THE NEW PARADIGM OF QUALITY CONTROL IN THE INDUSTRY 4.0 ERA

www.ikts.fraunhofer.de

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Management System
ISO 9001:2008
ISO 14001:2004
www.tuv.com
ID 1100005194

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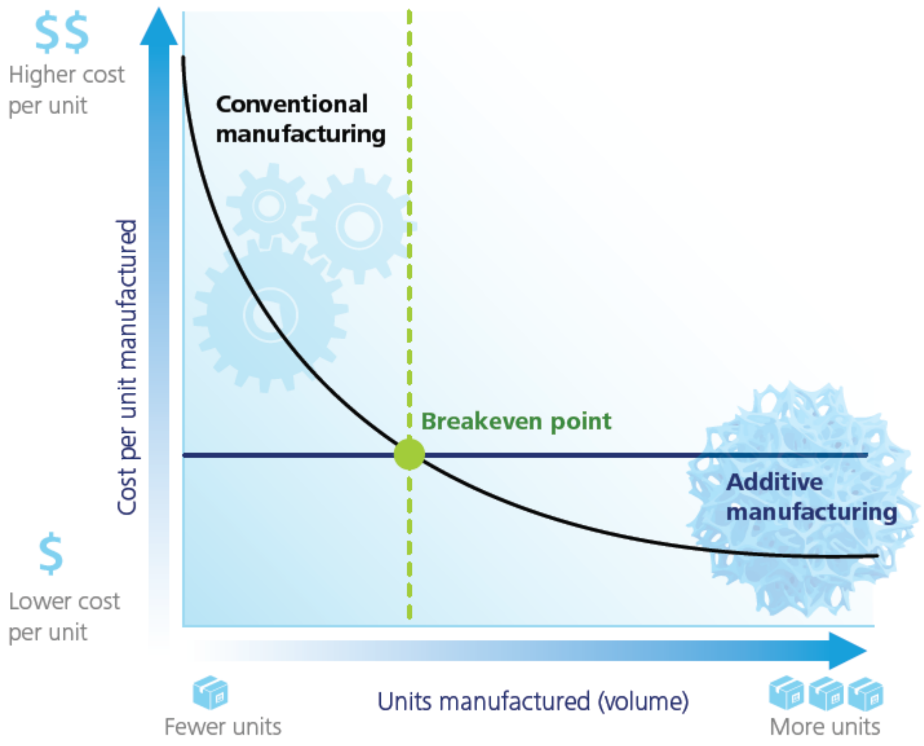
Industrie 4.0 – Internet of Things
Motivation: Individualised Production



Individualised Production based on 6 key steps:

1. Standardized individual steps
2. Modularisation
3. Computer Based Modelling and Configuration
4. Additive Manufacturing
5. Production Networks and Order Management Platforms
6. Automated Production

Focus on high volume production (scale effects) is replaced/added by customer centric individualized production

Individualised Production close to the customer is key of Industry 4.0

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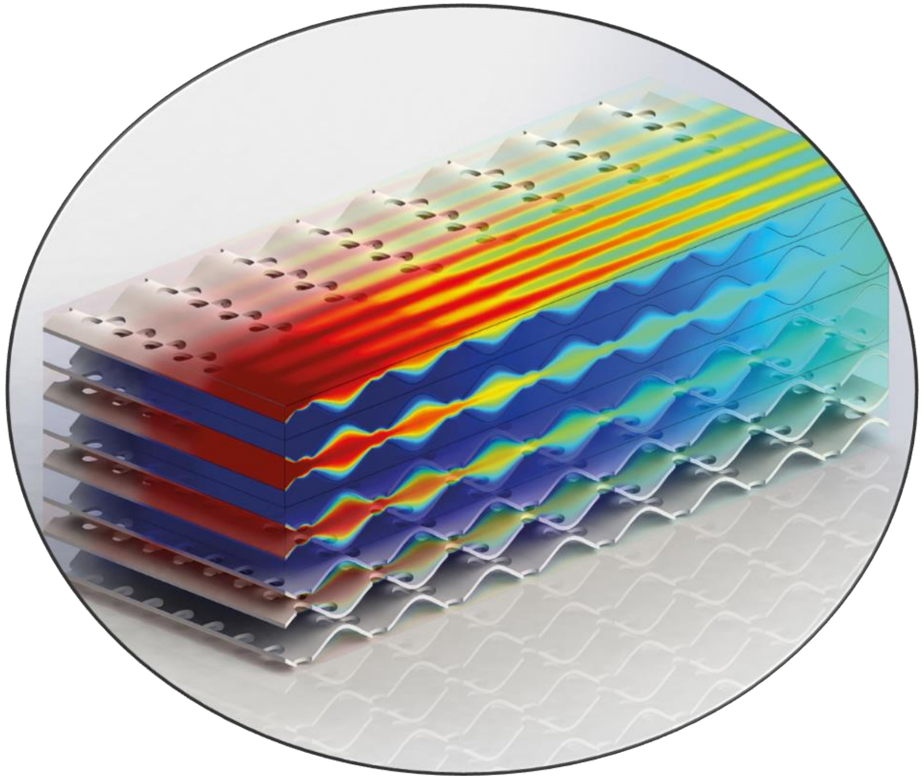
Paradigm shift in industrial quality insurance and non-destructive evaluation

- Etablished and optimized process chains
- statistical process control and quality management (Six Sigma)
- Testing of samples
- Tolerances for replacement

Industrie 4.0

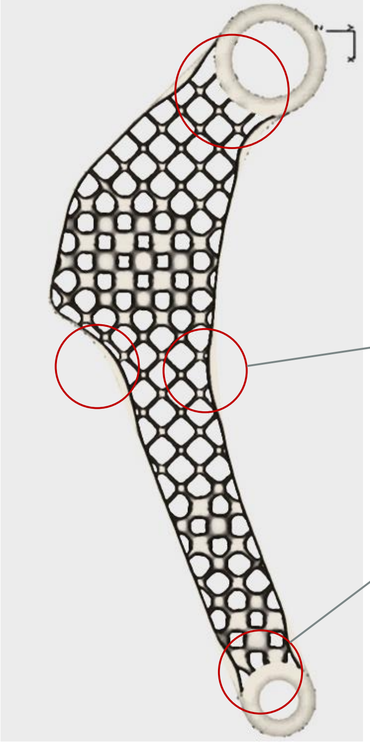
- manufacturing „on demand“ – configured by the customer
- Additive and classical methods
- New paradigm of Quality insurance
- Integrated Intelligence, Machine Learning

