Fraunhofer Entwicklungszentrum Röntgentechnik, EZRT

Intelligent Sensor Systems for Nondestructive Testing regarding Product Life Cycle

2. Kolloquium des GRK 2075
Braunschweig
5. – 6. Oktober 2017

Randolf Hanke

Fraunhofer Development Center X-Ray Technology EZRT

Some facts and figures

Sensor systems for monitoring along the entire Product Life Cycle

- Founded in 1998
- More than 100 full-time personnel
- Location Fürth, Würzburg, Deggendorf
- Budget:
  approx. 15 Mio. € (2016)
- Financing
  > 75 % Contract research
  < 25 % Basic funding

Intelligent Sensor Systems for Nondestructive Testing

Monitoring along Product Life Cycle

- **Development of system solutions for nondestructive**
  - Characterization (raw materials / materials)
  - Definition of parameters (product development)
  - Monitoring and control (production process)
  - Quality control (product)
  - Condition Monitoring (trade / operation)
  - Sorting of materials (recycling)
- **Generation of sensor based metadata**
  Computed Tomography, Ultrasound, Optics, MRI
  Thermography, Electromagnetics, MicroWave
- **Intelligent crosslinking**
  INTRA Stage within a single stage of PLC or
  INTER Stage between different PLC stages

➔ **Optimization**
of reliability, cost effectiveness and sustainability of new materials and products

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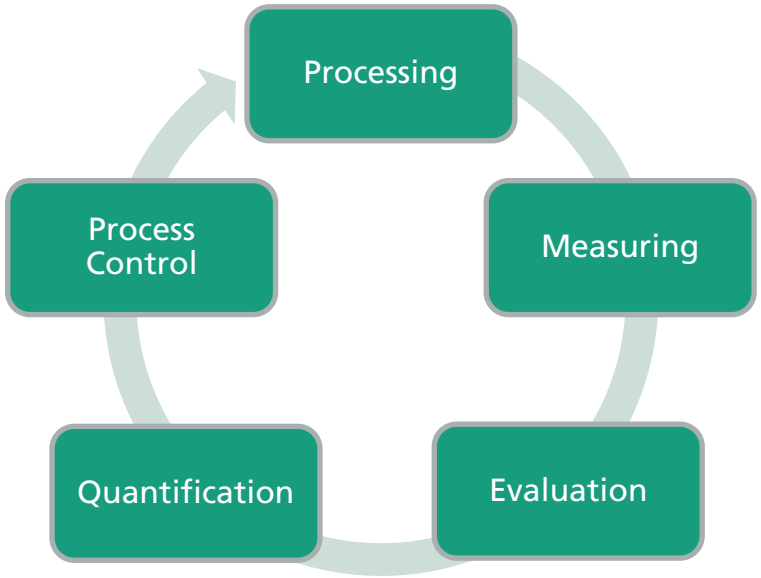
Intelligent Sensor Systems for Nondestructive Testing

Nondestructive Process Control – Intra Stage Feed back loop

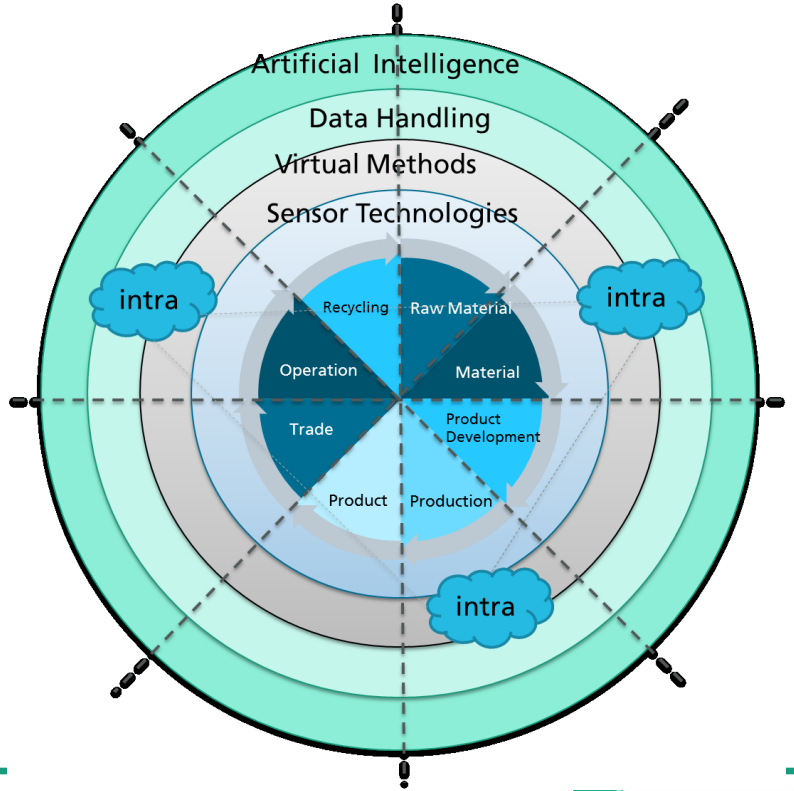
Feed back loop to production



Intelligent Sensor Systems for Nondestructive Testing

Nondestructive Process Control – Inter Stage Cross Linking

Cross linking in PLC



inter

intra

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Intelligent Sensor Systems for Nondestructive Testing

Future Impact

- **Cognitive sensor systems** for process control along Product Life Cycle
  - Material near, intelligent sensor systems
  - Sensor near, intelligent data analysis
- **Holistic consideration** of data analysis along the complete PLC
- **Expanding the I4.0 Data space** by data and information about material modification (Smart Materials Data) by influence of
  - Machines (influence of casting, forming, cut-off or joining processes during manufacturing)
  - Humans (wearing by individual operation) or
  - Environment (temperature, humidity, aging, fatigue)

Intelligent Sensor Systems for Nondestructive Testing

Smart Materials Data

Factory Data
Logistic Data
Cost Data
Processing Data

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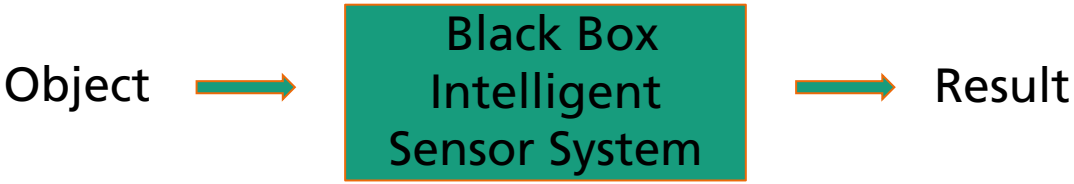
Intelligent Sensor Systems for Nondestructive Testing

The “Black NDT Box”

Intelligent NDT for Process Control – Monitoring along the PLC

Vision:



- For all components
- For all materials
- For all problems

The system { parametrizes, teaches, optimizes, adapts } itself

Intelligent Sensor Systems for Nondestructive Testing

General Objectives

Cognitive Sensor Systems

- refine classical NDT towards digitization, intelligent data analysis and process control
- generate
  - cognitive, auto adaptive sensor systems
  - predictive systems
  - hybrid sensor and actor systems
- support
  - intelligent data acquisition and
  - manipulation of characteristics and variables in PLC

Sensor systems and machines decide independently, how, when and what they measure and monitor!

Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example CT

Automated Parametrization (Orientation of Object)

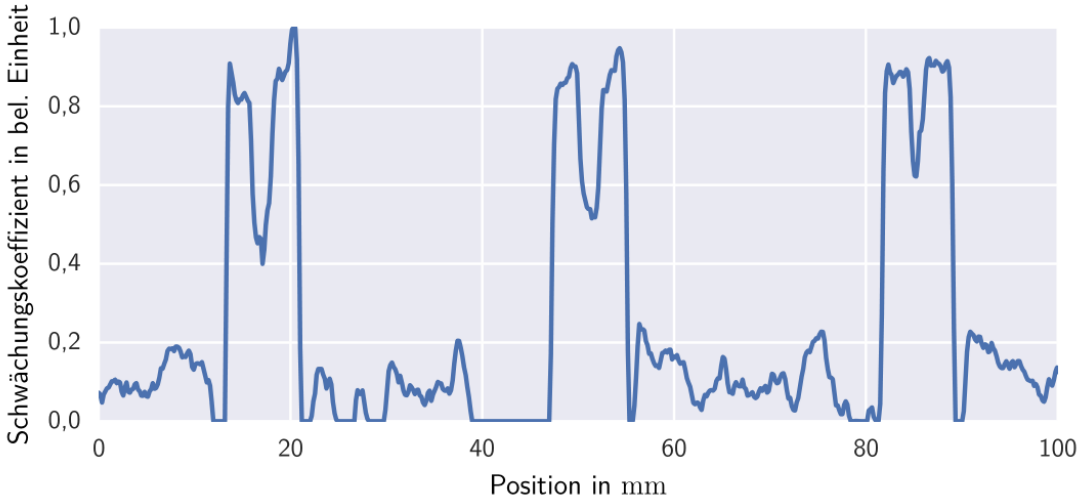
Source: R. Schielein, to be published

Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example CT

Automated Parametrization (Orientation of Object)

Problem: How is the cornet best aligned for least artefacts?



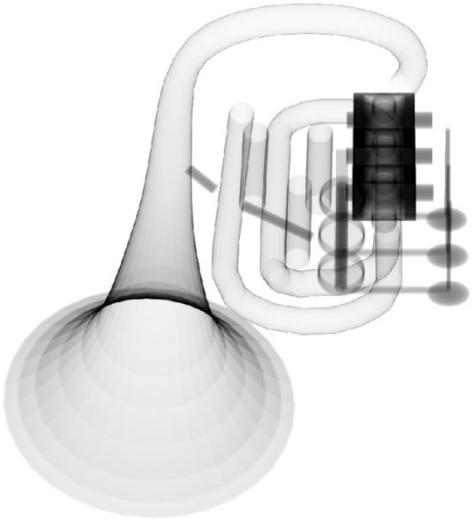
Source: R. Schielein, to be published

Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example CT

Automated Parametrization (Orientation of Object)

Original → Model → X-Ray Simulation



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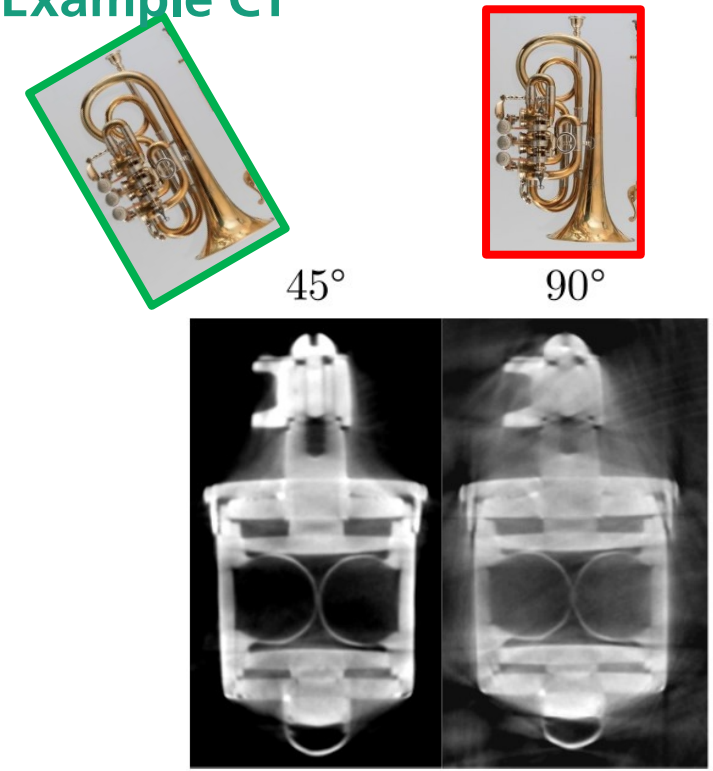
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example CT

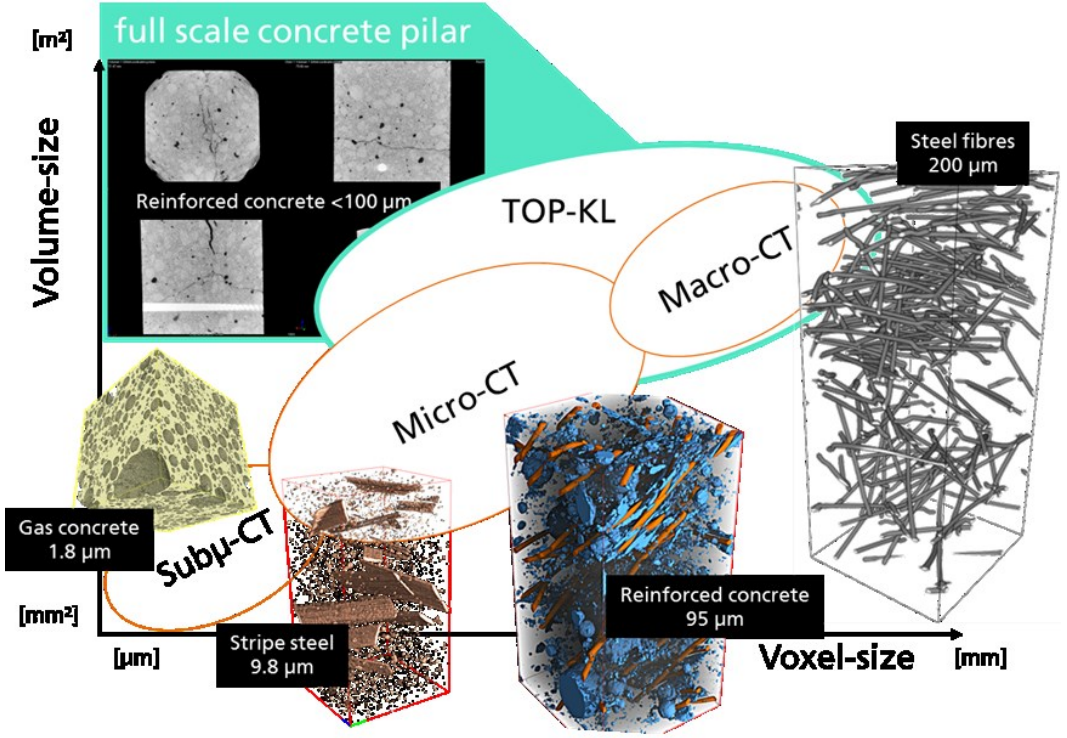
Experimental Validation



Source: R. Schielein, to be published

Intelligent Sensor Systems for Nondestructive Testing

Different scales of CT in civil engineering



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Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Dual Energy Radioscopy

