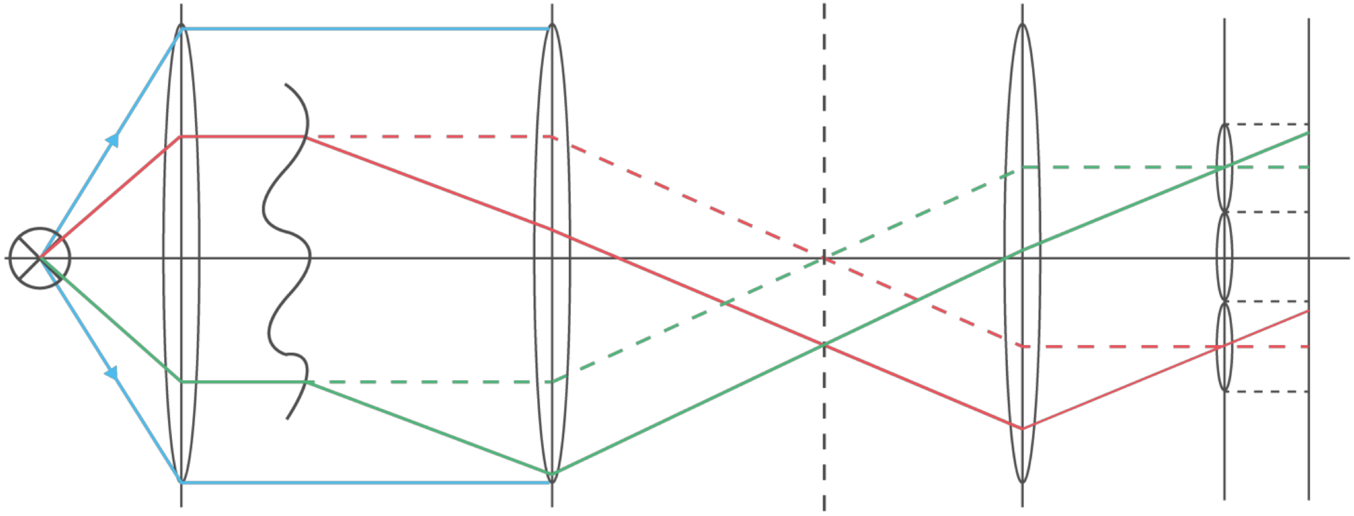
Light Field Methods for the Visual Inspection of Transparent Objects

17th EMVA Business Conference 18.05.2019

Dr.-Ing. Johannes Meyer



About Me

Johannes Meyer

- 2008 – 2014
  Bachelor & Master in Computer Science
  Karlsruhe Institute of Technology KIT (Germany)
- 2014 – 2018
  Dr.-Ing. (PhD) in Computer Science (Machine Vision)
  KIT & Fraunhofer-Institute of Optronics, System Technologies and Image Exploitation IOSB (Germany)
- Since 2019
  Lead Engineer Computer Vision
  ITK Engineering GmbH (Germany)

KIT
Karlsruhe Institute of Technology

Fraunhofer
IOSB

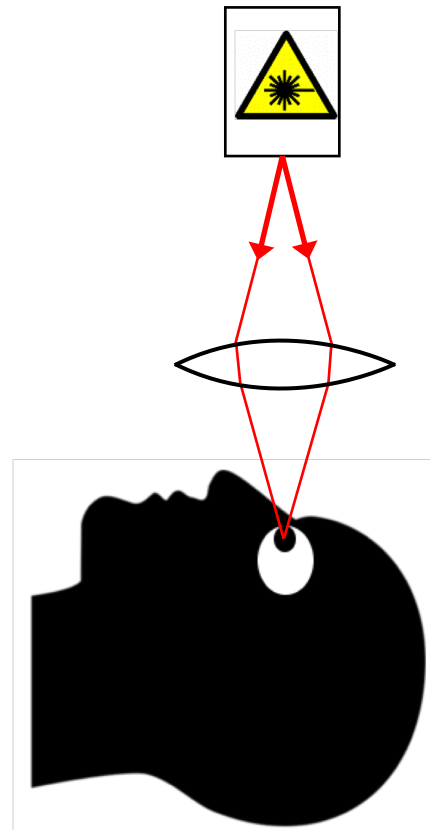
Visual Inspection of Transparent Objects

Transparent objects are widely used in diverse industries.

- Windshields

- Optical elements

- Medical applications



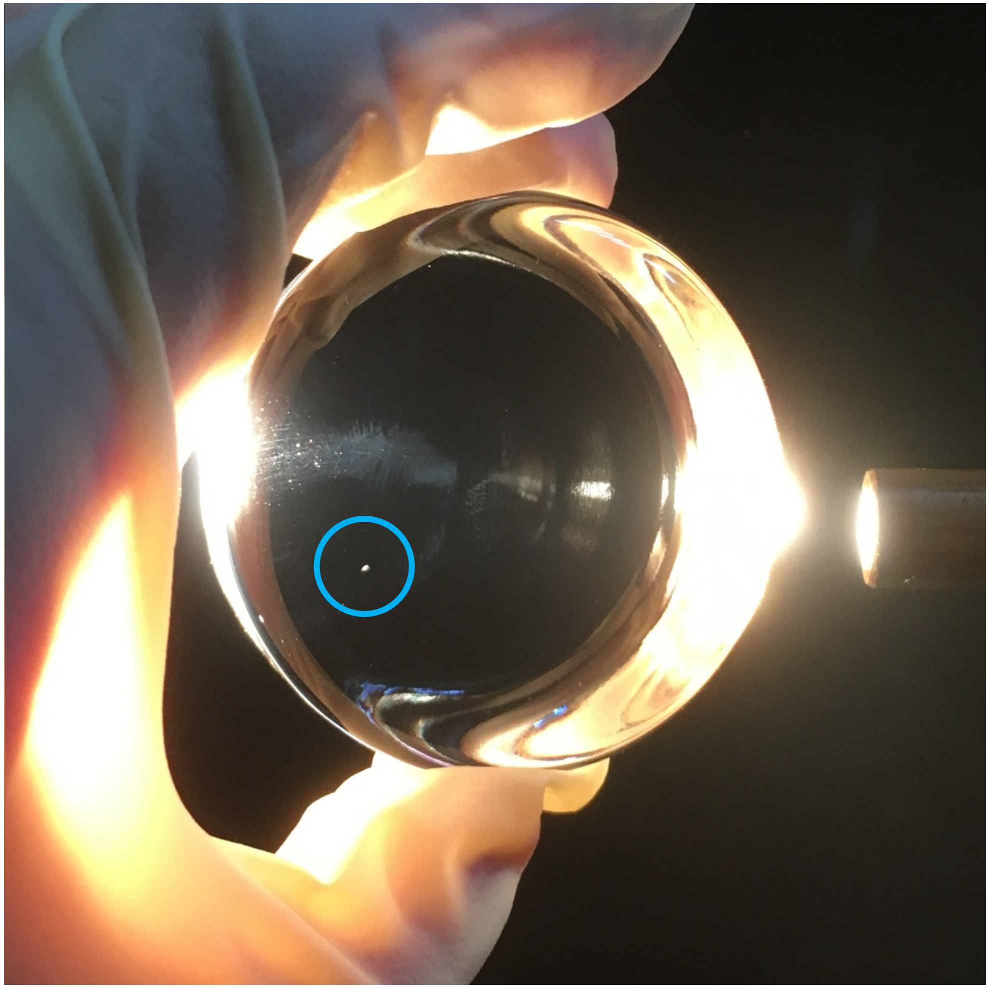
Visual Inspection of Transparent Objects

➔ Quality control is indispensable

Human inspectors

- look at the test object from multiple perspectives
- and acquire a light field of the test object.

➔ Tedious and fatiguing, subjective results, defects might be overseen.