The new paradigm of quality inspection
massive process data - linked to the individual component



- Quality control powders, pastes, inks, environment, logistics
- Material- and process diagnostics in-line during generation
- anisotropic and spatially resolved strenght- / stiffness- and stress data
- New understanding of interface mechanisms
- Feedback Loop to CAD-/FEA Models
- Data storage and data exchange along the value chain
- Products with integrated sensors
- 100% traceability across all the production steps
- Automated early warnings by big data Machine Learning

Spatially resolved NDE for AM components



Bilder: http://www.engineeringspot.de/2015/11/autodesk-within-intelligente-mikrostrukturen-sparen-gewicht/

Material parameters to look for

- material and process based anisotropic and spatially resolved quality data
  - Internal compressive stresses – bending fatique strength
  - Interface to „conventional“ tube components
- Feedback Loop to CAD-/FEA Models – „simulate as built“
- data as built are linked to any individual component

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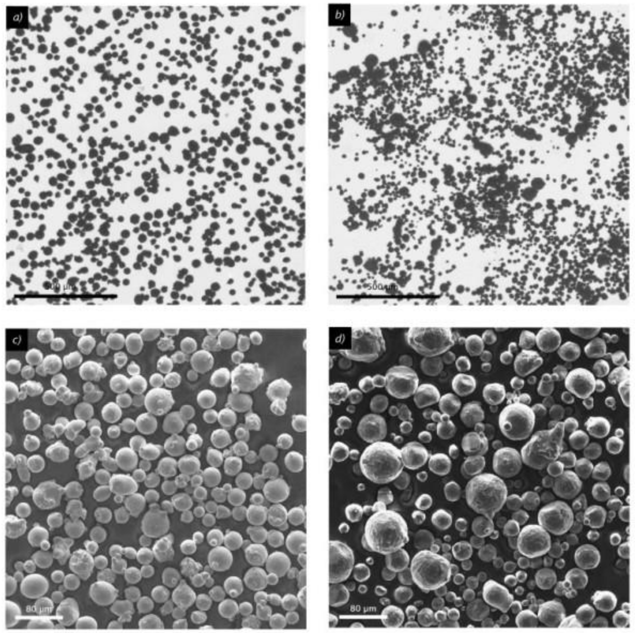
NDT and Additive Manufacturing
4 approaches

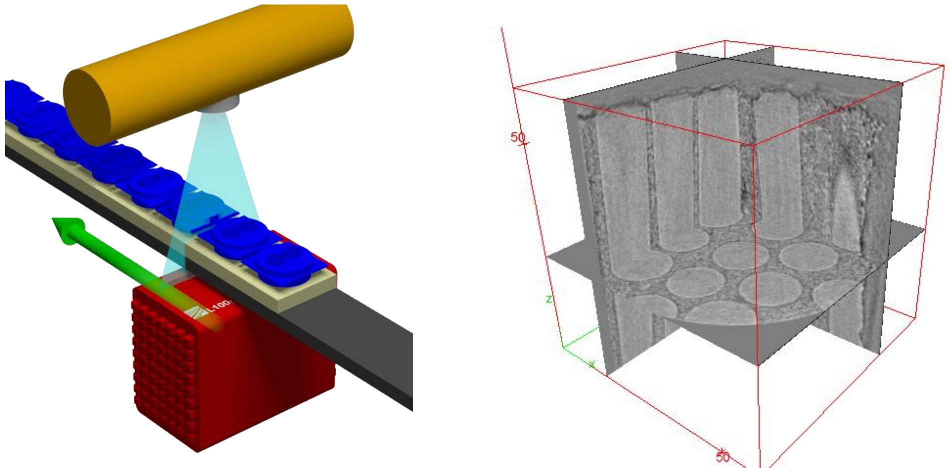
1. **Monitoring of Feedstocks and powders**
2. **Integral Inspection** of the component
3. **In-line monitoring of critical parameters**
   (delaminations, voids, porosity)
4. **Post process inspection in critical areas**
   (internal stresses, stiffness, cracks)



Source:
Zeiss Micrographs of steel (316L) (a, c) and AlSi10 (b, d) Powders used for powder characterization; a, b) Light microscopy, transmitted light, bright field, 80×; c, d) SEM, SE, WD 10 mm, EHT 10 kV, 500×

Integral NDT Methods

- Visual Inspection
- X-ray inspection
- Optical transmission
- Ultrasonics
- Thermography
- Sound analysis



100% component inspection X-ray line sensor
Quelle: Fraunhofer IKTS

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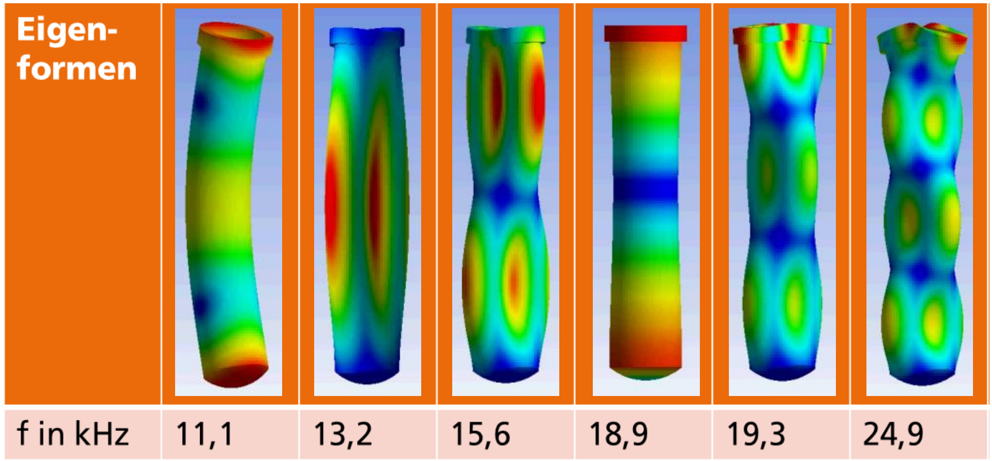
Acoustic analysis and pattern recognition

