
Deflectometry for the Inspection of Specular Surfaces

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Workshop on

“Non-destructive Inspection Technologies”

Zurich, 27. October 2011

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Overview

- **Basic ideas** of deflectometry
- Qualitative and quantitative **evaluation**
 - Deflectometric measurement data
 - Feature-based detection of defects
 - Reconstruction of the surface
- Inspection and reconstruction of **large and complexly shaped objects**

Image-based inspection of specular surfaces



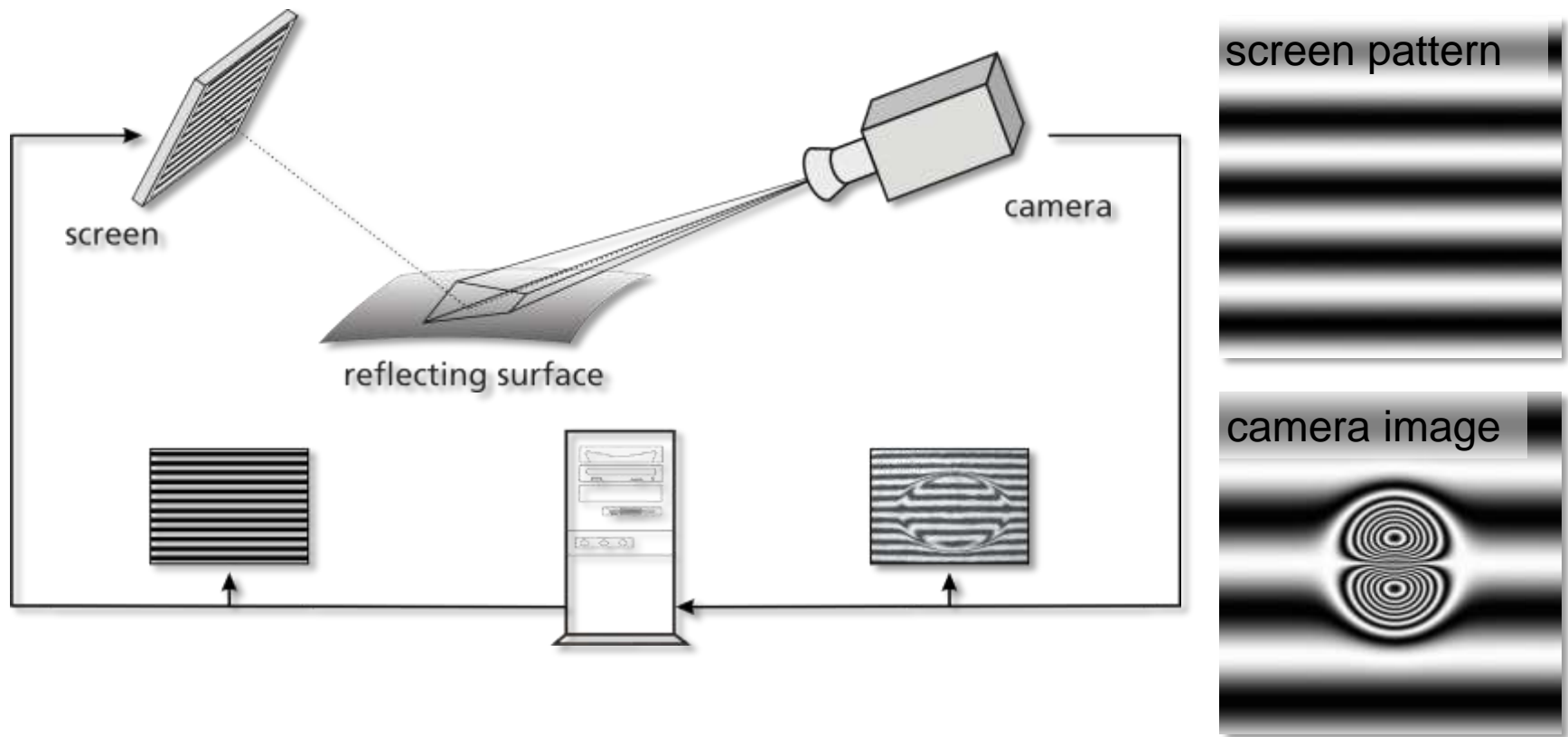
Basic idea of deflectometry

- Observation of the reflection of a structured environment



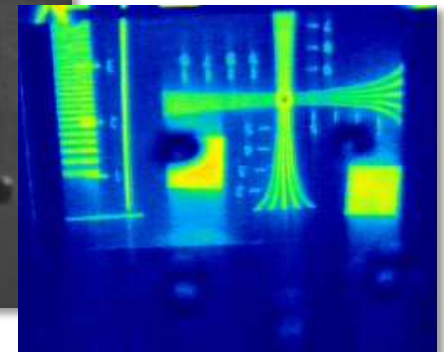
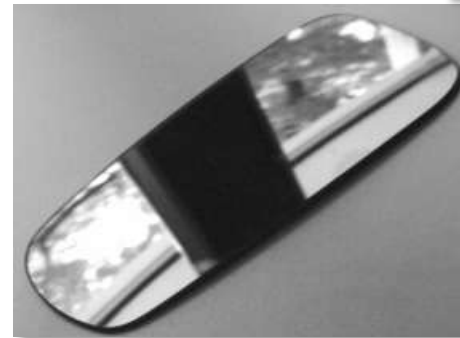
Deflectometric inspection principle

- Observation of the reflection of a structured environment
- Computer-based pattern generation and image evaluation

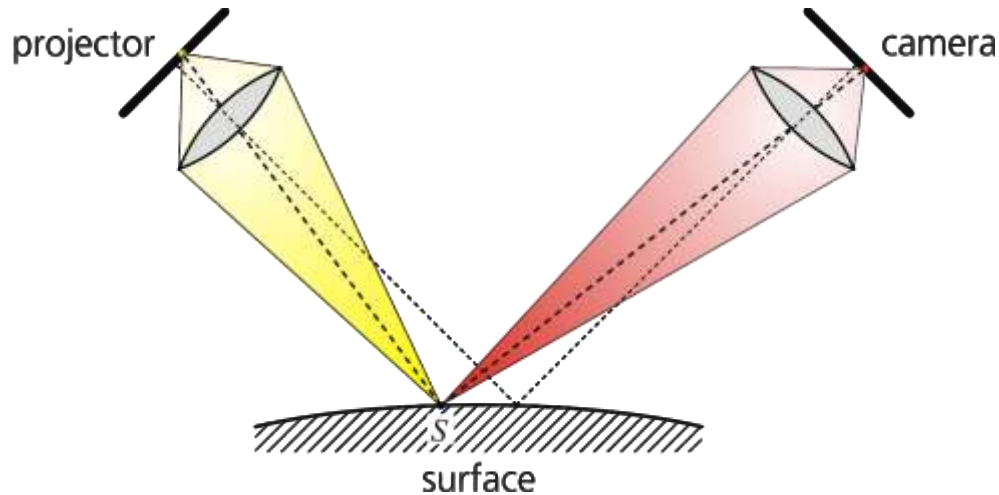


Preconditions of deflectometry

- At least partially **specular reflection**
Less suitable are
 - Mainly diffusely reflecting surfaces
 - Rough surfaces (e.g. unpainted metal sheets)
- **Only one reflection**
Less suitable are e.g.
 - Glass mirrors
 - Surfaces with multiple reflections
- Possible solution for rough surfaces:
IR deflectometry