RAW MATERIALS

Sorting, Identification and Evaluation of Raw Materials

Detection of raw diamonds

- Acquisition of two different X-ray images using different spectra, sorting with 1 m/s
- Separation of diamond (carbon) and rock (containing mostly calcium, silicon and aluminum) in these images

Low-energy image

high-energy image

carbon image

Kimberlite: 15-23 mm
Diamond – Size: 6-7 mm

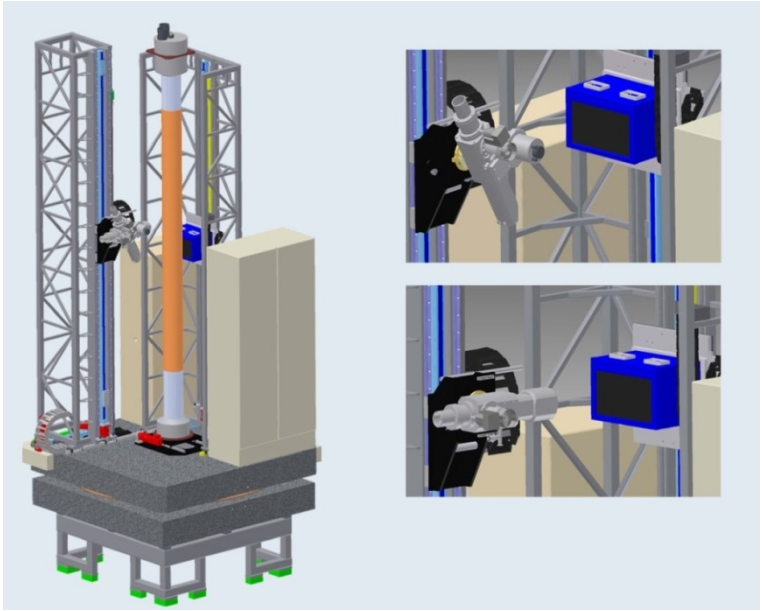
Intelligent Sensor Systems for Nondestructive Testing

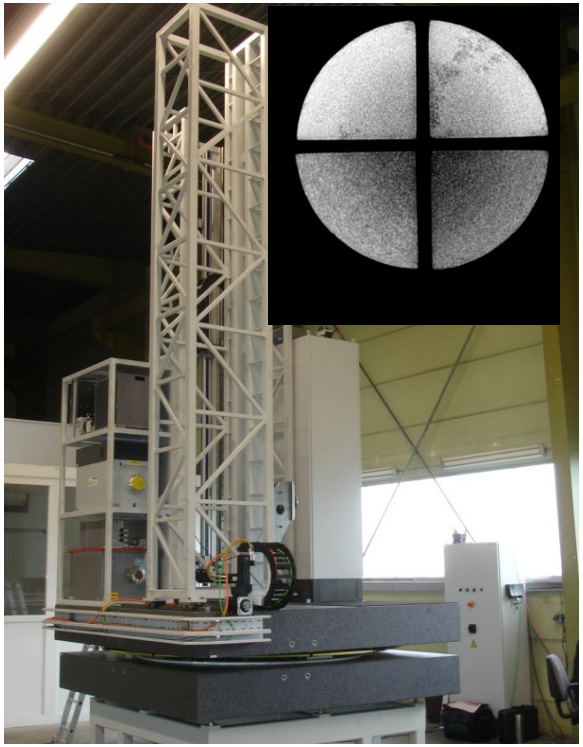
Intelligent Data Acquisition – Helical CT

RAW MATERIALS

Petroleum recovery by X-ray analysis

CT-Scanner for long drill cores up to 3 m and diameter 10 cm

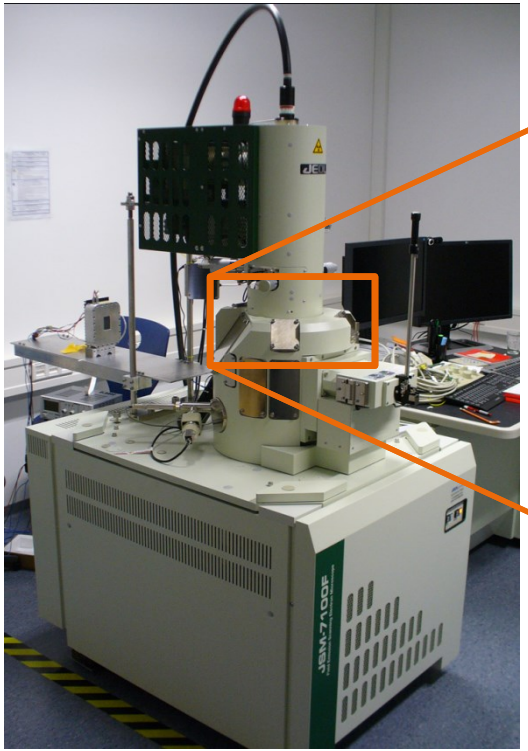


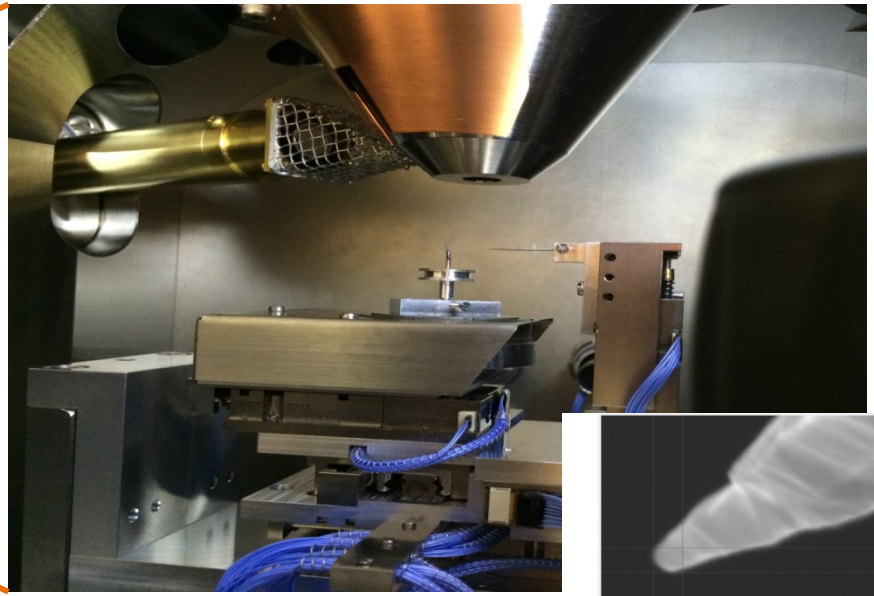


Intelligent Sensor Systems for Nondestructive Testi

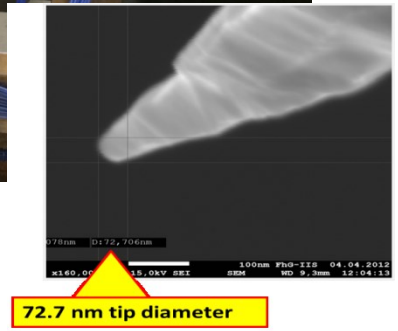
Intelligent Data Acquisition – Nano Computed Tomography