➢Integrale Method for fast failure detection
Sample: electrolyt tubes for Na/NiCl-cells (Project „Cerenergy“)



„sound“

Optimized fixation is a key step

„normal“ fixation:

optimised fixation:

(Signals transformed to audible frequencies)

Simple failures can be detected by listening

tubes with fracture:

aged material:

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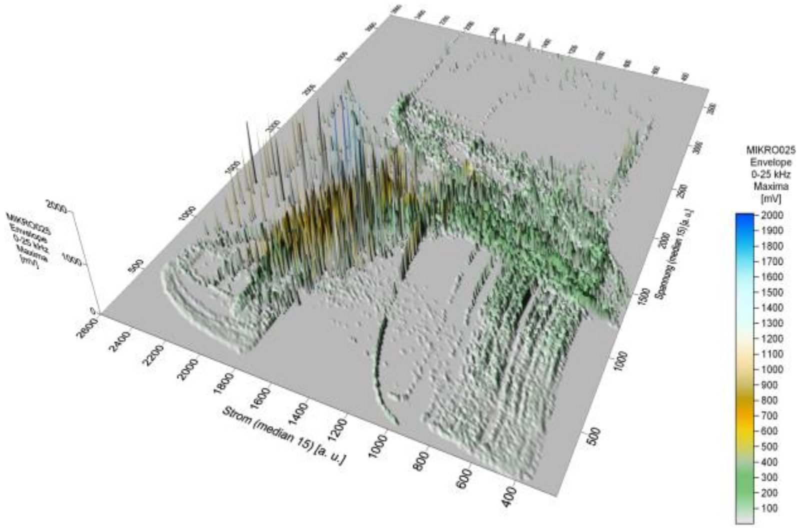
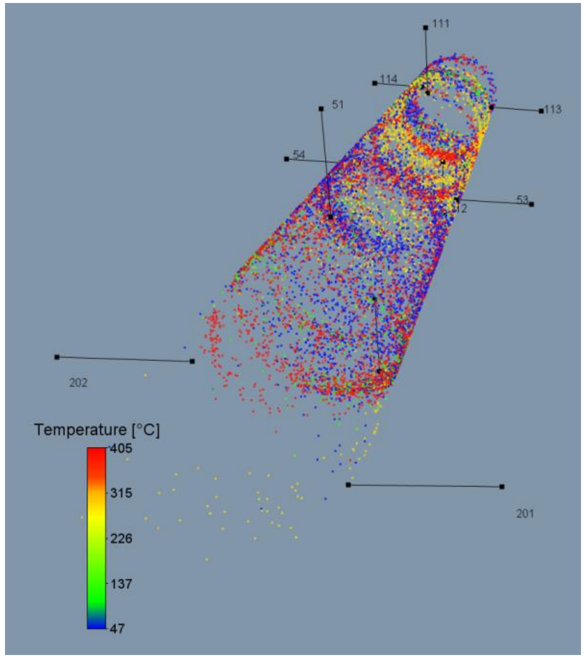
Acoustical Process Monitoring

- Simple Sensor configuration
- Acoustical signals merged with welding specific data in time domain
- Fingerprints of typical welding failures – machine learning task
- Multiple sensors – acoustic events can be located in a surface
- Ideal approach for large structural components



Fingerprint signal of welding current and acoustic data

Source: Fraunhofer IKTS



Acoustic monitoring of high temperature pipe components (500°C)

Source: Fraunhofer IKTS

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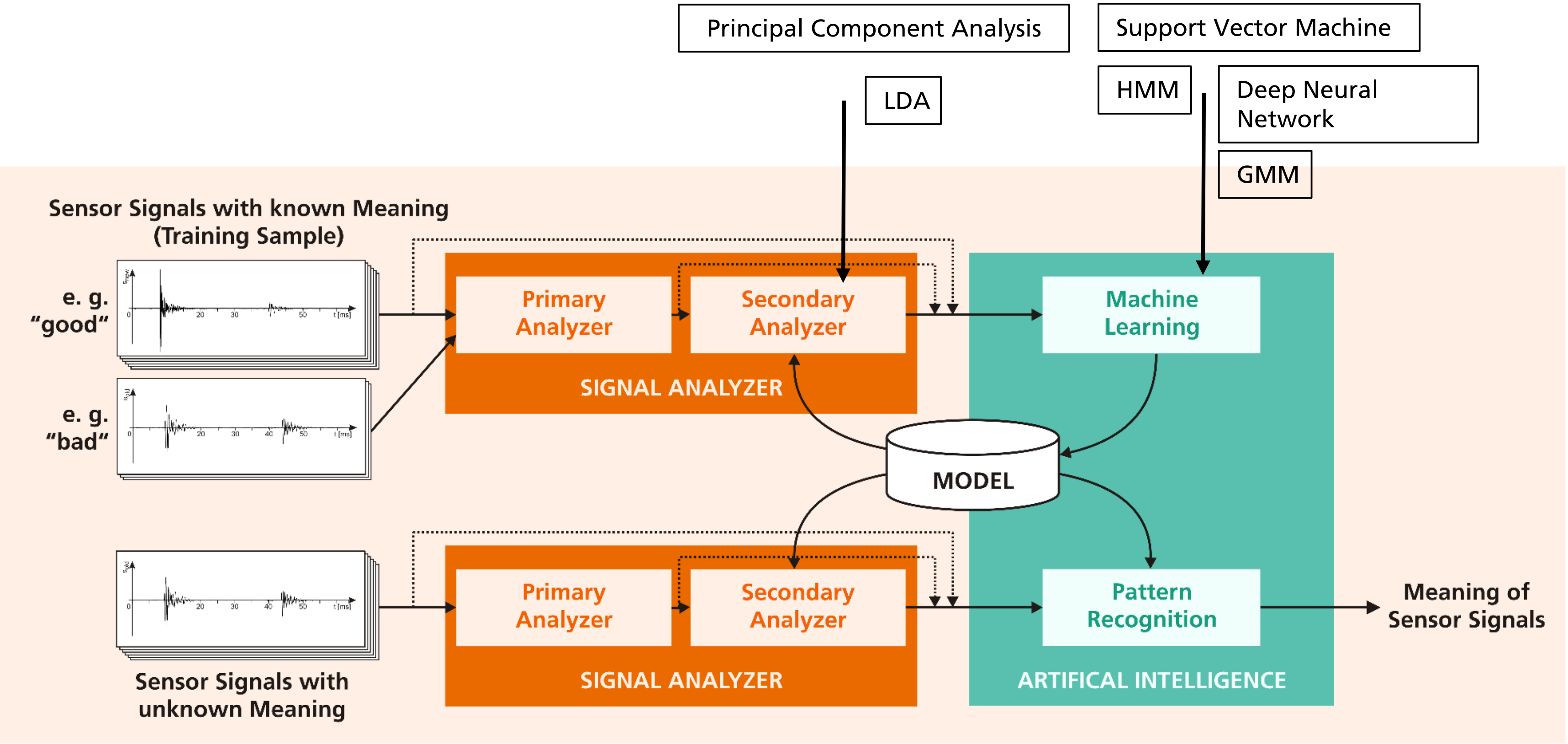
Machine Learning in Acoustic Analysis