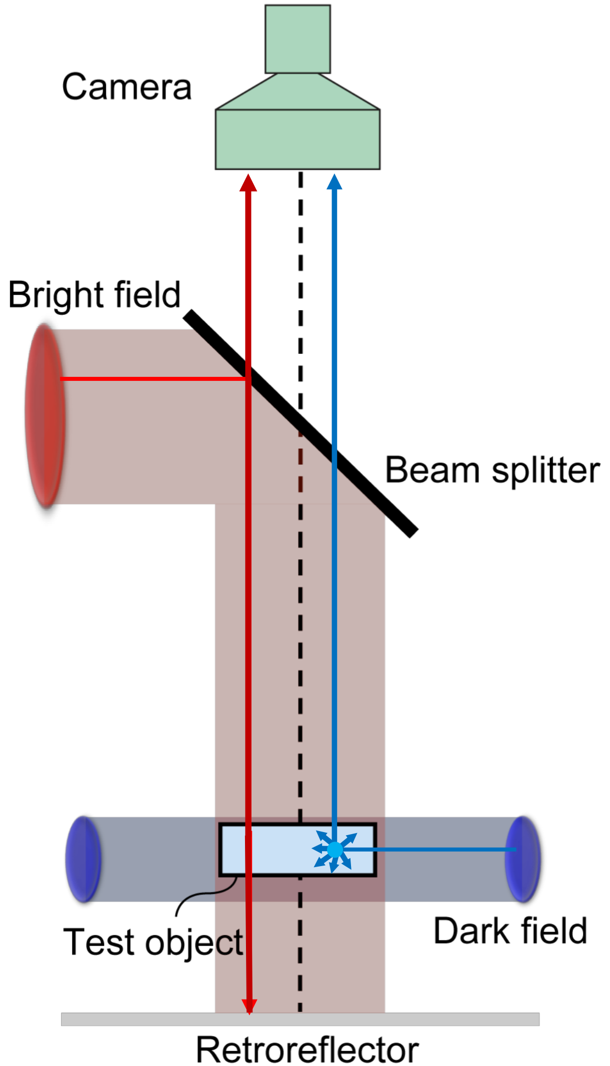
Visual Inspection of Transparent Objects

➔ Quality control is indispensable

Automated visual inspection (state of the art)

Multi-channel illumination for the visualization of different types of material defects.

- Bright field (red)
  ➔ Transparency profile
- Dark field (blue)
  ➔ Transparent, scattering structures on or in the test object



J.Meyer. Overview on Machine Vision Methods for Finding Defects in Transparent Objects. Tech. rep. IES-2015-08

Visual Inspection of Transparent Objects

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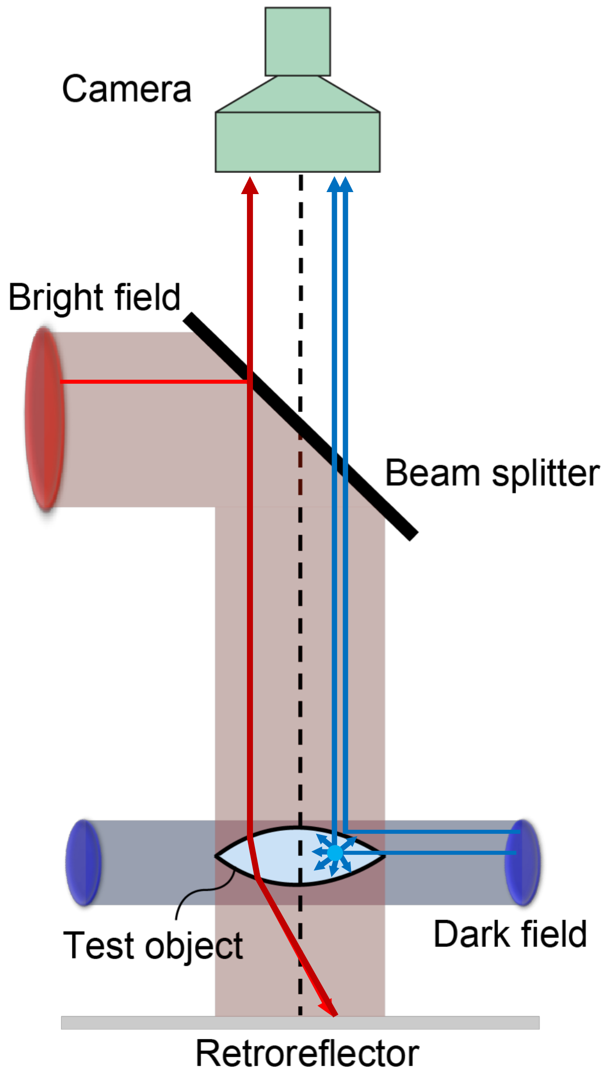
Multi-channel illumination for the visualization of different types of material defects.

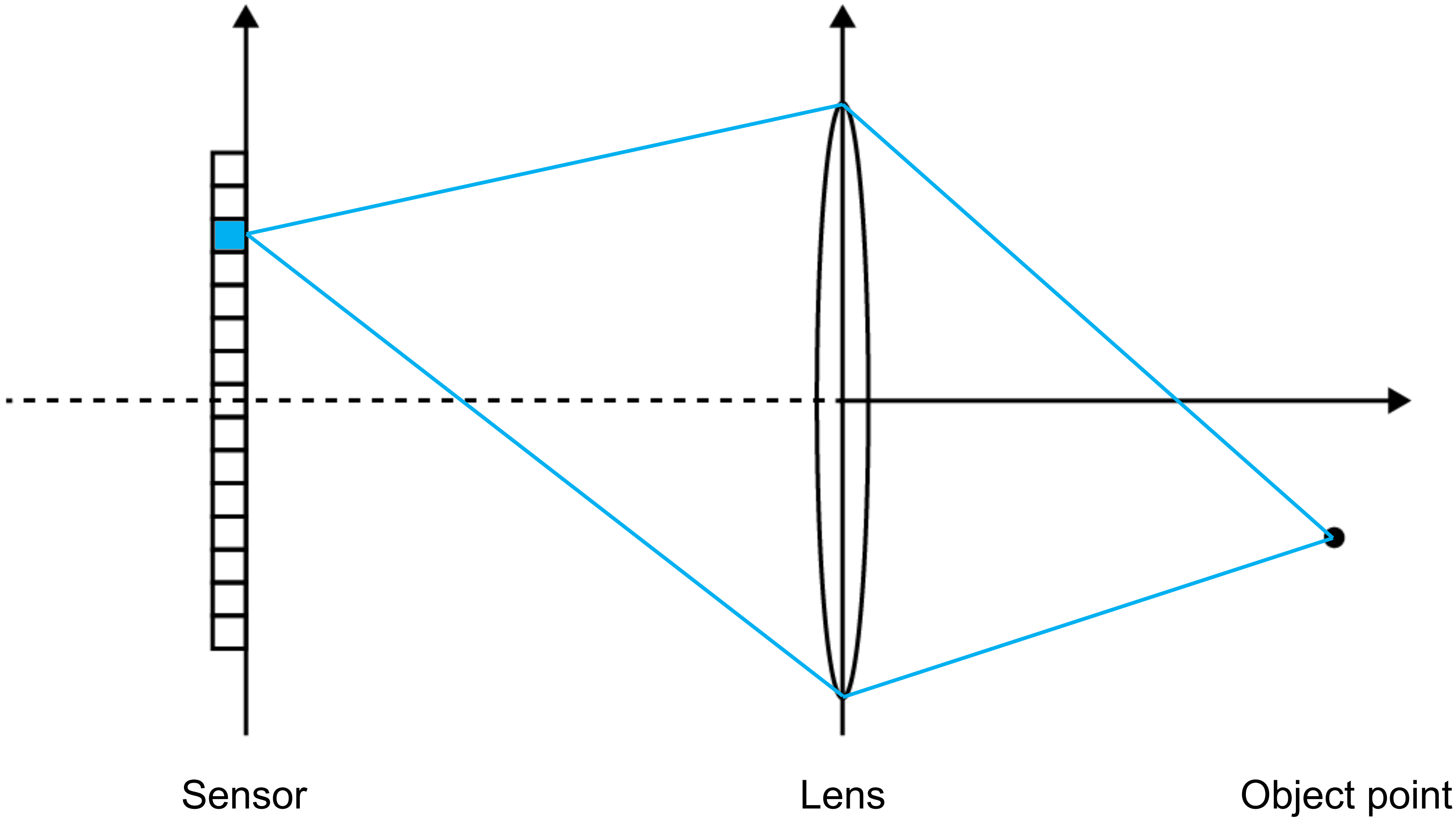
- Bright field (red)
  ➔ Transparency profile
- Dark field (blue)
  ➔ Transparent, scattering structures on or in the test object
- **Inspection of uncooperative, complex-shaped objects:**
  Well-designed, test object-specific arrangement of illumination sources is required.