MATERIALS





XRM II: Sample and X-ray source are inside of electron microscope



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Intelligent Sensor Systems for Nondestructive Testi

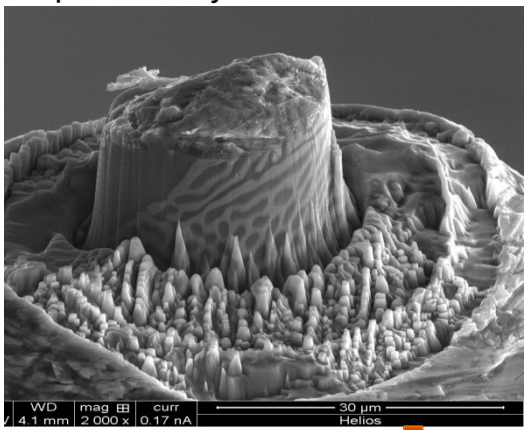
Intelligent Data Acquisition – Nano Computed Tomography

MATERIALS

Material analysis by Nano-CT microscopy, XRM-II

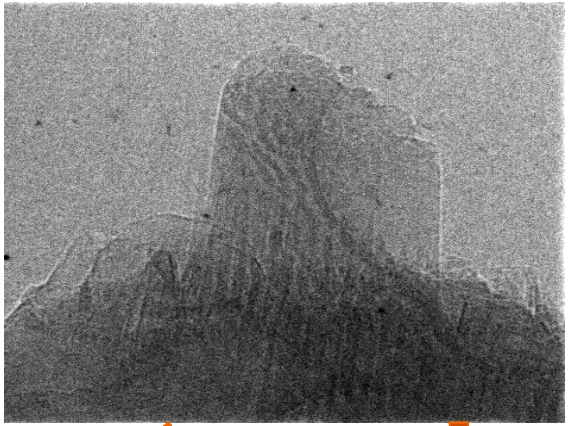
REM image

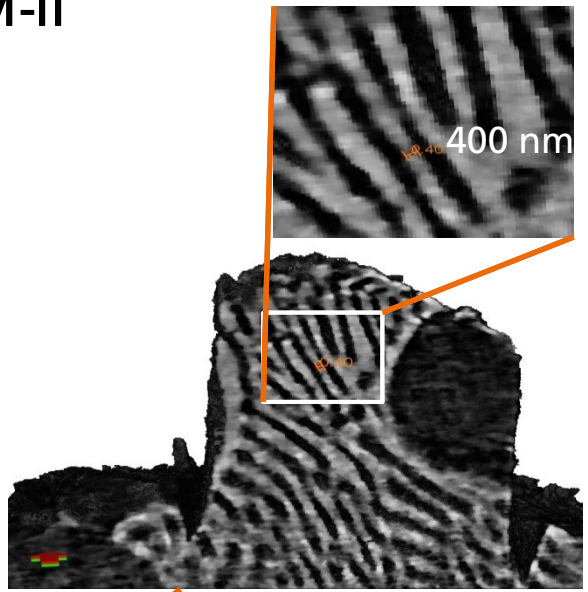
Preparation by focused ion beam



XRM II Nano image

Recording of 200 projections





Example of a 24 µm AlCu29 alloy

3D reconstruction and visualization of microstructures (eutectic lamellas)

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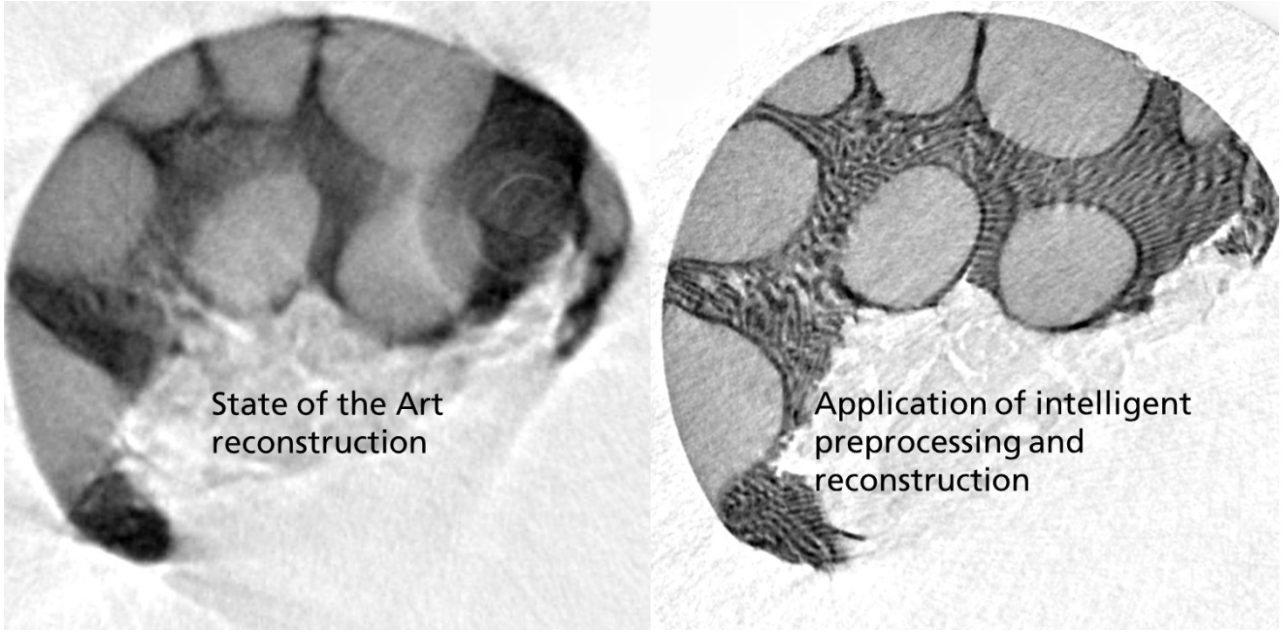
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Nano Computed Tomography