Basic Process Model

Hardware based autonomous voice dialogue System

Algoriths signal analysis pattern recognition on FPGA and DSP

Algorithms trained first

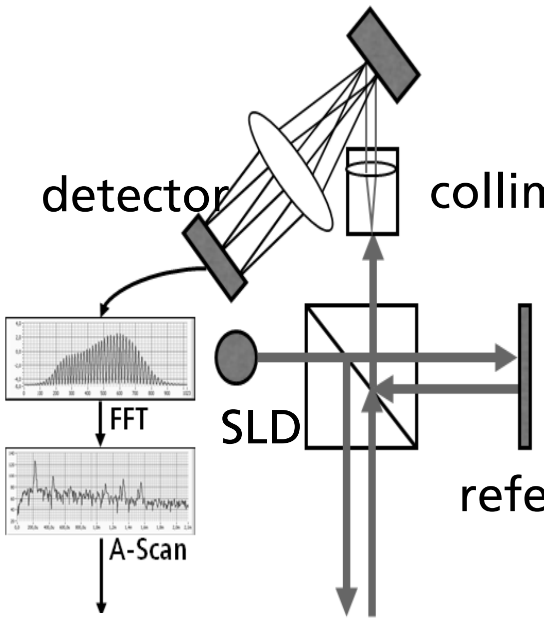
Background noise supression optionally

Inline methods for AM process monitoring

- Optical Monitoring
- Acoustical Monitoring
- Ultrasonics (continuous monitoring of to layers only)
- Optical Coherence Tomography
- Laser-Speckle- Photometry

Optical Coherence Tomography (OCT)

- **Fourier-Domain OCT-System**
- Shortwave coherent light source (SLD)
- splitted in sample- and reference arm
- Interference → FFT → depth-reflection -profile (A-Scan)
- Cross-section (B-Scan) by a sequence of A-Scans
- Tomogramm (3D) by a sequence of B-Scans



a) optical setup

b) Inspection system with automated classification

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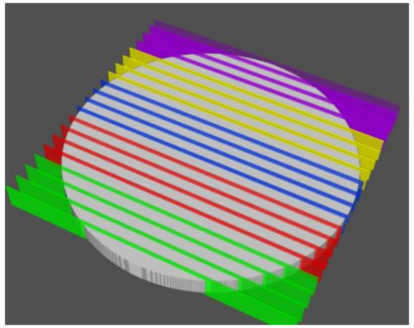
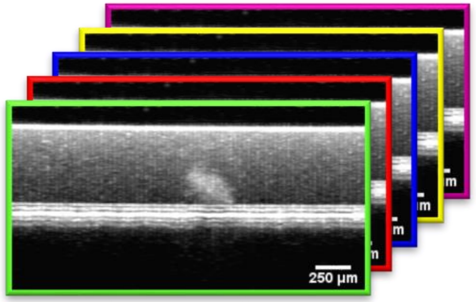
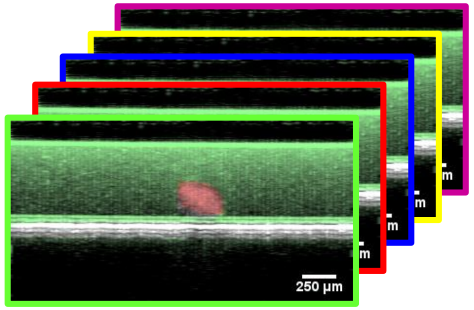
OCT Data analysis (circular foil)



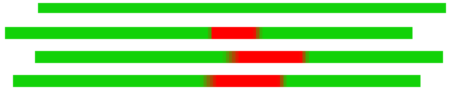
B-scan data
42 GB



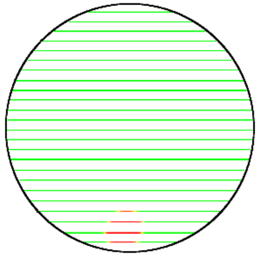
Cutting
Data compression
Contrast improvement
400 MB



Filtering
Automated classification
Failure detection
0,4 MB



projection
Top view
failures
0,4 MB



Top view
protocol
0,4 MB

High speed data processing with automated classification and failure detection

Application of Optical Coherence Tomography
Integration in 3D Additive Manufacturing Processes

