Real-Time Machine-Vision-Systems for an Automated Quality Monitoring in Context of Industry 4.0

Chair of Production Metrology and Quality Management
Laboratory for Machine Tools and Production Engineering (WZL)
RWTH Aachen University

Prof. Dr.-Ing. Robert Schmitt
Dip.-Ing. Dipl.-Wirt.Ing. Tobias Fürtjes

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Agenda

1. Introduction

2. Quality Assurance for Fiber-Reinforced Plastic

3. Fiber Measurement System (FMS)

4. Real-Time FMS for NCF-Production
Production engineering at the RWTH Aachen

**Machine Tools Laboratory (WZL)**
- Institut of the RWTH-Aachen
- established in 1906
- about 840 employees
  (about 250 research assistants)
- 10 000 m² office and laboratory area

**Fraunhofer Institute of Production Technology (IPT)**
- Institute of the Fraunhofer-Corporation
- established in 1980
- about 450 employees
  (about 124 research assistants)
- 3 000 m² office and laboratory area
- Associate-Institut in Boston/USA: CMI
  Fraunhofer Center for Manufacturing Innovation

**WZL Forum**
- Offer of further educational measures
  and workshops (e.g. Executive MBA)
Machine Tools Laboratory (WZL)
Department for Model-Based Systems

Mobile 3D and Image-Based Metrology
Laser interferometry, computer vision, thermography, photogrammetry, x-ray computed tomography, ultrasonics

Metrology Assisted Assembly
Robotics, sensor technology, location/positioning systems, process and capability analysis, industrial statistics

• Precision metrology in large volumes
• Metrology enabler for machine tools
• Structure monitoring under thermal conditions
• Computer vision applications
• Quality assurance on total RFP process chain

• Fixtureless assembly
• Assembly in motion
• Assembly operator active assistance
• Process evaluation
• Confidence- and capability proofing

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Industry 4.0: Combination of real and virtual world
Challenge for the production metrology?

Virtual world

- Database
- Component model
- Process model
- Machine model
- ... model
- Reactive plan & control
- Self-organized plan & control
- Adaptable plan & control
- Real-time capable plan & control

Real world

- Component status
- Machine status
- Process status
- Environment
- Human

For the Industry 4.0 the development of real-time capable metrology is necessary
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Mass Production Increase Demand for Metrology Performance

Requirements: Sufficient process capability, low unit costs & high volume production

- **Production process**
  - High reproducibility, low process variation
  - Low scrap quota, no oversizing
  - High part & process quality
    - Industrialization of the production
    - Significant reduction of production costs

- **Demand for metrology performance**
  - Time and cost efficient
  - Easy to handle
  - Real time
  - Automated
  - Fast

**Solution:** Automated and real-time capable multi-sensor quality assurance
Methods and Sensor Development for Automated FRP-Production

- 3D-digitalization of FRP-textiles and preforms for automated defect detection and classification
- Qualification of thermography for detection of damages respective their 3D properties
- Automated ultrasonic testing of CFRP parts
- Development and testing of innovative systems at the WZLs FRP-laboratory (camera-based systems, thermography, ultrasonic, CT)
- Integration und fusion of different sensor system considering real time conditions
- Development of testing processes for reliable defect detection in repair shops
Quality Assurance along the Process Chain

Optical sensor systems

Raw material, textile

Preforming

Preform handling

Integrated production processes

Part handling

Final part

Quality assurance

Testing of adhesive bonds

Crash defect

Delamination and inner folds

Fiber orientation

Defect detection

Sensor integration handling

Ultrasonic system

Thermography system

Process control

Sinusoidal excitation

Fourier transform analysis

IR-Source

IR-Source

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Fiber Measurement System for 3D-preforms

Process / Features

- Measurement of 3D-geometry and 3D-fiber orientation of composite preforms
- Robot based system for large composite structures
- Measuring frequency: Laser 10 Hz, camera ap. 10 Hz
- Working distance: ~ 60 mm

Accuracy

- Fiber orientation : +/- 0,18 °
- Geometry : +/- 0,5 mm
Fiber Measurement System FMS
Machine Vision for CFRP Textiles and Preforms

Surface  Geometry  Robotically guided

3D-fiber orientation

Defect Detecting – Waviness
Waviness Parallel to Surface

\[ \mu = 89,21° \]
\[ \sigma = 1,31 \]

Grid square 1

\[ \mu = 91,04° \]
\[ \sigma = 43,66 \]

Grid square 2

Experimental Results
Statistical Analysis of Chopped Fibers

Data analysis indicates preferred orientation on the surface.
Fiber Measurement System FMS
Automated Defect Detection and Classification

- Gaps
- Foreign objects
- Cavities
- Cracked seams
- Misaligned rovings

Length: 637.8 pixels
Area: 23368 pixels
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AutoNCF
Non Crimp Fabric (NCF) Manufacturing Process

**Motivation**
- Multiaxial NCF can be economically manufactured by a warp knitting machine with multiaxial weft insertion.

**„Why We Need Real-Time Systems“ and „What Does It Mean“**
- Real-Time systems a common used in critical environments (e.g. car, power plant)
- Allows a predictable time and system behavior in any cases
- In mass production the time for inline processes is limited and non-varying

⇒ For reliable quality monitoring and documentation and for the connection of different productions systems and participants (Industry 4.0) deterministic time behavior is needed

⇒ Integration of the sensor and control system in the warp knitting machine
AutoNCF Approach

- Development of a 3-component sensor data fusion-system
  - 2D-texture measurement
  - 3D-geometry measurement
  - X-ray based weight sensor

- Combination of real-time hardware and FPGA
  - NI PXI-Rack with real-time LabVIEW as working system and interface to the production world
  - FPGA-board for the time-optimized calculation of the algorithm
  - Parallelization of the structure-tensor algorithm
  - Adaptive estimation of the histogram
  → Real-time behavior

- Integration of the real-time FMS in the production process
  - Real-time Interfaces (e.g. Camera Link)
  - Dynamic defect map
AutoNCF

Results

- The 3-component sensor data fusion-system could be integrated into the warp knitting machine
- Through the sensor system an implementation of a control loop was possible
- The sensor-system works in real-time (currently: 23 Hz)
- The process capability could be significantly improved
- The defect map allows the first time a fully quality documentation
Evaluation of the RT-FMS

Reachable deterministic framerate
- Camera resolution of 2048 * 2048 pixel → **22.72 fps**

Measurement uncertainty (MU)
- Investigation of different parameter-sets
- MU from **0.0119° to 0.1314°**

Influence parameter on the MU
- Material type is the most critical for the random error

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influence on systematic error</th>
<th>Influence on random error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Integration</td>
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<td>0</td>
</tr>
<tr>
<td>Resolution</td>
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<td>+</td>
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<tr>
<td>Material</td>
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<td>++</td>
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<tr>
<td>Exposure time</td>
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<td>0</td>
</tr>
<tr>
<td>Aperture</td>
<td>+</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions and Future Prospects

Conclusions

- The developed RT-FMS allows a deterministic quality monitoring in context of Industry 4.0
- The RT-FMS could be integrated into the Warp Knitting Machine
- Through the deterministic quality assurance (22 FPS) the process control loop could be closed

Future prospects

- Especially regarding to Industry 4.0 concept real time systems plays a key role in the (future) production
- Development of other deterministic systems is needed
Thank you for your attention.

Questions?

Dipl.-Ing. Dipl.-Wirt.Ing. Tobias Fürtjes

Chair of Production Metrology and Quality Management
Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University

📞 +49 241/ 80 24782
✉️ T.Fuertjes@wzl.rwth-aachen.de