MATERIALS

Material analysis by Nano-CT microscopy, XRM-II

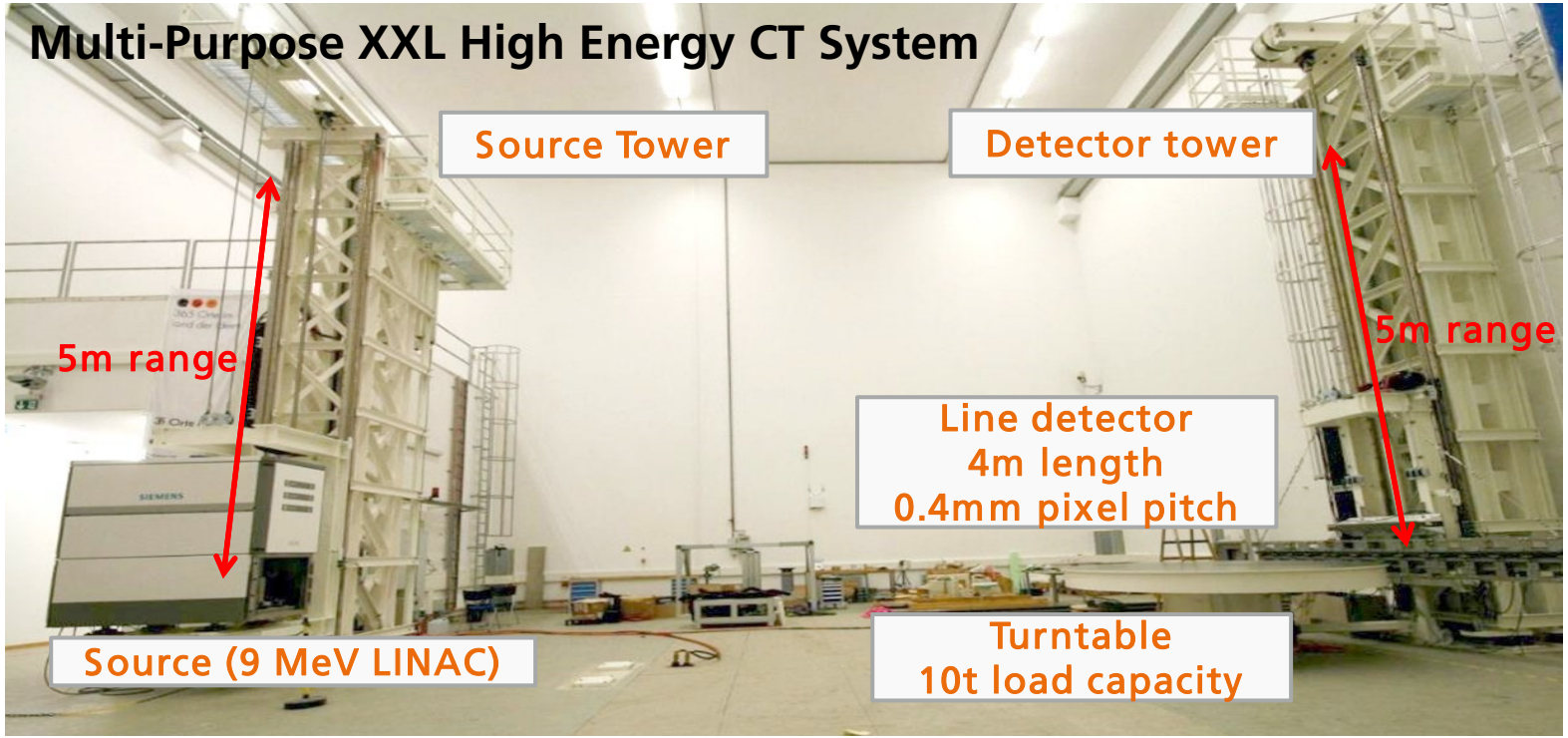
Data Preprocessing and intelligent reconstruction algorithms to enhance tomographic results



Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example XXL-CT

PRODUCT DEVELOPMENT



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Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Evaluation – Big Data

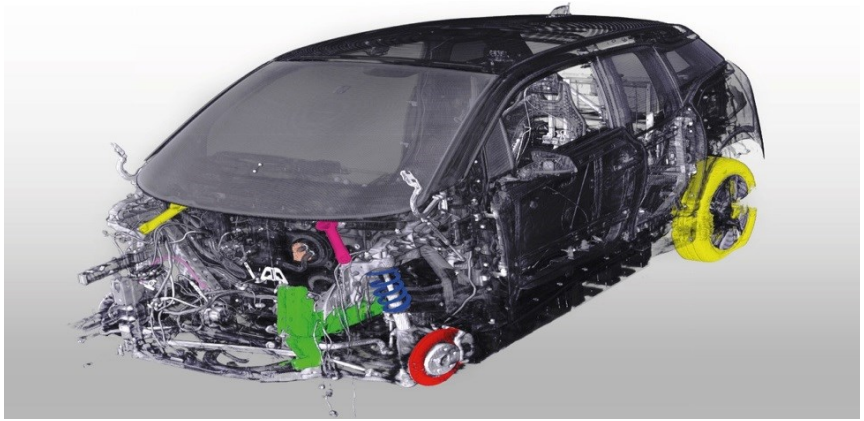
PRODUCT DEVELOPMENT

Optimization of parameters in process- and product development, definition of prototypes

Feature Extraction and Segmentation

XXL Computed tomography on crashed cars

- Intelligent nondestructive monitoring of complete (crashed) cars
- Segmentation of unknown structures



Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Evaluation – Big Data

PRODUCT DEVELOPMENT

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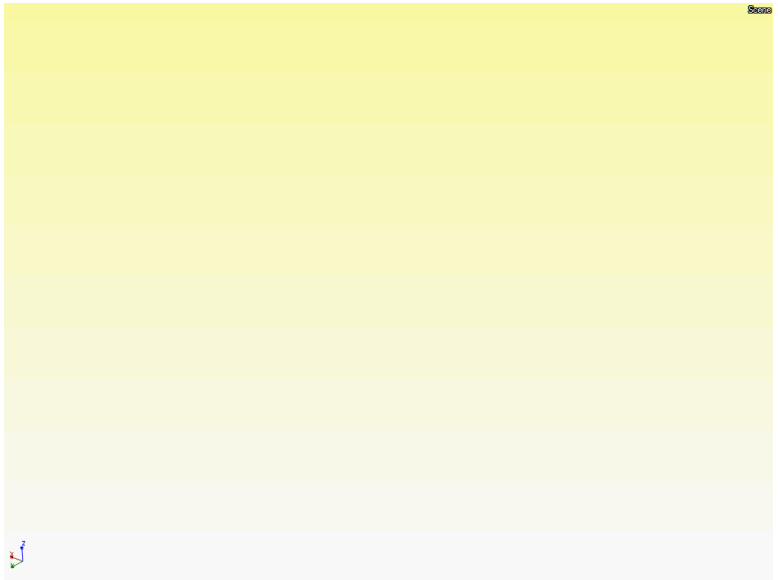


Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example XXL-CT

PRODUCT DEVELOPMENT

HECTOR – High-Energy Computed Tomography Ring

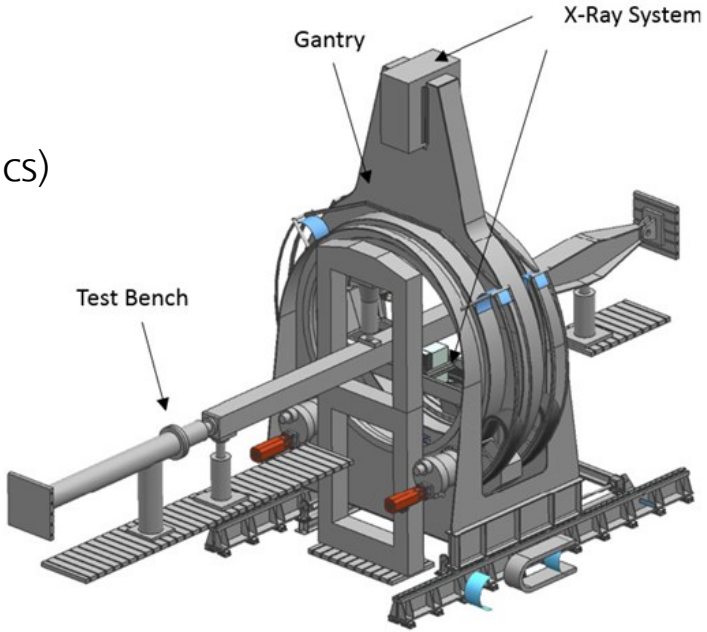
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Example XXL-CT

