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)
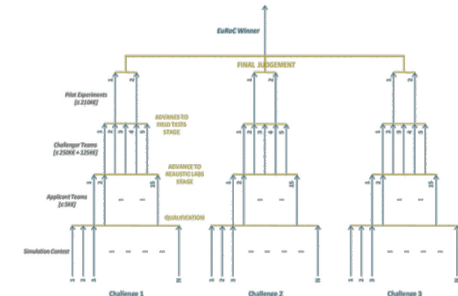
EuRoC - Advancing European Manufacturing

- **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 **A**utomotive **A**ssembly with **I**ndustrial Co-Worke**R**s
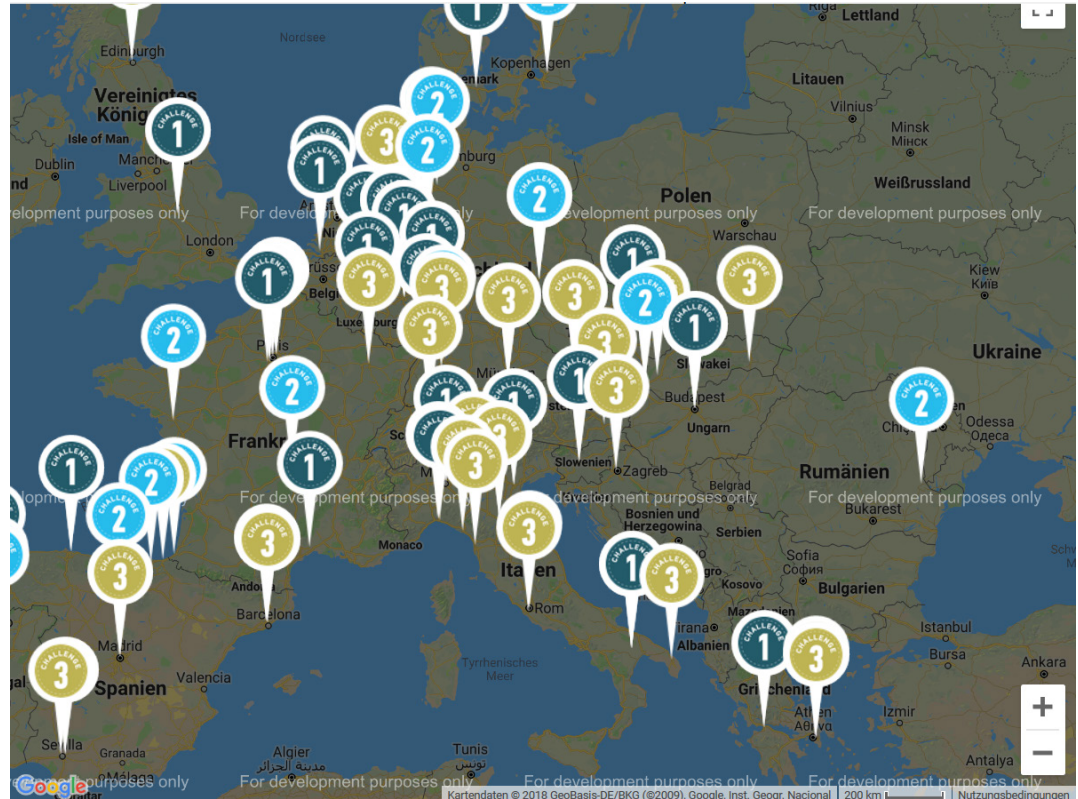
- FZI (challenger):
    - Software concept, design, integration
    - Development of the overall application

