The EZRT is a joint department of the Fraunhofer-Institutes IIS Erlangen and IZFP Saarbrücken/Dresden

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## EZRT - Facts & Figures

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EZRT - Location Fürth

“Technicum New Materials”

The Bavarian Secretary of State for Trade and Industry Dr. O. Wiesheu inaugurates the EZRT on July 4th 2000
Principles of Computed Tomography

Set-up of a CT system and scheme of measurement

Source

Cone Beam

Object

Axis of Rotation

Flat Panel Detector

Image reconstruction cluster

Data acquisition

High speed network

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Röntgentechnik

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Principles of Computed Tomography

Volume CT of Large Objects

Tube: 450 kV, 2 kW

Digital Flat Panel with 2048 x 2048 Pixel (40 cm x 40 cm)
Status of Computed Tomography

X-Ray Systems

Computed Tomography

- Object geometry
  - Axial
  - Planar

Radiography

- Film
- Digital

2D-Layers
3D-Volume
Laminography
Digital Tomosynthesis

Image Processing
# Status of Computed Tomography

## Reconstruction Methods

<table>
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<td><strong>Filtered backprojection</strong></td>
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<td><strong>(Feldkamp-type algorithm)</strong></td>
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Computed Tomography - Laminography

Analogues Method

- Focal layer is reconstructed
- Layers outside the focal plane are blurred
- Adapted for plane, laminar objects like e.g. Printed Circuit Boards

System Set Up

- Rotating Source
- Counter rotating Detector
- Object in focal plane
- Objects outside focal plane

Planar CT
Computed Tomography - Laminography

8 µm bonding wires
3D - Visualization

Inspection of electronic multilayer PCBs

Oblique radioscopic view

Different layers by Tomosynthesis Method

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Principles of Computed Tomography

Filtered Backprojection

- Simple backprojection of projection data $P$ into object space leads to smearing of details

- Compensation: convolution with a Point Spread Function (PSF) proportional to $\rho$
  (Lakshminarayanan & Ramachandran 1971)

- Filtering of projection data $P_f$

- Backprojection of $P_f$ into the volume
Principles of Computed Tomography

Filtered Backprojection

Spatial domain

Frequency domain

\[ R_\theta f(s) = Rf(\theta, s) = \int f(s \theta + t) dt \]

\[ f(x, y) = \int \int R_\theta \hat{f}(\omega) \omega e^{i2\pi \omega (x \cos \theta + y \sin \theta)} d\omega d\theta \]
## Status of Computed Tomography

### Industry

<table>
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<tr>
<th>Bio Imaging Research</th>
<th>Microna (FhG)</th>
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<tr>
<td>Comet, Feinfocus</td>
<td>Shake (FhG)</td>
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<td>GE-IT (FhG)</td>
<td>Werth (FhG)</td>
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<td>Hitachi</td>
<td>Zeiss (hwm, FhG)</td>
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<td>Phoenix</td>
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<td>Procon (FhG)</td>
<td></td>
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<tr>
<td>Scanco</td>
<td><strong>Typical Performance:</strong></td>
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<td>SkyScan</td>
<td>Resolution down to 1 μm</td>
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<tr>
<td>Wälischmiller</td>
<td>Reconstruction of $2048^3$ volumes</td>
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<tr>
<td>Viscom</td>
<td>Reconstruction time 3,7 s per $1024^2$ slice (Pentium 3 GHz)</td>
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<tr>
<td>VJ-Technologies</td>
<td>Scan times varying with resolution and object</td>
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<td>X-Tec</td>
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<tr>
<td>Yxlon</td>
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</table>

#### CT Systems

- **CT System CT-MINI, Procon**
- **CT System RayScan 200 (Hans Wälischmiller GmbH)**
Status of Computed Tomography