PRODUCT DEVELOPMENT

Multi-Purpose XXL High Energy Gantry CT System

Gantry concept with the integrated load device (Copyright MT-Mechatronics)



Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Evaluation – Big Data

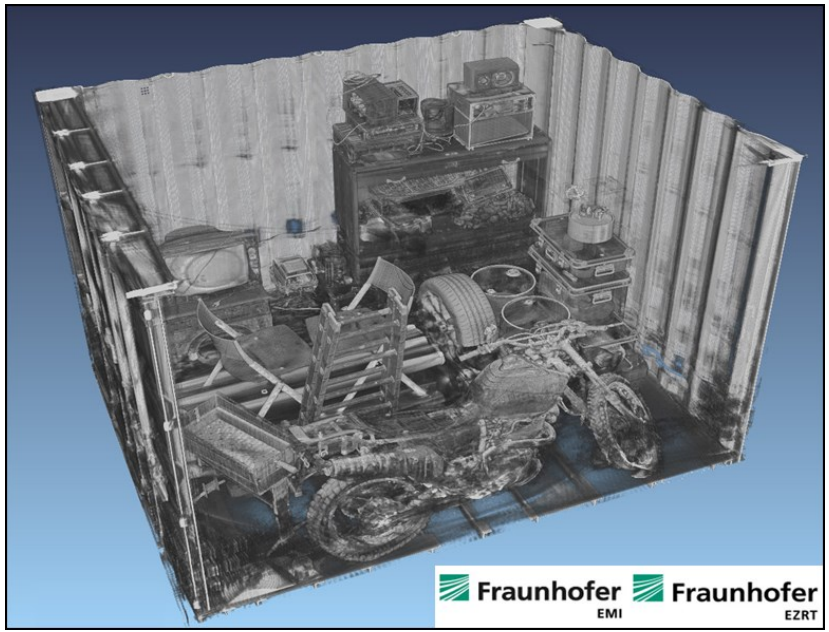
PRODUCT DEVELOPMENT

10” Sea freight container – 3D Scan

Feature Extraction and Segmentation

XXL Computed tomography on containers

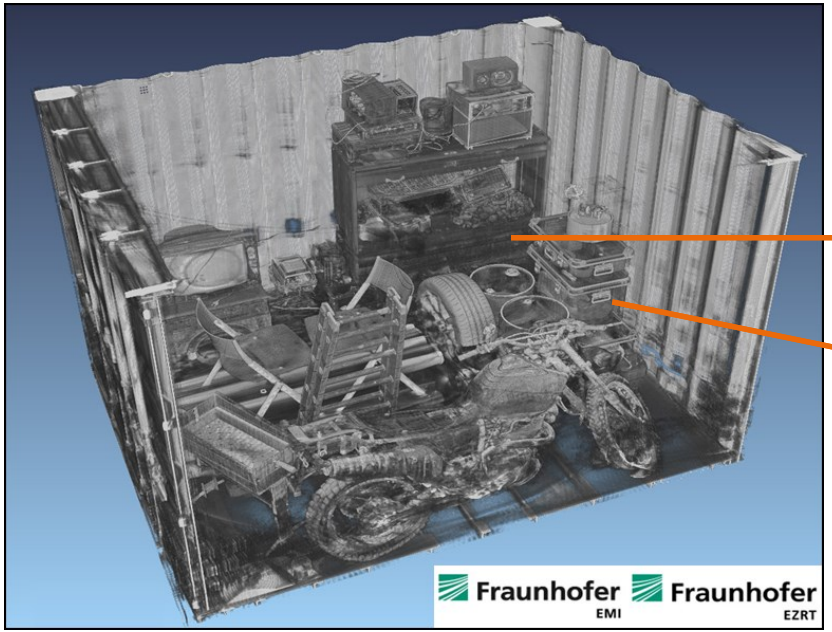
- Intelligent digital unpacking
- Comparison with freight documents

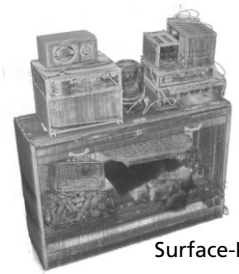


Intelligent Sensor Systems for Nondestructive Testing

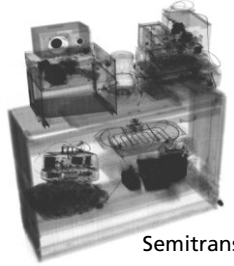
Intelligent Data Evaluation – Big Data

PRODUCT DEVELOPMENT



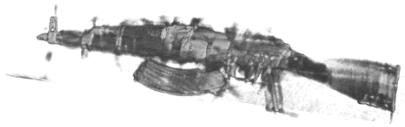


Surface-Rendering

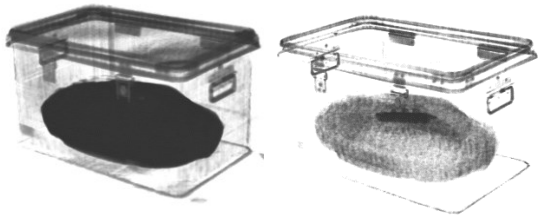


Semitransparent

Shot gun



Explosives



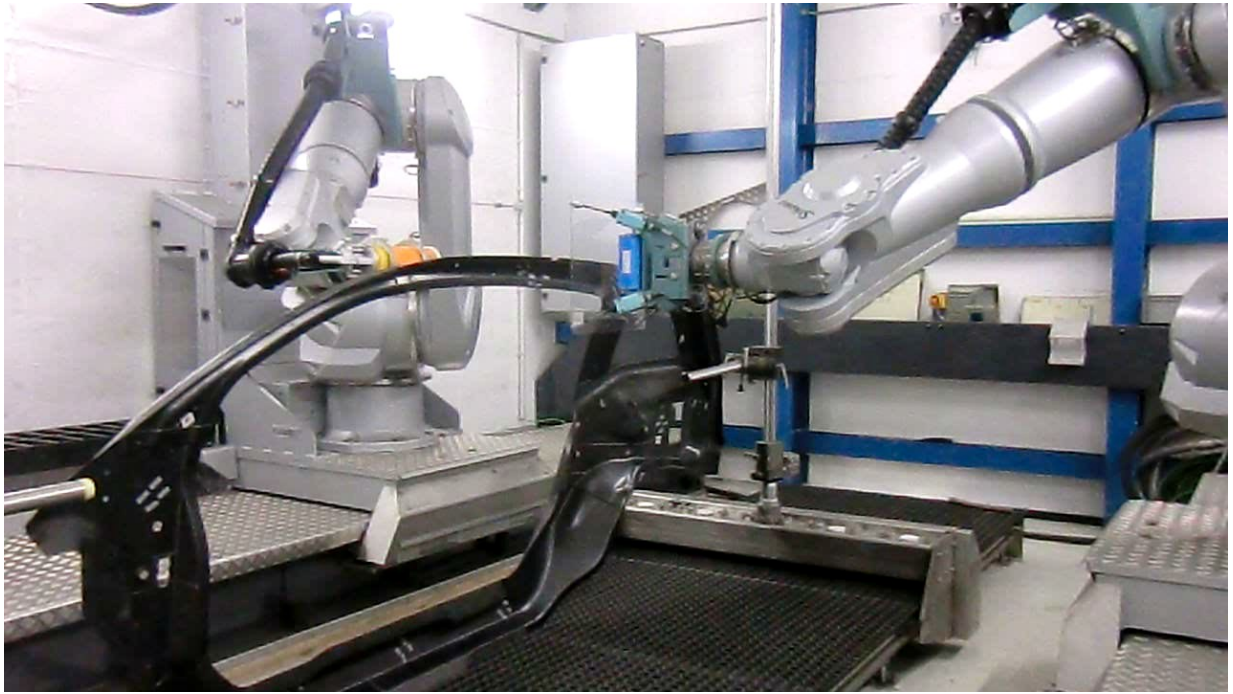
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Robot Based NDT

