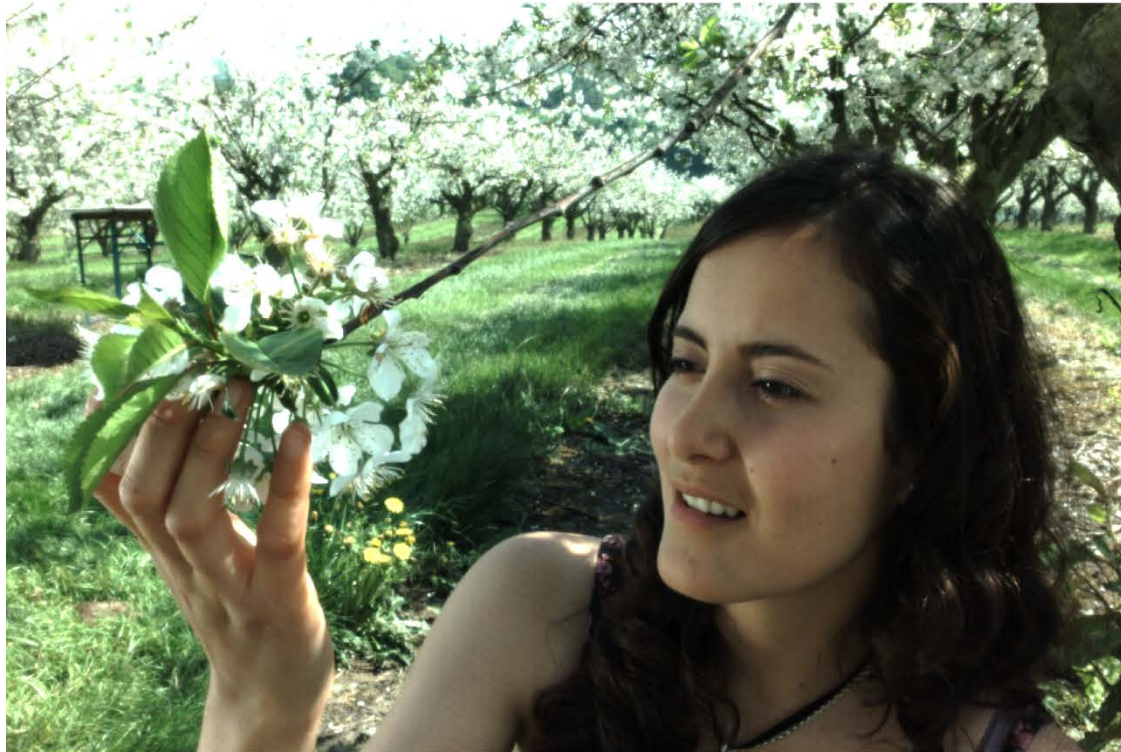
Total Focus Image

3D Rendering

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

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Total Focus Image

3D Rendering

Total Focus Image

3D Rendering

There is more depth resolution at the trees in the background.

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Total Focus Image



3D Rendering

Total Focus Image

3D Rendering

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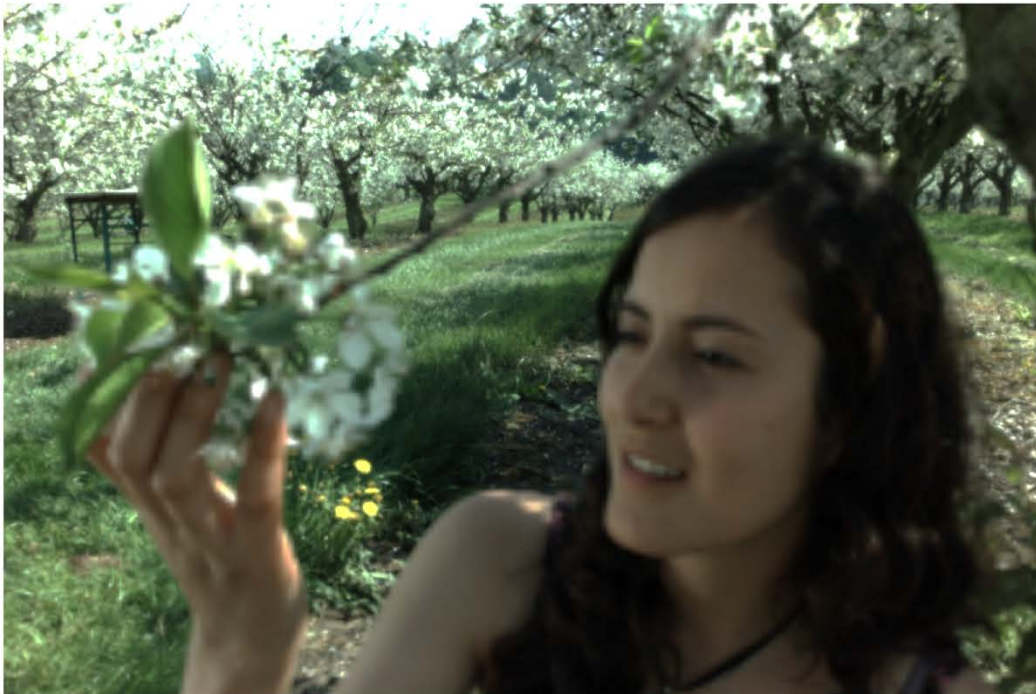
*Refocus*