J.Meyer. Overview on Machine Vision Methods for Finding Defects in Transparent Objects. Tech. rep. IES-2015-08

Light Fields

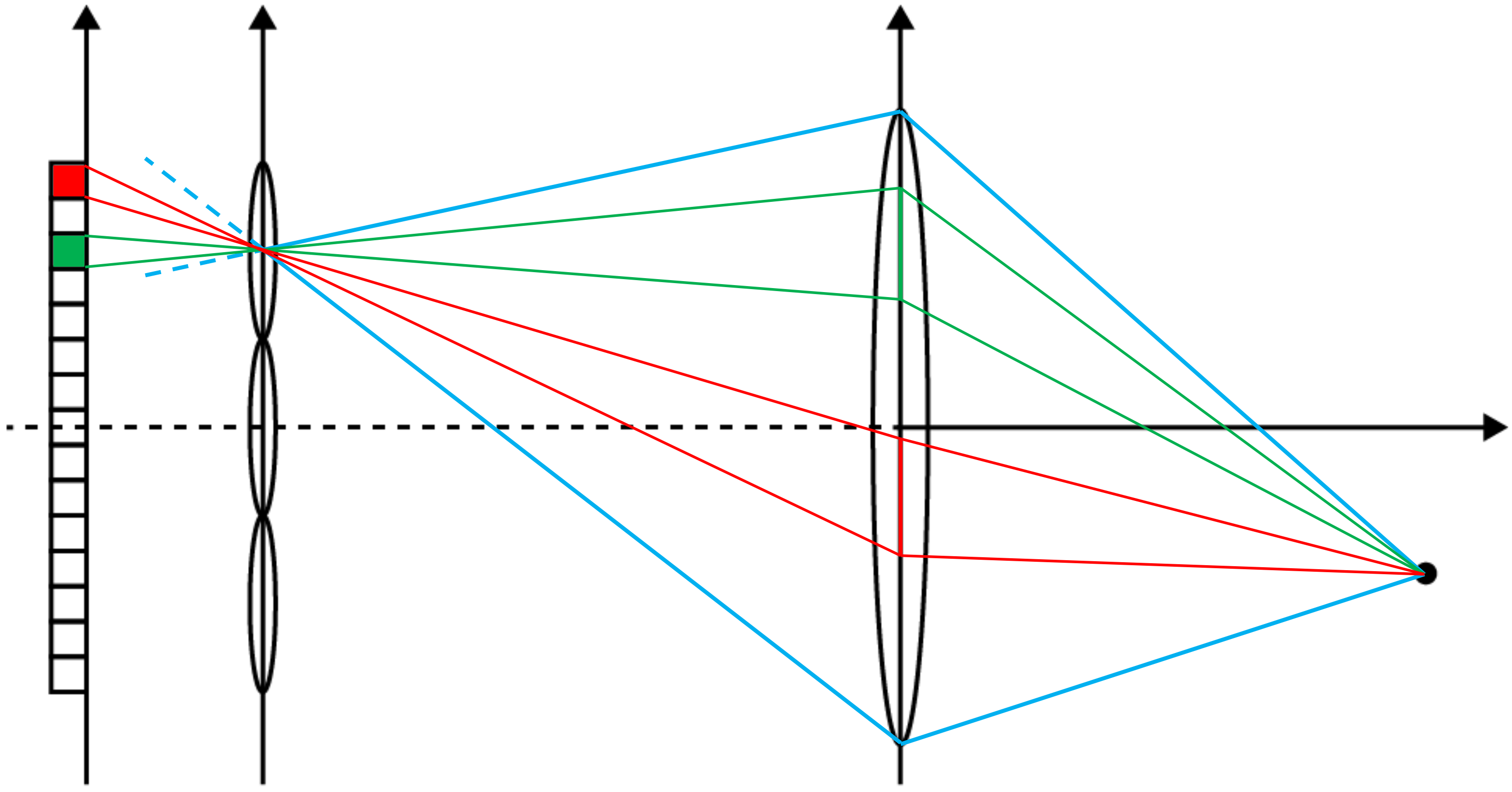
- Conventional thin lens camera



Light Fields

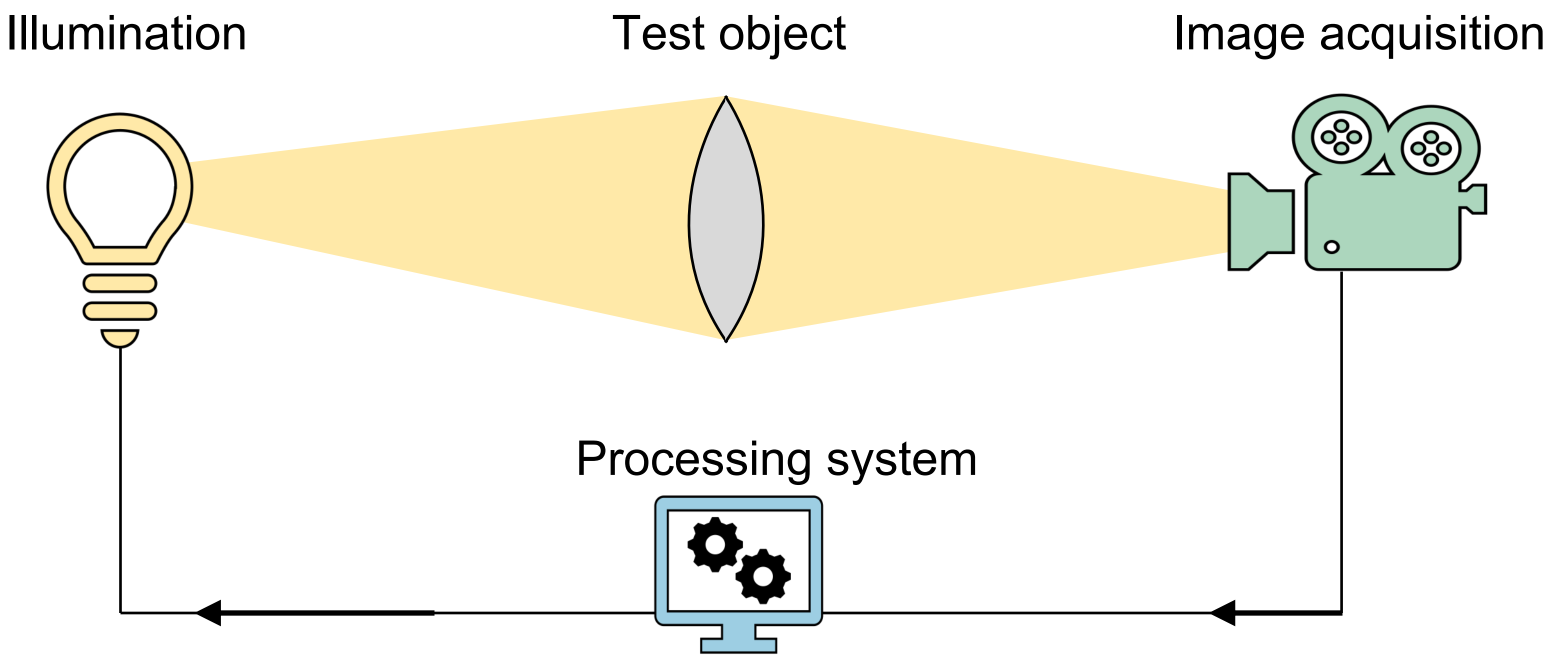
contain spatial and angular information about the light transport of a static scene.

- Light field camera



Light Field Methods for the Visual Inspection of Transparent Objects

Introduction of light field methods into the major parts of a visual inspection system