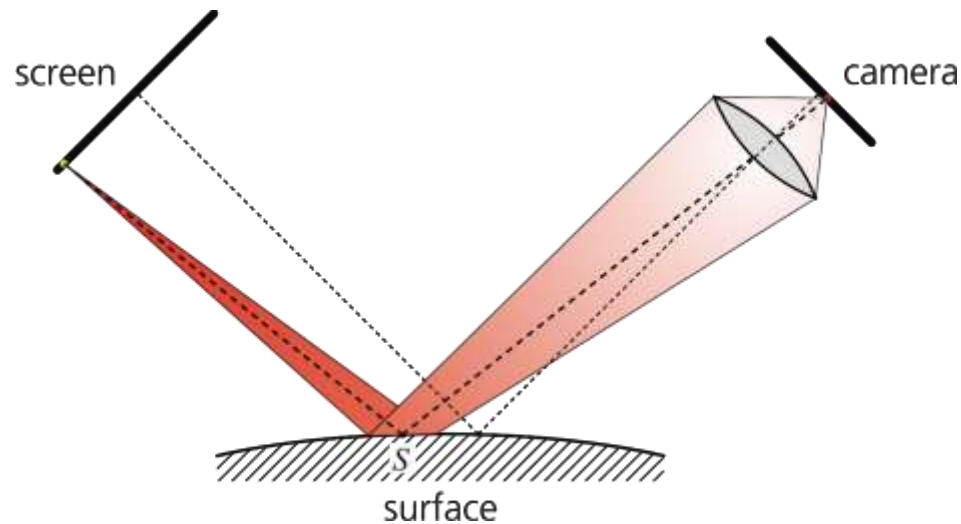


Comparison: Deflectometry – Structured light projection (1)



Structured light projection:

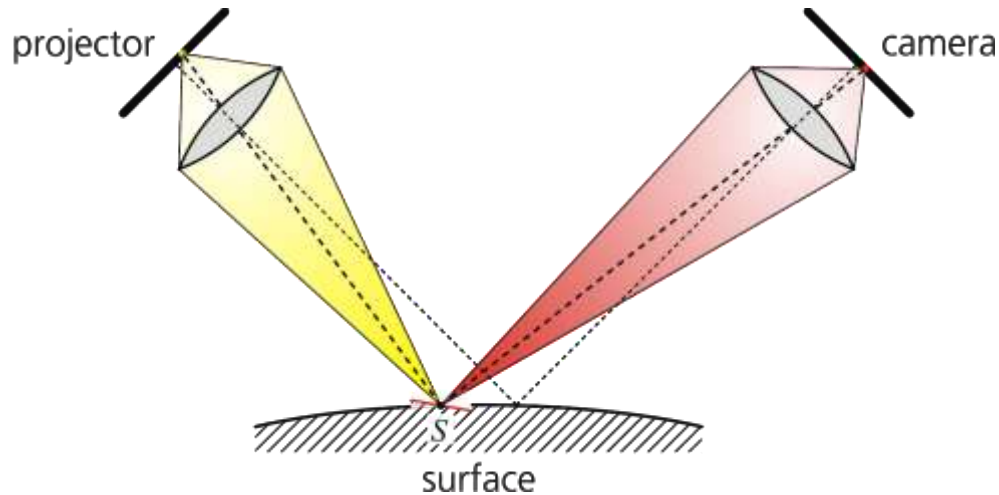
- Projector produces pattern on the surface
- Camera observes surface



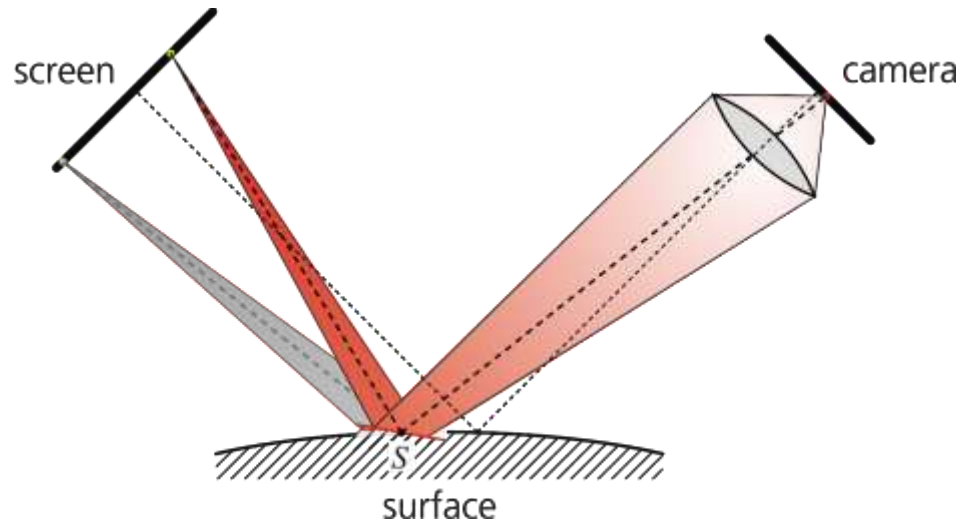
Deflectometry:

- Screen instead of projector
- Camera observes reflection of the screen

Comparison: Deflectometry – Structured light projection (2)



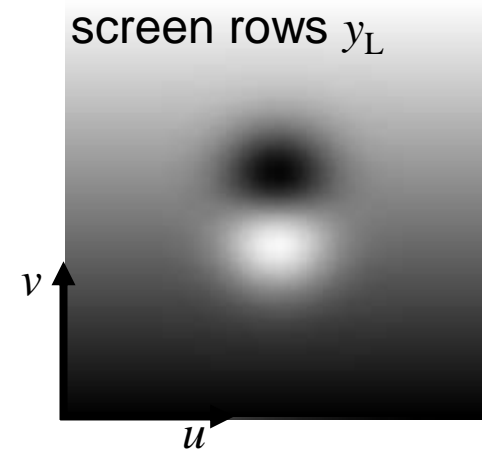
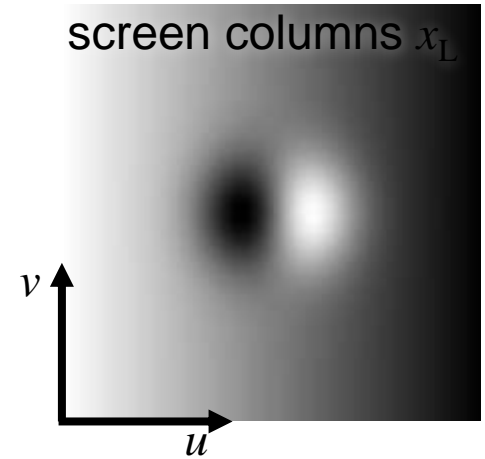
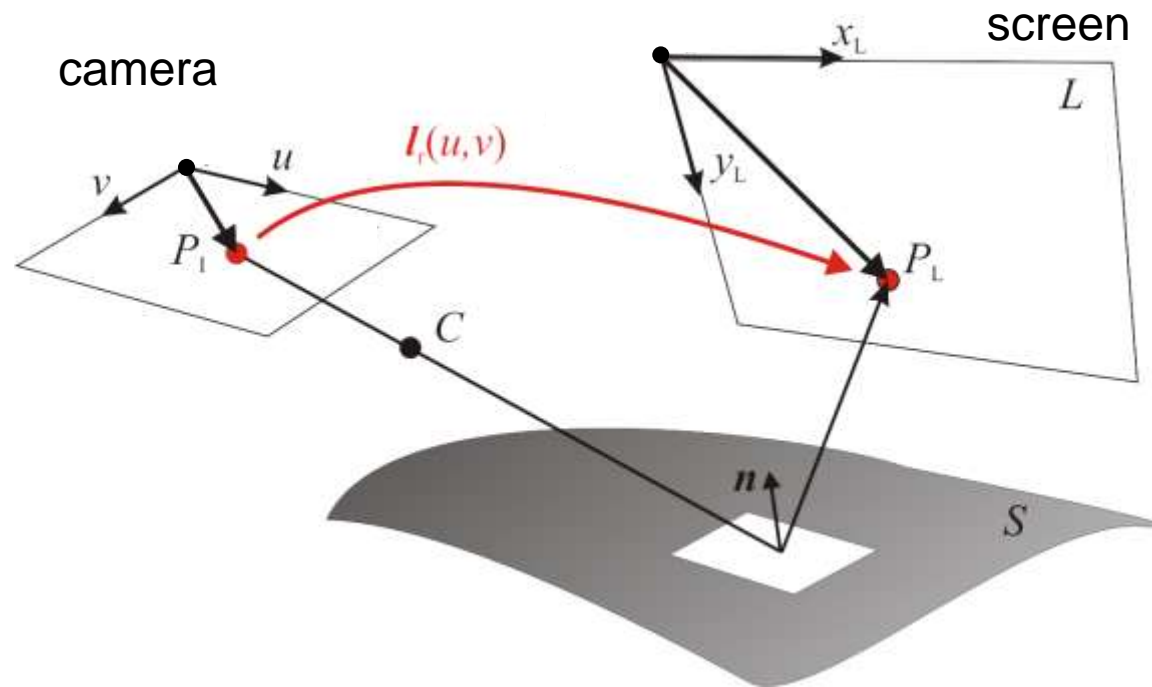
Structured light projection:
No sensitivity
to local surface inclinations