Focus onto the blossom close to the camera.

3D Rendering

*Refocus*



Focus onto the background far from the camera.

3D Rendering

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*Relighting*



Darken everything depending on its distance
from the focus plane.



3D Rendering

*Picture taken with Raytrix R11C camera*

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Camera used is R5 with 4MP CMOSIS sensor.

Microscope Setup

FoV ~ 1x1mm

Total Focus

3D Reconstruction

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# Particle Tracking Velocimetry
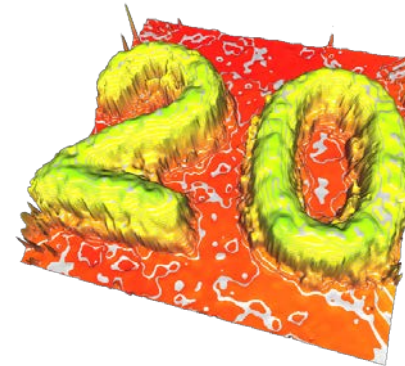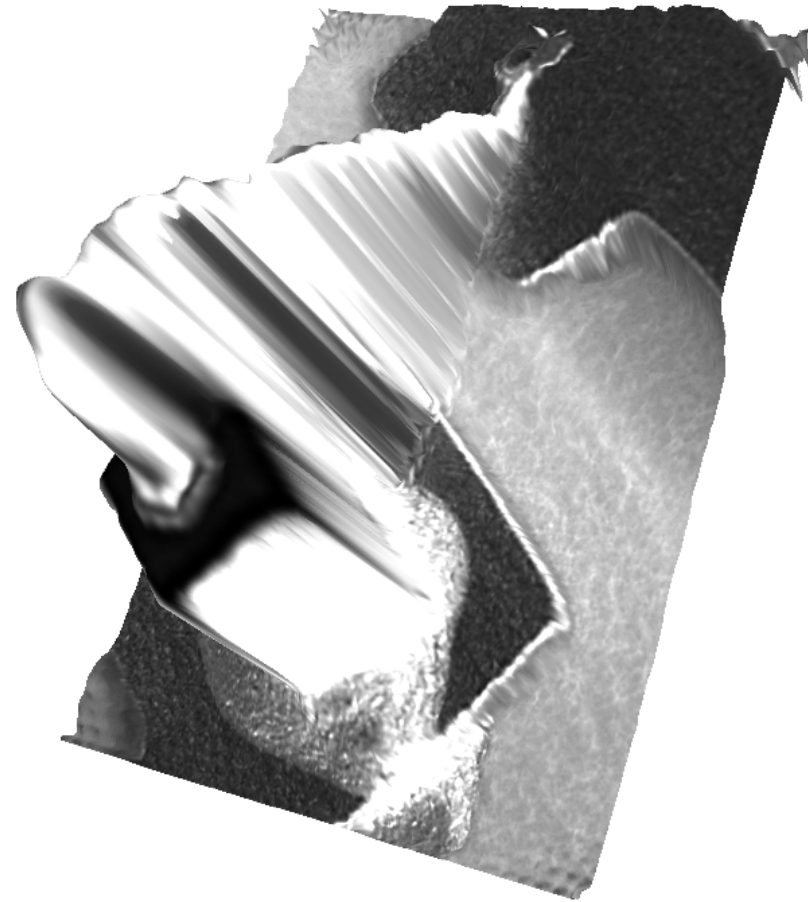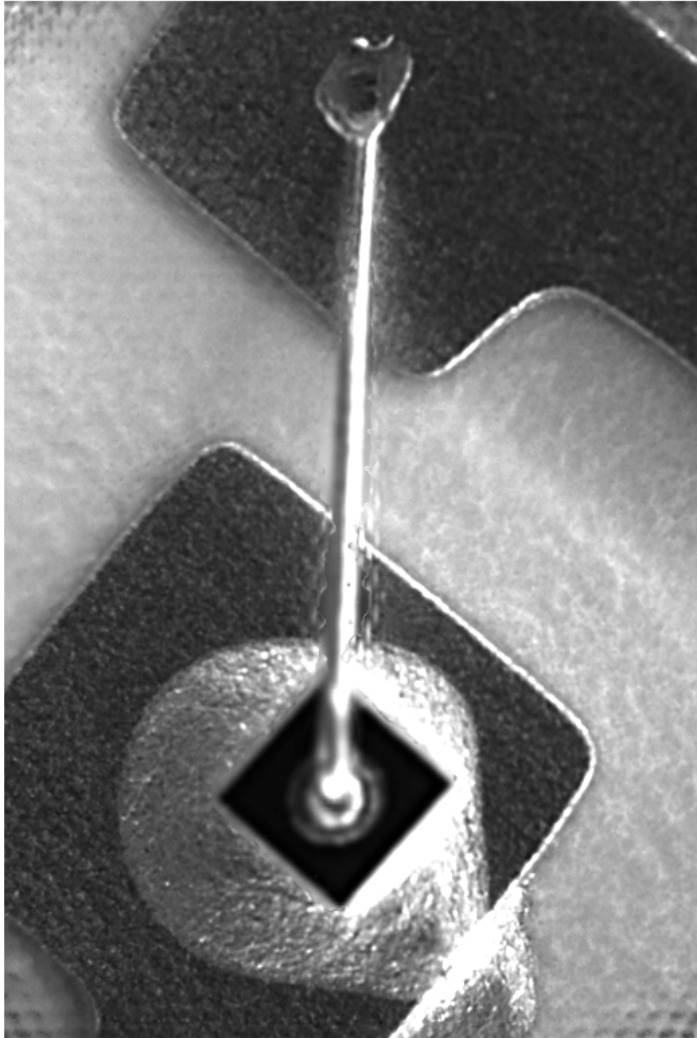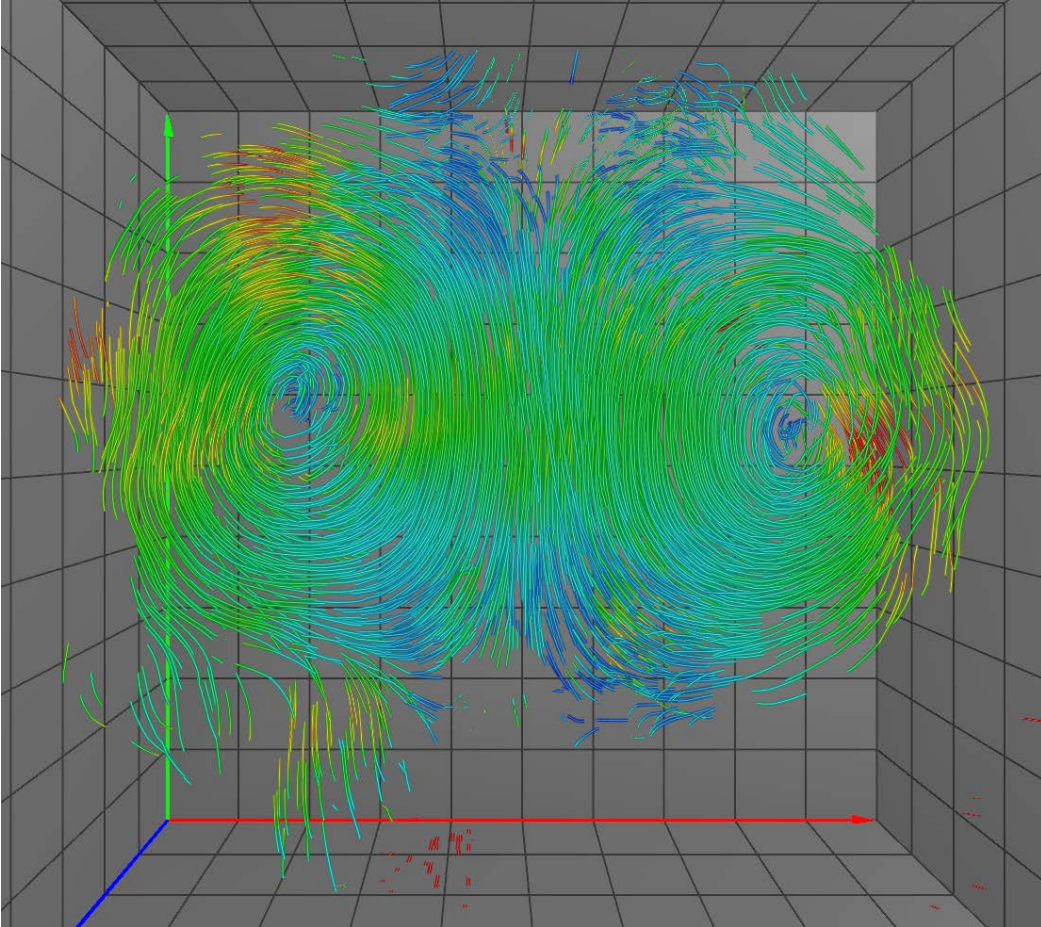
*Single Camera Volumetric PTV*
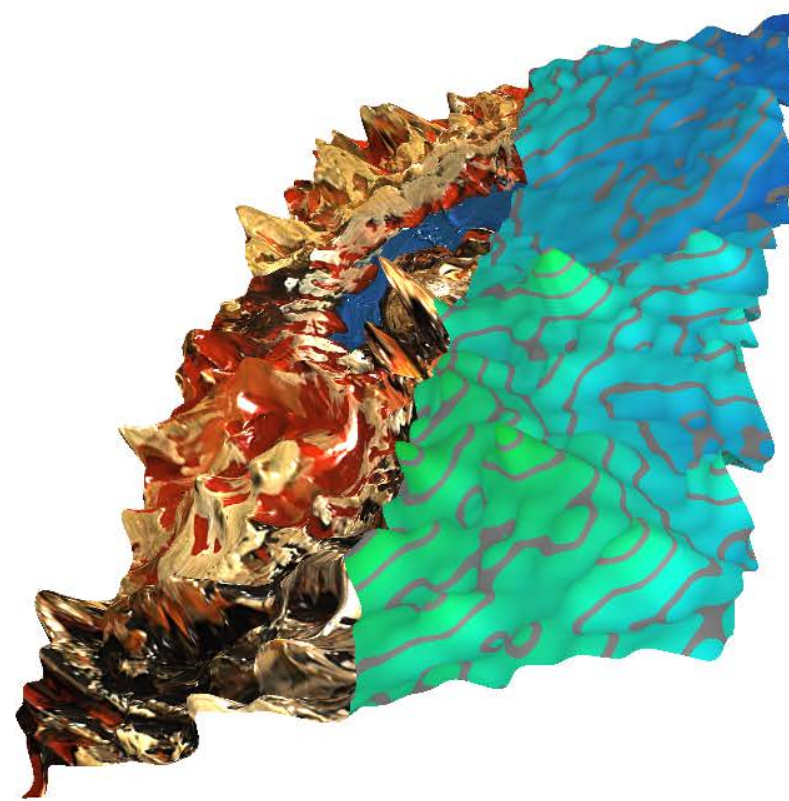


