Deflectometry for the Inspection of Specular Surfaces

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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

classification

dent

(crater, severity)

scratch

(area, severity)
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

- **abs. value of curvature**
- **Fourier transform**
- **radial sum of abs. value of Fourier transform**

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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!