PRODUCTION

Tomosynthesis
of a BMW i3
lateral frame

Trajectory 30°
64 Projections



Roboterbasierte XXL-µ-Computertomographie an Großbauteilen im Automobilbau, Holub, W.; et al; DGZfP Jahrestagung, Koblenz 2017

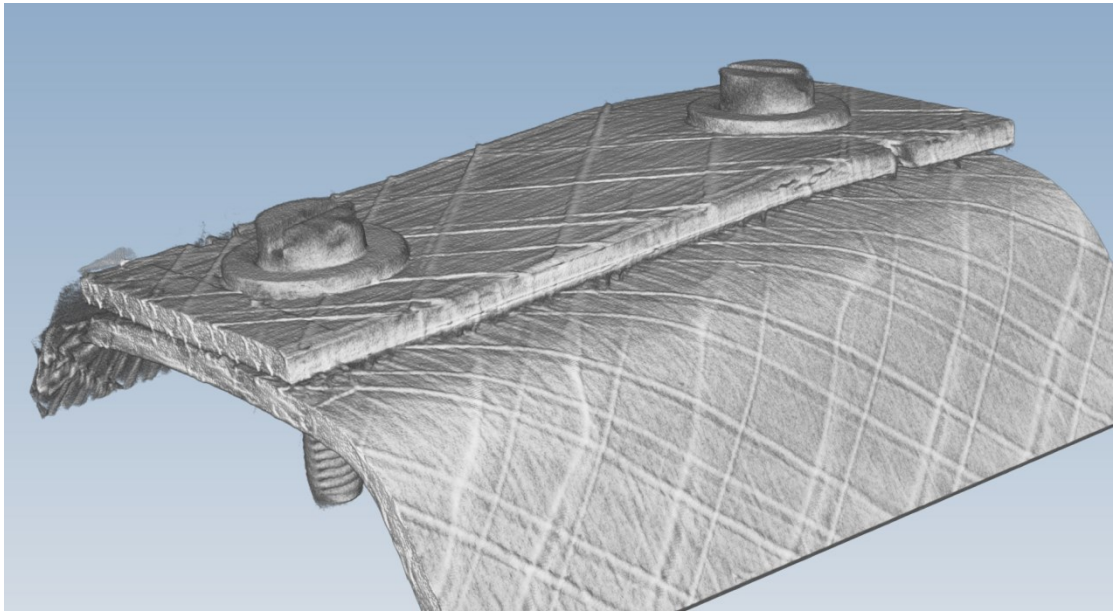
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Robot Based NDT

PRODUCTION

Laboratory µ-CT reconstruction of a BMW i3 lateral frame

Voxel size 45 µm



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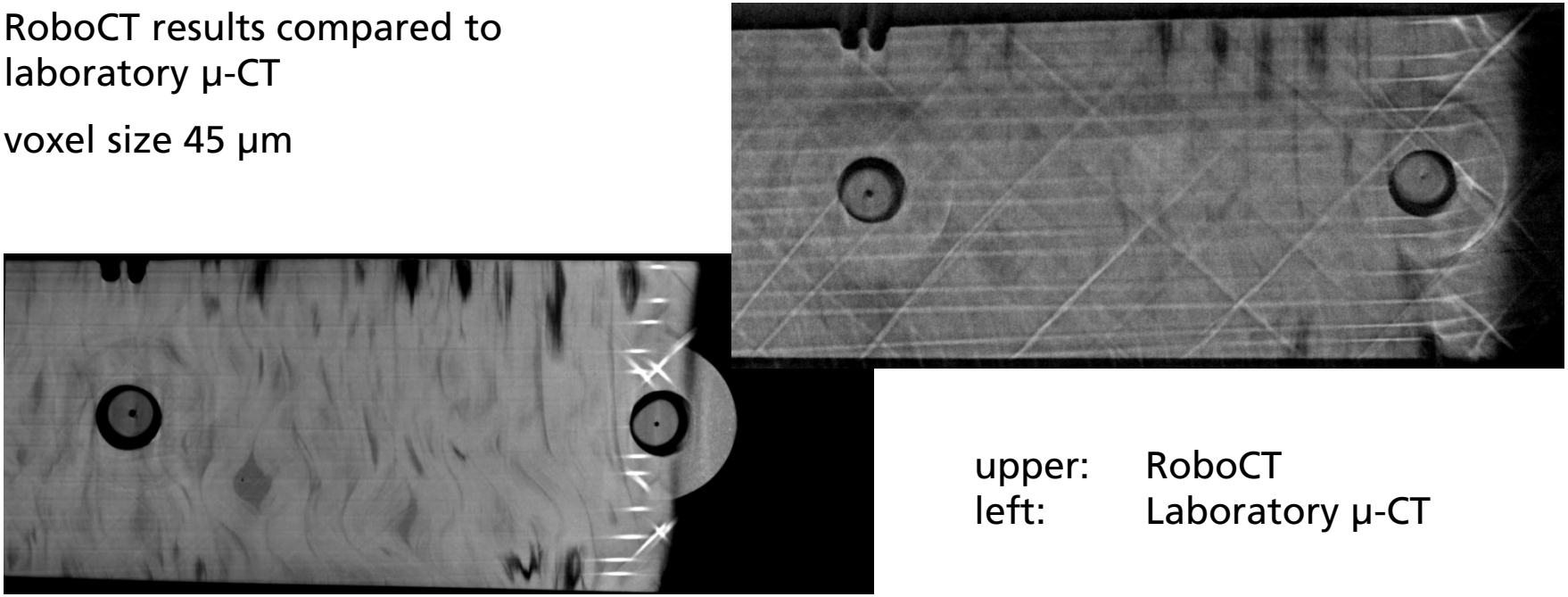
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Acquisition – Robot Based NDT

PRODUCTION

RoboCT results compared to laboratory µ-CT

voxel size 45 µm



upper: RoboCT
left: Laboratory µ-CT

Roboterbasierte XXL-µ-Computertomographie an Großbauteilen im Automobilbau, Holub, W.; et al; DGZfP Jahrestagung, Koblenz 2017

