Systematic Errors in Dimensional X-ray Computed Tomography

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Overview

- Industrial X-ray CT today
- Dimensional CT as a key technology in production metrology
- Errors sources and a good practice in CT scanning
- Conclusions and future works
Industrial X-ray CT today
Industrial X-ray CT today
Industrial X-ray CT today

Material Testing

Industrial X-ray CT

Material Analysis

Dimensional (geometrical) Metrology
Dimensional CT as a key technology in production metrology

Measurement of size, form, and position

CAD/CT comparison
Dimensional CT as a key technology in production metrology

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Dimensional CT as a key technology in production metrology

Measurement uncertainty $U$:

- We will never know the *true* value of a measurement
- Measurement results must be repeatable and reproducible
- What about systematic (effects) errors? **Should be corrected!**
Errors sources and good practice in CT scanning

CT

Image processing

Coordinate measurement

Geometrical measurand

Scanning Reconstruction

Surface determination

Coordinate measurement in the 3D model

Determination of size, form, and position

$\phi_1 = 15.24 \text{ mm}$

$\phi_2 = 18.87 \text{ mm}$
Errors sources and good practice in CT scanning

What are sources of systematic errors?

- Image artefacts
- Scaling (voxel size) error
- CT system limits (image blurring, noise)
- Metrological data evaluation strategy

Segmentation and surface determination errors
Errors sources and good practice in CT scanning

Can we use calibration artefacts?

Only for the compensation of effects linked to geometrical scanner misalignment or beam-hardening artefacts

- Calibrated masterpieces
- Systematic scanning and evaluation planning to avoid high systematic errors (blunder)
Errors sources and good practice in CT scanning

- Beam-hardening
- Cone-beam
- Misalignment
- Undersampling
- Truncation
- Ring artifacts
- Metal artifacts
- Noise artifacts
Errors sources and good practice in CT scanning

Cone-beam artefacts:

Circular sampling
Helical sampling
Errors sources and good practice in CT scanning

Standard vs. helical CT:

Voxel size: 105.7 µm³
Errors sources and good practice in CT scanning

Good practice:

- Tilted position of the workpiece
Errors sources and good practice in CT scanning

Beam-hardening:

\[ P = -\ln\left(\frac{I}{I_0}\right) \]
Errors sources and good practice in CT scanning

Beam-hardening correction:

- Step wedge
- Radiography
- Linerization of projections with inverse function
Errors sources and good practice in CT scanning

DTU beam-hardening correction GUI

Save your LUT or load images to be corrected

Correct images

Exit

Reset All

Correlation Function

Length in mm

0 10 20 30 40 50 60

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

Intensity

Load LUT

Load Step Wedge image

Insert calibration values

Compute new LUT

Save LUT
Errors sources and good practice in CT scanning

Beam-hardening correction:

Object (Al)  uncorrected  corrected
Errors sources and good practice in CT scanning

Beam-hardening correction:

Voxel size: \((156.7 \times 156.7 \times 179.3) \, \mu m^3\)
Errors sources and good practice in CT scanning

Good practice:

- Tilted position of the workpiece
- Using a prefilter
Errors sources and good practice in CT scanning

\[ m = \frac{SDD}{SRD} \]

\[ v = \frac{a}{m} \]

Calibrated length: 8,7678 mm

\[ v = 30 \, \mu m, \Delta v = 1 \, \mu m \]

Error: \[ \Delta l = 50 \, \mu m \]

\[ l = 1,5 \, mm \]
Errors sources and good practice in CT scanning

Variations are caused by inaccuracies of the SRD measurement (manipulator) and focus drift during scanning due to tube temperature changes superimposed.
Errors sources and good practice in CT scanning

Voxel size rescaling:

\[ \tilde{v} = v \cdot \frac{L_{\text{ref}}}{L_{\text{CT}}} \]
Errors sources and good practice in CT scanning

Good practice:

- In particular at high magnifications: Ball-bar must be scanned together with the workpiece.

Focus drift differs from scan to scan!
Errors sources and good practice in CT scanning

Depending on object, scanning parameters, system hard- and software
Conclusions and future works

- CT as a powerful and flexible tool in production metrology

- Variety of error sources and influence quantities in CT metrology

- Possibilities to reduce systematic errors (effects)

- Importance of a consistent procedure in CT scanning planning
Conclusions and future works

- Material, shape, penetration lengths
- Fixture, positioning, orientation
- Tube voltage, current, prefilter, detector settings
- Evaluation of detector images → histogram analysis
- Image quality (artefacts, sharpness, noise)
- Voxel histogram analysis, threshold tests
- Surface quality inspection
- Alignment
- Measurement strategy (elements, points, methods)
- Reference data available, repeated measurements
Invitation to Conference on

“Industrial Applications of CT Scanning – Possibilities & Challenges in the Manufacturing Industry”

June 12, 2012, 10:00-16:30
DTU, Building 101, meeting room 1
2800 Kgs. Lyngby, Denmark
Thank you very much!