Watertank with particles
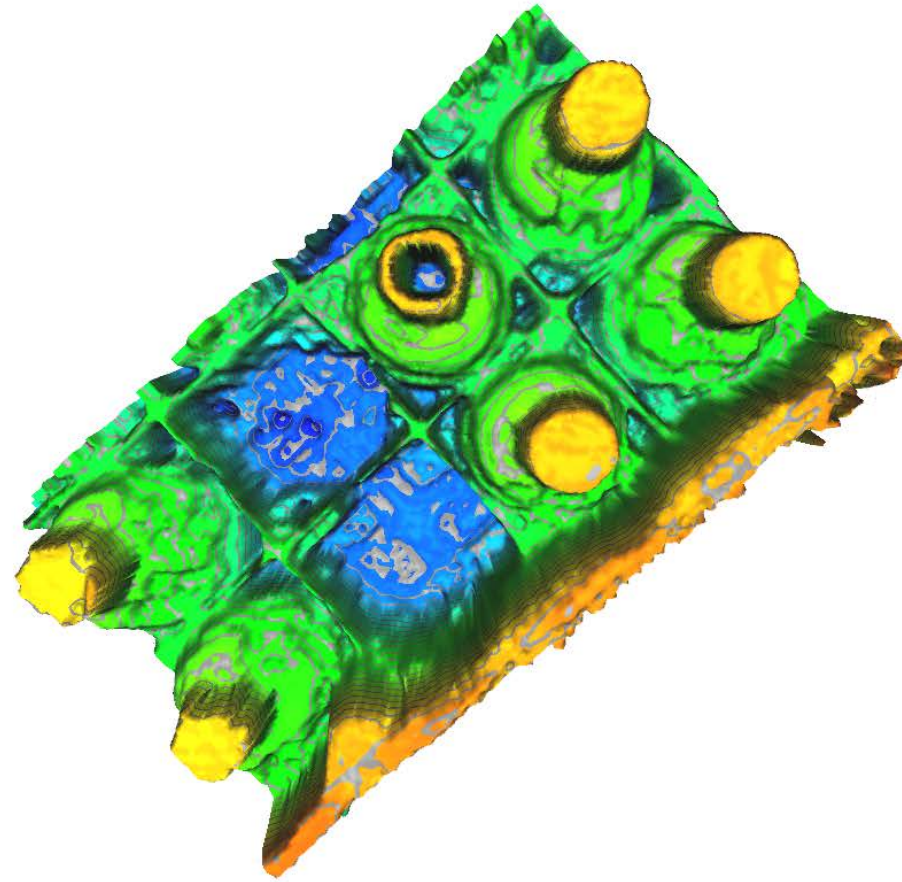
Laser

Raytrix Camera
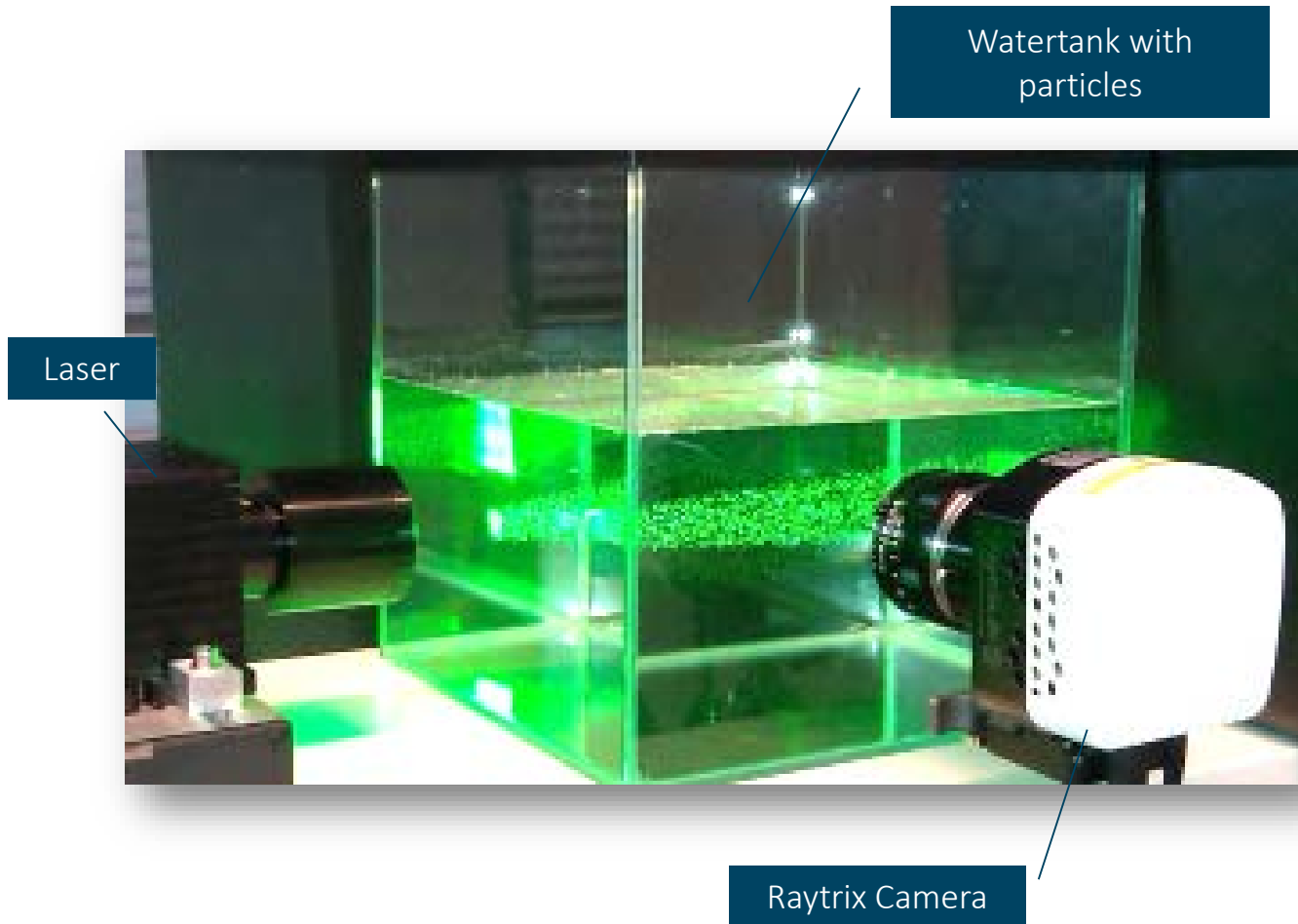
- Measure 3D flow of particles in water.

