Automated Production of Large Preforms Based on Robot-Robot Cooperation

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Outline

- Introduction: the Challenge
- Preforming with Cooperating Robots
- Video
- Experimental Validation
- Summary and Outlook
Introduction: the Challenge

- Large preforms
- High layup rates
- Many manual processes
- Potential issues
  - Material damages
  - Repeatability
  - Quality assurance
- Material attachment
- Robotic gripper weight for large cut pieces
Preforming Approach: Concept

- Large cut pieces up to 1.4 x 6 m
- Manual handling of cut pieces by 2 workers, i.e. 4 hands
- General idea: cooperating robots with 2 grippers

Process:
- Pick up without damage
- Transfer
- Exact, repeatable positioning
- Attachment
Preforming Approach: Grippers

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

- **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 device on linear actuator
Preforming Approach: Preliminary Testing

- Initial steps
  - Gripper integration and controls
  - Validation of gripper principle
  - Optimization

- Preliminary test setup
  - Validation of positioning accuracy
  - Small sample cut piece 225 x 555 mm
  - Laser scanner for high accuracy measurements
Preforming Approach: Setup

- **Setup**
  - Permeable surface for pick-up
  - Rectangular cut pieces
    - Dry NCF
    - 2.0 x 1.22 m
  - Thermoplastic binder
  - Two grippers, each 7 active modules

- **Geometric conditions**
  - Material forms catenary curve
  - Gripper position and orientation adjusted to catenary
Preforming Approach: Catenary

- Catenary can be computed for individual gripper-gripper positions

- Parameterised program: $x$, $z$, $\alpha$

- Assuming constant length and width, then:
  - $z(x) = a \cosh\left(\frac{x-x_0}{a}\right) + z_0$
  - $l = 2a \sinh\left(\frac{w}{2a}\right)$
  - $F = \frac{mg}{\coth\left(\frac{w}{2a}\right)}$

- Here: distance $w = 1698$ mm, length $l = 1778$ mm, hence: radius $a = 1607$ mm, angle $\alpha = 28.8^\circ$, $m = 1.35$ kg, $F = 13.75$ N
Preforming Approach: Process

**Pick-up**
- Permeable table surface
- Resulting forces depending on gripper distance
- Gripper movements in 3 increments
- Cut piece forms catenary

**Transfer on linear track**
- Grippers keep their relative position and orientation
Preforming Approach: Process

Positioning

- Gripper no. 1: first cut piece edge held in position
- Activation of thermoplastic binder

Attachment

- Individual gripper movements
- Gripper no. 2 releases cut piece (now free for local cut piece attachment)
Preforming Approach: Video
Preforming Result

- Key aspects:
  - Positioning accuracy (absolute, relative)
  - Cut piece accuracy (boundary curve)
  - Cut piece deformation
  - Lay-up rate

- Pushing boundaries
  - Cut piece 1.22 x 6.0 m
  - NCF +/-45°
  - 4.06 kg
# Layup Rate

<table>
<thead>
<tr>
<th></th>
<th>Initial testing</th>
<th>2 m Video</th>
<th>2 m expected</th>
<th>6 m expected</th>
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<tbody>
<tr>
<td>Pick-up [s]</td>
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<td>13</td>
<td>8</td>
<td>12</td>
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<tr>
<td>Transfer [s]</td>
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<td>20</td>
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<tr>
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<td>7</td>
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<td>Mass [g]</td>
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<tr>
<td>Layup rate [kg/h]</td>
<td>7.53</td>
<td>39.62</td>
<td>131.74</td>
<td>265.94</td>
</tr>
</tbody>
</table>

- **Time [s]**
  - Return
  - Binder
  - Positioning
  - Transfer
  - Pick-up

- **Mass [g]**
  - Initial Testing
  - 2 m Video
  - 2 m expected
  - 6 m expected

- **Layup rate [kg/h]**
  - Initial Testing
  - 2 m Video
  - 2 m expected
  - 6 m expected
Cut Piece Deformation

- Preliminary testing
  - Small test coupons
    max. 350 x 644 mm (W x L)
  - Unidirectional force applied
    max: 4.4 N

- Results for small test coupons
  - Elongation
    max: 2.1 mm
  - Lateral indentation
    max: -1.33 mm
Experimental Setup

- Specimen (cut pieces)
  - NCF, +/-45°, 2.0 x 1.22 m
  - Weave, 0/90°, 2.0 x 1.30 m

- Experiment
  - Flat table surface
  - Pick-up, catenary, transfer, re-positioning on table
  - Measurement of cut piece deformation

- Measurement method: photogrammetry
  - Camera Panasonic Lumix DMC-TZ7
  - Software EOS Photomodeler 2011
Experimental Setup

- Cut piece preparation
  - Attachment of coded targets
  - Positioning on table with limit stop

- Measurement
  - Rigid bar for scaling
  - Reference set of 6-8 photos
  - Set of photos of „deformed“ cut piece

- Processing
  - 3D computation of target coordinates in Photomodeler
  - Assessment of change of distance between pairs of targets
Experimental Results

**Weave**

- Change in width
- Elongation

**NCF +/-45°**

- Change in width
- Elongation

Precision of a single target position: 0.25 - 0.45 mm
Summary

- **Preforming approach with cooperating grippers does work**
  - Preliminary tests on positioning accuracy show good results
  - Grippers extended to full length
  - Implementation with KUKA RoboTeam
  - Cut pieces up to 2 m length have been handled
  - Process demonstrated: Pick-up, transfer, positioning and attachment

- **Measurement of cut piece deformation**
  - First assessment of influence on cut pieces
  - Preliminary results show little deformation
  - More testing required
  - No other cut piece damages observed

- **Fast process; high lay-up rates possible**

- **This is work in progress…**
Pushing boundaries
Outlook

Medium term development goals
- Short cycle time → increase of layup rate
- High process stability → possible process qualification

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

Next Steps
- Current gripper allows single curvature:
  Next generation gripper (for double curvature) in development with KUKA Systems
- Further testing of cut piece accuracy
- Optimization of process parameters
Outlook

- **Robotics scenario**
  - Gripper application in newly built multifunctional robotic cell at the DLR Augsburg
  - Industry and Institutes are welcome to do research on our robotics platform
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Preforming Approach: Cooperating Robots

- Kuka RoboTeam features:
  - **Geolink:**
    Geometrically linked TCPs (pseudo-closed kinematic chain)
    Slave robot follows master’s TCP
  
  - **ProgSync:**
    Simultaneous start of instructions
  
  - **Sync Movements:**
    Synchronized movements (start and end of movement)
  
  - **RemoteCommand:**
    Issuing commands to other team members
Preforming Approach: Cooperating Robots

- Cooperation of (industrial) manipulators (especially synchronized movements)

- Possible approaches:
  - No synchronization (calculation & teaching of required movements)
  - Single controller manages all participating joints (Single master)
  - Synchronization of multiple controllers (Master - Slave)

- Here: Application of KUKA RoboTeam technology package
  - Master/Slave approach
Preforming Approach: Cooperating Robots

- Chosen configuration:
  - **Pick-Up from table:**
    ProgSync (at start of program and incremental pickup stages) and GeoLink (after final pickup position)
  - **Transfer on linear track:**
    Sync movements (no GeoLink for linear tracks because of 7-axis redundancy)
  - **Positioning in mould:**
    combination of GeoLink (for positioning) and ProcSync (for attachment) statements
  - Slave gripper control through remote commands