- Inverse light field illumination
- Light field generator, concept & prototype

- Light field gradient processing methods
- SNR-based image fusion algorithms

- Laser deflection scanner
- 4f-light field camera

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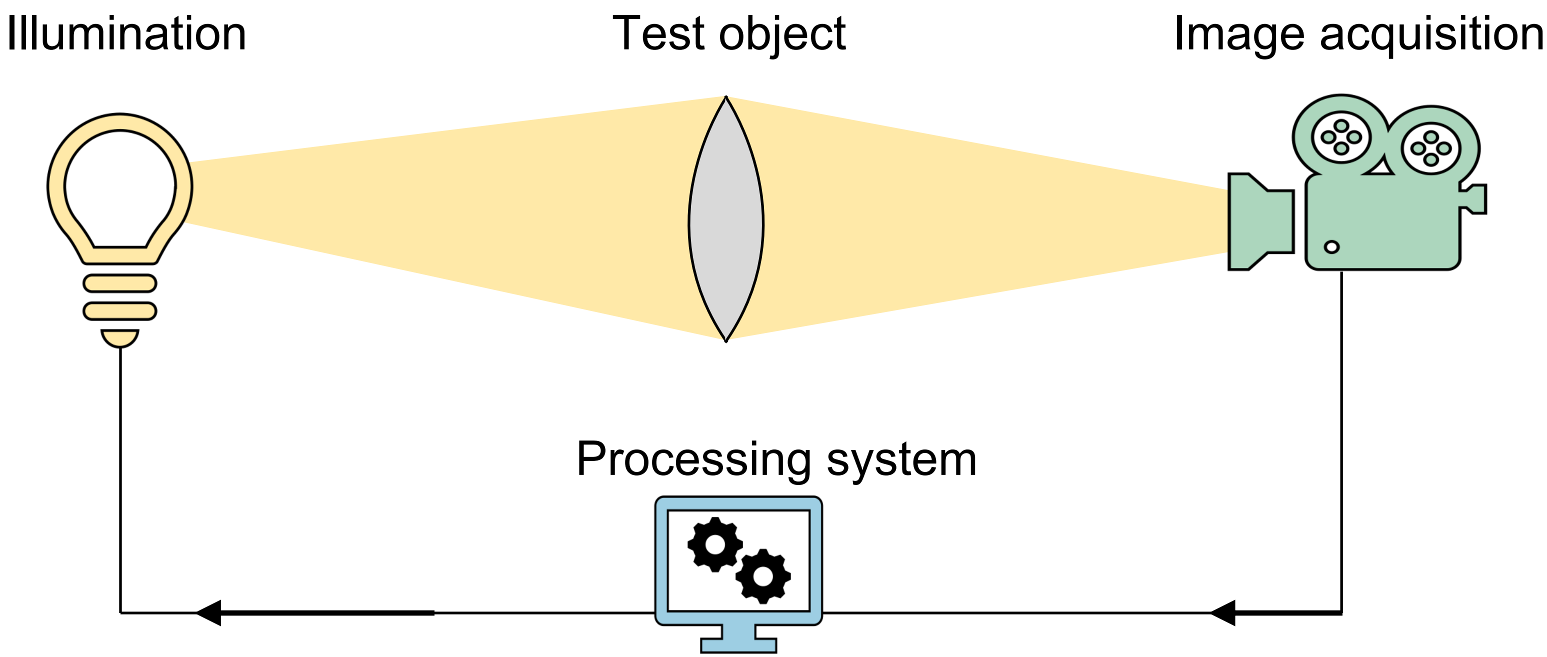
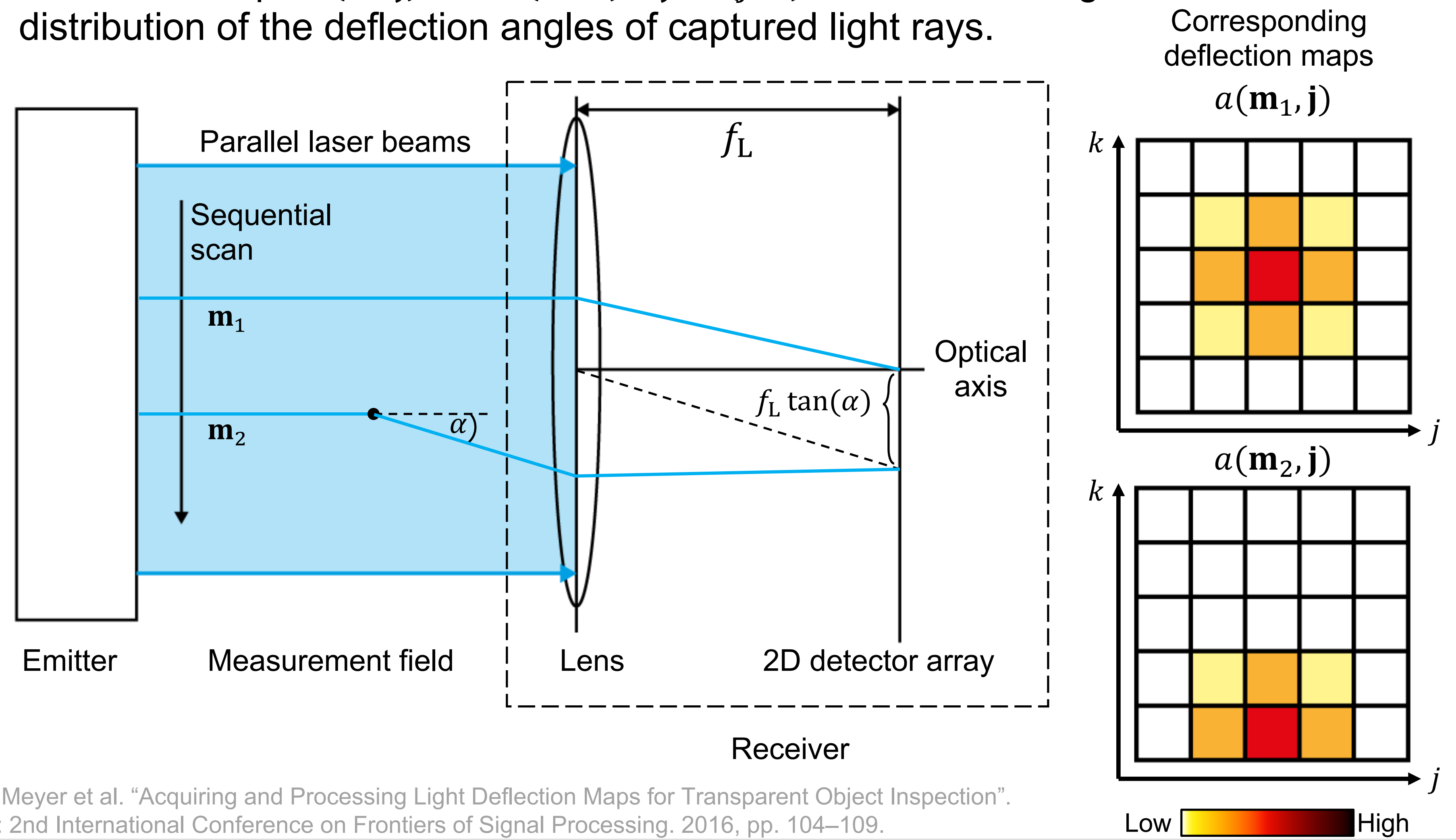


Illumination	Processing system	Image acquisition
✚ Inverse light field illumination	✚ Light field gradient processing methods	✚ **Laser deflection scanner**
✚ Light field generator, concept & prototype	✚ SNR-based image fusion algorithms	✚ 4f-light field camera

Laser Deflection Scanner

Deflection maps $a(\mathbf{m}, \mathbf{j}), \mathbf{m} = (m, n)^{\mathrm{T}}, \mathbf{j} = (j, k)^{\mathrm{T}}$ contain the angular distribution of the deflection angles of captured light rays.

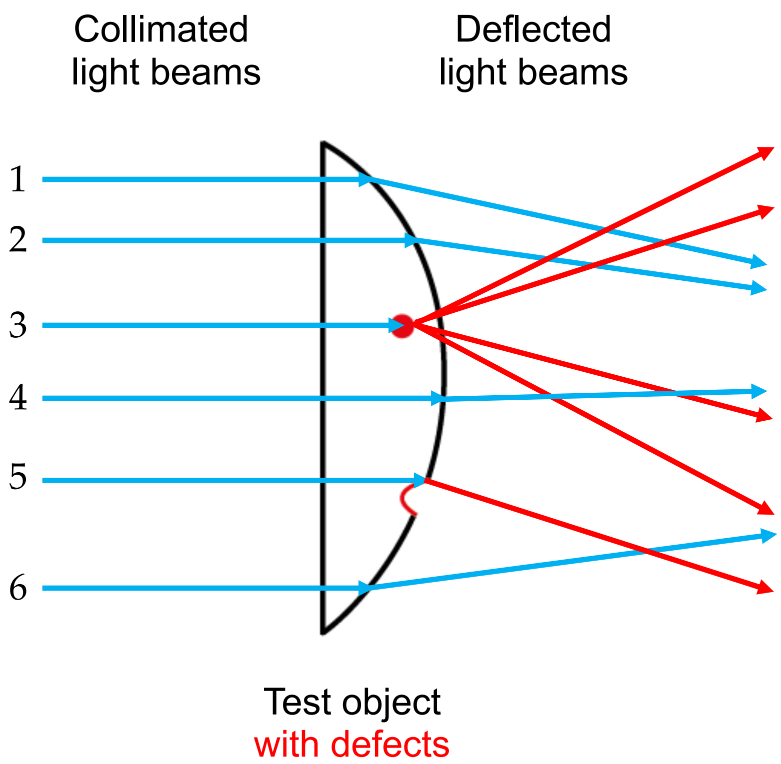


J. Meyer et al. "Acquiring and Processing Light Deflection Maps for Transparent Object Inspection". In: 2nd International Conference on Frontiers of Signal Processing. 2016, pp. 104–109.