- Single light field camera.

- Simple metric calibration.

- In a typical measuring volume of 72x48x40mm we have a depth resolution < 0.4mm with an R29.

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## Calculated 3D flow from light field data

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*Picture taken with Raytrix R29M camera*

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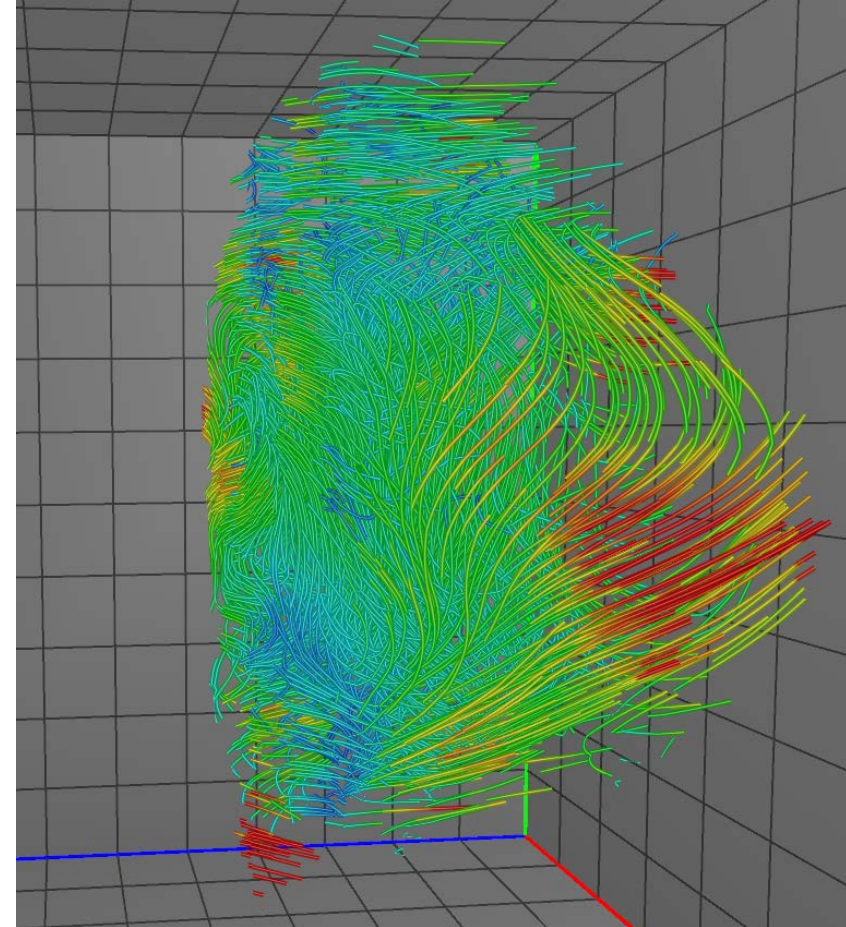
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*Connector*
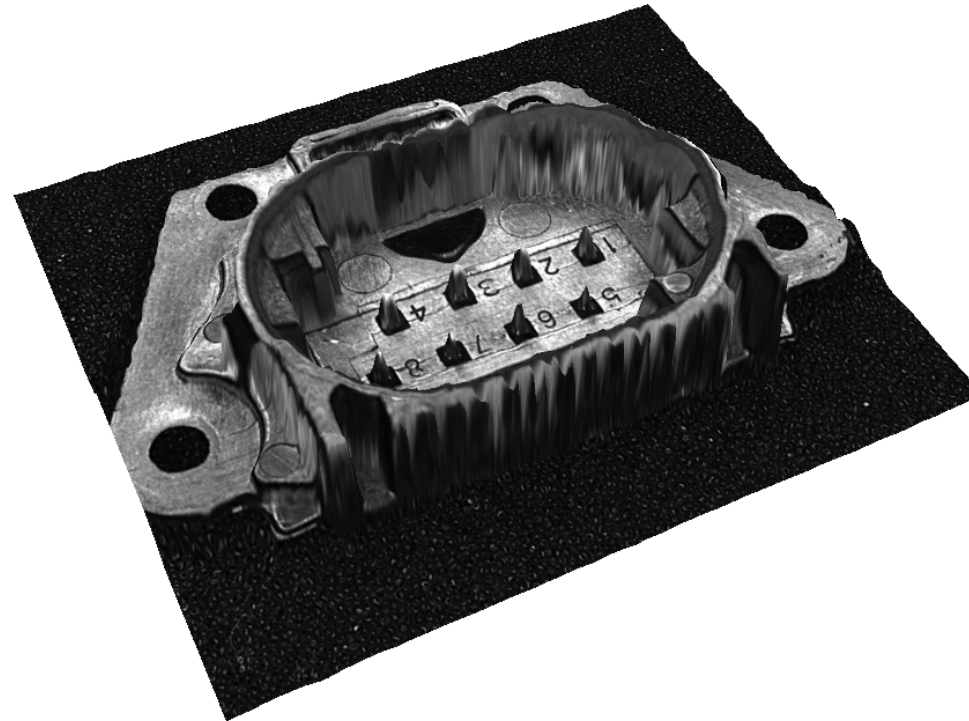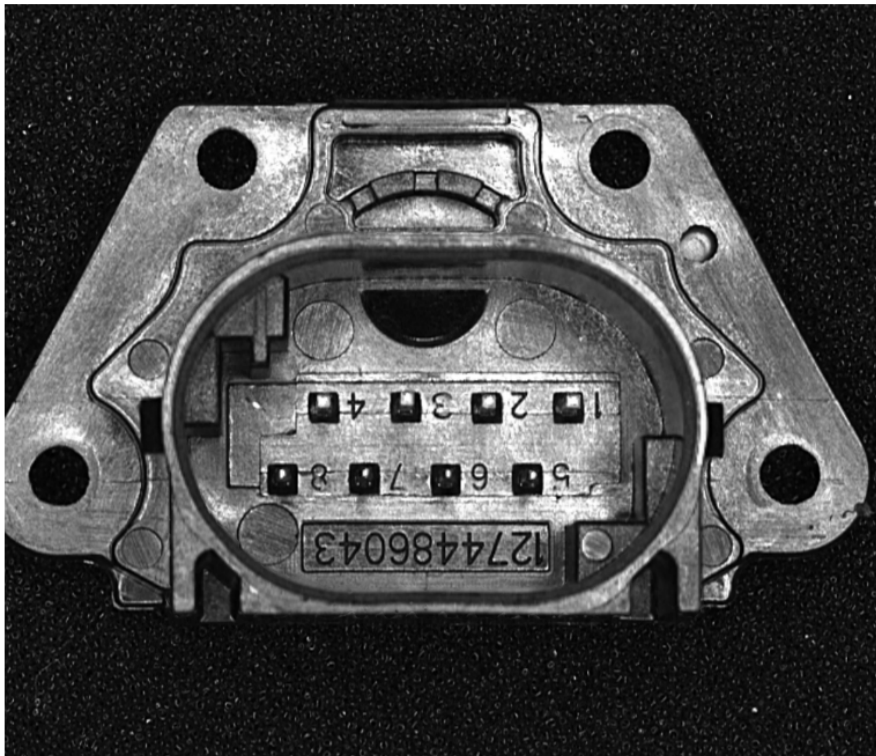