Deflectometry:
High sensitivity
to local surface inclinations

Acquisition of deflectometric measurement data

Deflectometric registration



- Coding of the positions on L by means of an image series
- Assignment:
Camera pixel (u, v) \rightarrow screen position (x_L, y_L)

Evaluation of deflectometric measurement data

Possible foundations:

- Observed stripe pattern
- Deflectometric registration

Feature-based detection of defects

- Evaluation of **local features**, e.g. stripe frequency and deformations, matt spots
 - + Fast
 - Suitable features necessary for each inspection task

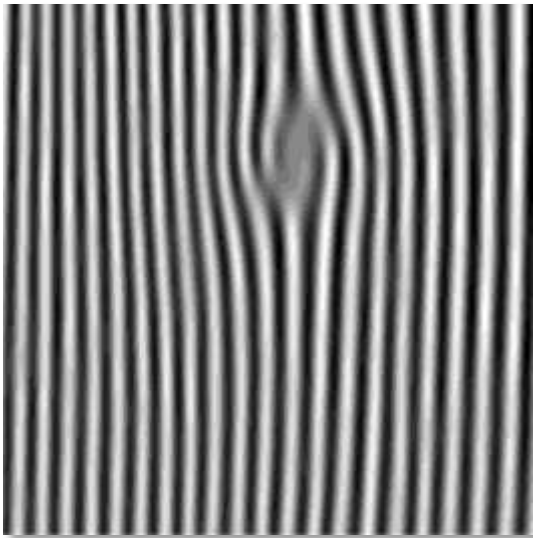
Reconstruction of the surface geometry

- + Generation of quantitative geometric information: measurement
- More complex than feature-based detection of defects
- Additional information required

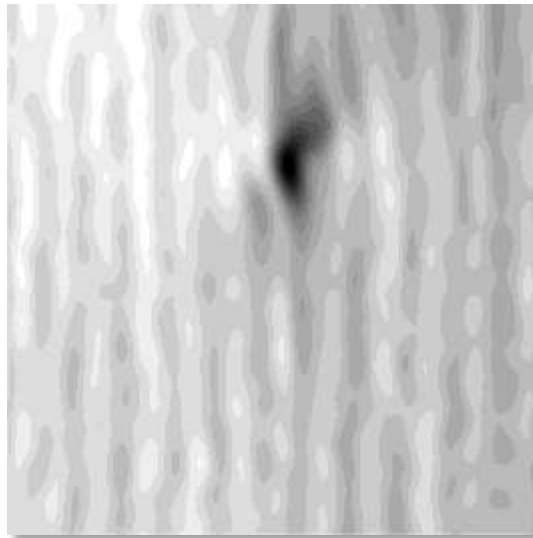


Feature-based detection of defects (1)

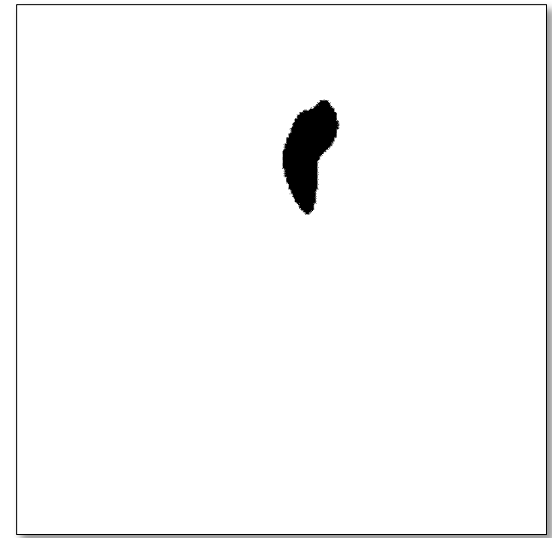
Example: **Local stripe frequency**
for the inspection of a polished pressing tool



Reflection
of the stripe pattern



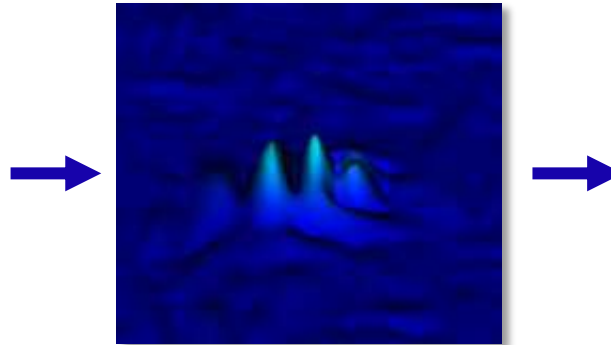
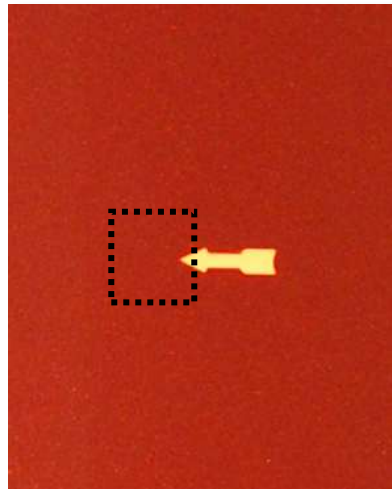
Feature: absolute value of the
local spatial frequency
(»stripe frequency«)



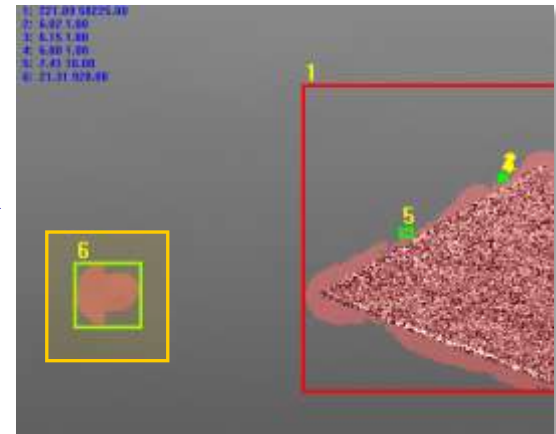
Result of
classification

Feature-based detection of defects (2)

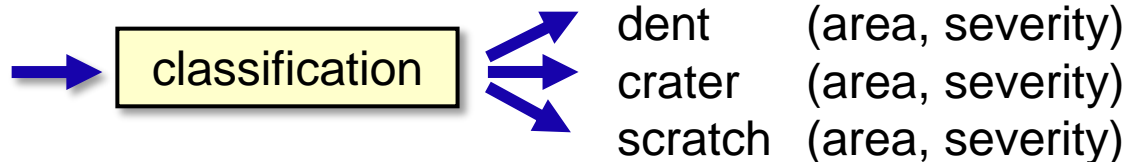
Example: **Local curvature**
for the inspection of painted surfaces



