FLEXIBLE AUTOMOTIVE ASSEMBLY WITH INDUSTRIAL CO-WORKERS

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EuRoC - Advancing European Manufacturing

- European Robotics Challenges
  - EU Seventh Framework Program (FP7) funded
  - Bring innovative technologies from research to industry
- 3 industry relevant challenges
  - Reconfigurable Interactive Manufacturing Cell
  - Shop Floor Logistics and Manipulation
  - Plant Servicing and Inspection
- Competition over multiple stages
  - > 100 Teams in open call (simulation stage)
  - 45 (first stage), 15 (second stage), 6 (final stage)
EuRoC - Advancing European Manufacturing

- **Duration**
  - 2014 – 2018

- **Participants**
  - > 100 Teams from all over Europe

- **Coordinator**
  - Bruno Siziliano

- **Grant**
  - 8.3 Mio €
  - 7.0 Mio € for challenges
Team FLA²IR

FLexible Automotive Assembly with Industrial Co-WorkeRs

- FZI (challenger):
  - Software concept, design, integration
  - Development of the overall application

- MRK (system integrator):
  - Hardware integration, safety
  - Construction of gripper

- OPEL (end user):
  - Use-Case requirements
  - Feasibility checks & support
Use Case – Mounting of Polymer Sealings

- Mounting of flexible polymer sealings
  - Flexible polymer strips with pins
  - 35-39 pins clipped into holes
  - Ergonomically straining for workers

- Challenges for the Use Case
  - Various doors & sealings
    - Fast teaching required
  - Flexible polymer handling
    - Flexible dexterous manipulation
  - Contact based clip insertion
    - Robot needs to „feel“ the pins
  - Large door & human workspace
    - Safe industrial robot required
Opel’s Motivation to Participate in EuRoC

- Usage of ROS on the shop floor
  - Development of concept to use lab technologies in the plant
  - Advanced technologies in production (Standards need to be met)

- Choice of application
  - High sophisticated, unconventional challenge
  - Force sensitive assembly
  - Moving line & ambitious cycle time
  - High equipment availability
  - Scalability of technology
  - Low cost approach

- Not automatable until now!
EuRoC Development Stages

Stage II a: Benchmarking
- Car door module assembly
- 2D localization of module & door
- 6D path for module assembly & screws
- Adaptation of pick-and-place application
- Integration on benchmark hardware

Stage II a: Freestyle
- Virtual objects from 3D point clouds
- 6D surface trajectory from 2D contour
- 6D paths on 3D object surfaces
- Interactive tool to draw 2D contour
- Integration on freestyle hardware

Stage II b: Showcase
- Fine localization of clips (3D & 2D data)
- Localization of elastic polymer sealing
- Clip assembly paths with visual servoing
- Interactive tool to teach clip positions
- Tool prototype & Safe industrial robots
- Evaluation: concepts use case automation

Stage III: Pilot experiments
- Hybrid position & force control
- Safe tool for polymer sealing assembly
- Reactive behaviours for safe interaction
- Evaluation: final use case automation
- Risk assessment - human robot teams
Benchmarking – Car Door Inlay Mounting

- Learning of object poses
  - Extraction of contour from stitched point clouds
  - ROS Node to publish TFs of dynamic objects
  - Manual taught positions relative to these TFs
- Adaptive execution
  - SMACH state machines for increased reuse
  - FZI Motion pipeline for adaptive paths
  - Poses & trajectories relative to generated TF
- Force based operations
  - Force controlled insertion & screw assembly
  - Manipulation strategies with "compliant wrist"
Freestyle – Intuitive Teach-In & Adaptation

- Intuitive graphical trajectory teach-in
  - Trajectory is generated by drawing it onto a 3D model
  - Automatic adaptation to workpiece surface
- Force based surface exploration by a robot
  - Trajectory is learned by a executing point-to-point movement
  - The robot adapts a spline interpolation to the surface structure
- Online adaptation of trajectories by user interaction
  - Changes to previously taught trajectory can be applied intuitively
  - Little previous knowledge/expertise required, usable by non-experts
Freestyle – Intuitive Teach-In & Adaptation

https://youtu.be/yky_VfquO-8

CAD2Path allows easy path generation on a 3D Model
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Fast Intuitive Teach-In