*Picture taken with
Raytrix R5M camera.*
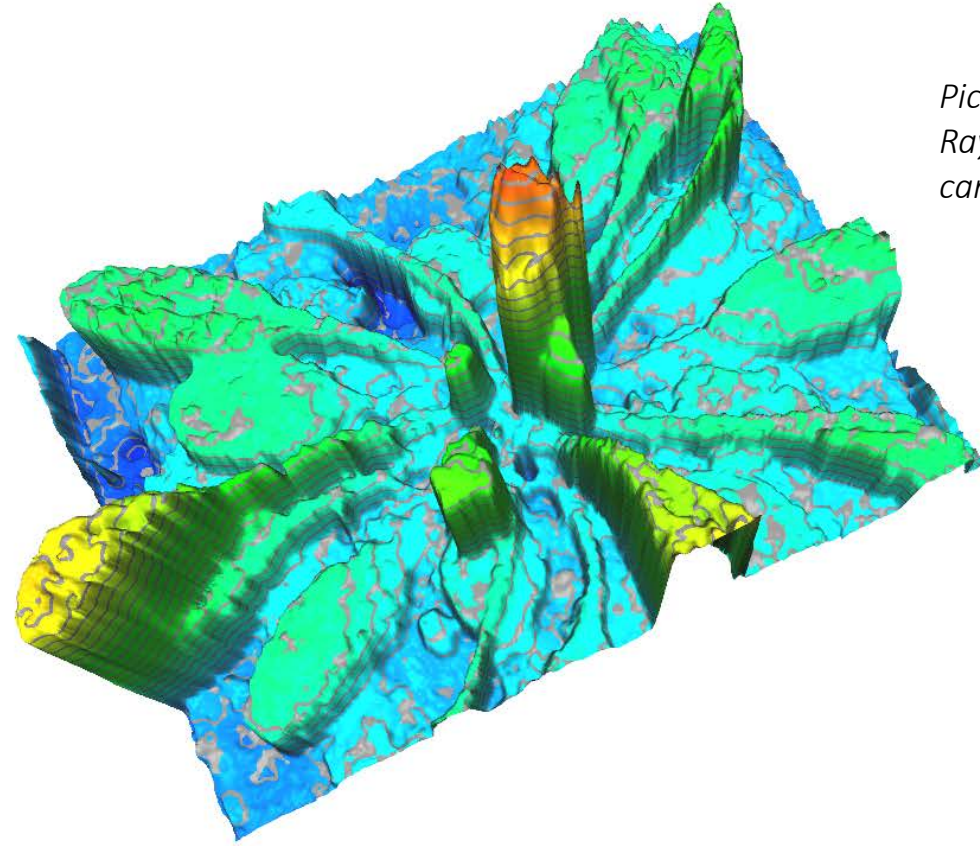
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# Plant Growth Analysis