Feature: curvature,
approximated from
the deflectometric
registration

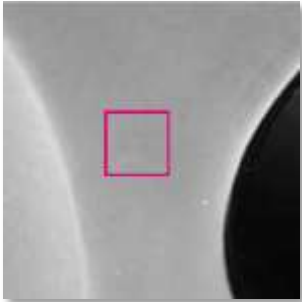


Detection:
surface defect



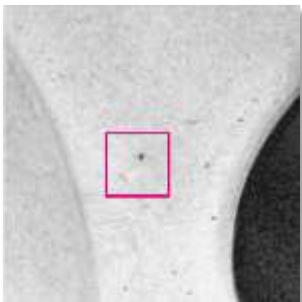
Feature-based detection of defects (3)

Example: Fusion of several criteria for the assessment of a surface



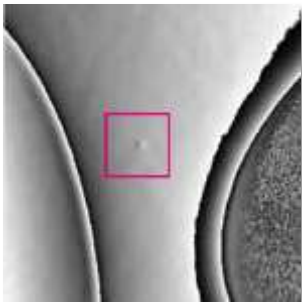
Synthetic gray image

- Appearance corresponds to homogeneous illumination
- Serves to detect reflectance defects



Modulation image

- Contains gloss information
- Serves to detect matt spots



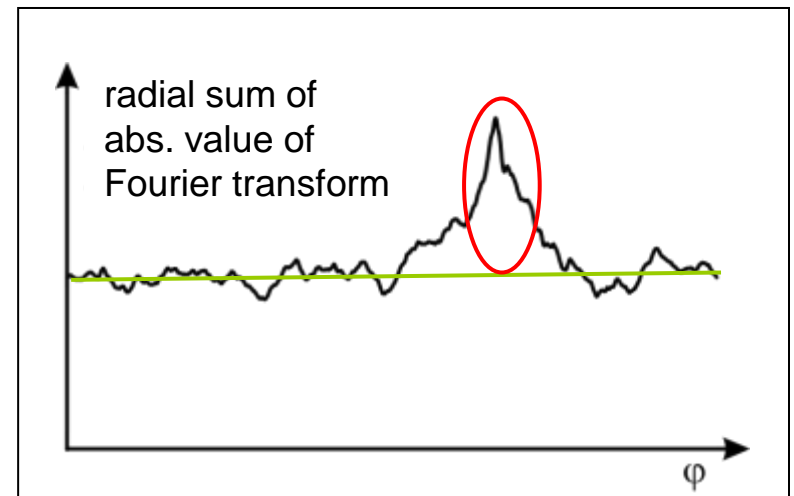
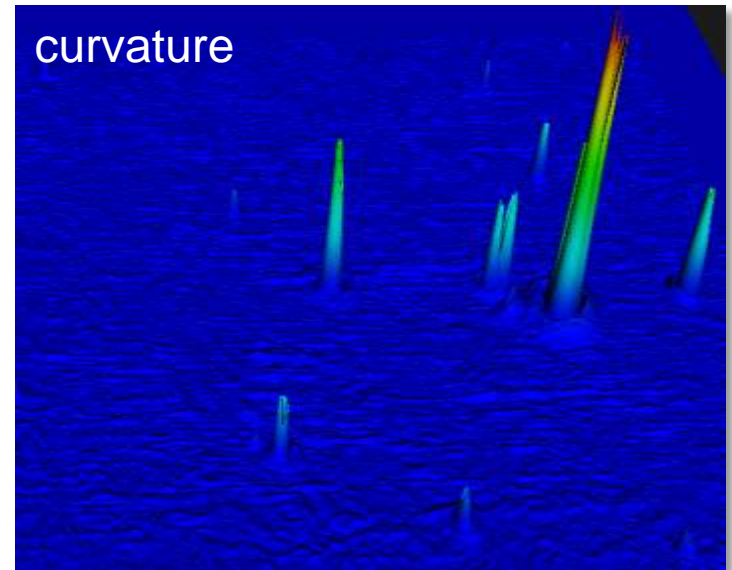
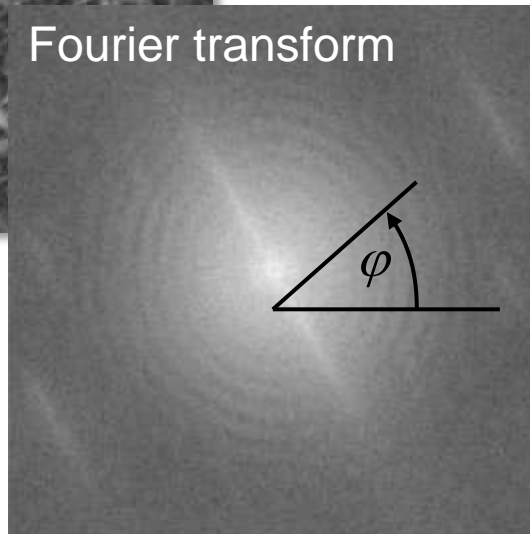
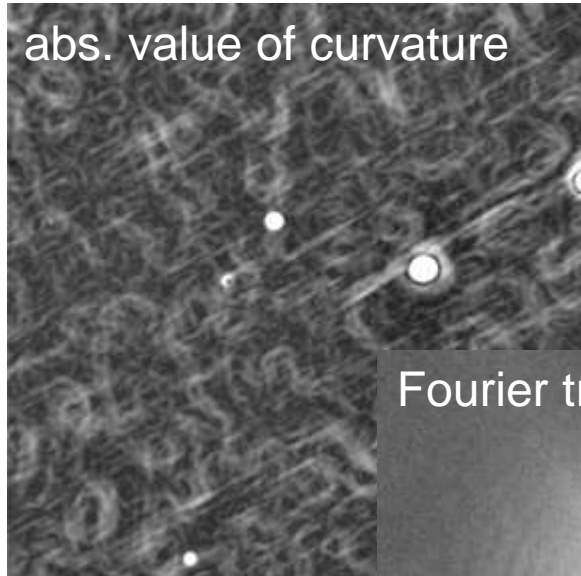
Phase image

- Contains information on surface inclinations
- Serves to detect scratches, dents, craters

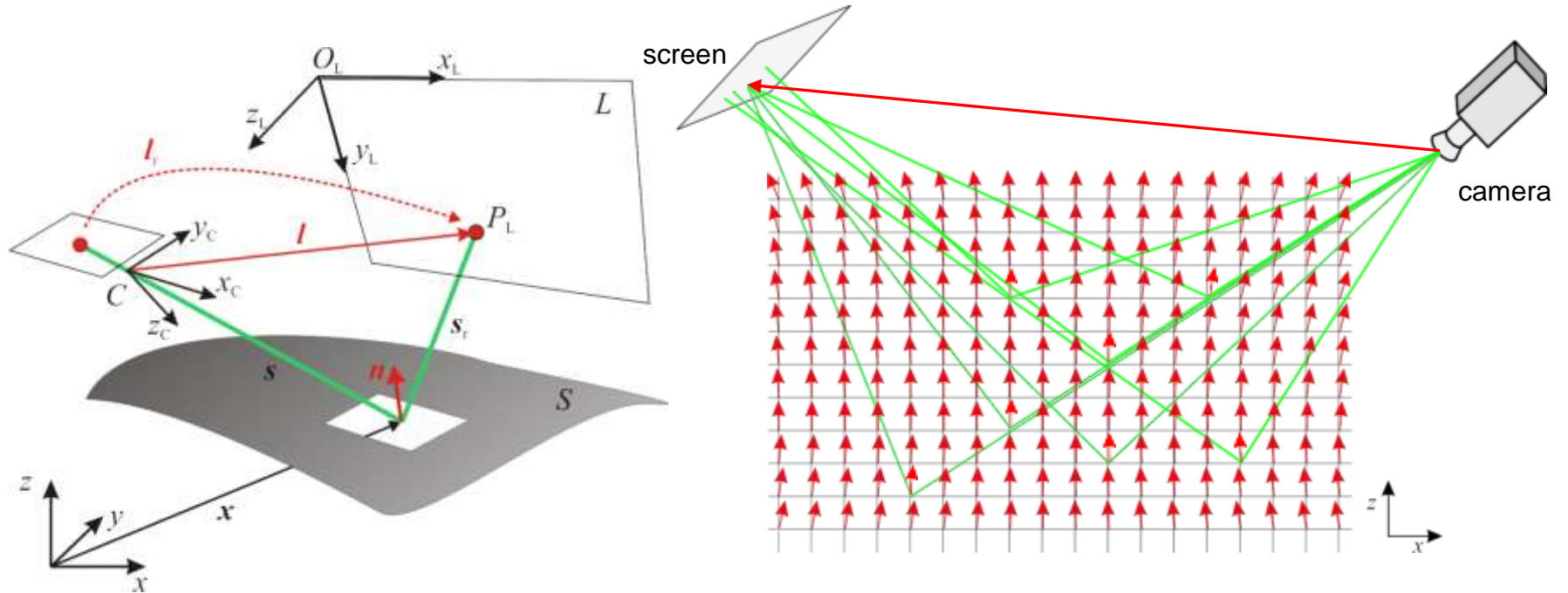
Source: Carl Zeiss OIM GmbH

Feature-based detection of defects (4)