Light deflection maps

Core idea: sense and evaluate
the propagation direction of the light

Corresponding deflection maps



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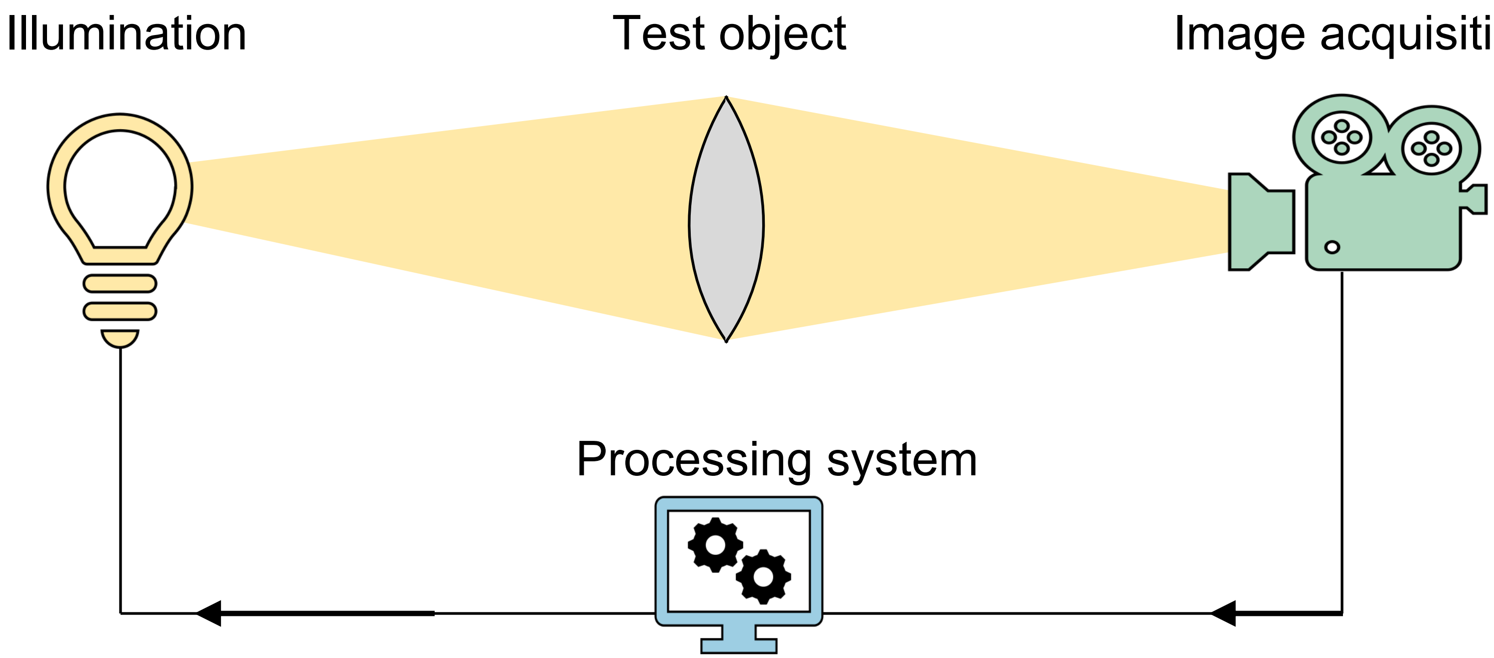

- **Inverse light field illumination**
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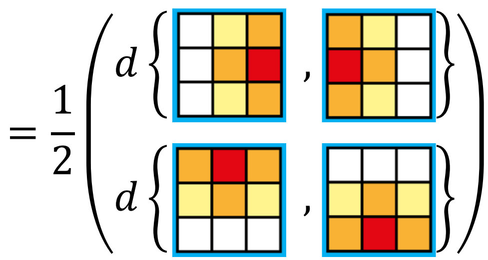
Deflection Map Processing

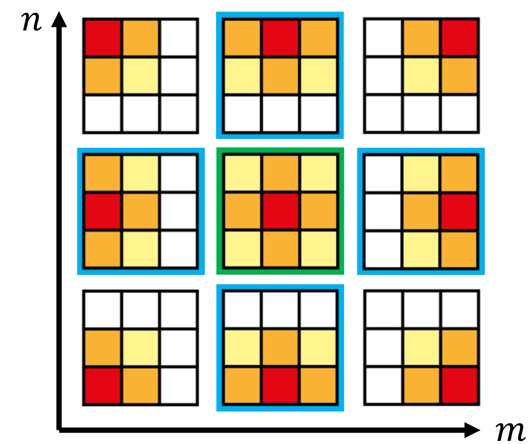
Defect ➔ discontinuities between spatially adjacent deflection maps.

- Approximate the spatial gradient $\mathrm{grad}_{\mathbf{m}}\, a(\mathbf{m},\mathbf{j})$ of the deflection maps

$$\mathrm{grad}_{\mathbf{m}}\, a(\mathbf{m},\mathbf{j}) \approx \frac{1}{2}\begin{pmatrix} d\left\{a\left(\mathbf{m}+\binom{1}{0},\mathbf{j}\right), a\left(\mathbf{m}-\binom{1}{0},\mathbf{j}\right)\right\} \\ d\left\{a\left(\mathbf{m}+\binom{0}{1},\mathbf{j}\right), a\left(\mathbf{m}-\binom{0}{1},\mathbf{j}\right)\right\} \end{pmatrix}$$



Spatially adjacent deflection maps

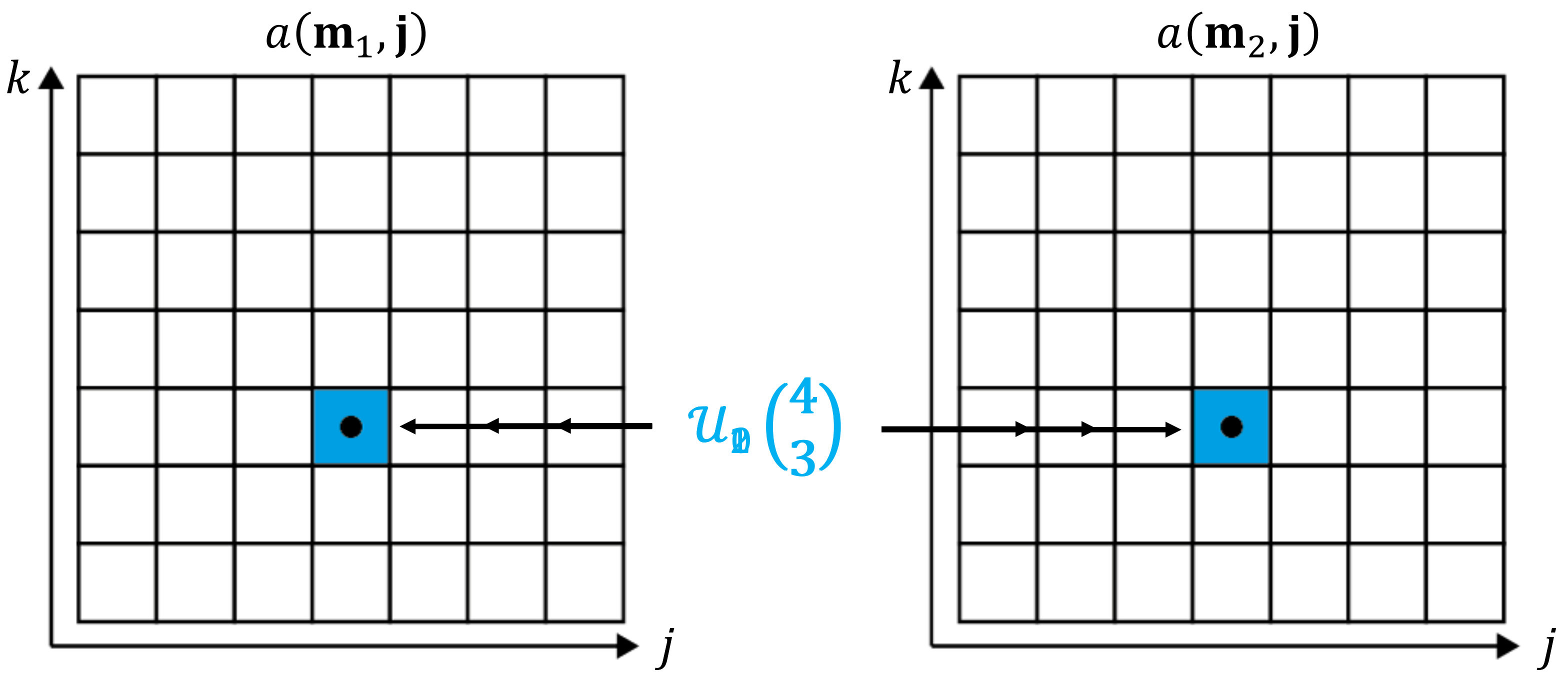


- A suitable distance function $d\{\cdot,\cdot\}$ has to be defined.
- Further (conventional) image processing can be performed on $\|\mathrm{grad}_{\mathbf{m}}\, a(\mathbf{m},\mathbf{j})\|$.

J. Meyer et al. “About the Acquisition and Processing of Ray Deflection Histograms for Transparent Object Inspection”.
In: Irish Machine Vision & Image Processing Conference Proceedings. 2016, pp. 9–16.

Generalized Cramér-von Mises Distance

$$\mathrm{CMD}\big(a(\mathbf{m}_1,\mathbf{j}), a(\mathbf{m}_2,\mathbf{j})\big) = \sum_{\mathbf{j}\in\Omega} \sum_{b=0}^{b_{\max}} \left(\sum_{\mathbf{p}\in\mathcal{U}_b(\mathbf{j})} a(\mathbf{m}_1,\mathbf{p}) - \sum_{\mathbf{p}\in\mathcal{U}_b(\mathbf{j})} a(\mathbf{m}_2,\mathbf{p}) \right)^2$$



J. Meyer et al. “General Cramér-von Mises, a Helpful Ally for Transparent Object Inspection Using Deflection Maps?” In: Scandinavian Conference on Image Analysis. 2017, pp. 526–537.