Research
- Argonne National Lab, Chicago / USA
- Bundesanstalt für Materialforschung und –prüfung (BAM, Berlin / Germany)
- EMPA, Switzerland
- Fraunhofer-Gesellschaft EZRT (Saarbrücken, Fürth)
- General Electric Global Research
- Lawrence Berkeley National Laboratory, USA
- Leti, Grenoble / France
- Siemens, Medical Solutions (Germany)
- Synchrotron-facilities: Bessy, Anka, DESY, ESRF (G/F)
- University Linköping / Sweden
- University Saarland, Germany
EZRT fields of expertise

Automation for industrial Radioscopy and Tomography

- manipulation
- computer-architecture
- system know-how
- software
  - algorithms
  - distributed systems

- X-ray generation
- X-ray detectors
- system design
**EZRT product development and business fields**

*Micro CT* for high resolution Volume Tomography on micro systems

Example: plastic micro gear

*Macro CT* for fast Volume Tomography on lightweight components

Examples: Al wheels, motor blocks, metal foams
EZRT product development and business fields

Bench Top System *CT-MINI* for fast and high resolution Volume Tomography

CT for the laboratory

CT for industrial 3D-metrology

nominal / actual geometry comparison

Biological sample

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EZRT research areas today

- Sub-μ radioscopy and CT
- New applications of automated 2D / 3D Image processing
- 3D / CAD data fusion
- Industrial process integrated CT: “inline CT”
- High speed radioscopy, dynamic radioscopy in μs range
- Development centre for non-destructive testing of new materials in aerospace, funded project by Bavarian government, 4 years, start April 2005
Artifacts - Methods for Projection Image Correction

Physical effects that cause a degradation of image quality

- Beam-hardening with polychromatic radiation
- Scattered radiation
  - scatter processes within the object
  - primary radiation scattered within the detector
- Properties of the detection system
  - Image Lag
  - Degradation
  - Pixel defects
  - Non-Linearities
Status of Computed Tomography

Artefacts and Means for Reduction

• Combination of pre- and post-processing steps
• IAR: Iterative, reference-less and multistage correction method (right)
• Ring Artefact Suppression (below)
EZRT research areas today

Artefakt Reduction by Simulation of Scattered Radiation

Scattered radiation of an Al-block

Projection of a step wedge (Al)

Scattered radiation of the step wedge
Status of Computed Tomography

Fast Inline 3D Computed Tomography

Motivation

- No quantitative information on defects possible by transmission radioscopy
- 3D CT can provide complex spatial information about a component and contained unwanted elements therein
- Evaluation based on 3D methods is less prone to artifacts than 2D methods
- Fast computers and algorithms allow for pace keeping reconstruction and analysis
- Relatively low resolutions necessary for NDT tasks
Status of Computed Tomography

Fast Inline 3DComputed Tomography:
Results of a fast scanning combined with image processing

3D-CT and defect recognition, 100 s

3D-CT and defect recognition, 25 s
Status of Computed Tomography

Inspection Tasks in the Field of Aerospace

- Highly absorbing materials
- Composites with low contrast
- Very large objects
- High resolution

Stabilizer of a Rotor Blade
Turbine Blade
Status of Computed Tomography

Challenge Turbine Blades

Combination of highly absorbing material with complex structure

High resolution CT to visualize small boreholes (< 50 µm)
Status of Computed Tomography

Challenge Rotor Blades

Composite Material

• Carbon/Glass fiber reinforced plastics

• Complex weaved structures

• Low contrast of embedded materials
Status of Computed Tomography

Inspection tasks in the field material characterization

3D image processing and evaluation of carbon fiber reinforced plastics (CFC)
Status of Computed Tomography

Inspection tasks in the field of automotive
3D Defect Visualization of Wheel Samples

Center Region

Spoke Region

Rim Region

CT Processed Samples
Status of Computed Tomography

Inspection tasks in the field of biology

Lily

Bug

Seed of a sugar beet

Trachea of a butterfly cocoon
Status of Computed Tomography

Micro Gearbox: 2.8 µm Voxel resolution

lubricating grease
Status of Computed Tomography

Archaeology

Reconstruction of a terracotta head made by the African Nok culture

By courtesy of the laboratory Kotalla
Status of Computed Tomography

Paleontology

CT reconstruction from about 400 x-ray images of the slab with the hidden Ganoid fish