Example: **Texture analysis**
Detection of grinding marks



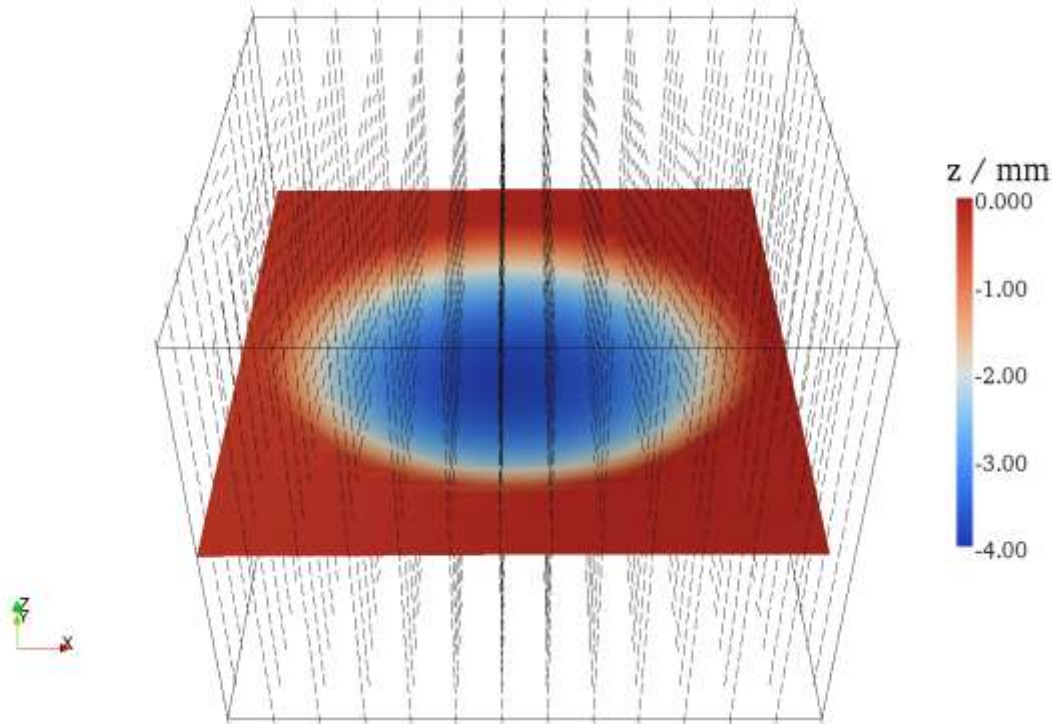
Reconstruction of surfaces (1)



Deflectometric data acquisition yields spatial **normal field**

Reconstruction of surfaces (2)

Challenge: Identify the surface that fits best with the measured normal field

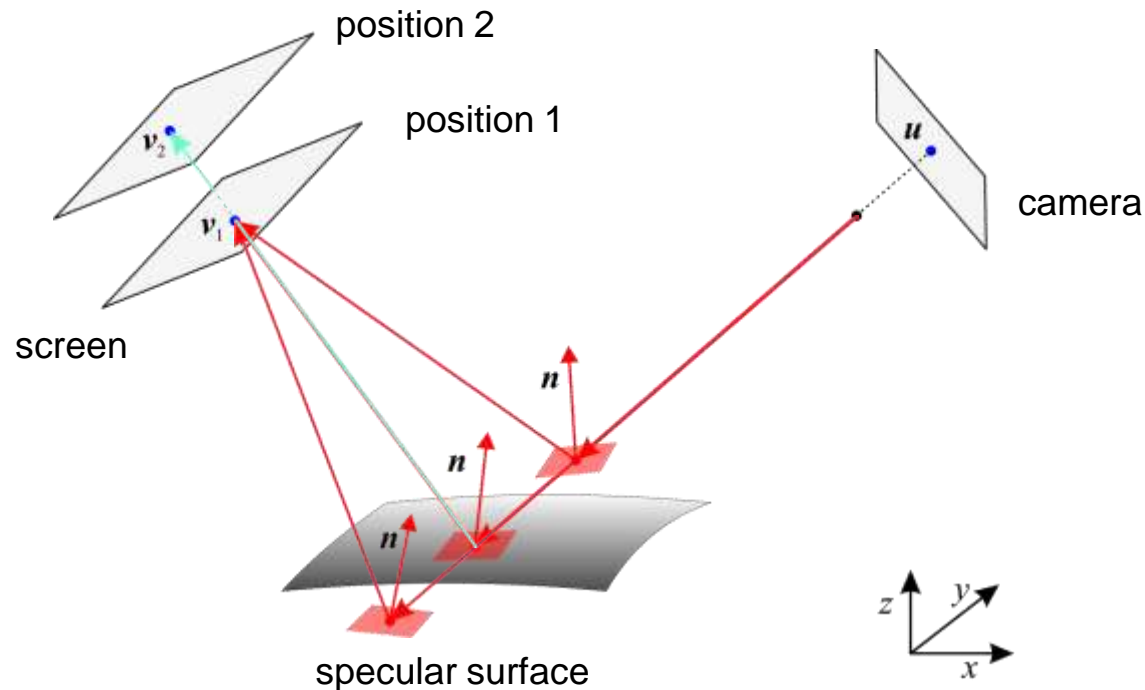


Normal field is compatible with **one-dimensional** solution manifold
→ **Regularization** of the problem required

Additional information for the reconstruction (1)