Generalized Cramér-von Mises Distance

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$$|\Omega|=N,\quad b_{\max}=\sqrt{N}$$

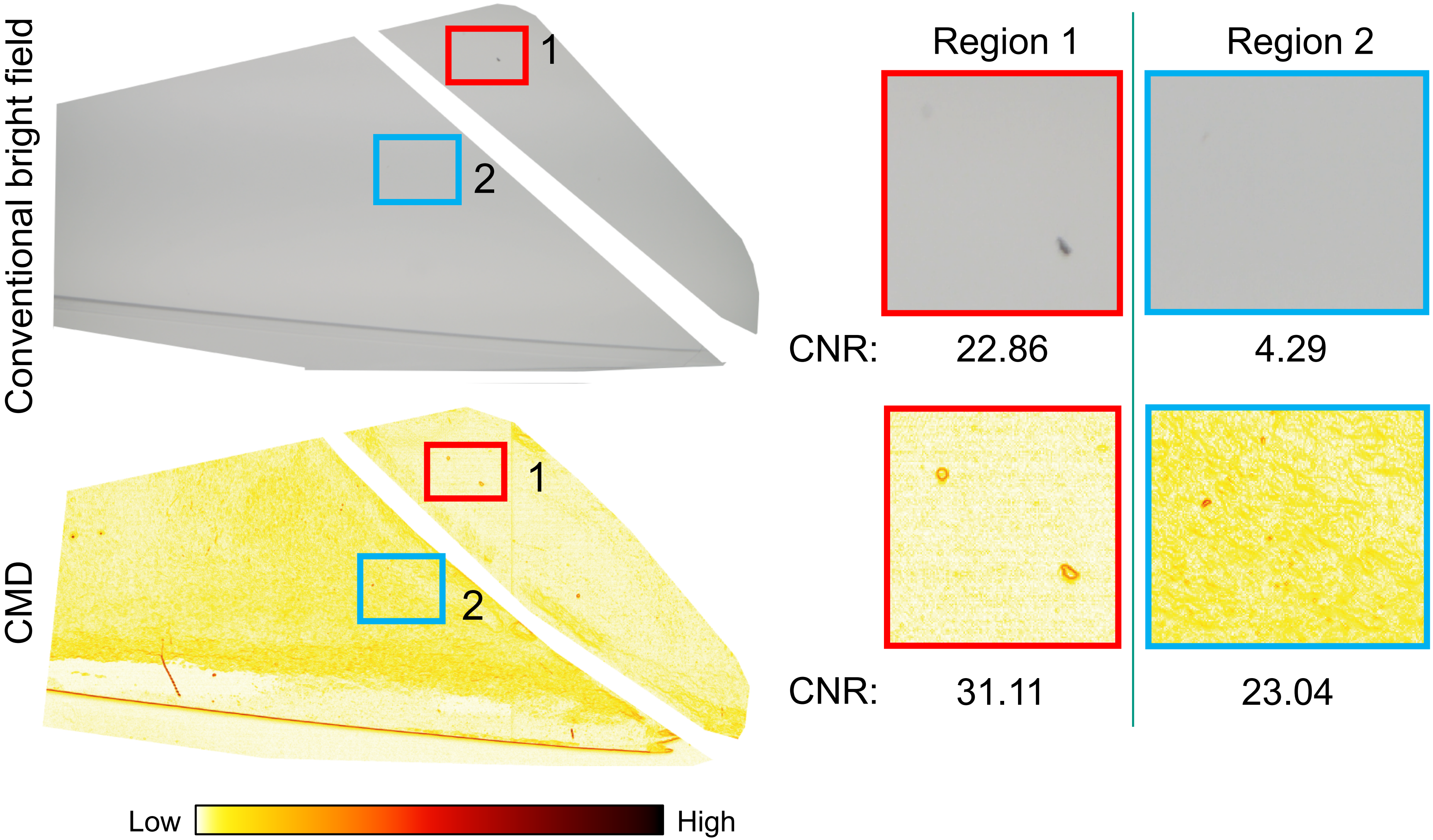
- Naïve implementation ➔ $O(N^{2.5})$
- fastCMD-algorithm ➔ $O(N^{1.5})$

J. Meyer et al. “fastGCVM: A Fast Algorithm for the Computation of the Discrete Generalized Cramér-von Mises Distance”.
In: 25th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision. 2017, pp. 147–152.

Experiments

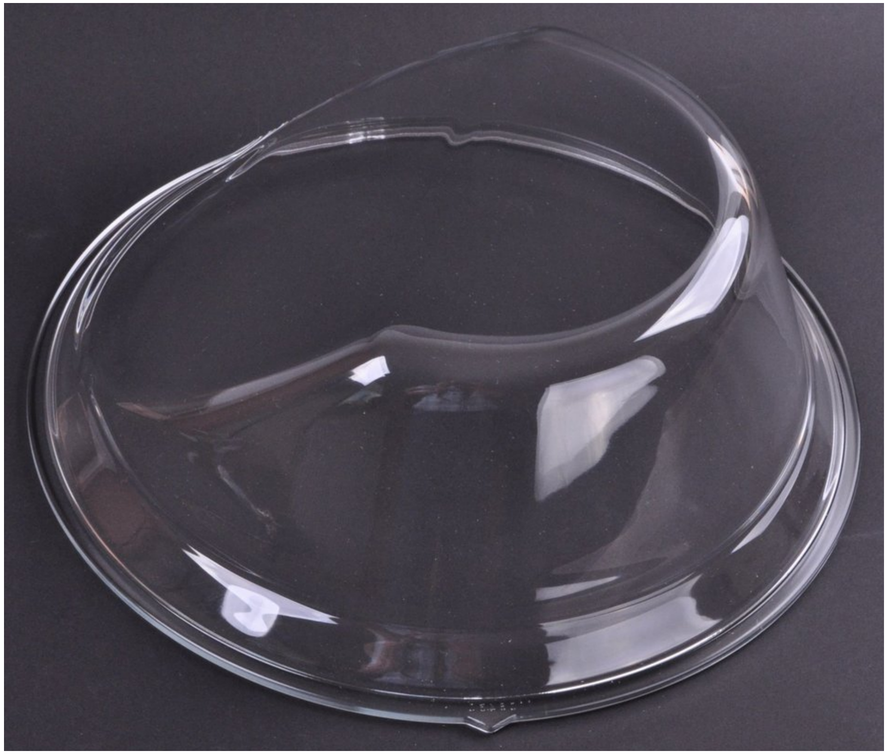
Automotive headlamp cover imaged with a laser deflection scanner prototype.