By courtesy of Dr. Viohl, Eichstätt
Future Trends in Computed Tomography

Microsystems → Nanosystems
Offline CT → Inline CT
Qualitative → Quantitative
Stationary → Mobile

Nano CT to achieve highest-resolution volume data of nano-systems with voxel size below 100 nm

Inline CT for fast 3D inspection of light metal parts, scan- and evaluation in less than 25 s

Industrial 3D-Metrology with
Computed Tomography

Robot-CT to inspect very large objects on site by mobile CT

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Future Trends in Computed Tomography

Quantitative CT - QCT

CT as an instrument to measure a physical property at an arbitrary point in space

Levels of improvement:
- Exact measurement of primary intensity
- Precise linearization of the projection images
- Reduction of scattered radiation: e.g. by a-priori knowledge on the inspected part
- Multi-material beam-hardening correction
- Dual-energy-methods: two scans with different high-voltage

Dual Energy CT of a cube made of plexiglas and aluminum
Progress Towards Sub-µm CT

Challenge Sub-µ CT:
The limiting factor is the focal spot size of about 1.3 µm (fwhm)

Measurement with about 2 µm resolution

Biological sample – cocoon of a butterfly
Progress Towards Sub-µm CT

Carbon fibre reinforced materials

resolution: 2 µm
Progress Towards Sub-µm CT
High-resolution CT with grey cast iron

Fragment of cast iron with 1 mm size (ca. 2 µm voxel size). The probe contains fiber-like lamella of graphite or cementite
Progress Towards Sub-µm CT

High-resolution CT of glass fibers with 850 nm voxel size
Integration of New X-Ray Sensor Technologies

Low energy – high contrast measurements

Sensor: MediPix 2
X-ray tube: MCB-20
(5 – 20 kV)

Usability: Polystyrene, plastics, organic materials

The experiments were conducted in collaboration with the Physical Institute IV (University of Erlangen-Nuremberg), Prof. Dr. Gisela Anton
Integration of New X-Ray Sensor Technologies

Direct converting detector

Technical data:

- Sensor material: CdTe
- Pixel size: 100 μm x 100 μm
- Number of pixels: 252 x 1014
- Area: 25.2 x 101.4 mm²
- DQE: > 90% at 60 keV
- Energy range: 15 – 300 kV
- Frame rate: up to 50 fps
Integration of New X-Ray Sensor Technologies

Low Energy CT

Slice of a fiber composite floor cover

Carbon fiber mat at 35 kV
Integration of New X-Ray Sensor Technologies

Low Energy CT

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<th>Sticky tape step wedge:</th>
<th>ESD foam:</th>
<th>Cigarette:</th>
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<tr>
<td>8 kV / 40 mAs</td>
<td>8 kV / 6 mAs</td>
<td>12 kV / 7 mAs</td>
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Metrology with Computed Tomography

Metrology: Extracting Surface Data

Nominal / Actual Value Comparison

STL Data

Surface Visualization

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Mobile Computed Tomography

Robot AidedComputed Tomography

Very large objects (e.g. aircraft wings or fins) can be inspected on site by mobile CT.

One robot carries the X-ray source, a second one the detector.

→ precise positioning and robot communication necessary.
The Future in 3D Industrial Computed Tomography

Outstanding capabilities of CT in NDT today

1. Material testing
2. Dimensional Measurement
3. Control of integrity and completeness

Fields of progress in the near future

1. Detector systems with higher dynamic, greater area and better efficiency
2. X-ray sources providing higher intensities with small focal spots
3. Algorithms for ROI-reconstructions from a limited number of projections
4. Efficient means to reduce artifacts from beam hardening and scattered radiation
Acknowledgment

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