Automated Production of Large CFRP Preforms: Challenges and Solutions along the Process Chain

04 July 2012

Dr. Tobias Gerngross

DLR

Outline

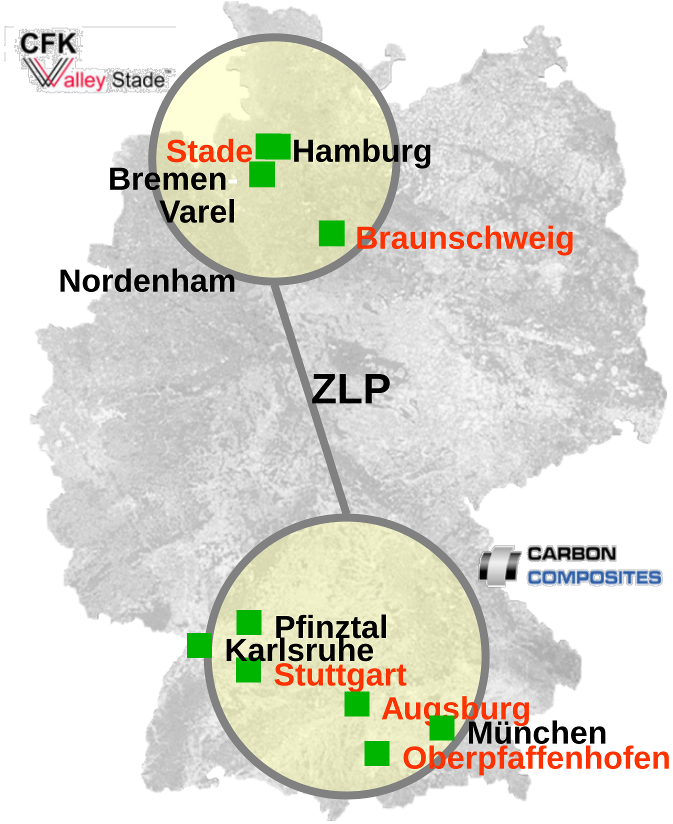
- Introduction
- Automation along the Process Chain
    1. Process Preparation
    2. Preforming with Cooperation Robots
    3. Chain of Errors & Inline Quality Assessment
    4. Enhancing Accuracy on a Flexible Robotics Platform
- Summary and Outlook

Introduction

DLR Center for Lightweight Production Technology

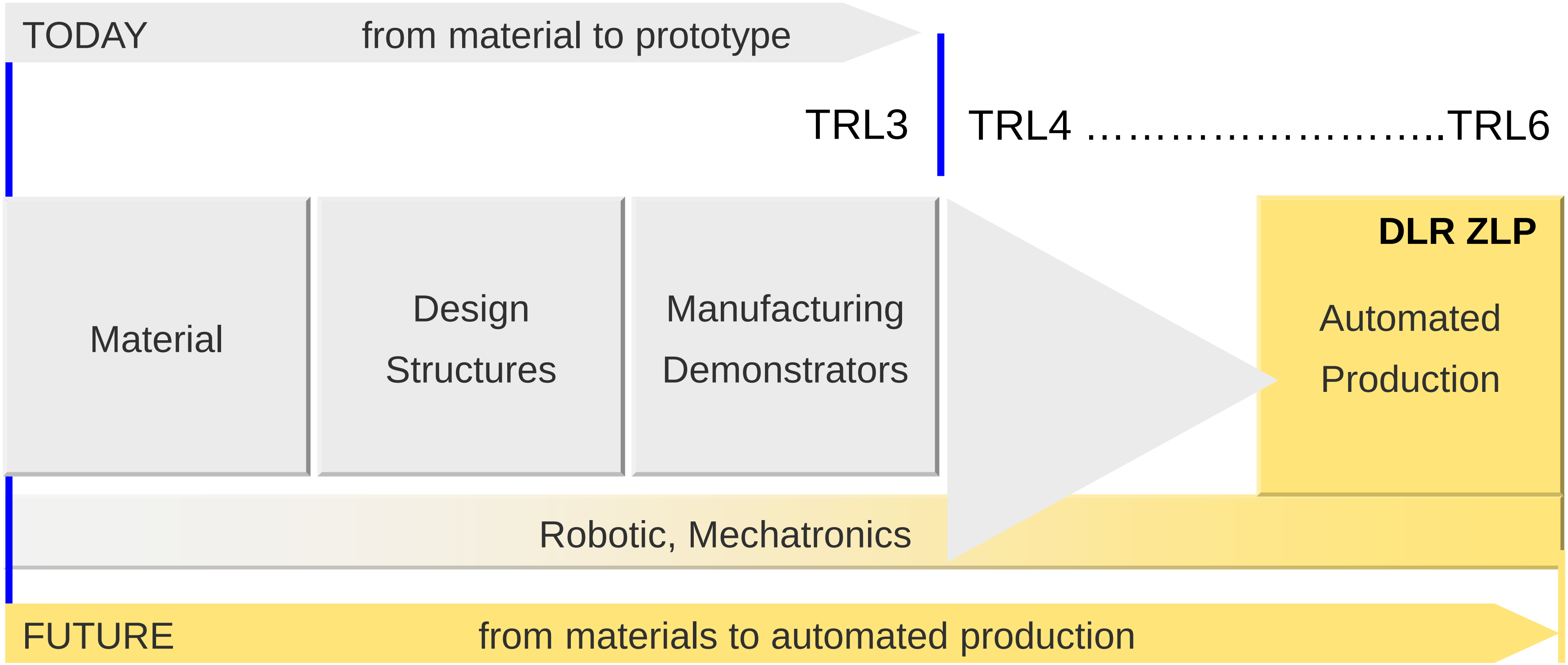
ZLP Site Stade

ZLP Site Augsburg



Introduction

Providing Technology Readiness for Industrialization



TODAY from material to prototype

TRL3

TRL4 ....TRL6

Material

Design Structures

Manufacturing Demonstrators

DLR ZLP

Automated Production

Robotic, Mechatronics

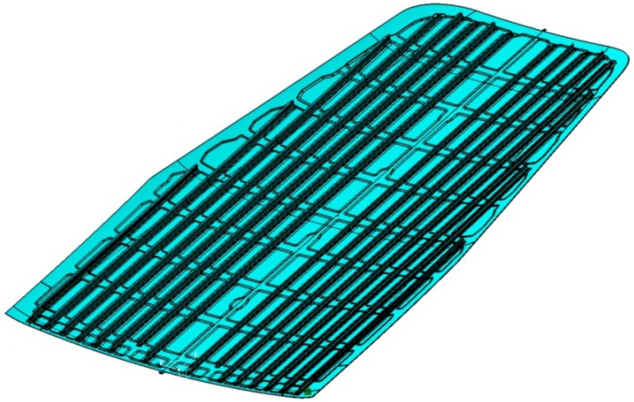
FUTURE from materials to automated production

Introduction

Production of Large Aerospace Structures

Challenges for an automated composite production:

- High layup rates
- Many manual processes involved
- Potential issues
    - Material damages
    - Repeatability
    - Quality assurance
- Robotic gripper weight for large cut pieces



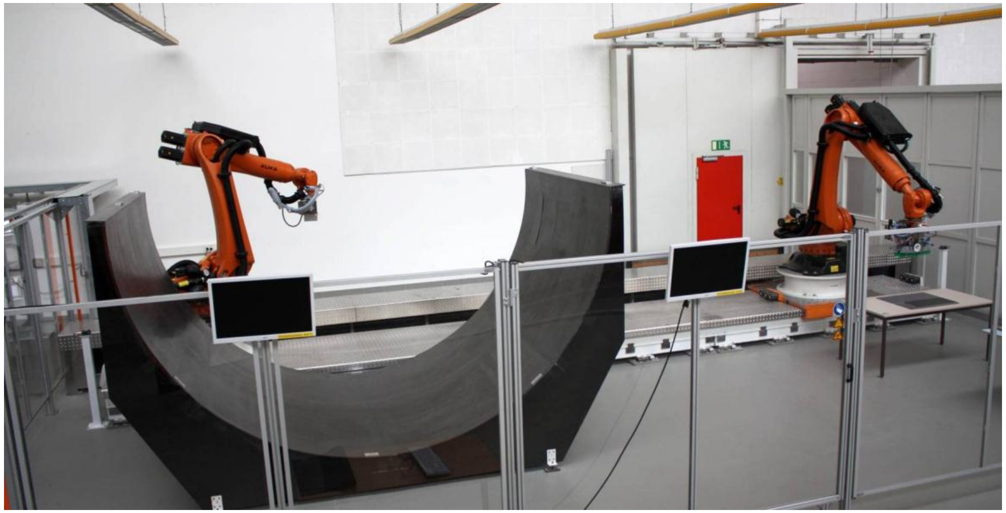
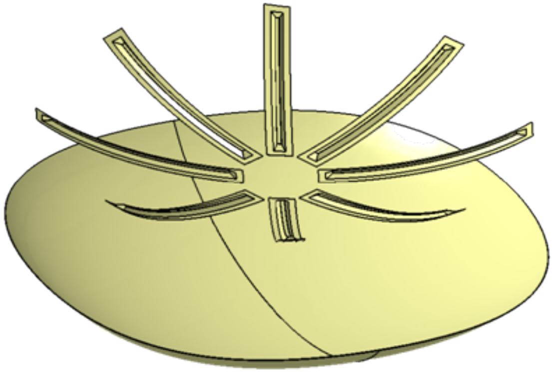