Elimination of the ambiguity by means of e.g. **specular stereo**

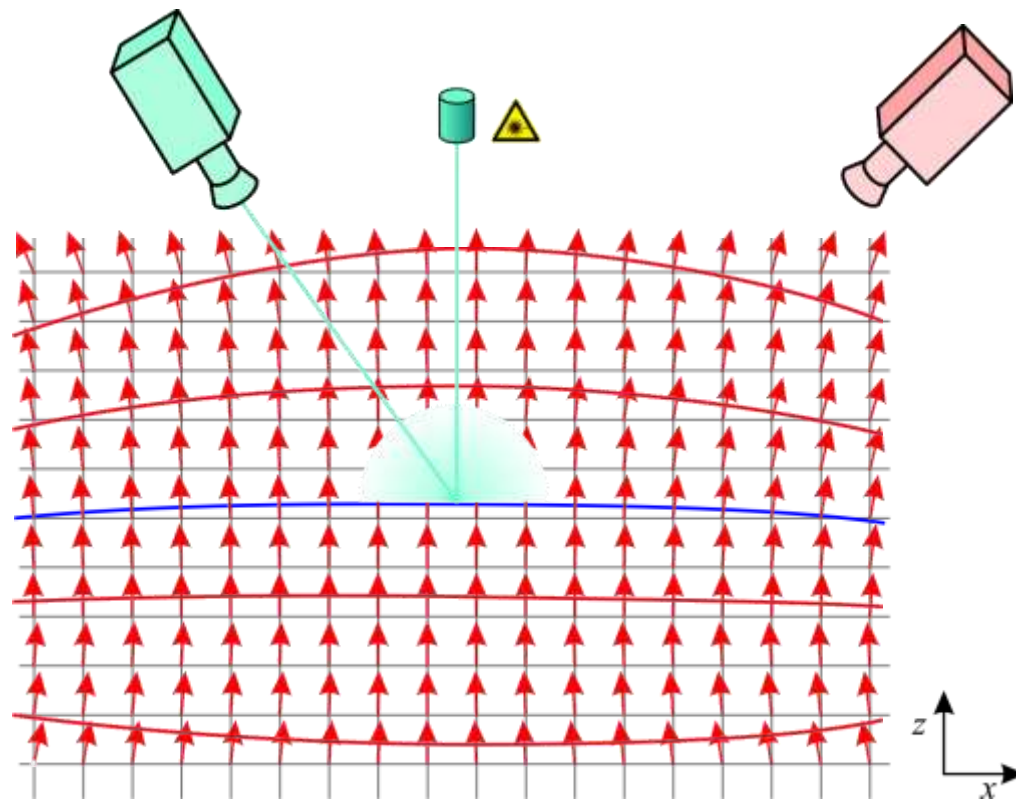
- Two screen positions or
- Two cameras



Additional information for the reconstruction (2)

Elimination of the ambiguity by means of e.g.
inhomogeneous surface measurement

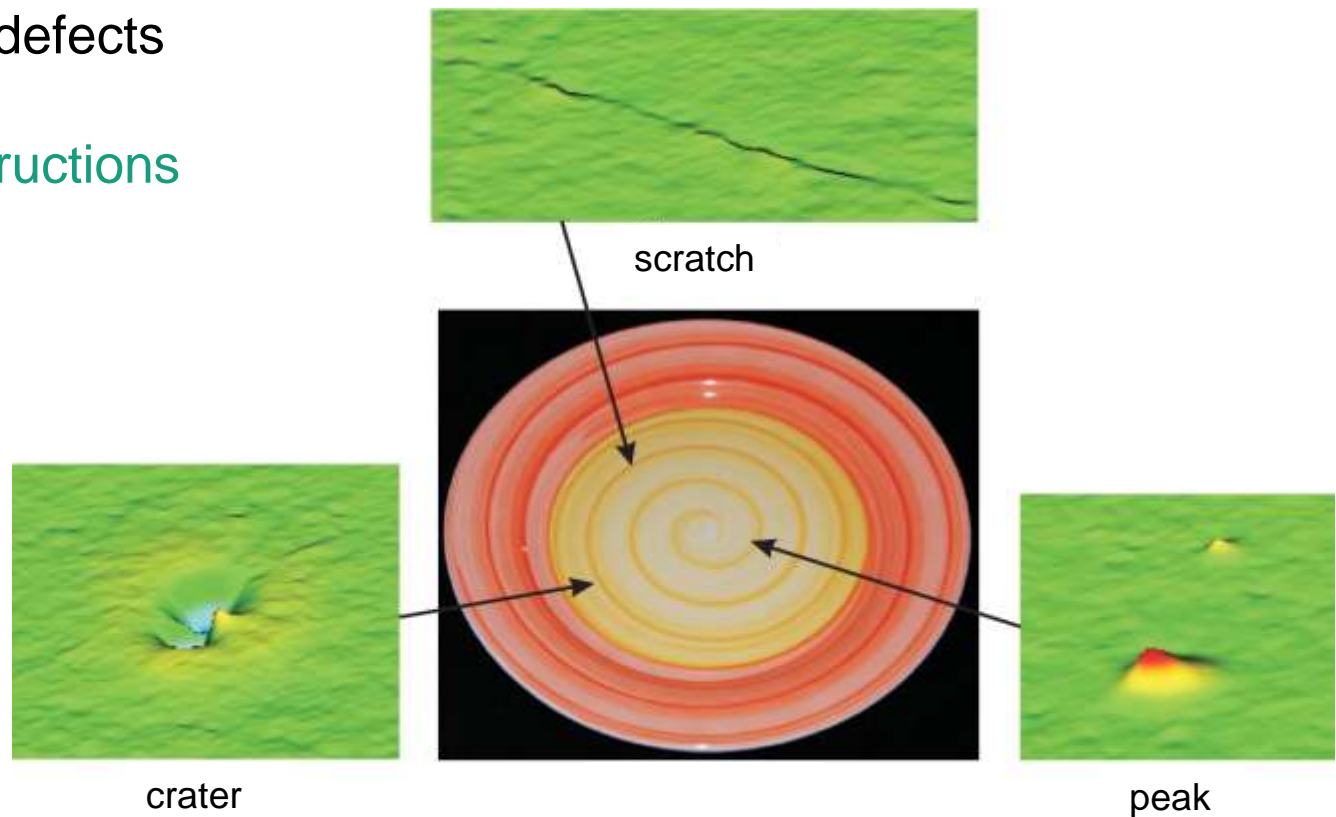
- Laser triangulation of a surface point



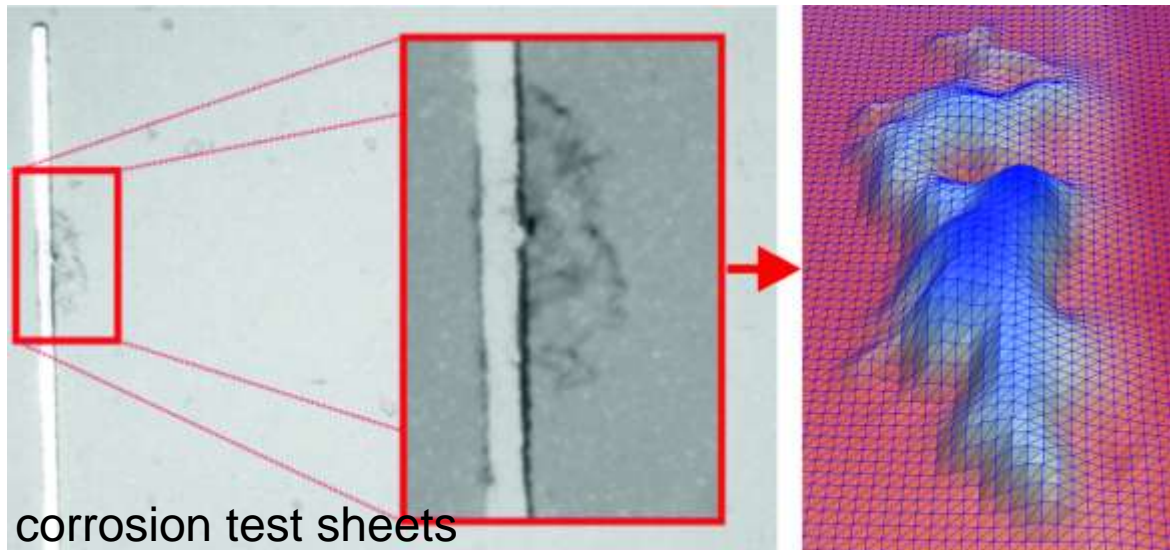
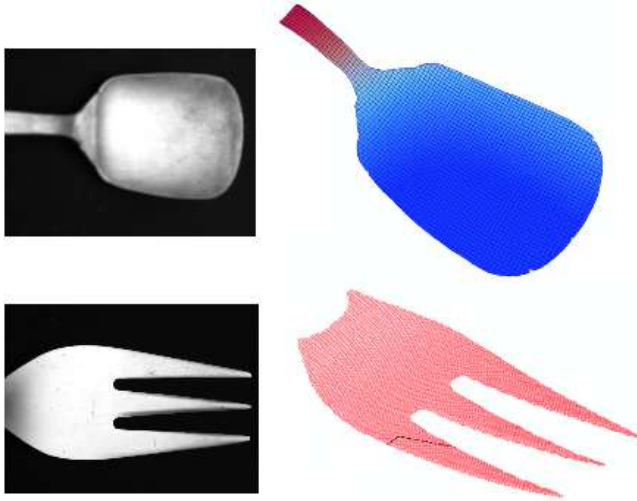
Additional information for the reconstruction (3)