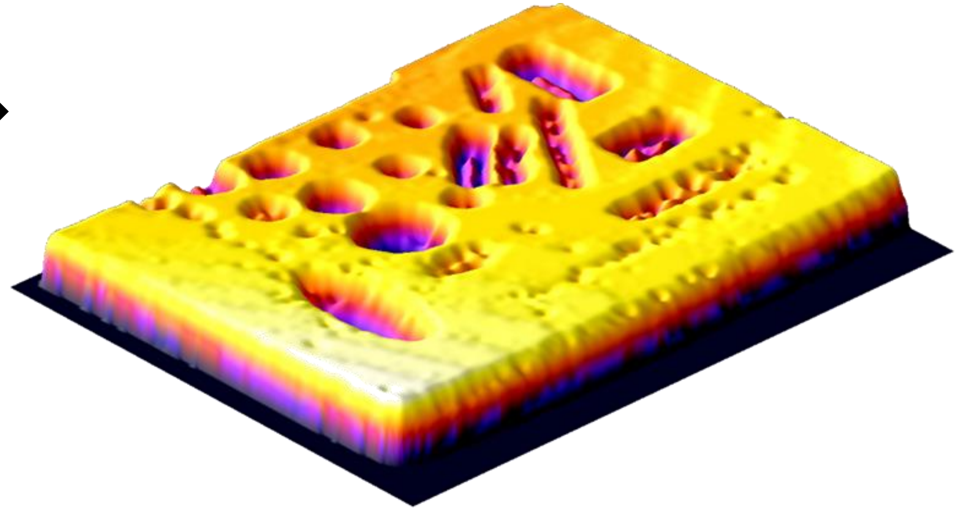
Advantages

Direct feedback → processing parameters can be adjusted during processing (geometry, position, volume)

voxel-by-Voxel generation of the 3D model as generated → safety and traceability

Certification of batch size 1 manufacturing

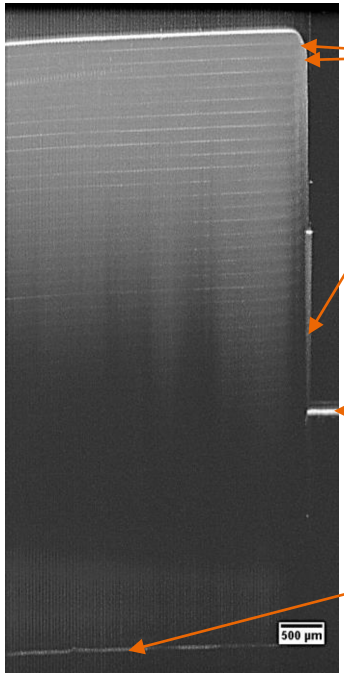
Manufacturing and quality inspection in a single process



OCT 3D-data of additiv manufactured ceramics
Source: Fraunhofer IKTS

Optical Tomography with ceramics

Application: green bodies based on LCM additive manufacturing



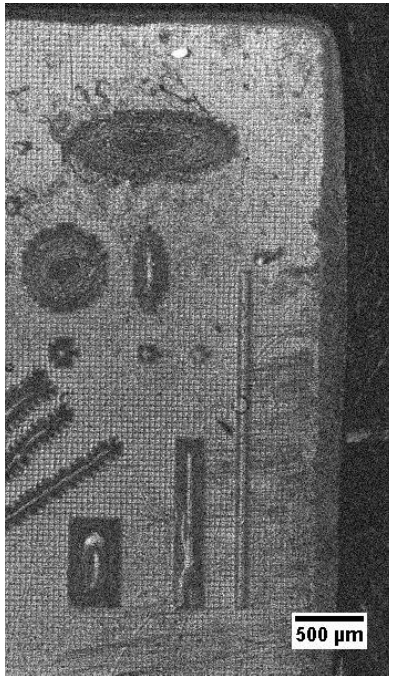
Layer distance 25µm

Layer structure visible

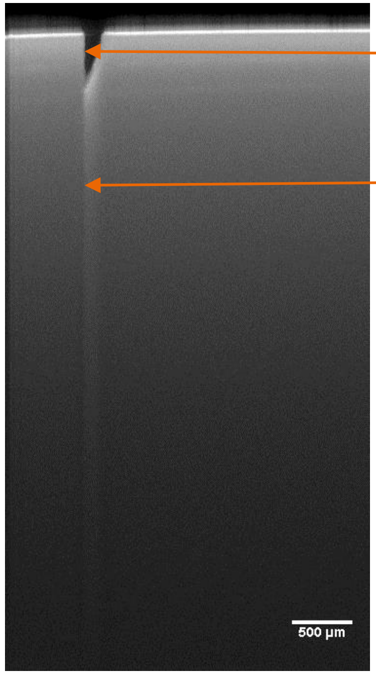
Table reflection

Backside signal

CROSS-CUT



(vertical view on the „bottom layer“)



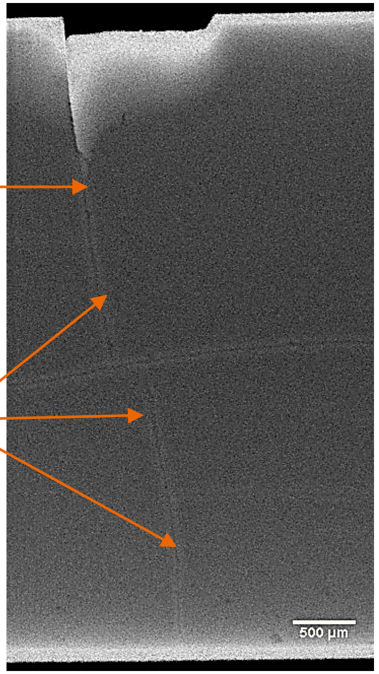
CROSS-CUT

Notch at the surface

cracks

Layer structure invisible

Surface cracks



(vertical view on the „top layer“)