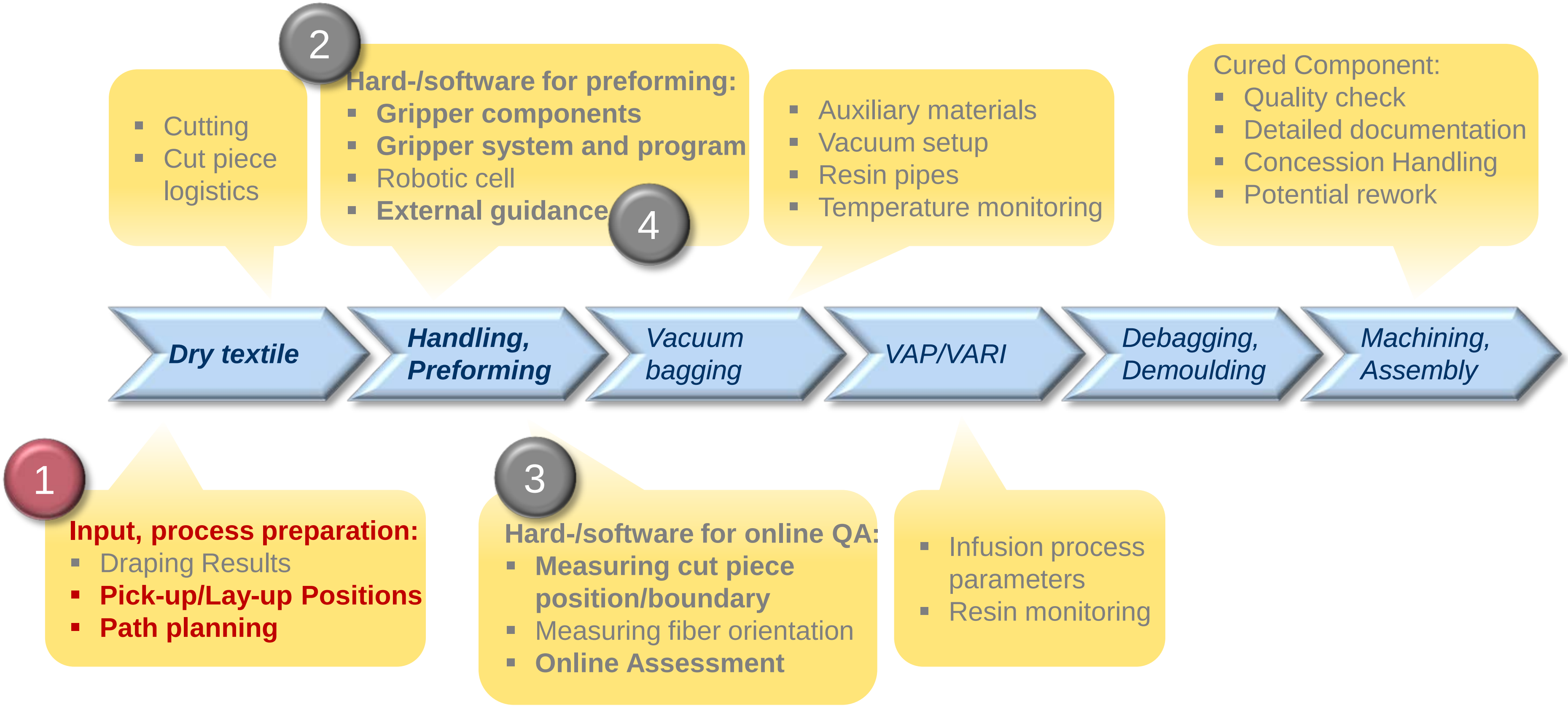
Image: DLR, Robotic test cell



Images: Premium Aerotec GmbH
Top: Cargodoor A400M
Below: Pressure Bulkhead A350

Automation along the Process Chain

Focus in this presentation



- Cutting
- Cut piece logistics

2

Hard-/software for preforming:
- **Gripper components**
- **Gripper system and program**
- Robotic cell
- **External guidance**

4

- Auxiliary materials
- Vacuum setup
- Resin pipes
- Temperature monitoring

Cured Component:
- Quality check
- Detailed documentation
- Concession Handling
- Potential rework

Dry textile → ***Handling, Preforming*** → *Vacuum bagging* → *VAP/VARI* → *Debagging, Demoulding* → *Machining, Assembly*

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Input, process preparation:
- Draping Results
- **Pick-up/Lay-up Positions**
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Hard-/software for online QA:
- **Measuring cut piece position/boundary**
- Measuring fiber orientation
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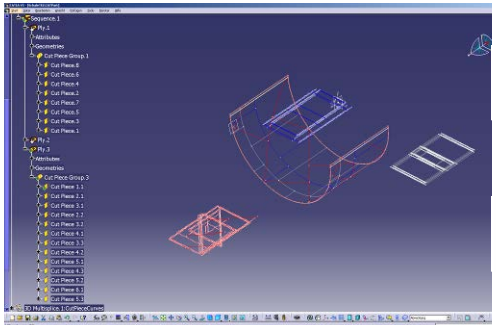
- Infusion process parameters
- Resin monitoring

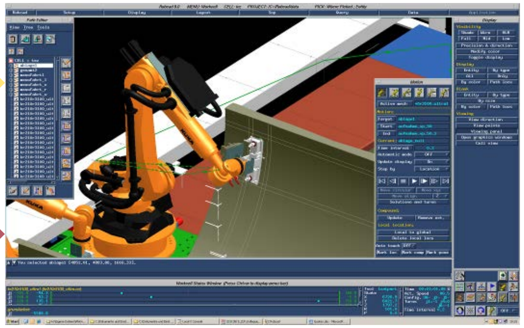
Automation along the Process Chain

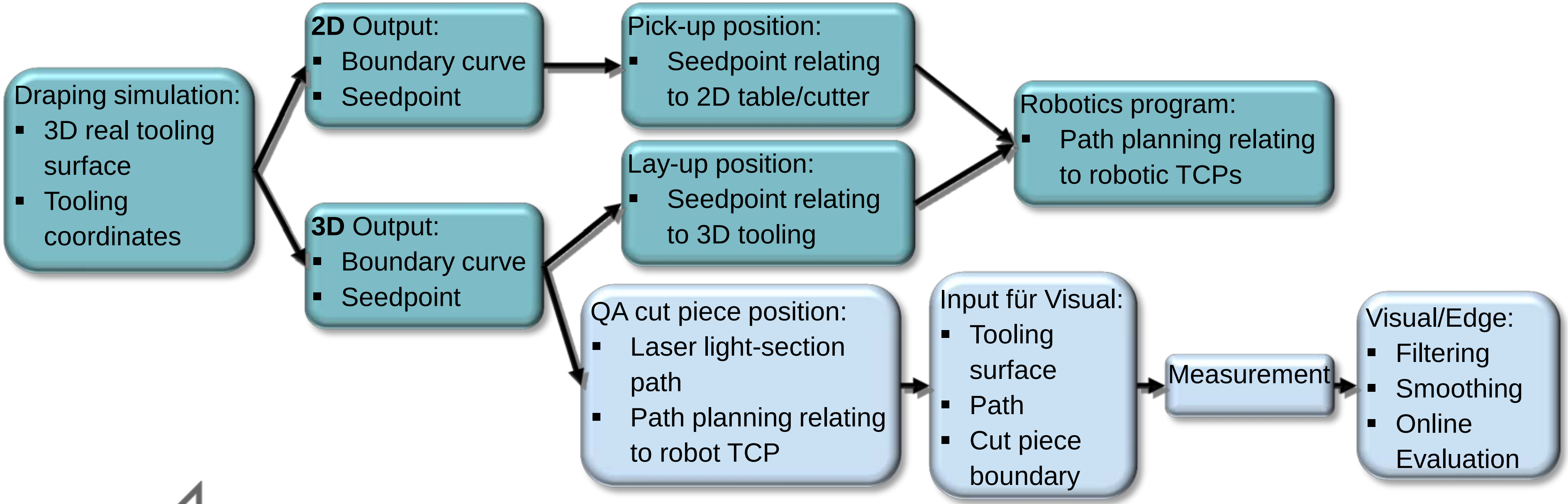
Process Preparation



Status Quo: manual process preparation

Vision: design to manufacture





Draping simulation:
- 3D real tooling surface
- Tooling coordinates

2D Output:
- Boundary curve
- Seedpoint

3D Output:
- Boundary curve
- Seedpoint

Pick-up position:
- Seedpoint relating to 2D table/cutter

Lay-up position:
- Seedpoint relating to 3D tooling

Robotics program:
- Path planning relating to robotic TCPs

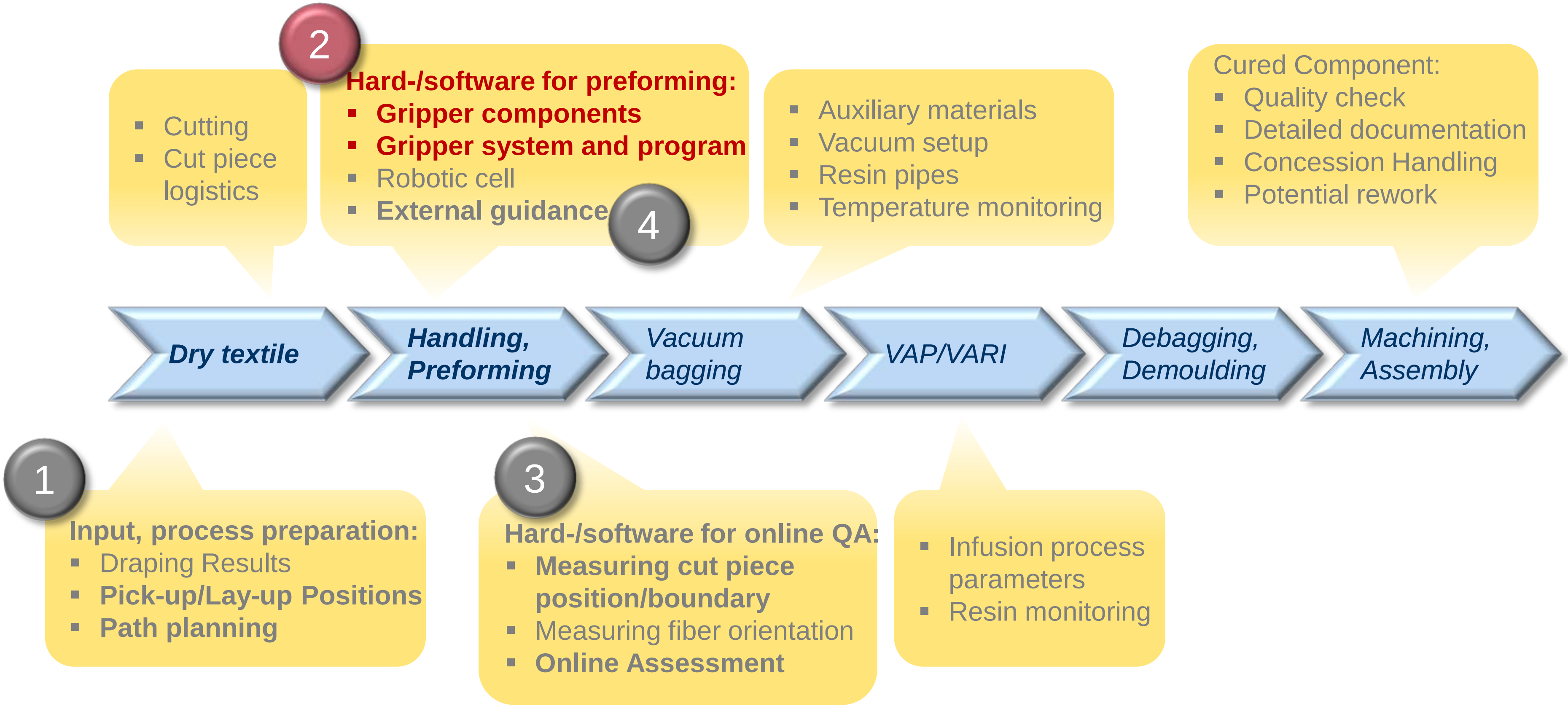
QA cut piece position:
- Laser light-section path
- Path planning relating to robot TCP