Elimination of the ambiguity by means of e.g.
assumptions on the surface

- Assumption: Undisturbed surface is flat
- Detection of defects
by means of
local reconstructions



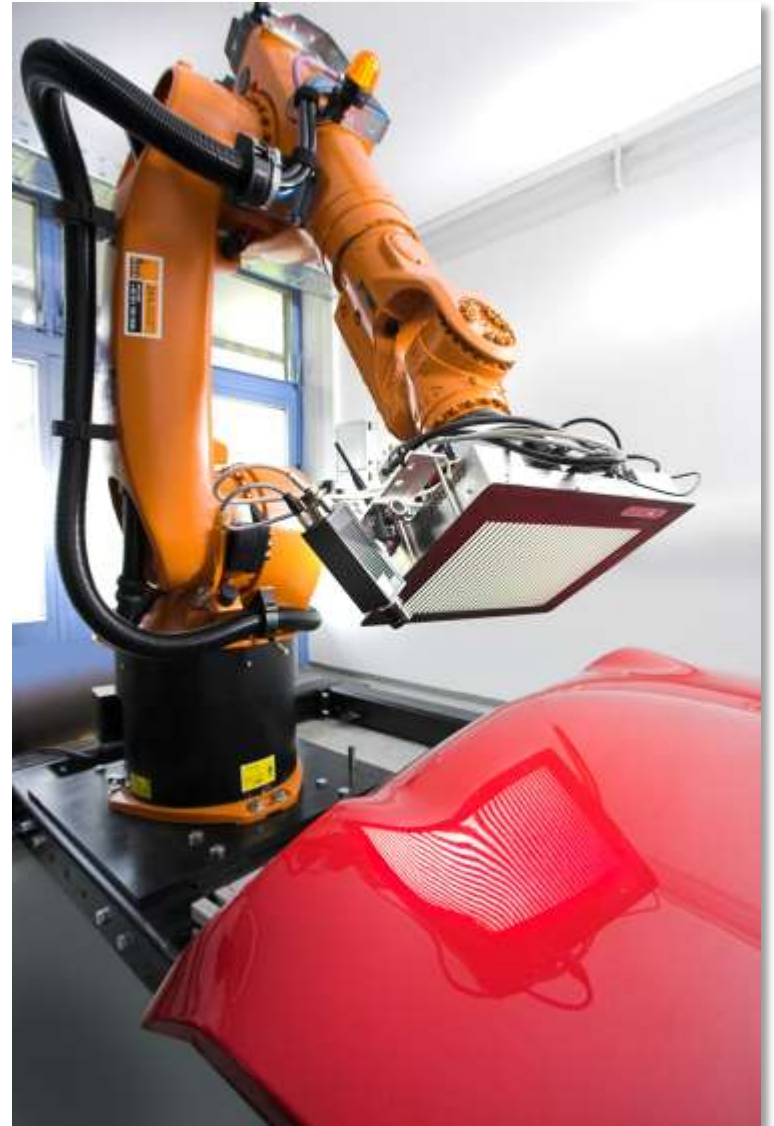
Examples of reconstructions



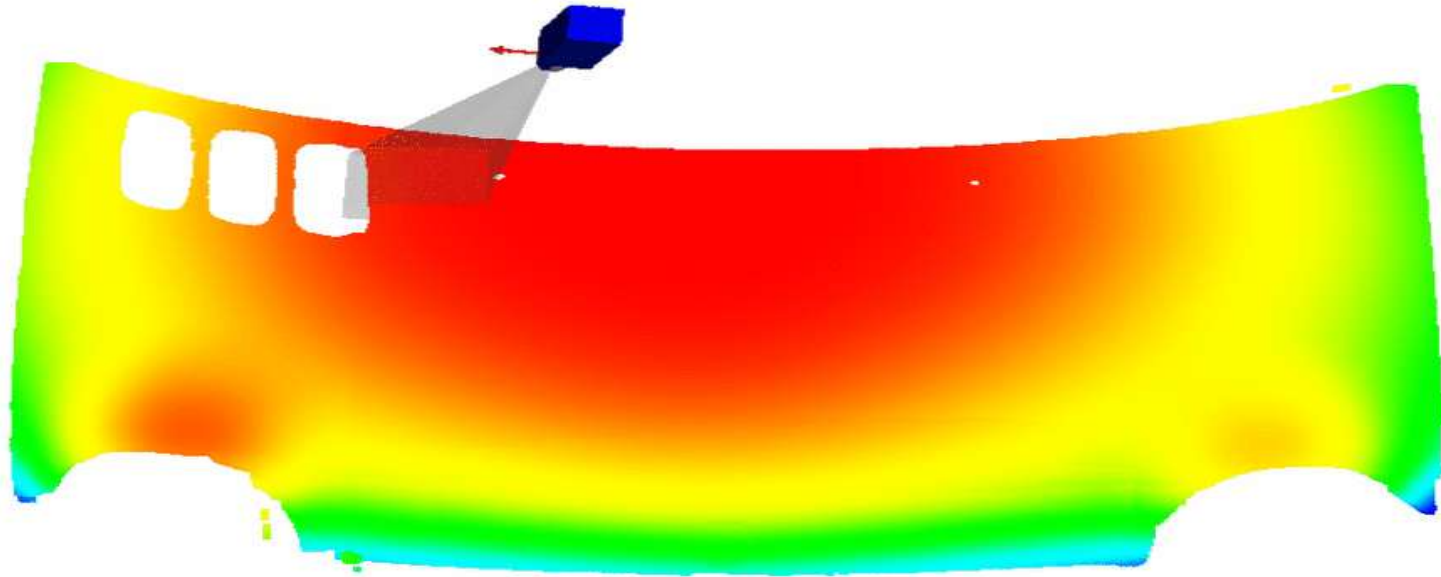
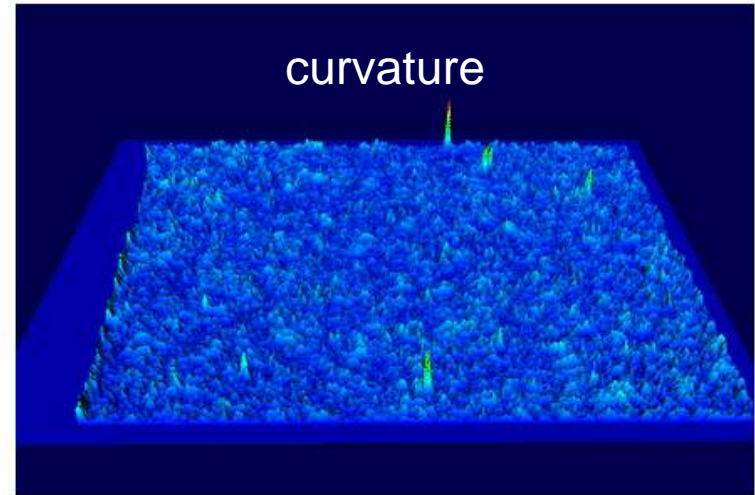
corrosion test sheets

Inspection of large objects

- Use of **sensor heads**:
Rigid combination of screen and camera
- Positioning by means of **industrial robots**
- **Tessellation** of the entire surface, then stitching of the reconstruction patches