Al_2O_3 AM test body

X;Y resolution: 12,5µm
Z (depth) resolution: 8µm

Zr_2O_3 test body

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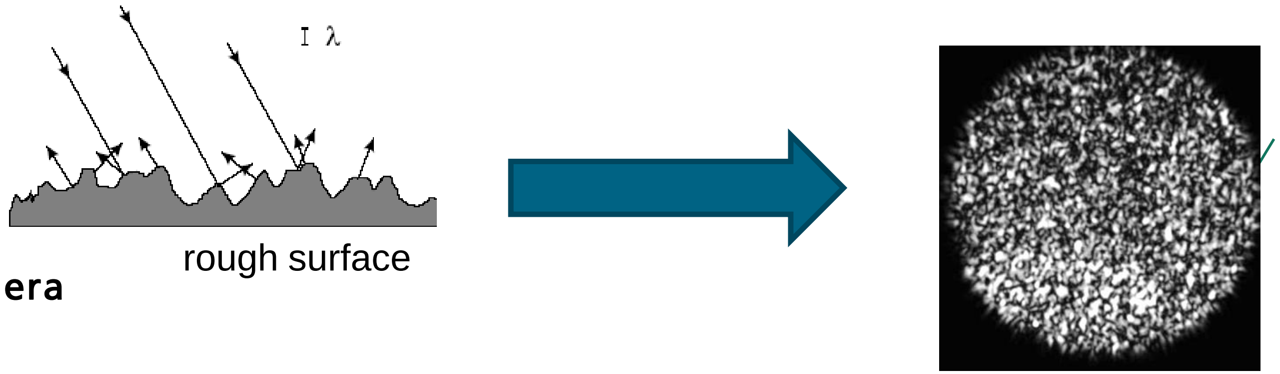
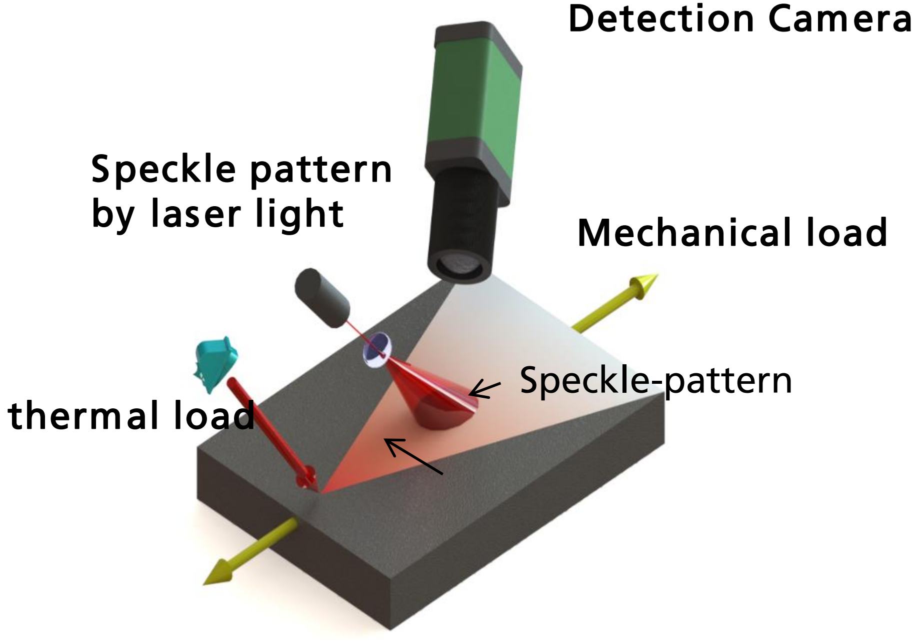
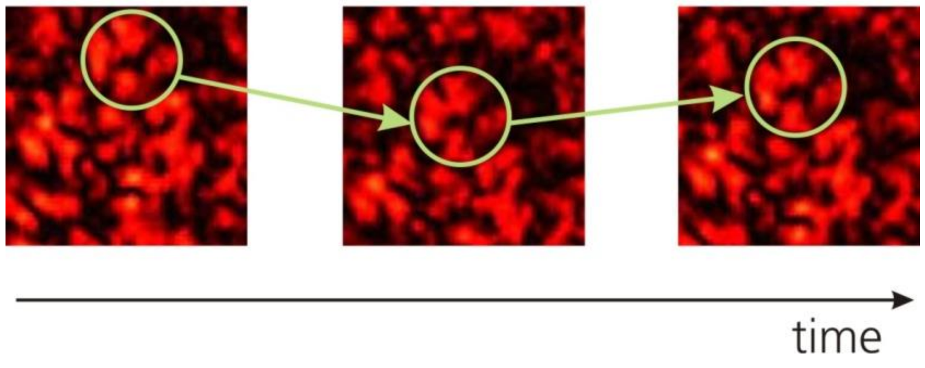
Laser Speckle Photometry LSP