Input für Visual:
- Tooling surface
- Path
- Cut piece boundary

Measurement

Visual/Edge:
- Filtering
- Smoothing
- Online Evaluation

Automation along the Process Chain



Dry textile → **Handling, Preforming** → *Vacuum bagging* → *VAP/VARI* → *Debagging, Demoulding* → *Machining, Assembly*

- Cutting
- Cut piece logistics

2

Hard-/software for preforming:
- **Gripper components**
- **Gripper system and program**
- Robotic cell
- **External guidance** 4

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Cured Component:
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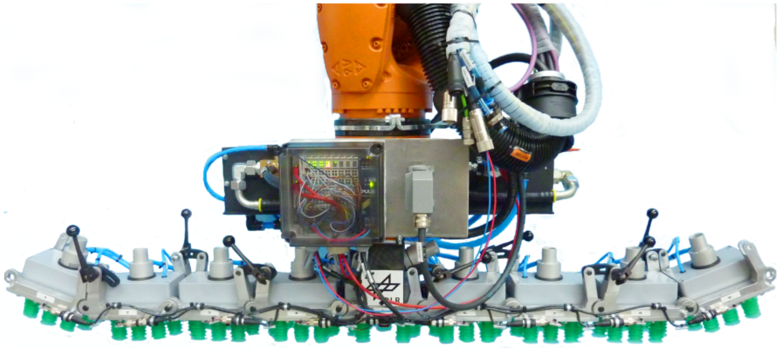
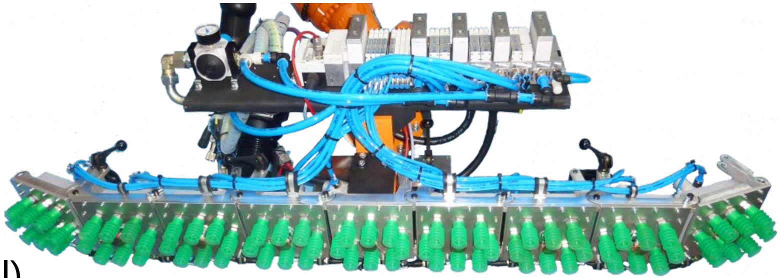
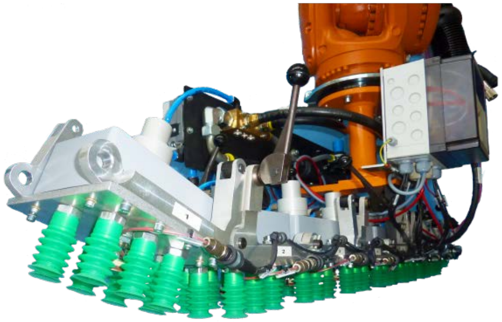
Preforming Solutions







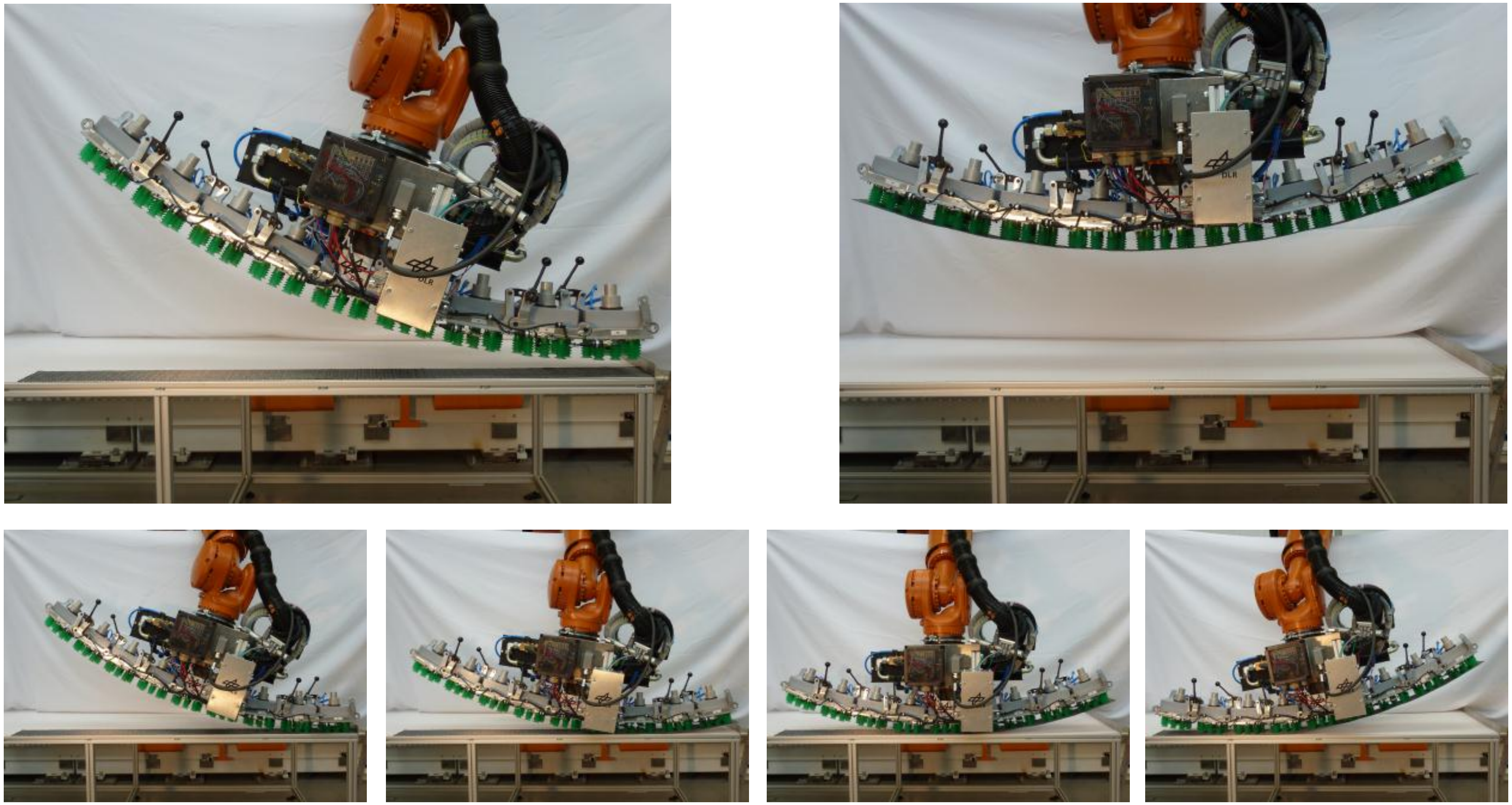
Gripper principles

- Modularity
- Flexible adjustment of deformation
- Vacuum (low pressure), high volume flow
- Supply: 6 bar, 24 V, EtherCat

Gripper details

- Components:
    - Valve cluster by Festo
    - Bus module by Beckhoff
    - Gripper mechanics by Kuka Systems
- Bellows suction pads (optimized for choice of material)
- Activation of thermoplastic binder by heating devices on linear actuators

Preforming Solutions

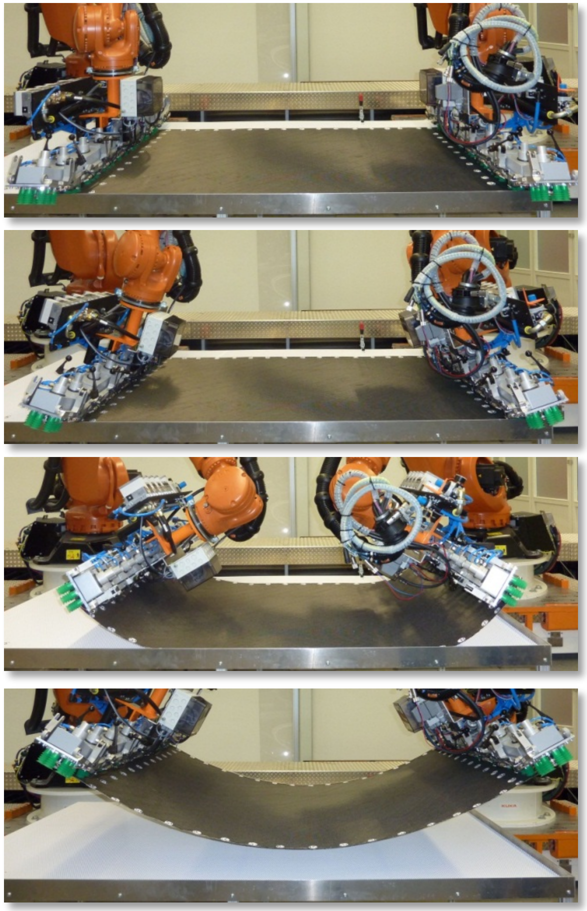


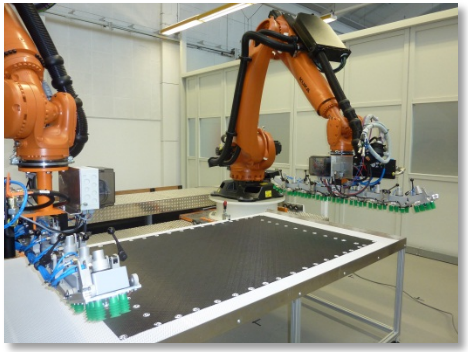
Preforming with Cooperating Robots

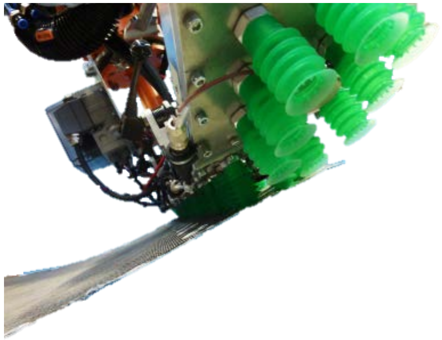
Pick-up

Pick-up

- Rectangular cut pieces
    - Dry NCF, 2.0 x 1.22 m
    - Thermoplastic binder
- Resulting forces depending on gripper distance
- Gripper movements in 3 increments
- Cut piece forms catenary