- **CAD-2-Path**
  - Web based tool (runs in browser)
  - Path automatically follows object surface
  - Cartesian trajectory for ROS pipeline

- **Teach-in of clip positions**
  - Hole-Tool to set support points for clips
  - Guided generation of all hole poses (TFs)
  - Automatic generation of support paths

*Teach-in of full assembly process in under 5 minutes*
Flexible Polymer Handling

- Special jaws for industrial gripper (PG+70)
  - Cheap, only jaws are specialized
  - Pneumatic piston for faster insertion
- Sealing can be clamped
  - Precise insertion of pins
  - Stretching of sealing is possible
- Sealing can glide freely
  - No regrasping, continuous movement
  - Next pin is precisely localized

Successful handling of flexible Polymers with a low cost gripper
Feeling the Pin

- Add-on Compliance control for robots
  - Virtual force/impedance/admittance control
  - Robot independent with virtual model
  - ROS-Control interface for easy use

- Dexterous manipulation
  - Insertion of clips is detected by forces
  - Robot reacts to work piece (e.g. collisions)
  - Optimal alignment during push in

Dexterous, force-based assembly enables many new use cases

Safe Human Robot Interaction

- Layered safety concept
  - Laser scanner safety zones
  - Worker is tracked in 3 zones
  - Hard PLC safety in inner zone
- Smooth stop of robot
  - Extension of ROS-I driver to enable “pause”
  - Hard PLC safety triggers emergency stop if robot is not fast enough

Safe human robot collaboration with no impact on the process
https://youtu.be/BX2dWxLMWeQ
(older version, the one shown will be released as soon as possible)
Using ROS-Industrial on the Shop Floor

Tools for visualization & available drivers speed up development

Robot independent developments such as force control & intuitive teach in

Easy prototyping speeds up development and integration of new hardware

Combining proven safety & adaptive approaches enables a certified safety system with ROS
Transferability for Other Applications

- Safety concept based on standard and proven equipment
- Risk assessment for production conditions approved by in-house machine and plant safety team
- Open work space attractive for general assembly (GA) applications with moving lines
Transferability for Other Applications

- Safety concept
  - Machine unloading in press shop
  - Machine loading in body shop
  - Handling of components and subassemblies
  - Screwing and mounting operations in Powertrain and GA
Transferability for Other Applications

- Force sensitivity implemented with ROS
  - Screwing and mounting operations in Powertrain and GA
  - Initial results for moving line
Transferability for Other Applications

- CAD2Path – Easy offline teaching
  - Adhesive bead application in body shop and GA (over 130 m adhesive)
  - Sealer application in paint shop (up to 40% saved programming time est.)
  - Early test with the Zafira window
End User Feedback

- Evaluating CAD-2-Path with a user study
  - Diverse combination of testers: planners, group leaders, offline programmers
  - Goal: Program sealing assembly in 15 min
  - All users mastered the task immediately

- Results of Questionnaire
  - Very intuitive and impressive speed-up
  - Meets robot programmers’ needs

**CAD-2-Path was considered a technological Game Changer!**

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Conclusion – Lessons Learned

- ROS is feasible for implementations in production environments
- Combination with pragmatic safety equipment possible
- Feasibility of human robot collaboration in „real“ collaboration
- Flexibility/robustness and cycle time are contrary requirements
- Easier applications to be in focus first (not assembling ≈ 40 pins in < 60 s)
- Force sensitivity needs to be much faster
- Parallelization of processes to meet cycle times is not always an option
Bringing ROS to the Shop floor - Next Steps

- Application in moving line needs to be proven
- Speeding up force sensitivity
- Combination with vision systems
- First implementation in production
- Increase of CAD2Path product maturity
Thanks for your attention!

Questions?

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More At:

http://www.euroc-project.eu/index.php?id=flaair
https://www.youtube.com/user/FZIchannel