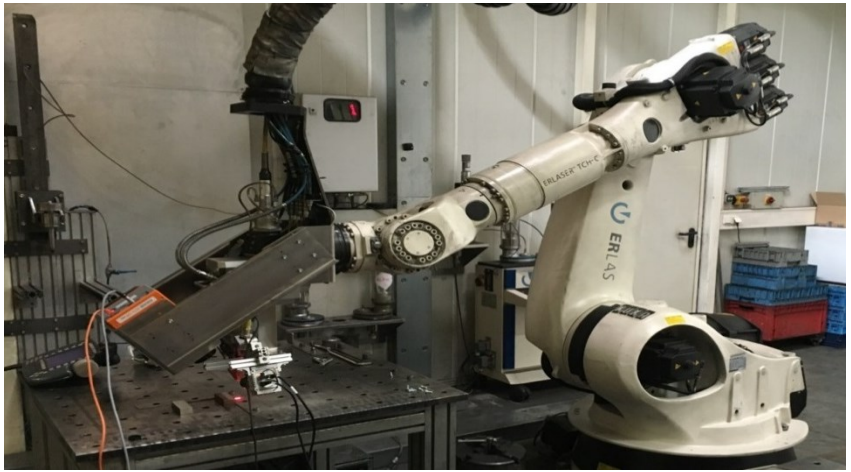
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Multimodal Monitoring

PRODUCTION

In-situ defect detection and dimensional measurement for process control in additive manufacturing by thermal imaging and laser sheet triangulation

- Direct recording of layer quality
- Detection of defects
- In-situ error correction
- Flexibility allows adaption to further production processes



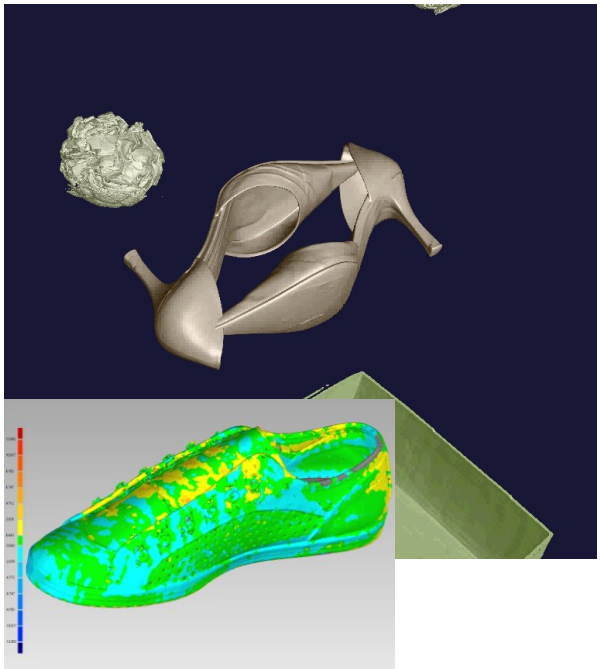
BFS Research Alliance „Next generation tools“

Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Data Fitting for e-commerce

TRADE

Automated Shoe Fitting in eCommerce Business



- Up to now huge monetary and ecological damage by high return rates in mail order selling because of bad fitting
- Application of intelligent CT for efficient extraction of inner shoe structure and shape
- Precise recommendation of shoe size by 3D modelling helps to reduce returns dramatically
- Expanding to further articles like clothing in preparation
- www.mifitto.com

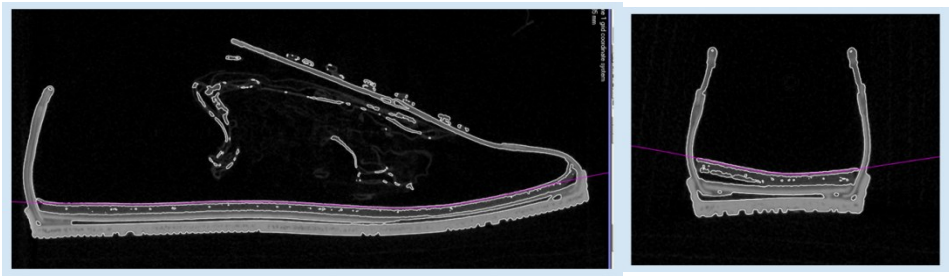
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Data Fitting for e-commerce

TRADE

- Special Inline CT system
- Tomography of packaged shoes for size recommendation
- Up to 4000 shoes per day depending on season
- Automated data and contour extraction

HeiDetect XS CT: Inline CT machine



Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Building Inspection and Monitoring

OPERATION

Potential Field Mapping

Corrosion

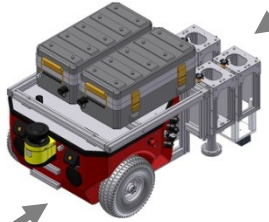
BetoScan

Microwave

Moisture

Ultrasound

Voids, Thickness, Cracks



Eddy Current + Radar

Concrete Reinforcement

Concrete Cover

- Air Temperature
- Object Temperature

Concrete Resistance

rel. Air Humidity

Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Building Inspection and Monitoring

OPERATION

LimaTest – nondestructive corrosion inspection for light poles

- Compact inspection system with EMAT sensors
- Fast data pre-processing
- Laptop for device control, data recording and visualization
- Automated storage of measured data and inspection sheet generation
- Integrated user and inspection profile management
- Manual mode or manipulator mode for motor-driven 360° scans

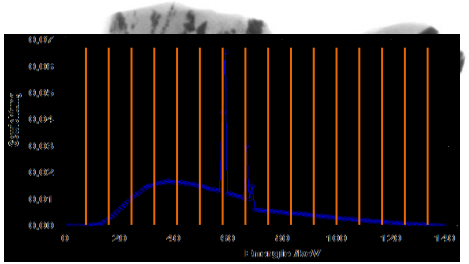
LimaTest in manual mode

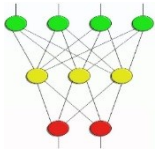
Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Deep Learning

RECYCLING

Disassembling by intelligent material selective X-Ray Inspection

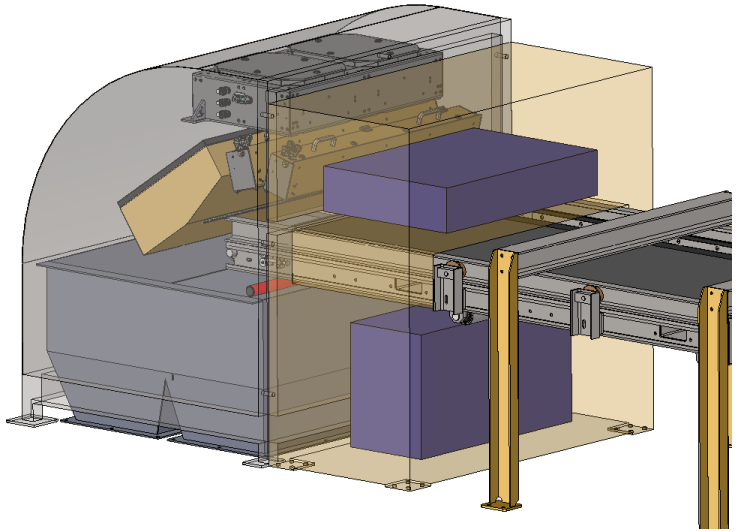




Multiple energy channels, structural information from X-ray images

neural network

sorting decision



Intelligent Sensor Systems for Nondestructive Testing

Intelligent Data Analytics – Example Recycling

RECYCLING

Disassembling of electronics by material selective X-Ray Inspection