Preforming with Cooperating Robots

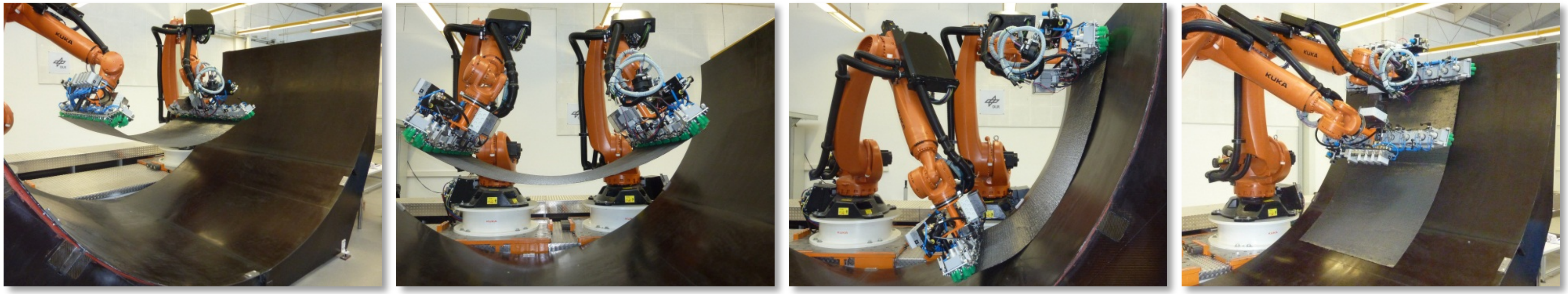
Lay-up

Transfer on linear track and positioning

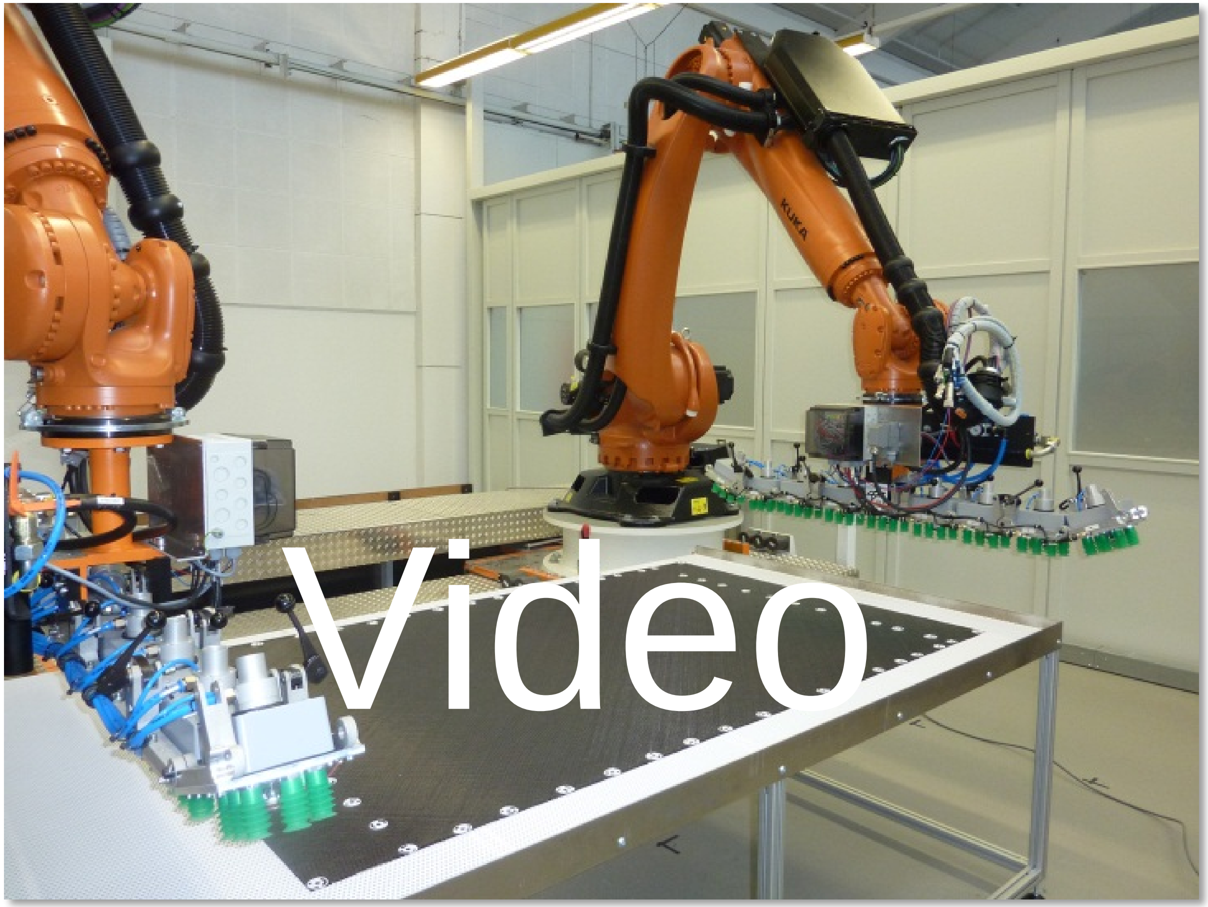
- Grippers keep their relative position and orientation

Attachment

- Grippers hold cut piece edges in position
- Activation of thermoplastic binder
- Individual gripper movements

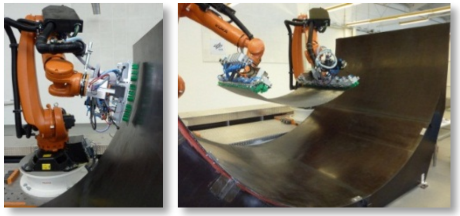


Preforming with Cooperation Robots

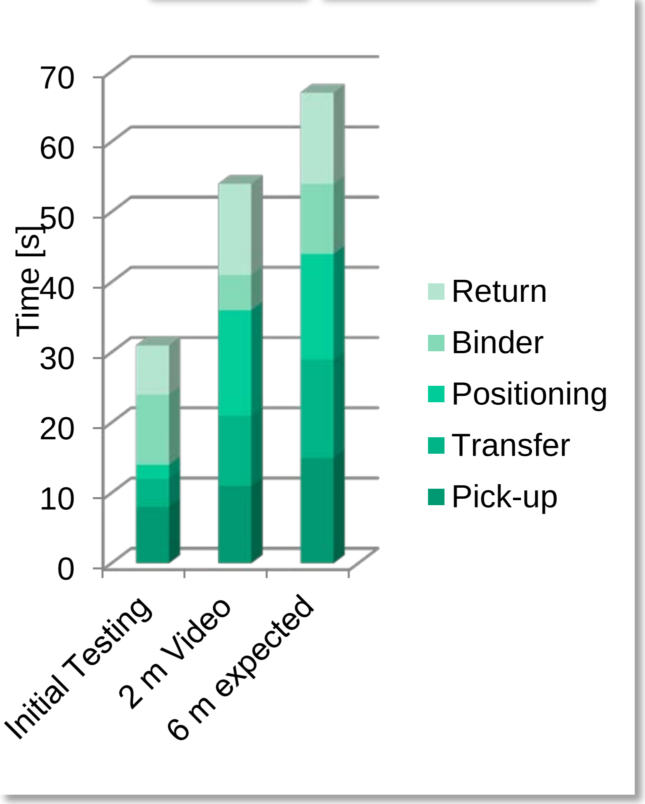


Preforming with Cooperation Robots

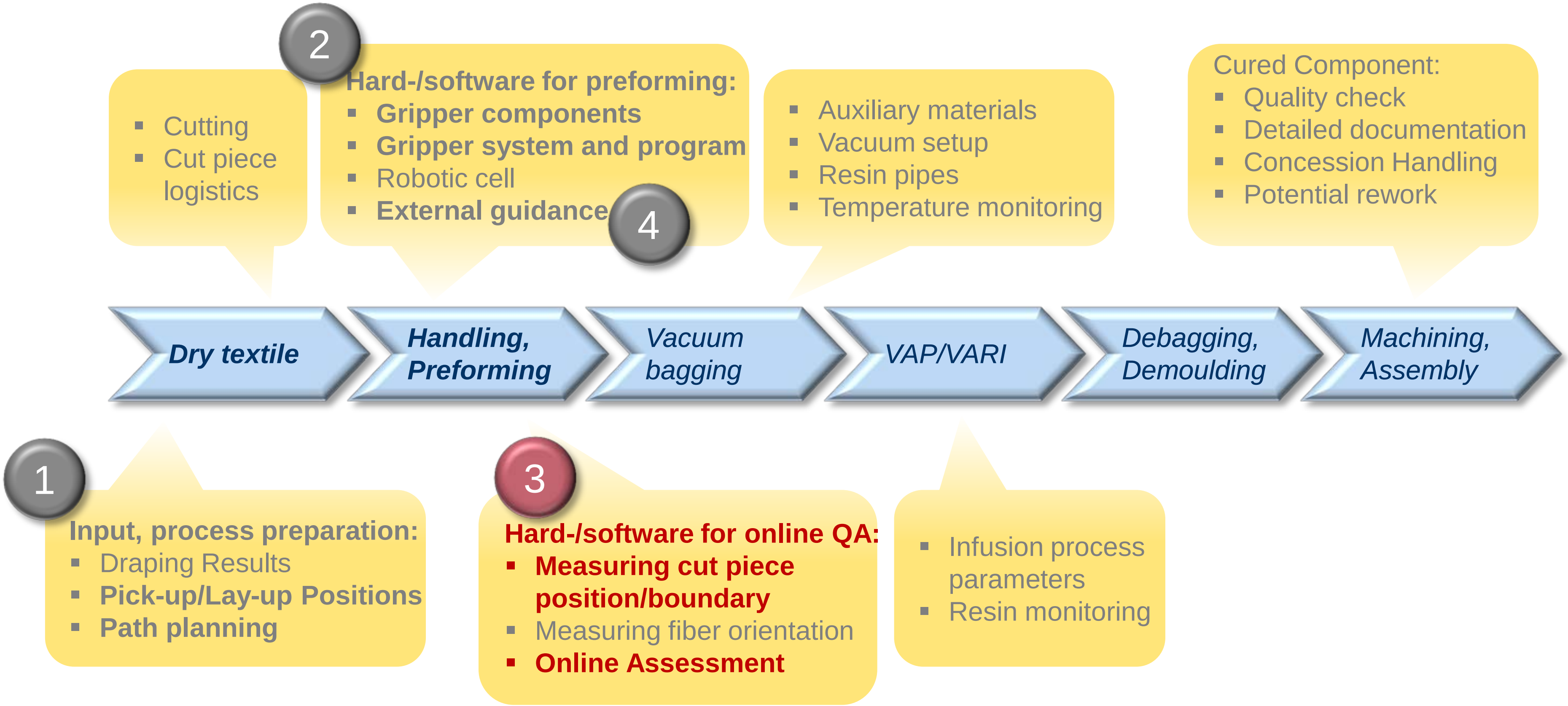
Performance



	Initial testing	**2 m Video**	***6 m expected***
Pick-up [s]	8	11	*15*
Transfer [s]	4	10	*14*
Positioning [s]	2	15	*15*
Binder [s]	10	5	*10*
Return [s]	7	13	*13*
Mass [g]	69	1354	*4063*
Layup rate [kg/h]	**7.53**	**90.27**	***218.31***