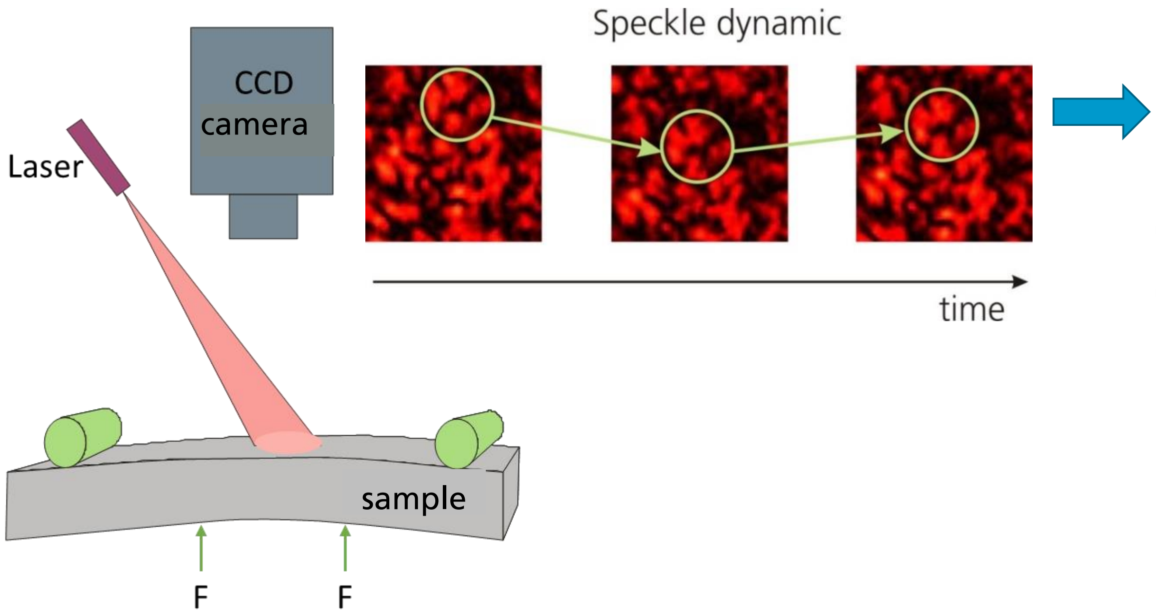


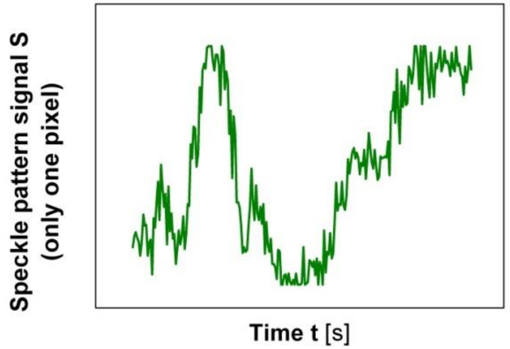
a) schematic setup

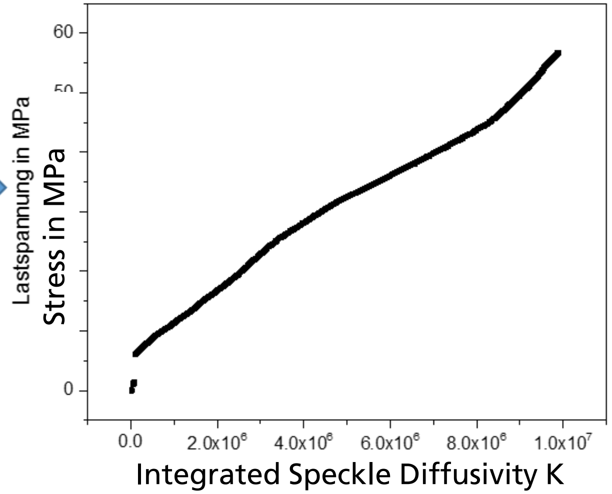


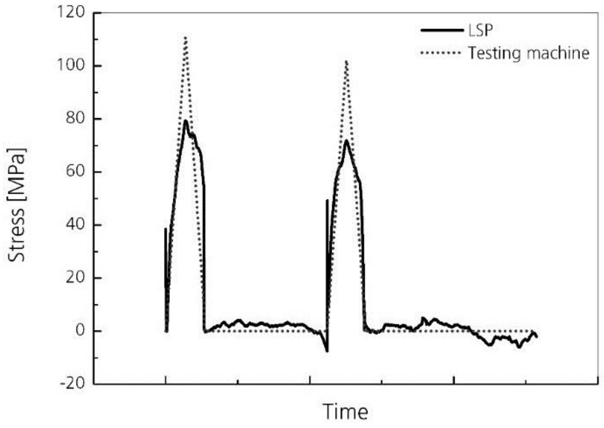
b) Speckle pattern dynamics

Approach to measure stresses in materials by LSP







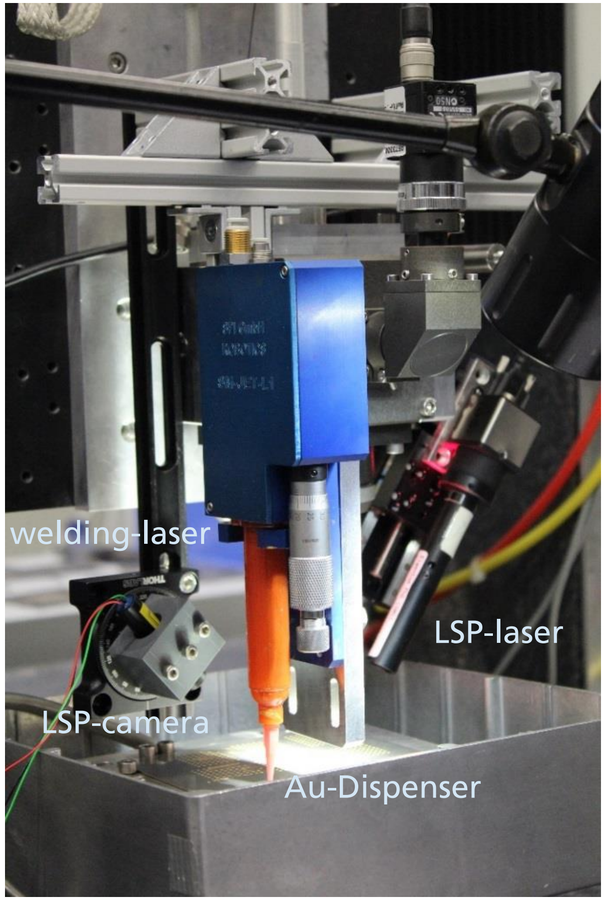


Stresses and porosities correlate with thermal diffusivity measured by speckle pattern movements

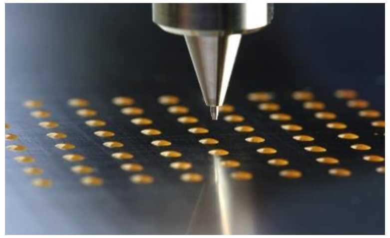
Ulana Cikalova, Juergen Nicolai, Beatrice Bendjus, et al., "Laser speckle photometry: contactless nondestructive testing technique", Proceedings of SPIE Vol. 8413, 84130X