Experiments

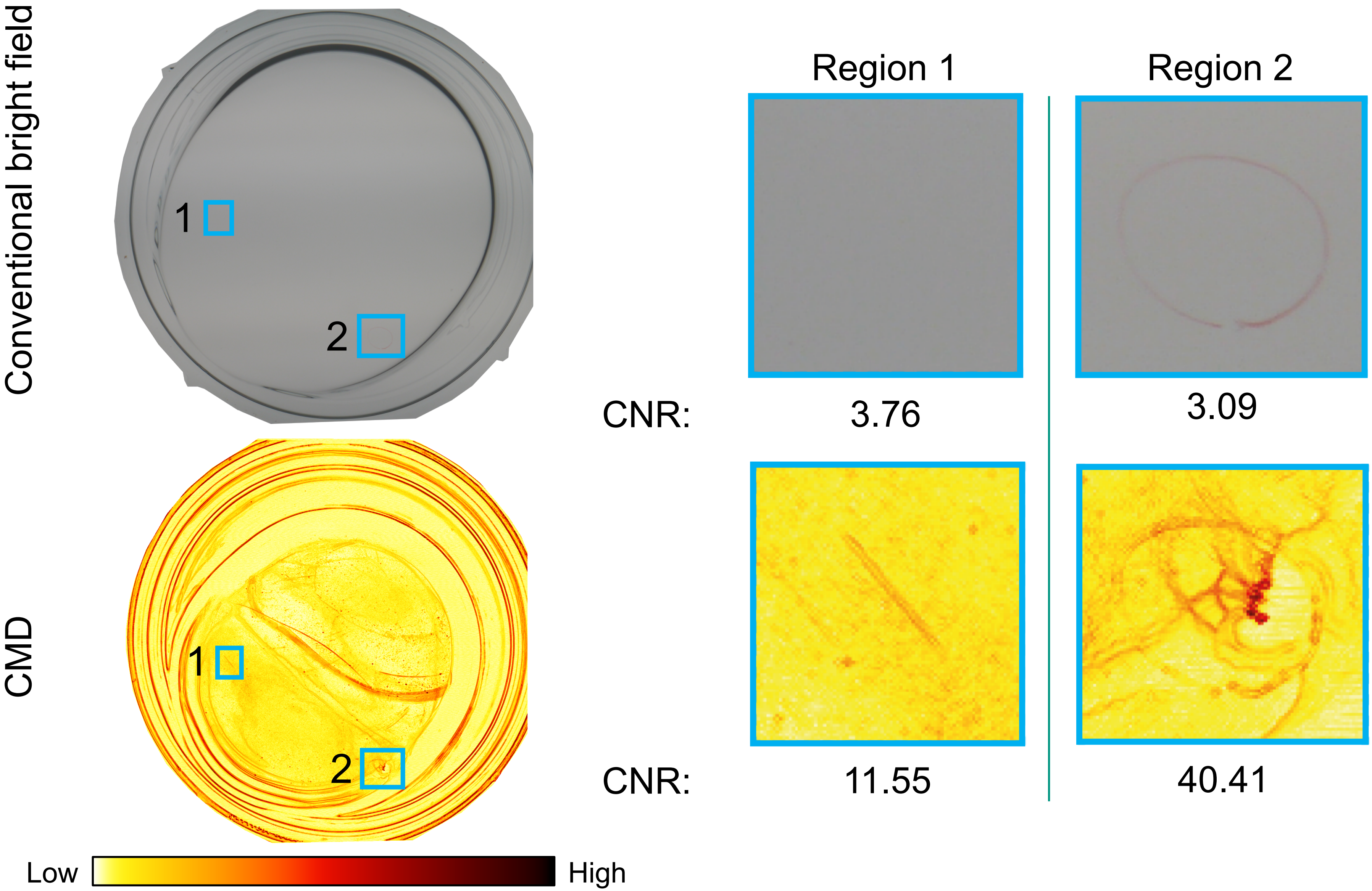


Experiments

Washing machine door glass imaged with a laser deflection scanner prototype.



Experiments



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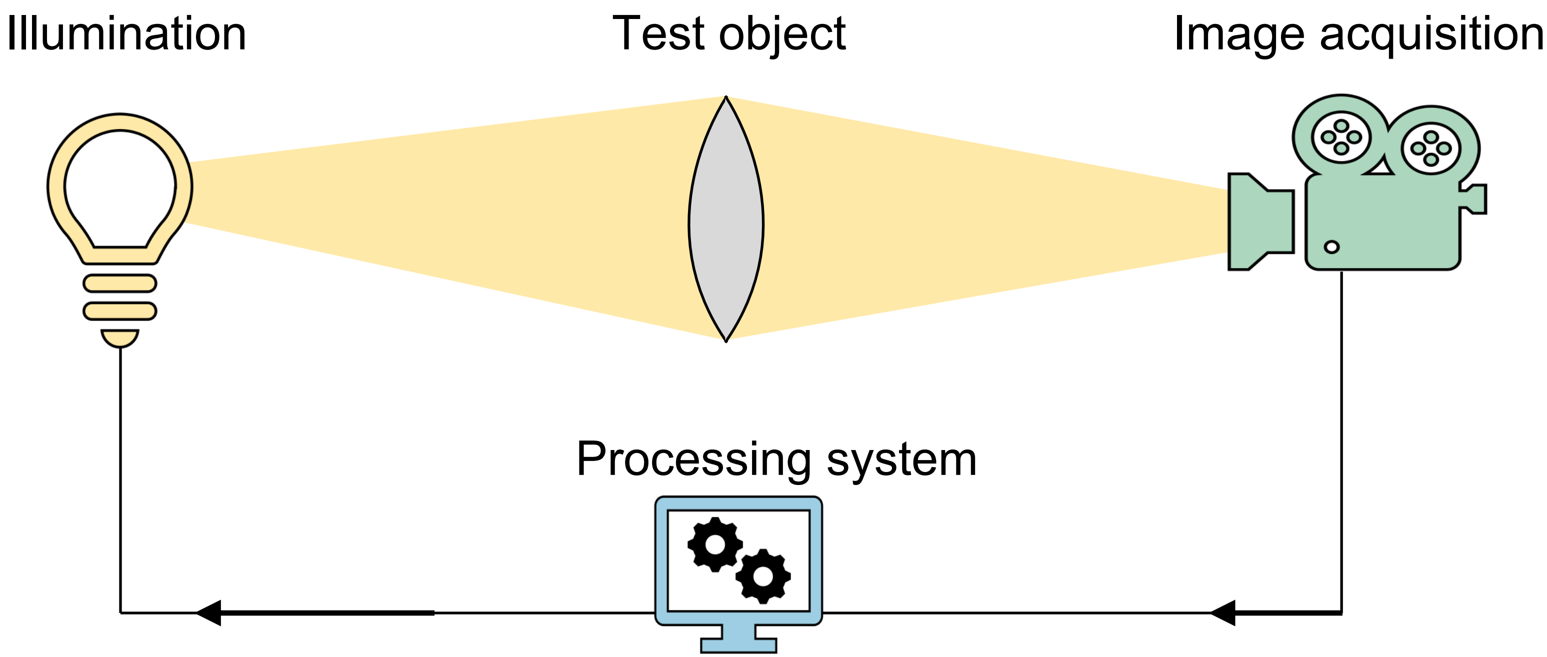

- **Inverse light field illumination**
- Light field generator, concept & prototype

- Light field gradient processing methods
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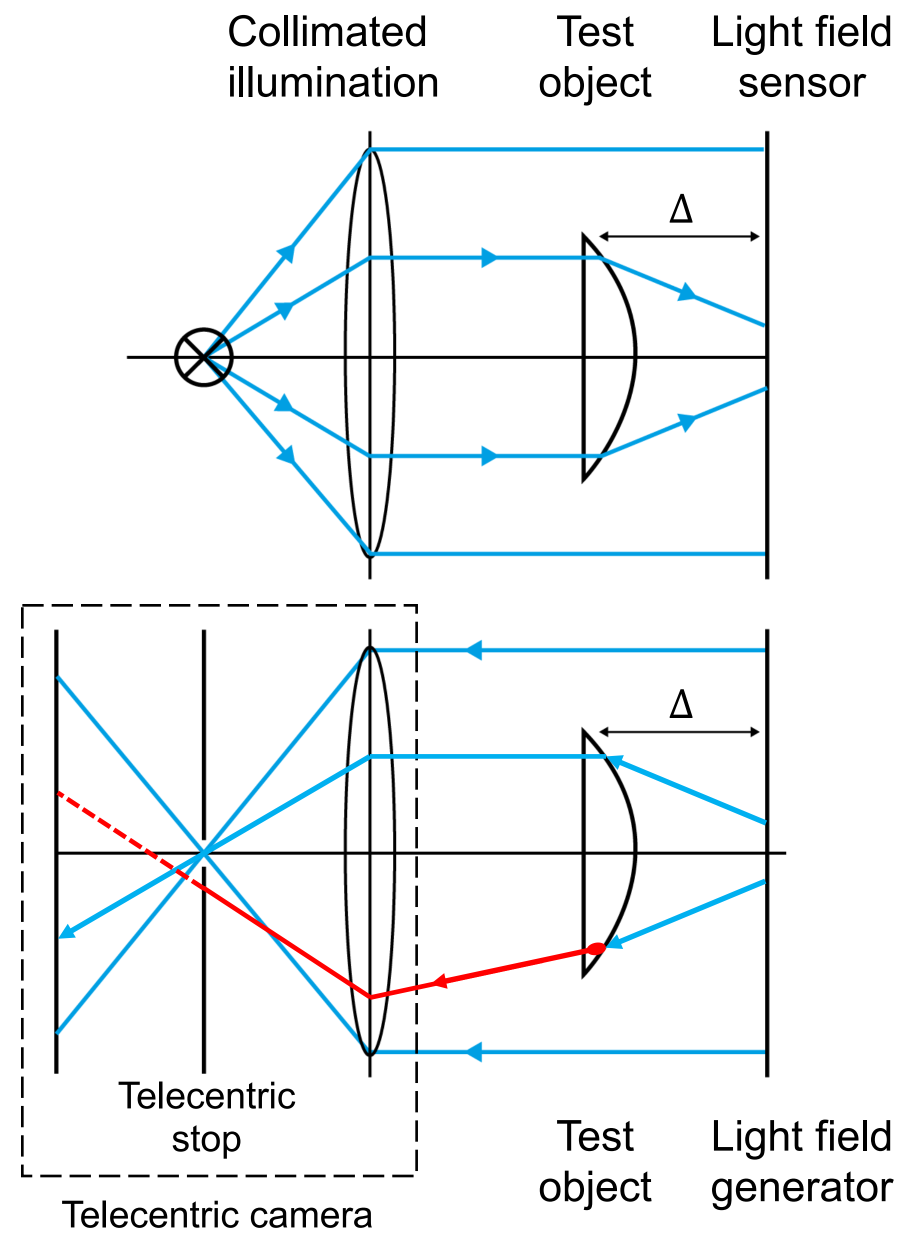
Inverse Light Field Illumination

Idea: Light transport inversion.