Automation along the Process Chain



2

Hard-/software for preforming:
- **Gripper components**
- **Gripper system and program**
- Robotic cell
- **External guidance**

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- Cutting
- Cut piece logistics

- Auxiliary materials
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Cured Component:
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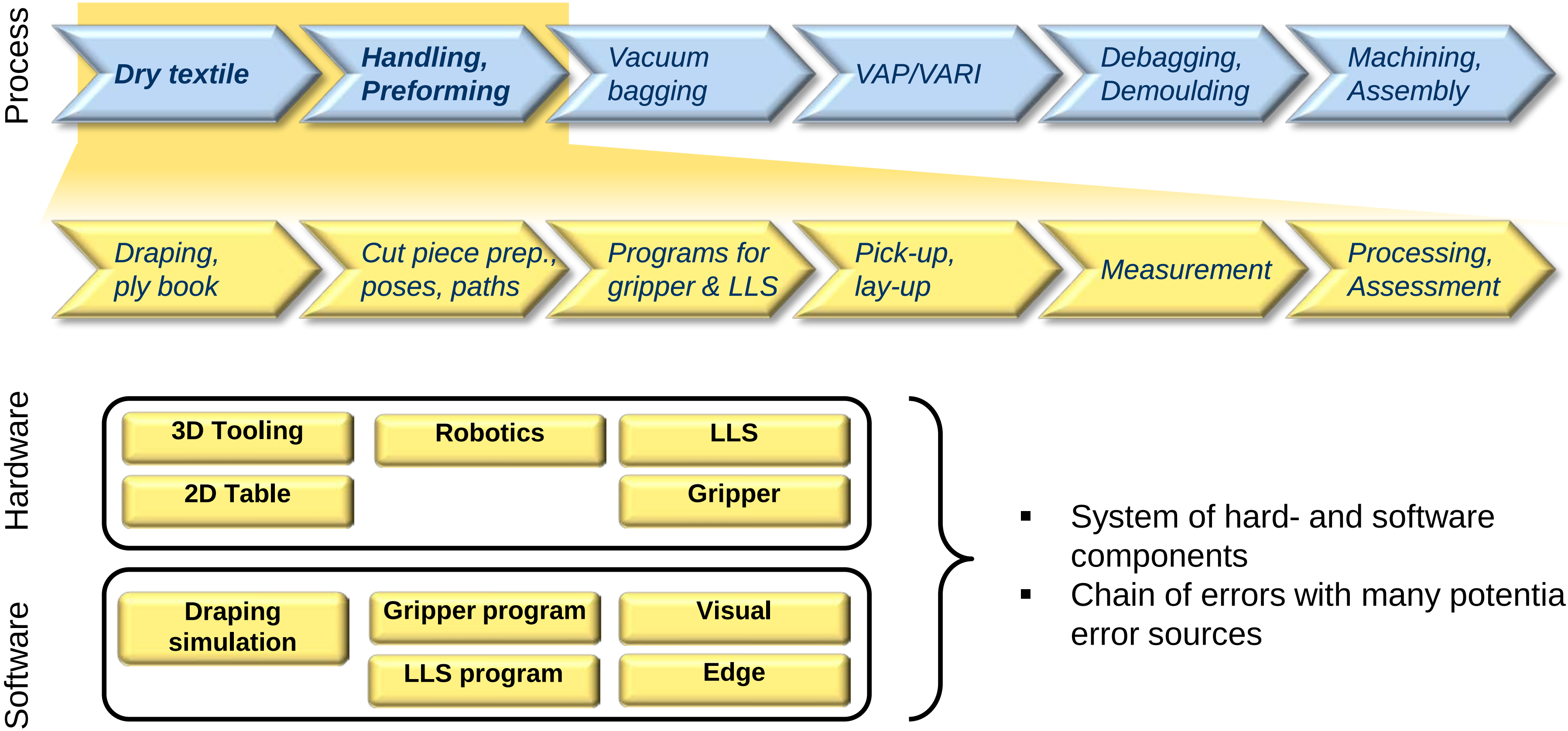
Control on Process Accuracy

Chain of Errors



Process

Dry textile → *Handling, Preforming* → *Vacuum bagging* → *VAP/VARI* → *Debagging, Demoulding* → *Machining, Assembly*

Draping, ply book → *Cut piece prep., poses, paths* → *Programs for gripper & LLS* → *Pick-up, lay-up* → *Measurement* → *Processing, Assessment*

Hardware

3D Tooling

2D Table

Robotics

LLS

Gripper

Software

Draping simulation

Gripper program

LLS program

Visual

Edge

- System of hard- and software components
- Chain of errors with many potential error sources

Control on Process Accuracy

Chain of Errors

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Hardware

3D Tooling
- Base system
- Exact surface geometry
- Matching reality and theory

2D Table
- Base system
- Cut piece position and orientation

Robotics
- Null frame (base localization)
- Robot accuracy (absolute, repeated)
- External axis alignment
- Calibration (loads & poses)

LLS
- Tool center point
- Mechanical installation
- LLS accuracy

Gripper
- 9 Tool center points
- Adjustment of gripper modules

Software

Draping simulation
- Draping simulation strategy

Gripper program
- Load data
- Pick-up and lay-up poses
- Forces on material
- Material deformation

LLS program
- Load data
- LLS orientation

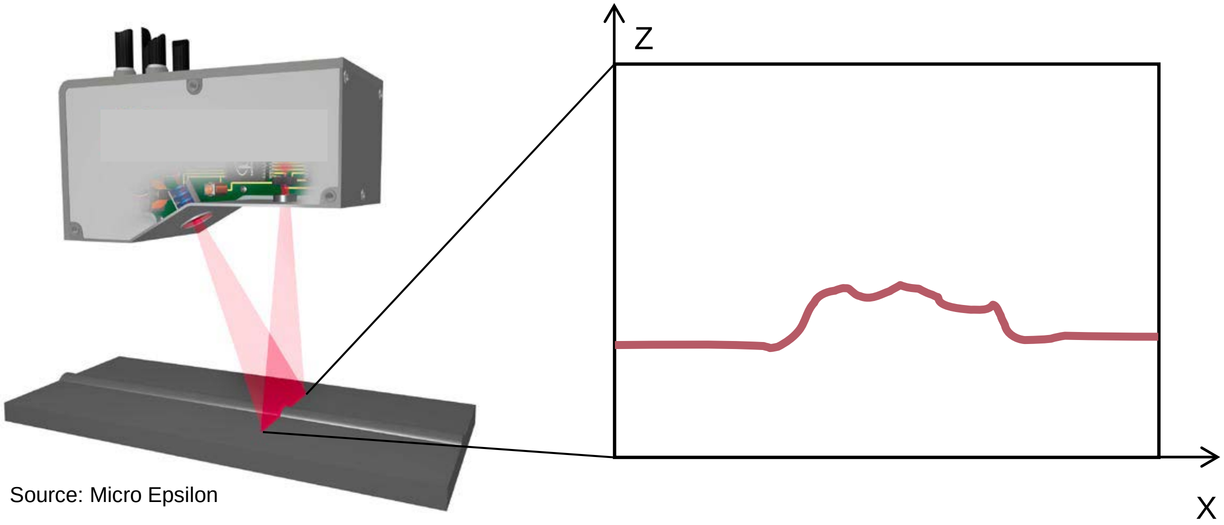
Visual
- Coordinate systems
- Sensor parameters

Edge
- Signal to noise ratio
- Detection algorithm and filters
- Smoothing
- Shading
- Material Surface

Online Quality Assessment

Concept for Position Accuracy

- Laser light section sensor
- Goal: flexible tool to cover a wide range of research scenarios
- Feasibility study: Laser scanner guided by an industrial robot



Source: Micro Epsilon

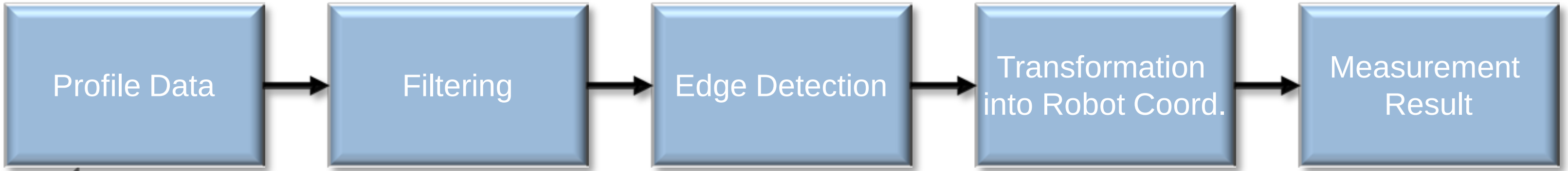
Online Quality Assessment

Measurement of Position Accuracy

- Measurement along boundary curve
- Signal quality material dependent

- Signal processing:
  - Filtering & Algorithm for edge detection
  - Transformation to global robot coordinates
  - Comparison to expected boundary curve