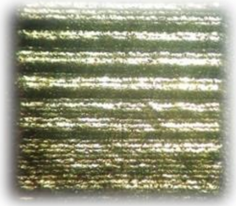
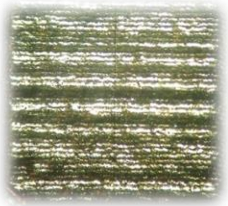
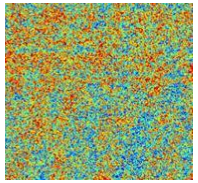
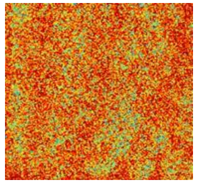
Application of Laser-Speckle-Photometry (LSP)

Inline-Monitoring of spot welding of gold contacts for electronics industry



Source: Fraunhofer IKTS + Fraunhofer ILT



Gold-contact area:		
Key LSP parameter:		
Mean fractal dimension:	$D_F = 1.37$	$D_F = 1.66$
Gold content:	87 m%	86.6 m%

Integrated NDT
Monitoring of critical parameters during AM job processing

Advantages

- limitations of penetration depths by certain methods can be overcome
- voxel-by-Voxel generation of the 3D model as generated → safety and traceability
- Certification of batch size 1 manufacturing
- Manufacturing and quality inspection in a single process

Materials Data Space

Representation of material data along the value chain (raw materials – processing – in use – Recycling)

Link between component parameters and various microstructures and compositions

Quality assurance along the value chain

Learning from data

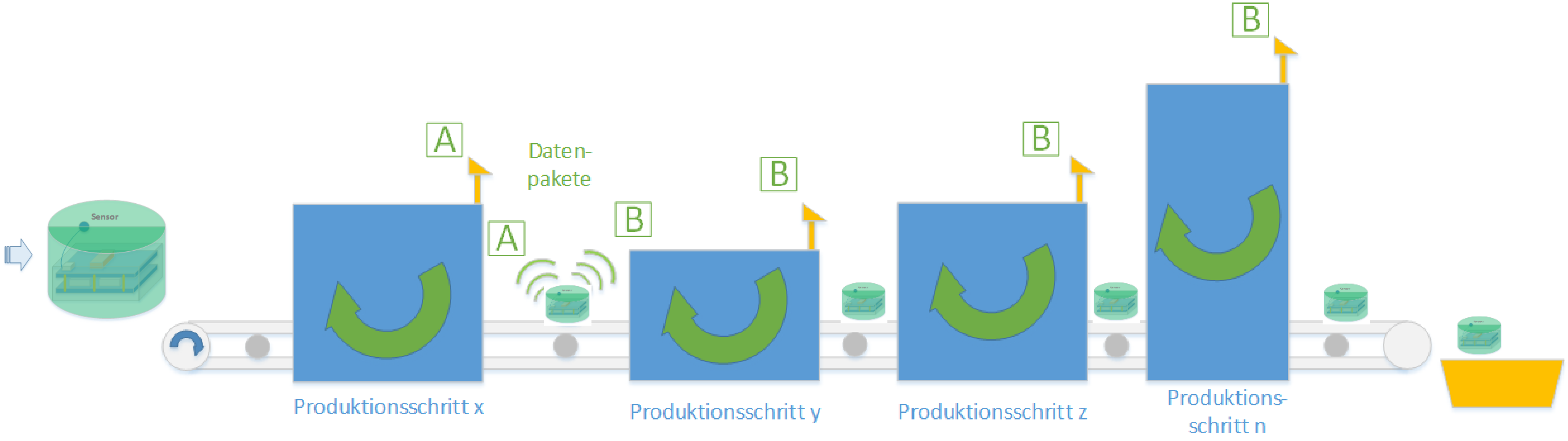
Digitalisation of material and structural data as base for new business models (e.g. predictive maintenance, …)

Industrie 4.0 - Smart Machine Sensor
Sensors mimics the product loads and movements

Sensors mimics the product loads and movements in a packaging machine

Focus: Optimized Machine Design, faster commissioning at customer site

Approach: Miniaturized sensor in the product form

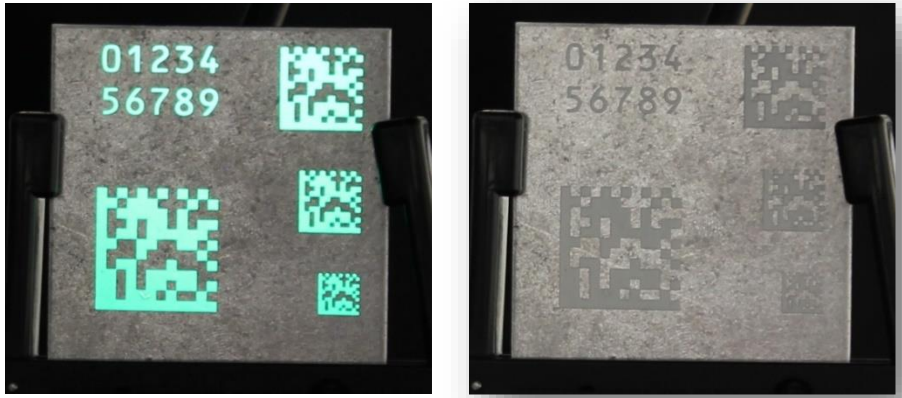


CeraCode® using ceramic luminiscents:
Product labels and process control

- luminiscent particle inks for barcodes / QR-Codes
- extremly robust, unforgeable labeling
- traceability under harsh environments
  (high temperature, chemicals, EMV, …)
- Sensoric information of process parameters
  (temperature, radiation, gas pressure, …)
- Confirmed for series manufacturing after 3 month test
  in automotive industry

1 28016 69167 5

printed CeraCode®



High-temperature product labeling of a component under UV light vs- daylight

Summary

1. Highly loaded or functionally critical components **require** individual NDT inspection
2. In-situ or inline NDT methods, in combination with other sensor signals, of the path to **process based quality inspection** for individual components
3. Fraunhofer IKTS develops some promising concepts for in-line NDT methods
4. The **new paradigm** of quality management:

   massive process data - linked to the individual component

   offers attractive new business models for the industry

Many thanks for your interest !

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