- **Offline phase**:
  Acquisition of a reference light field of a defect-free test object.

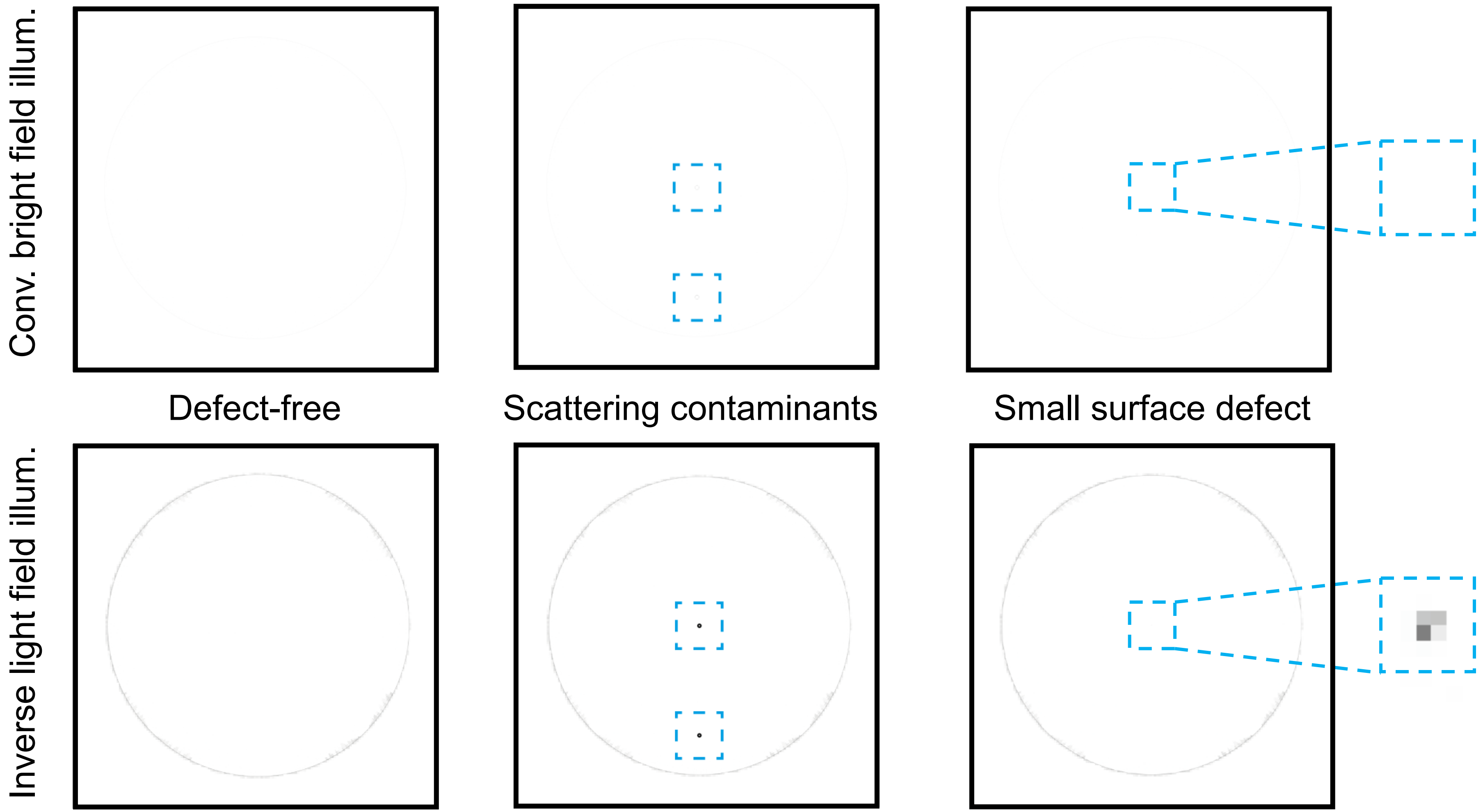
- **Online phase**:
  Inspection of other test objects via illumination with the reference light field and image acquisition using a telecentric camera.



J. Meyer et al. “Simulation of an Inverse Schlieren Image Acquisition System for Inspecting Transparent Objects”. In: Electronic Imaging. 2016, pp. 1–9.

Simulated Experiments

Inverse light field illumination of a double-convex lens.

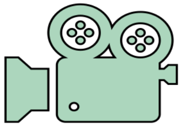


Conclusion

Light field methods

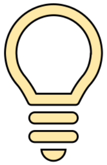
- enable the automated visual inspection of complex-shaped transparent objects,
- without the need of tediously adapting the system to the test object on hand.

Outlook



- Realize the laser deflection scanner in a retroreflector-based arrangement (➔ easier setup).

- (Further) Speed up the gradient calculation.
- Inspection of structured transparent objects by means of an AR model.



- Dynamically adapt the emitted light field to the test object on hand to increase the robustness against geometrical variations.

… and Now?

Since 2019: Lead Engineer Computer Vision @

- Employing methods of computer vision to support the development of (white box) solutions in various fields:






Sensor Fusion

Segmentation

Visual Inspection

Localization

Object Detection

Surveillance

COMPUTER VISION

www.itk-engineering.de/en/

Many thanks for your attention, questions welcome!

Get in touch: mail@meyerj.de

List of Publications

J. Meyer. “Visual Inspection of Transparent Objects – Physical Basics, Existing Methods and Novel Ideas”.
Tech. rep. IES-2014-04, pp. 37-47

J. Meyer. “Overview on Machine Vision Methods for Finding Defects in Transparent Objects”.
Tech. rep. IES-2015-08, pp 103-112.

J. Meyer, T. Längle, J. Beyerer. “Acquiring and Processing Light Deflection Maps for Transparent Object Inspection”.
In: 2nd International Conference on Frontiers of Signal Processing. 2016, pp. 104–109.

J. Meyer. “Next on Stage: ‘MC ViSi’ – a Machine Vision Simulation Framework”.
Tech. rep. IES-2015-08, pp 71-83.

J. Meyer, T. Längle, J. Beyerer. “About acquiring and processing light transport matrices for transparent object inspection”.
In: tm-Technisches Messen (2016), pp. 731–738.

J. Meyer, T. Längle, J. Beyerer. “About the Acquisition and Processing of Ray Deflection Histograms for Transparent Object Inspection”.
In: Irish Machine Vision & Image Processing Conference Proceedings. 2016, pp. 9–16.

J. Meyer, T. Längle, J. Beyerer. “Acquisition and processing of light transport matrices for automated transparent object inspection”.
In: Forum Bildverarbeitung. 2016, pp. 75–86.

J. Meyer, R. Gruna, T. Längle, J. Beyerer.
“Simulation of an Inverse Schlieren Image Acquisition System for Inspecting Transparent Objects”.
In: Electronic Imaging. 2016, pp. 1–9.

J. Meyer, T. Längle, J. Beyerer. “fastGCVM: A Fast Algorithm for the Computation of the Discrete Generalized Cramér-von Mises Distance”.
In: 25th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision. 2017, pp. 147–152.

J. Meyer, T. Längle, J. Beyerer. “General Cramér-von Mises, a Helpful Ally for Transparent Object Inspection Using Deflection Maps?”.
In: Scandinavian Conference on Image Analysis. 2017, pp. 526–537.

J. Meyer, T. Längle, J. Beyerer. “Towards light transport matrix processing for transparent object inspection”.
In: Computing Conference. July 2017, pp. 244–248.

J. Meyer, T. Längle, J. Beyerer. “Optical realization and calibration of a light field generator”.
In: Proceedings of SPIE Optical Systems Design. Vol. 10693. 2018, pp. 1–10.

J. Meyer, W. Melchert, M. Hartrumpf, T. Längle, J. Beyerer. “SNR-optimized image fusion for transparent object inspection”.
In: Proceedings of SPIE Photonics Europe. Vol. 10677. 2018, pp. 1–11.

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- Washing machine door glass:
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- Washing machine:
  https://www.immer-besser.de/media/catalog/product/cache/4/image/9df78eab33525d08d6e5fb8d27136e95/w/d/wdb030wcs.jpg
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  http://bacteriostaticwater.com/media/catalog/product/cache/1/image/300x/040ec09b1e35df139433887a97daa66f/s/t/sterile-glass-vial-10ml.png
- Color maps:
  Kovesi, Peter. "Good colour maps: How to design them." *arXiv preprint arXiv:1509.03700* (2015).