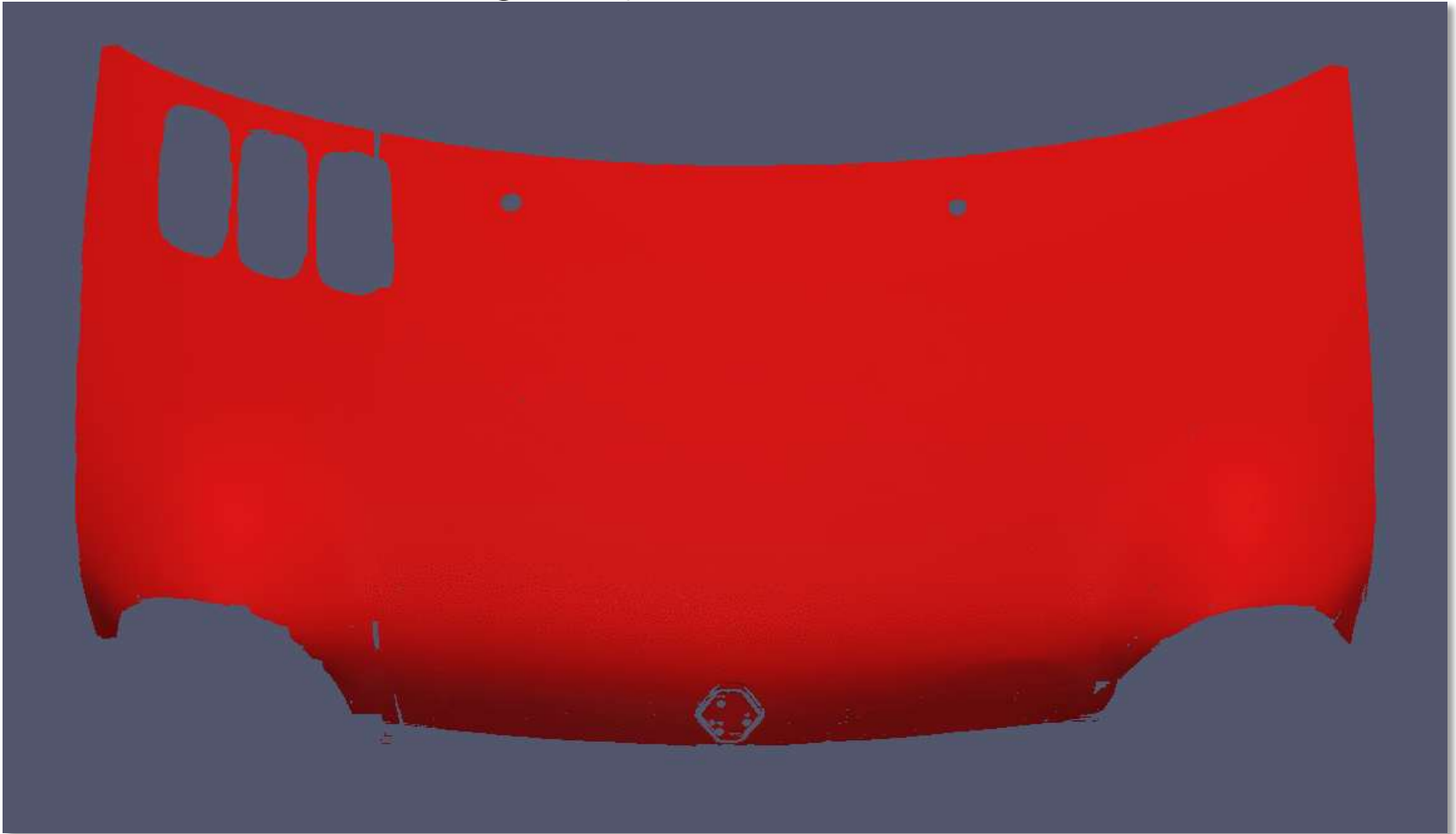
Reconstruction of large objects (1)



Reconstruction of large objects (2)



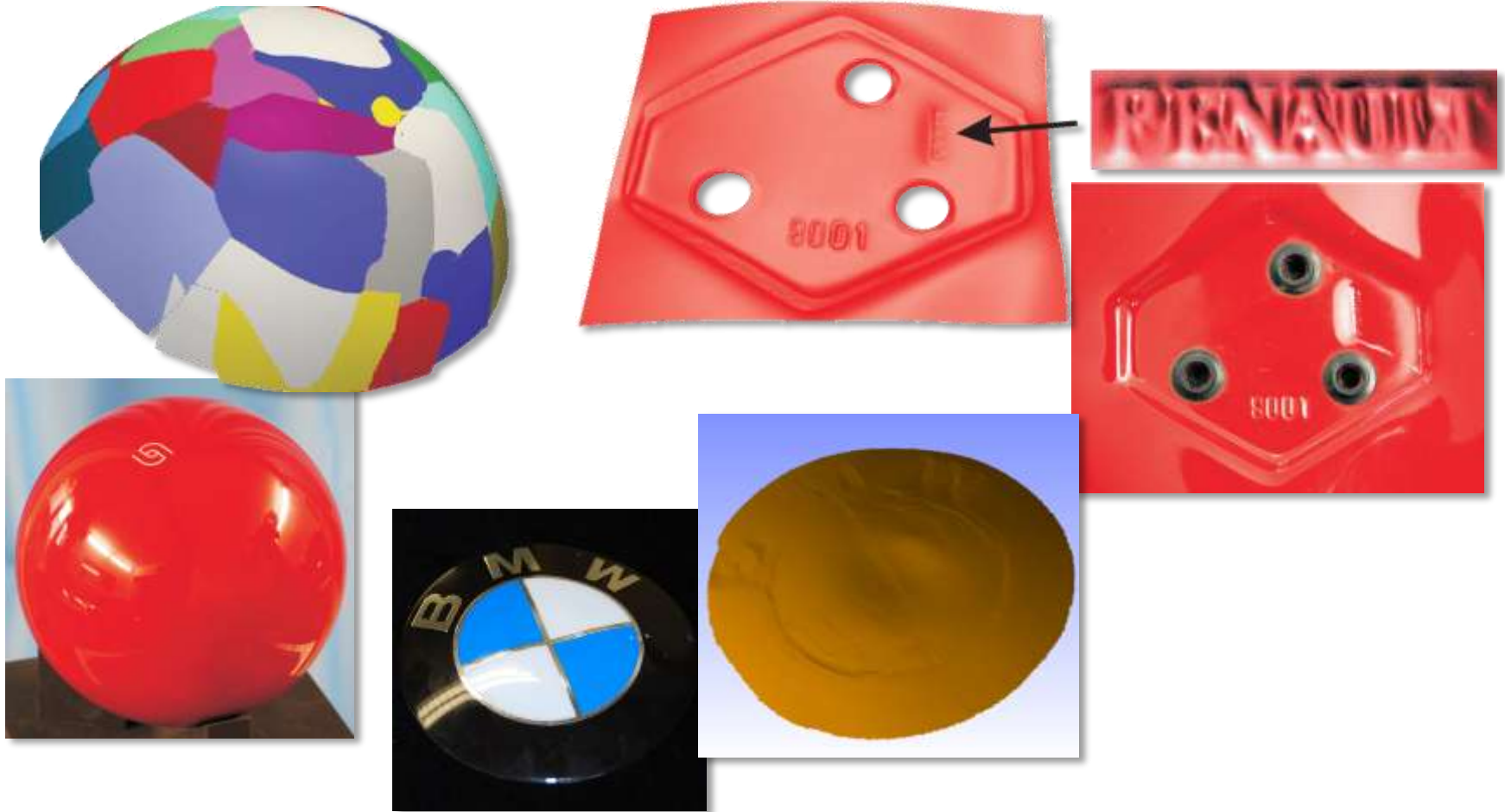
Reconstruction of large objects (3)



Reconstruction by means of global triangulation (about 3 mio. triangles),
regularization by multi-stereo in overlapping regions

Reconstruction of large objects (4)

Stitching of several deflectometric reconstructions



Summary

- Deflectometry: Image-based inspection method for (partially) specular surfaces
 - Illumination: Display of patterns on a screen
 - Observation of the reflections in the surface
- Strength and Weaknesses:
 - Very high sensitivity (waves, dents)
 - For geometric reconstruction: Additional information required
- Inspection of large objects by using a deflectometric sensor head and stitching of several overlapping reconstructions

Thank you for your interest!