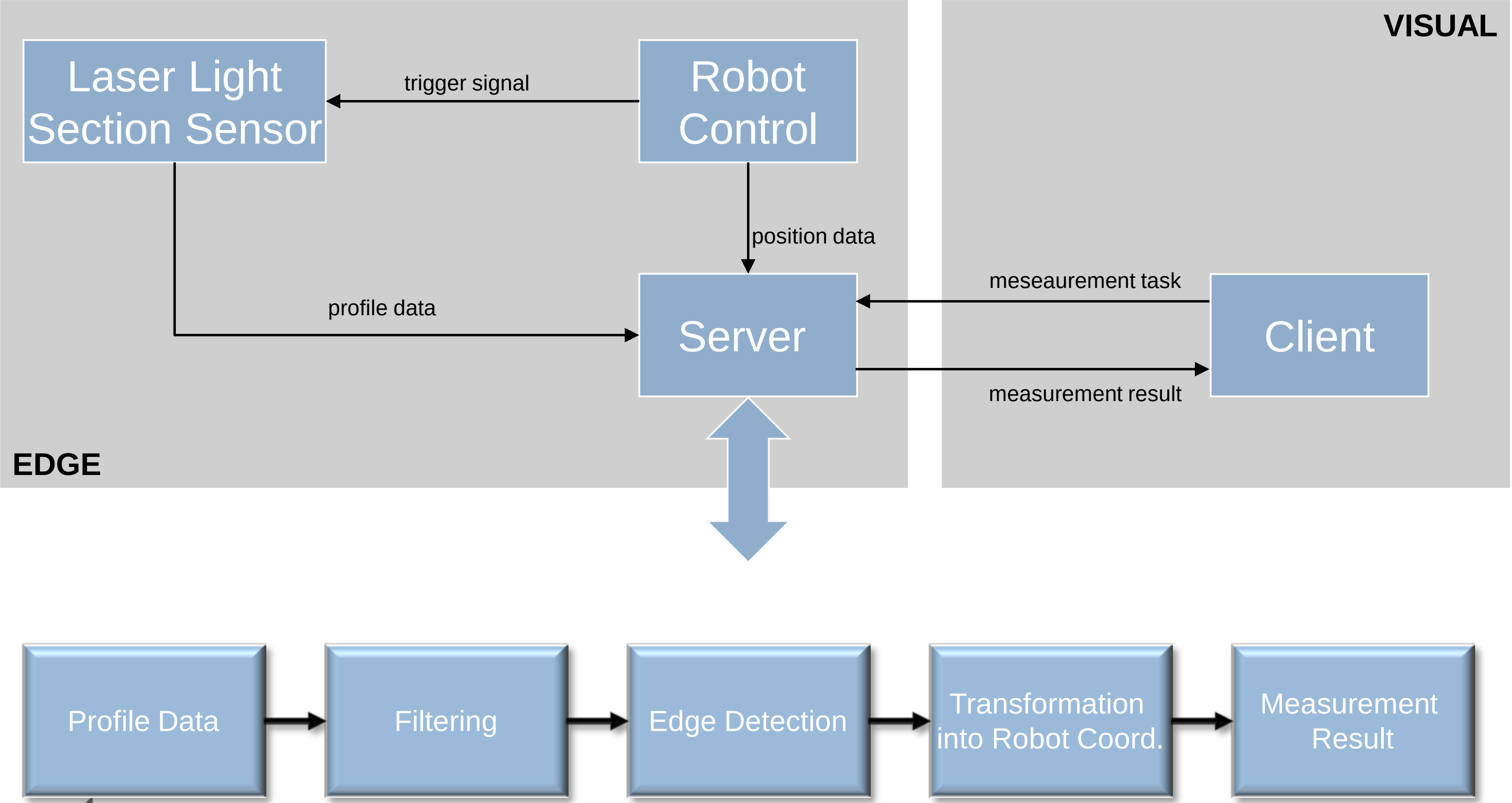
→ Measurement system independent of geometric complexity and composite definition



Profile Data → Filtering → Edge Detection → Transformation into Robot Coord. → Measurement Result

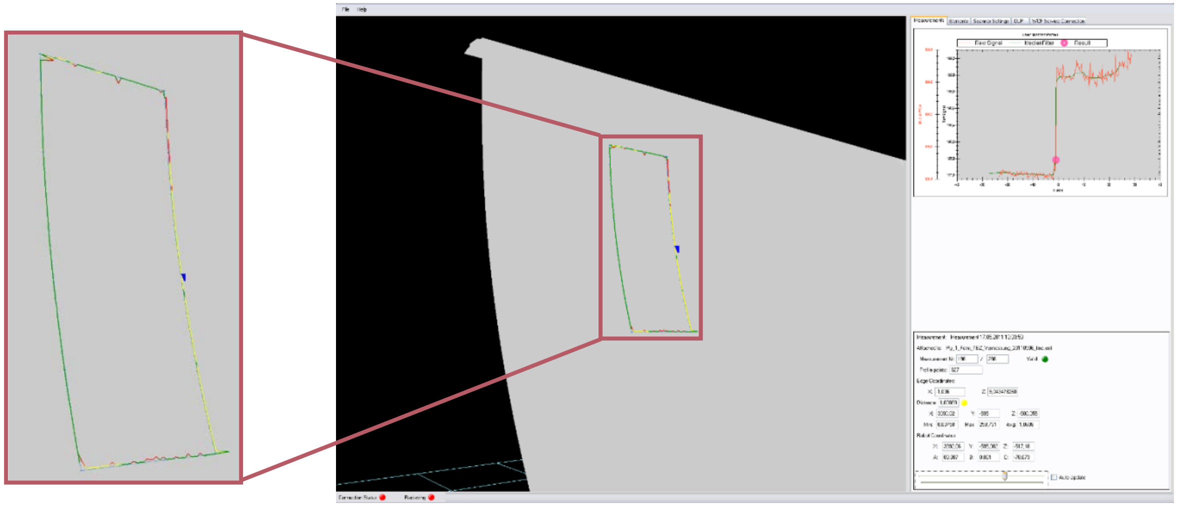
Online Quality Assessment

Concept for Position Accuracy



Online Quality Assessment
Processing

- Visualization of multiple geometry features, ply book definitions and measurement results
- Live evaluation of measurement vs. CAD reference (Catia CPD)



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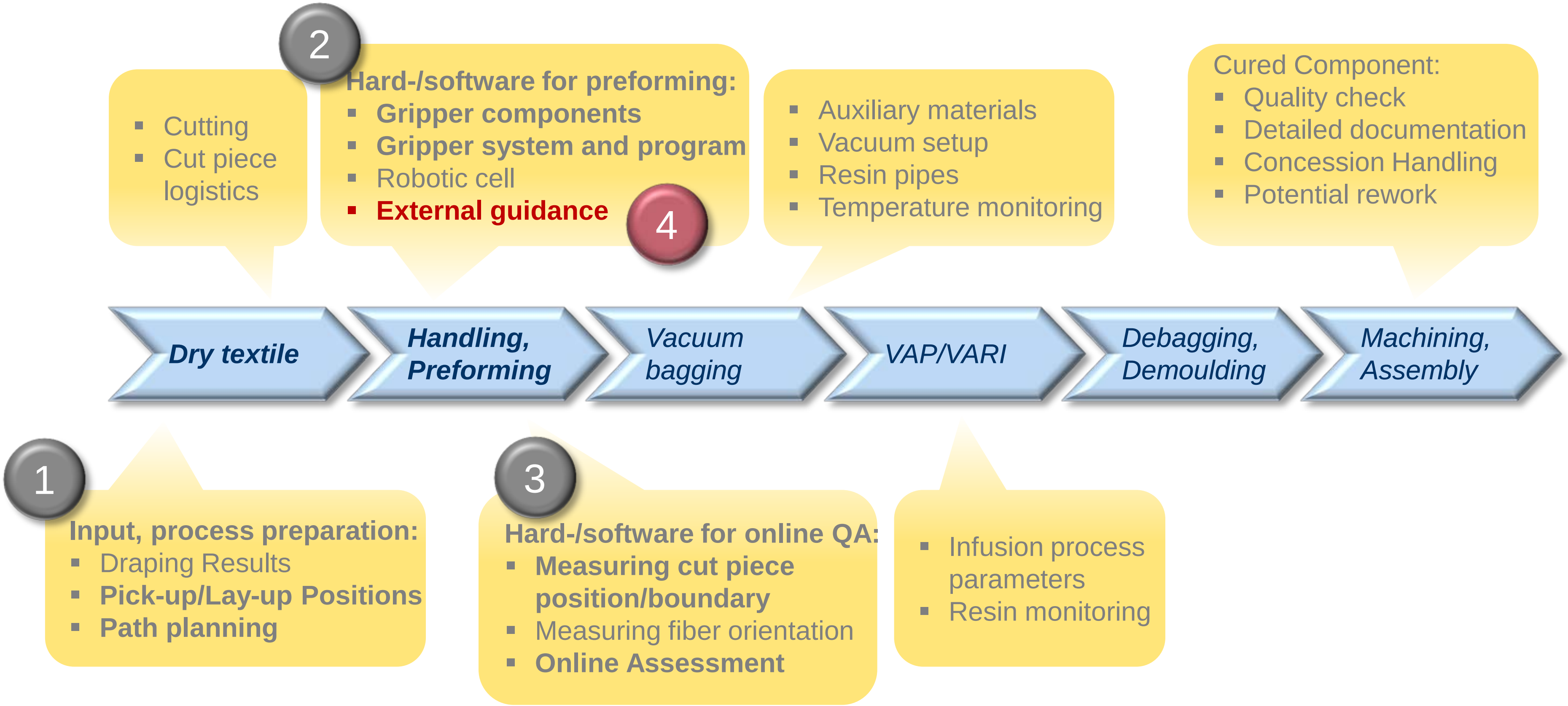
Online Quality Assessment

Automation along the Process Chain



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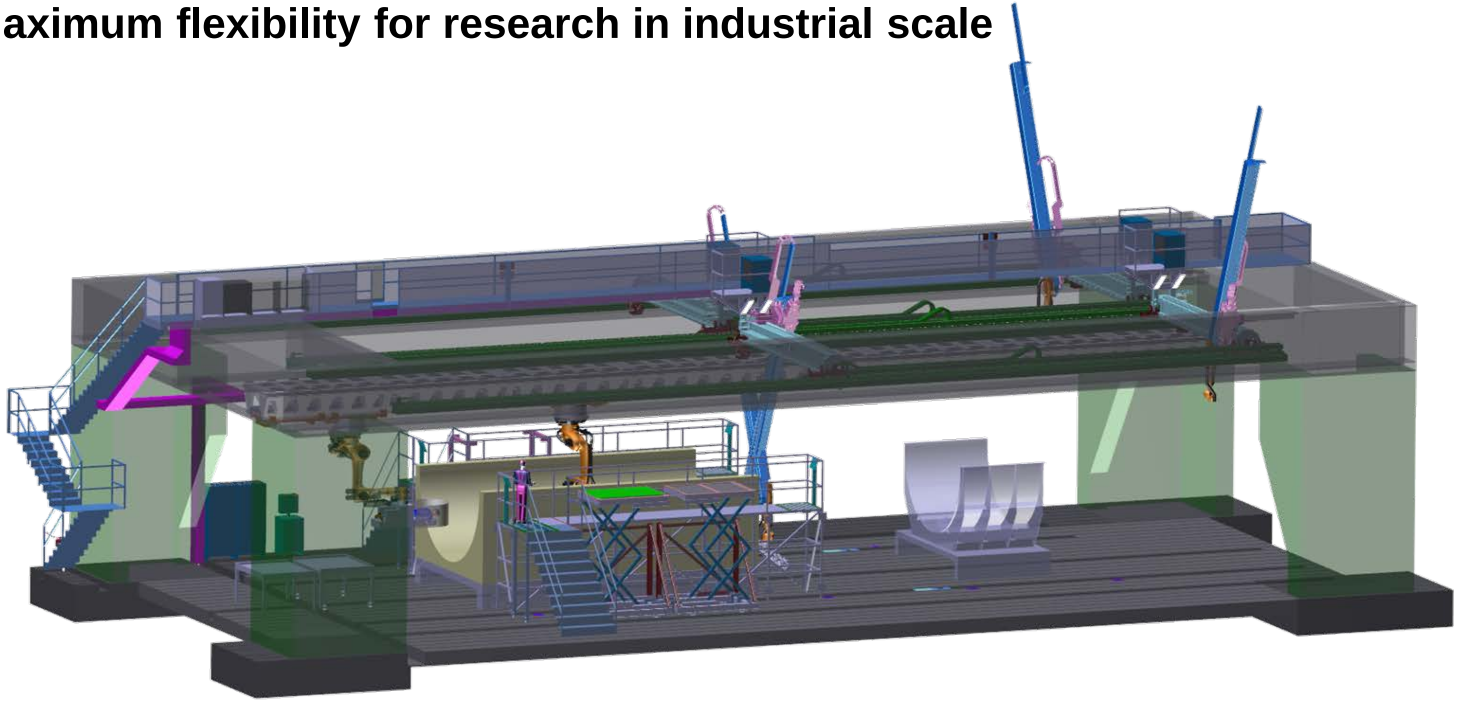
DLR