*Picture taken with Raytrix R11C camera*

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# Content

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## Single shot

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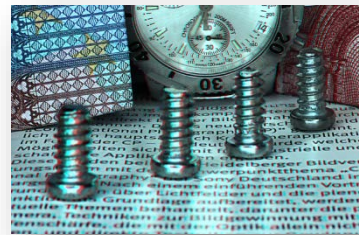- High effective resolution
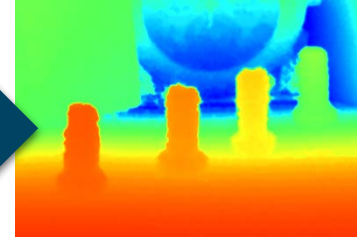


## Depth Map

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

### 3D-Data

### 3D-View

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

### All-In-Focus

### Image Processing

- selective per-pixel focus
- Variable view point horizontally and vertically
- Variable 3D-zoom effect

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Download the free *TrixViewer*
for Windows® and MacOS® and
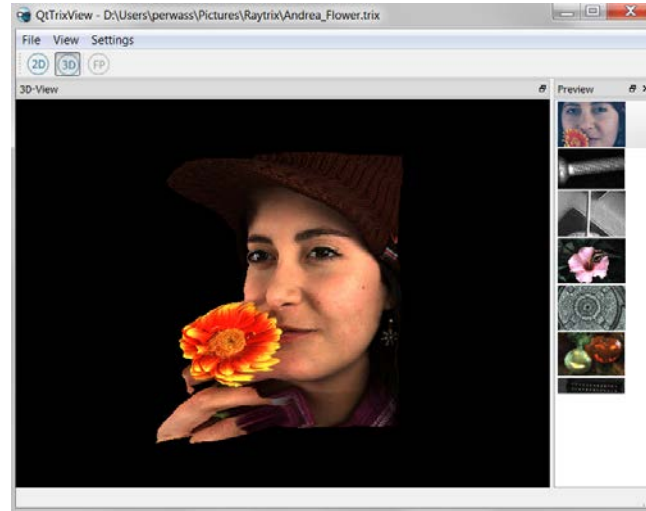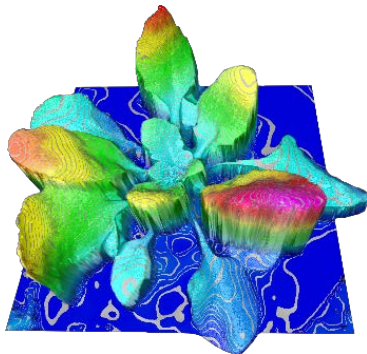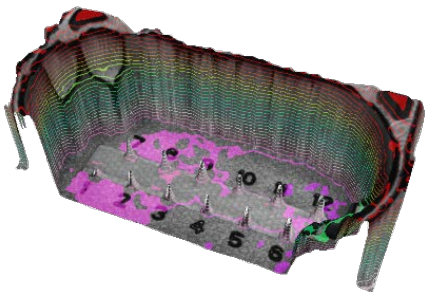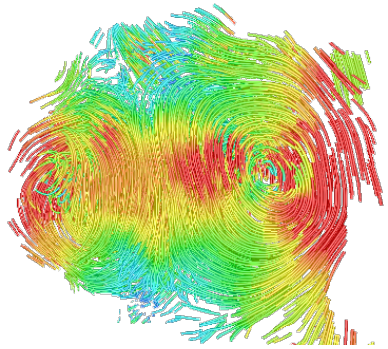*raw light field data* from
## www.raytrix.de

# Contact

Please contact us for more information and a quote.


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24118 Kiel
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