Flexible Robotics Platform
Vision

- Up to four gantry robots and two six-axis robots
- Large space for fixtures and tools
- Easily reconfigurable virtual cells

→ **Maximum flexibility for research in industrial scale**



Enhancing Accuracy on a Flexible Robotics Platform

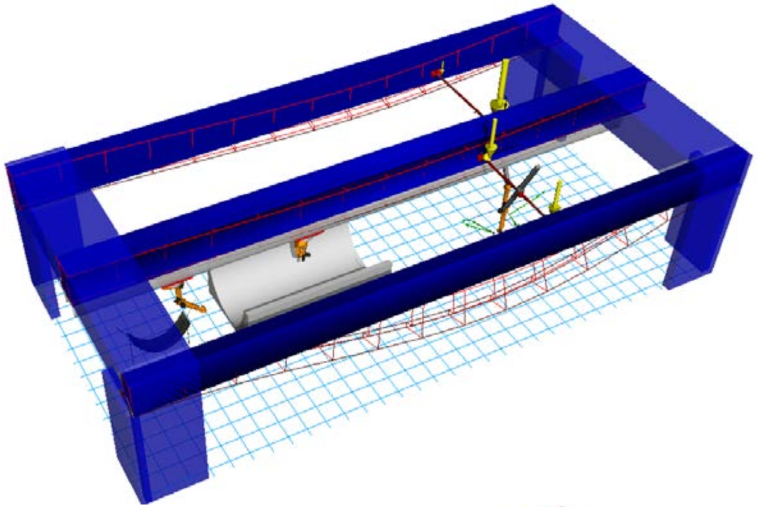
Gantry deformations

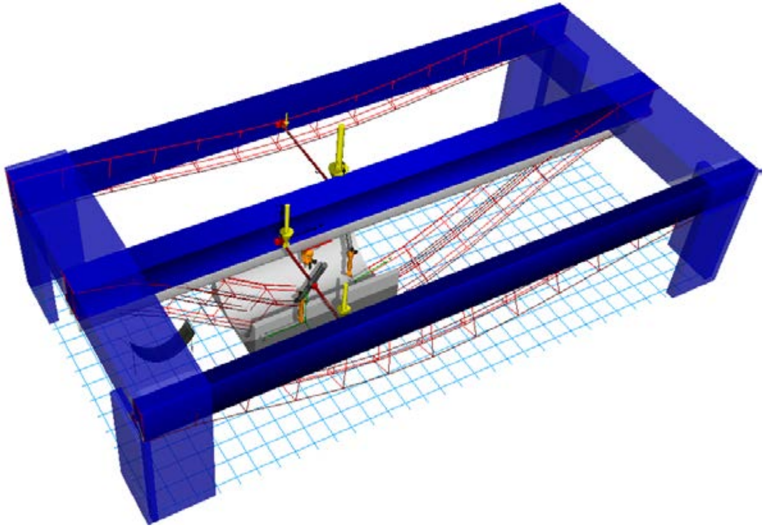
Challenge

- Ceiling mounted robots cause deformations in gantry structure
- Dependence on load distribution (robot and gantry positions)

Solution: external guidance

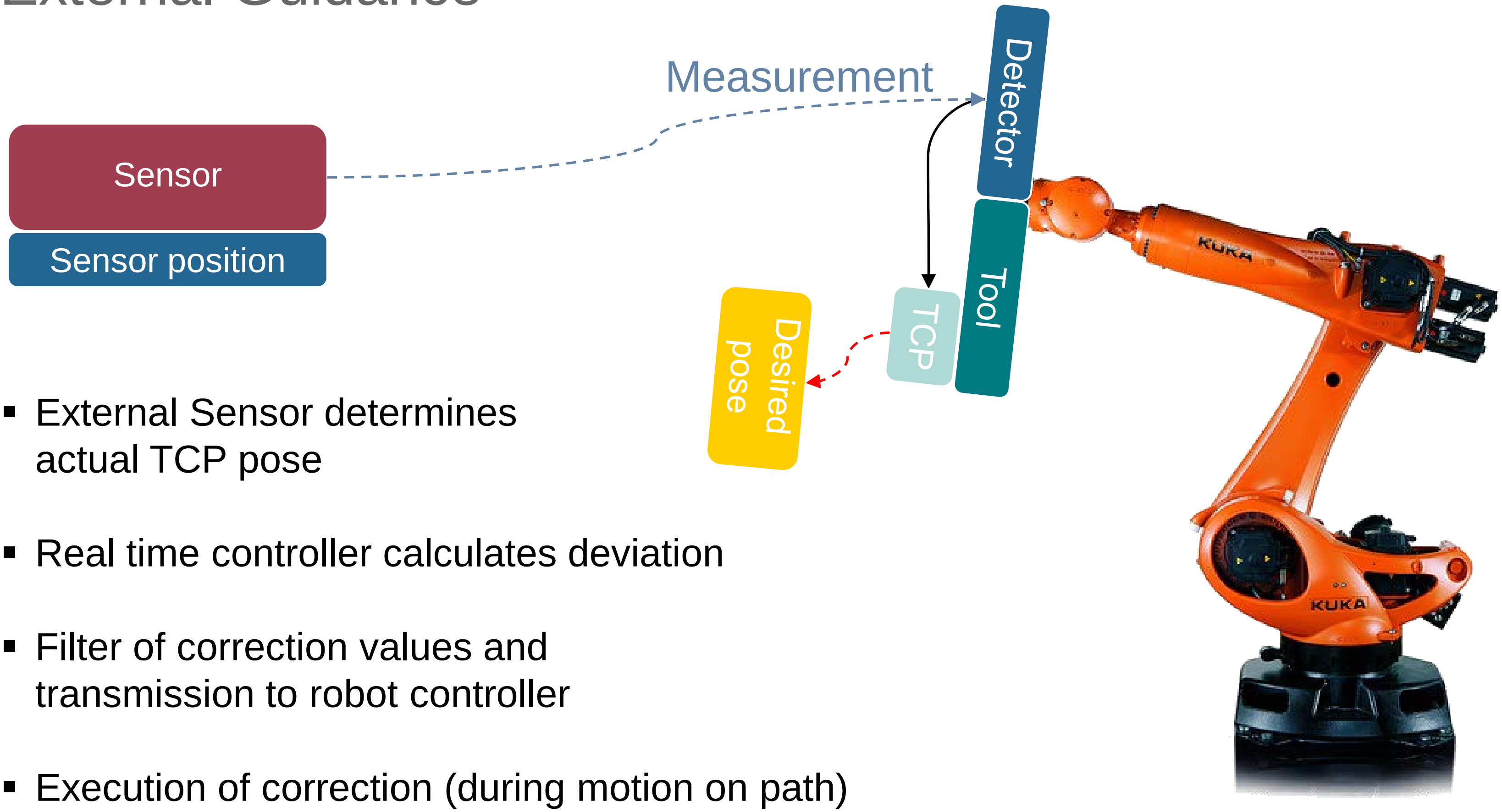
- Monitor robot and gantry positions
- Compensate for deviations





Enhancing Accuracy on a Flexible Robotics Platform

External Guidance



- External Sensor determines actual TCP pose
- Real time controller calculates deviation
- Filter of correction values and transmission to robot controller
- Execution of correction (during motion on path)

Enhancing Accuracy on a Flexible Robotics Platform

Measurement system selection

Laser Tracker

Large volume

Very high accuracy

Single beam source

6D measurement possible (tracking single point)

Laser Tracer

Large volume

Highest accuracy

Multiple beam sources (movable)

6D measurement possible (tracking multiple points)

Indoor GPS

Scalable volume

High accuracy

Multiple beam sources (static)

6D possible measurement (tracking multiple points)

Camera CMM

Limited volume

High accuracy

6D possible measurement (tracking multiple points)

IMU & AHRS

Unlimited volume

Medium accuracy (integration)

independent of external system

6D measurement possible (as source)

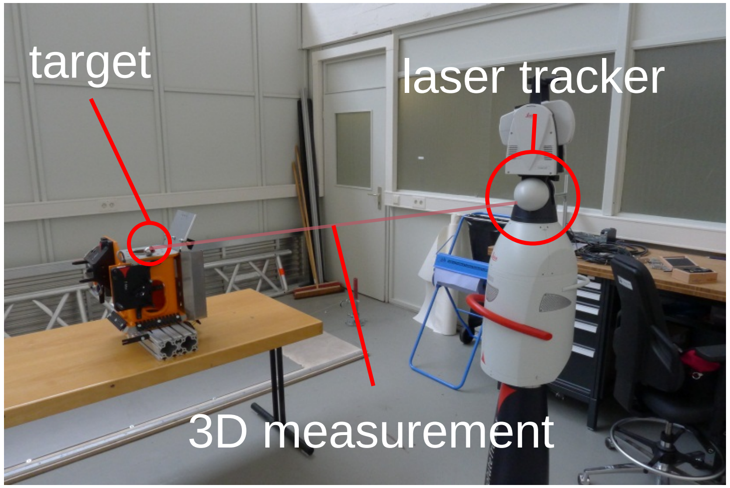
Selection of laser tracker as reference system
(open software architecture allows integration of different sensors)

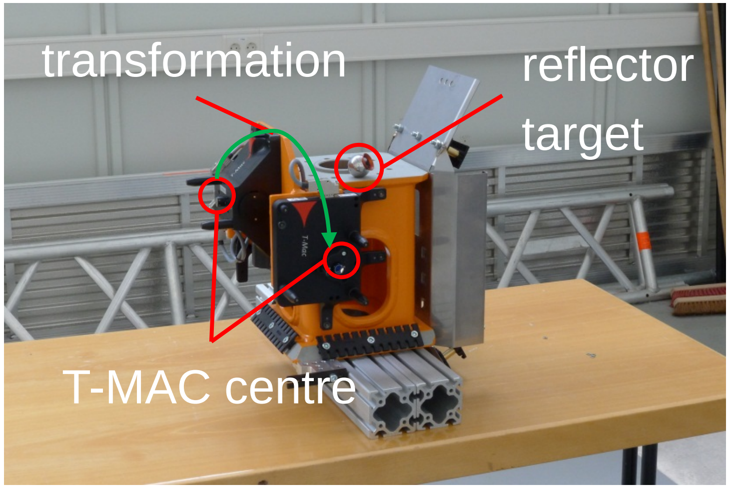
Image sources: FARO, Etalon, Nikon metrology, VectorNav

Enhancing Accuracy on a Flexible Robotics Platform

System Components

- Sensor: laser tracker Leica AT901LR with T-CAM
- Detector: multi-sided probe with Leica T-MACs
- Controller: industrial embedded PC - Beckhoff CX1030





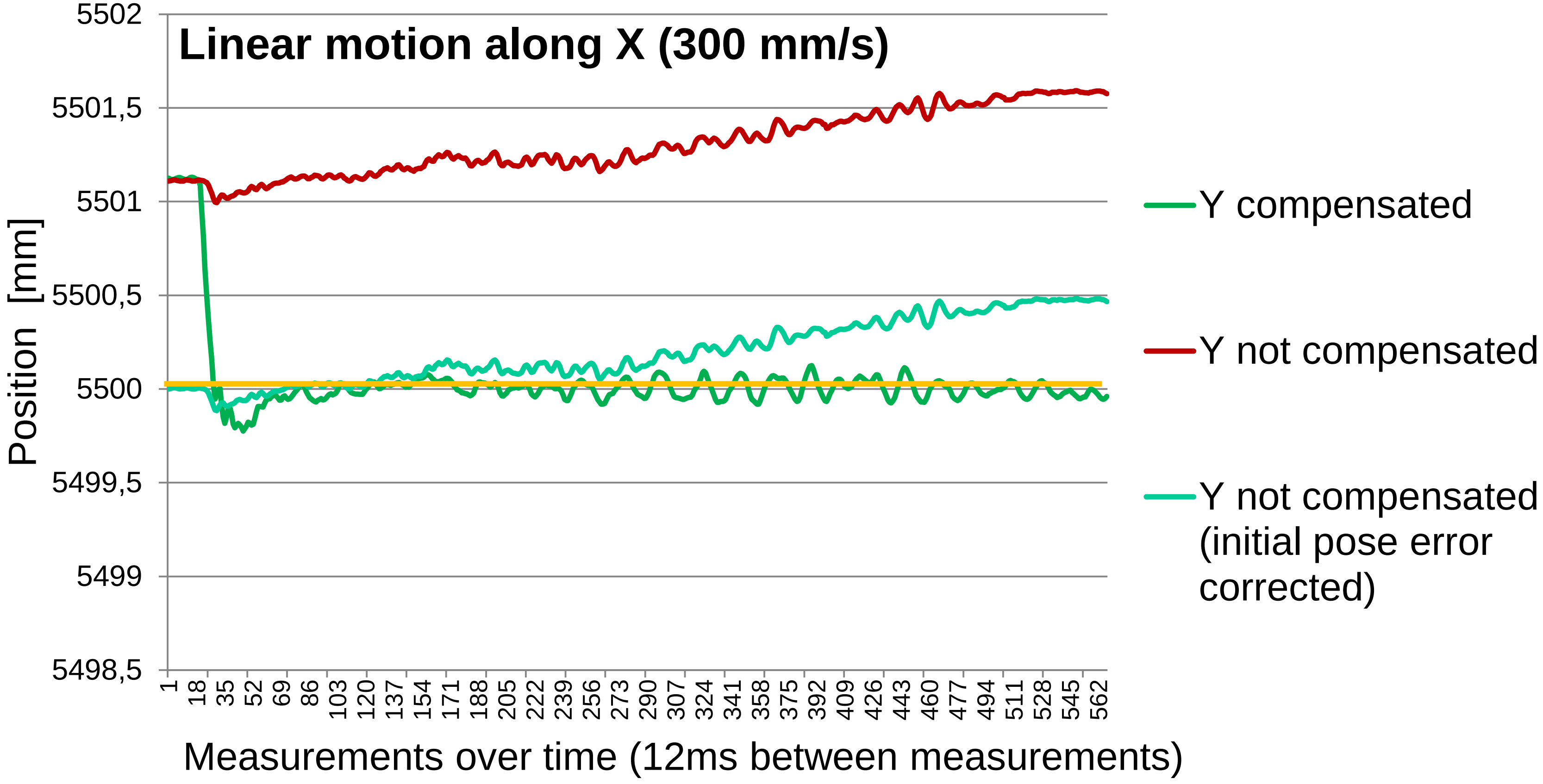
Enhancing Accuracy on a Flexible Robotics Platform

Experimental setup

- Comparison of normal and compensated linear motions.
- No advanced filtering of compensation data, only absolute deviation between real and desired pose is used
- Cell configuration: KR 210 R3100 ultra, KRC4, KSS 8.1.7, RSI 3.0

Enhancing Accuracy on a Flexible Robotics Platform

Preliminary results 1



Enhancing Accuracy on a Flexible Robotics Platform

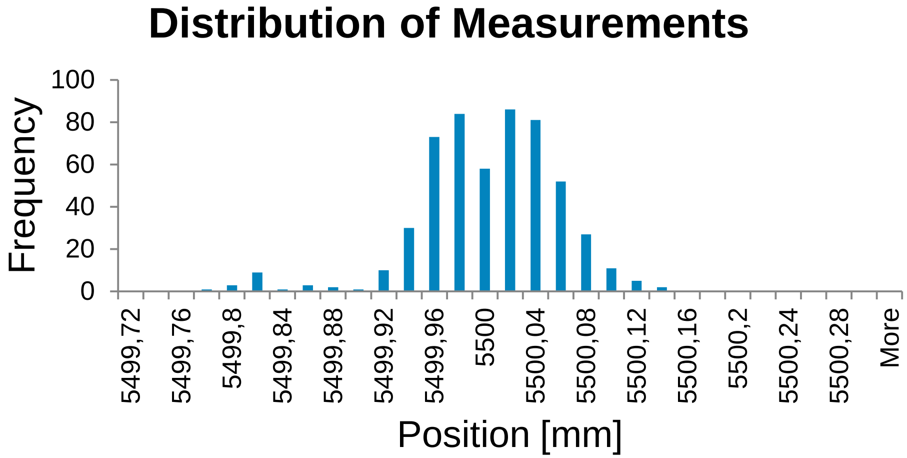
Preliminary results 2

- Initial pose error from previous motion approximately 1.11mm
  (complex motion patterns
  with initial pose correction currently under development)

- Motion (and compensation) start around time index 22, robot is pulled on path in approx. 100ms

- Non-compensated motion shows drift along positive X

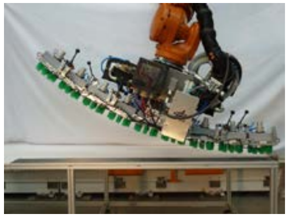
- After initial correction:
  average path error 0.07mm
  σ: 0.05
  min: -0.224mm
  max 0.125mm

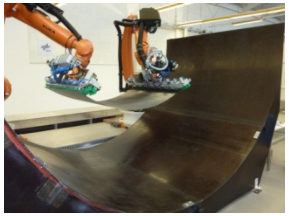


Summary

Dry textile → ***Handling, Preforming*** → *Vacuum bagging* → *VAP/VARI* → *Debagging, Demoulding* → *Machining, Assembly*

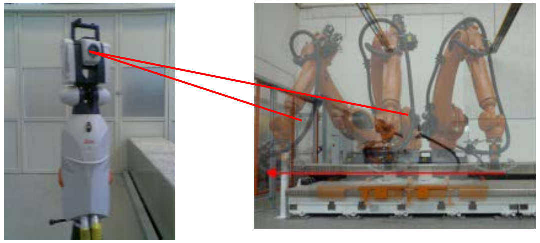
- **Preforming process**
  - **Process preparation**
  - **Gripper solution**
  - **Preforming process with cooperating robots**





- **Online quality assessment**
  - **Laser light section sensor**
  - **Measurement of cut piece boundary**
  - **Online assessment of positioning accuracy**

- **Enhanced accuracy in robotic cell**
  - **External guidance approach**
  - **Setup with laser tracker**
  - **Successful compensation in test setup**

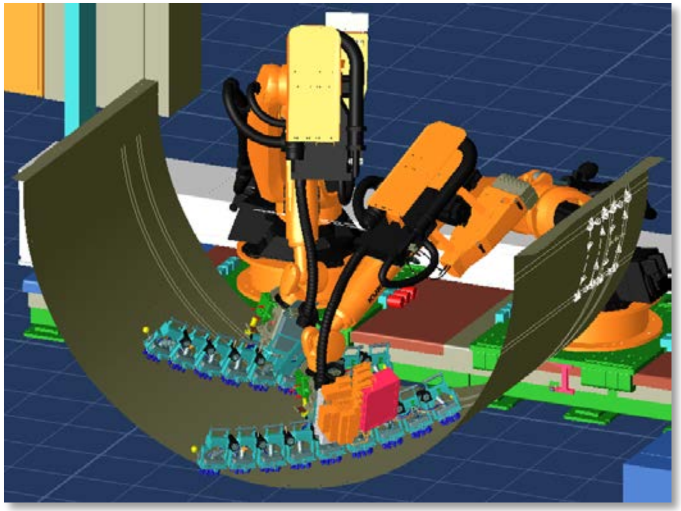


Outlook

- **Medium term development goals**
  - Range of possible geometries → large variety of structural components
  - High process stability → possible process qualification
  - Integrated OLP tool → fast process preparation

- **Possible improvements**
  - Flexibility of gripper kinematics
  - Improved heating system for faster binder activation
  - Integration of quality control system

- **Next Steps**
  - Current gripper allows single curvature:
    Next generation gripper (for double curvature)
    in testing with KUKA Systems
  - Implementation of integrated OLP approach



Acknowledgement

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Stadt Augsburg

AUGSBURG INNOVATIONS PARK

Bundesministerium für Wirtschaft und Technologie