- 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
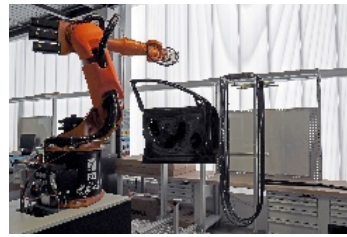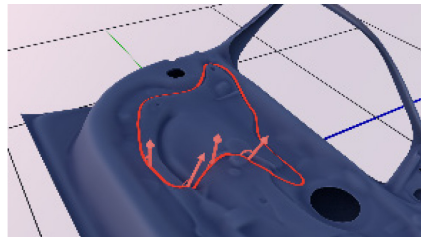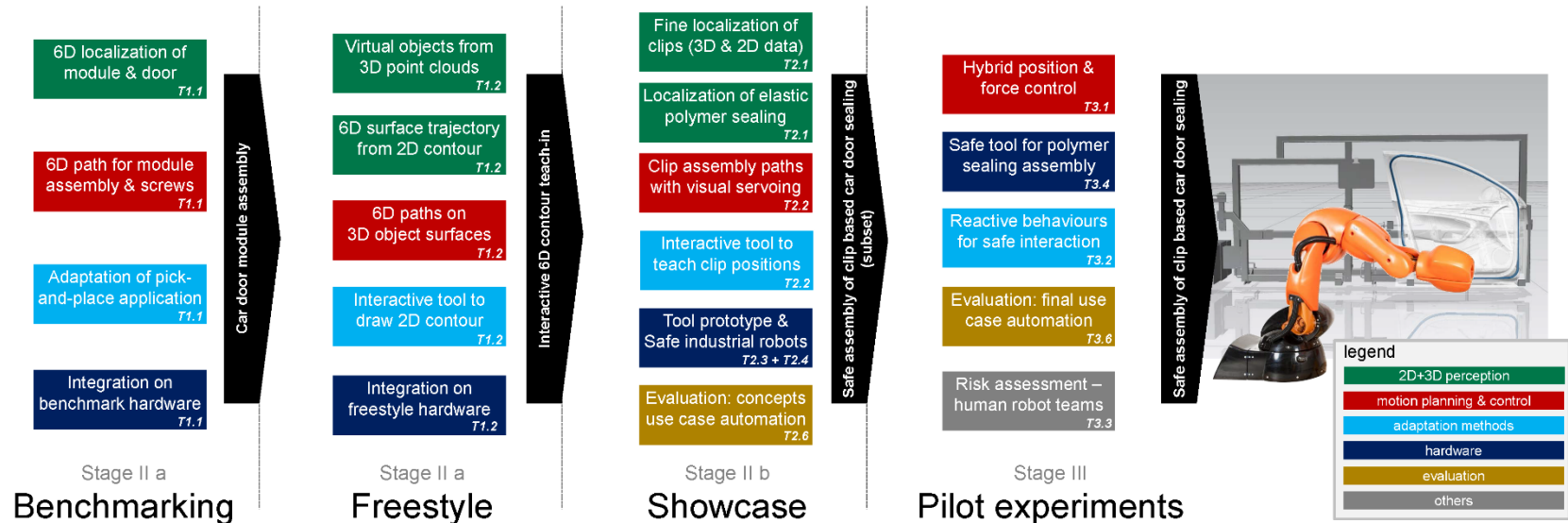   - **Safe industrial robot required**

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**
- 6D localization of module & door — T1.1
- 6D path for module assembly & screws — T1.1
- Adaptation of pick-and-place application — T1.1
- Integration on benchmark hardware — T1.1

Car door module assembly

Stage II a — **Freestyle**
- Virtual objects from 3D point clouds — T1.2
- 6D surface trajectory from 2D contour — T1.2
- 6D paths on 3D object surfaces — T1.2
- Interactive tool to draw 2D contour — T1.2
- Integration on freestyle hardware — T1.2

Interactive 6D contour teach-in

Stage II b — **Showcase**
- Fine localization of clips (3D & 2D data) — T2.1
- Localization of elastic polymer sealing — T2.1
- Clip assembly paths with visual servoing — T2.2
- Interactive tool to teach clip positions — T2.2
- Tool prototype & Safe industrial robots — T2.3 + T2.4
- Evaluation: concepts use case automation — T2.6

Safe assembly of clip based car door sealing (subset)

Stage III — **Pilot experiments**
- Hybrid position & force control — T3.1
- Safe tool for polymer sealing assembly — T3.4
- Reactive behaviours for safe interaction — T3.2
- Evaluation: final use case automation — T3.6
- Risk assessment – human robot teams — T3.3

Safe assembly of clip based car door sealing

legend
- 2D+3D perception
- motion planning & control
- adaptation methods
- hardware
- evaluation
- others

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"

Benchmarking – Car Door Inlay Mounting

https://youtu.be/GNZqJz-N6NA
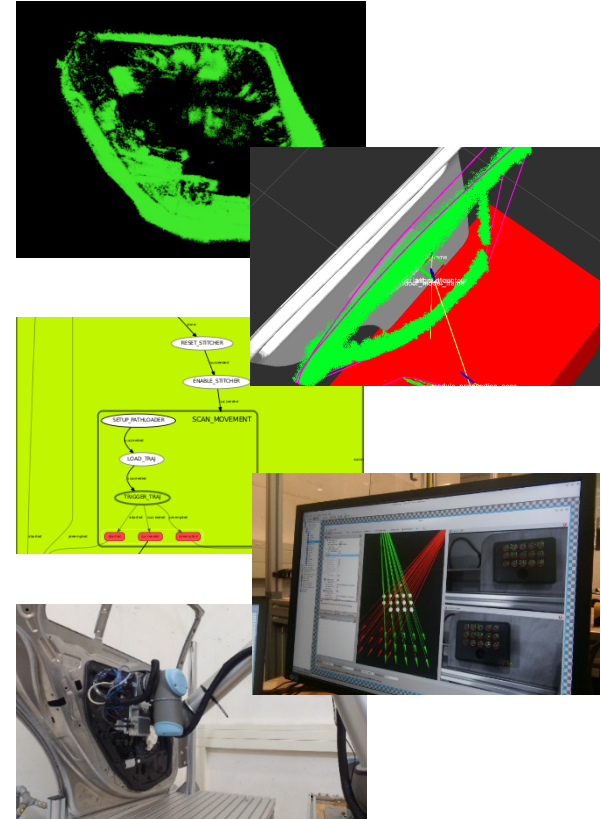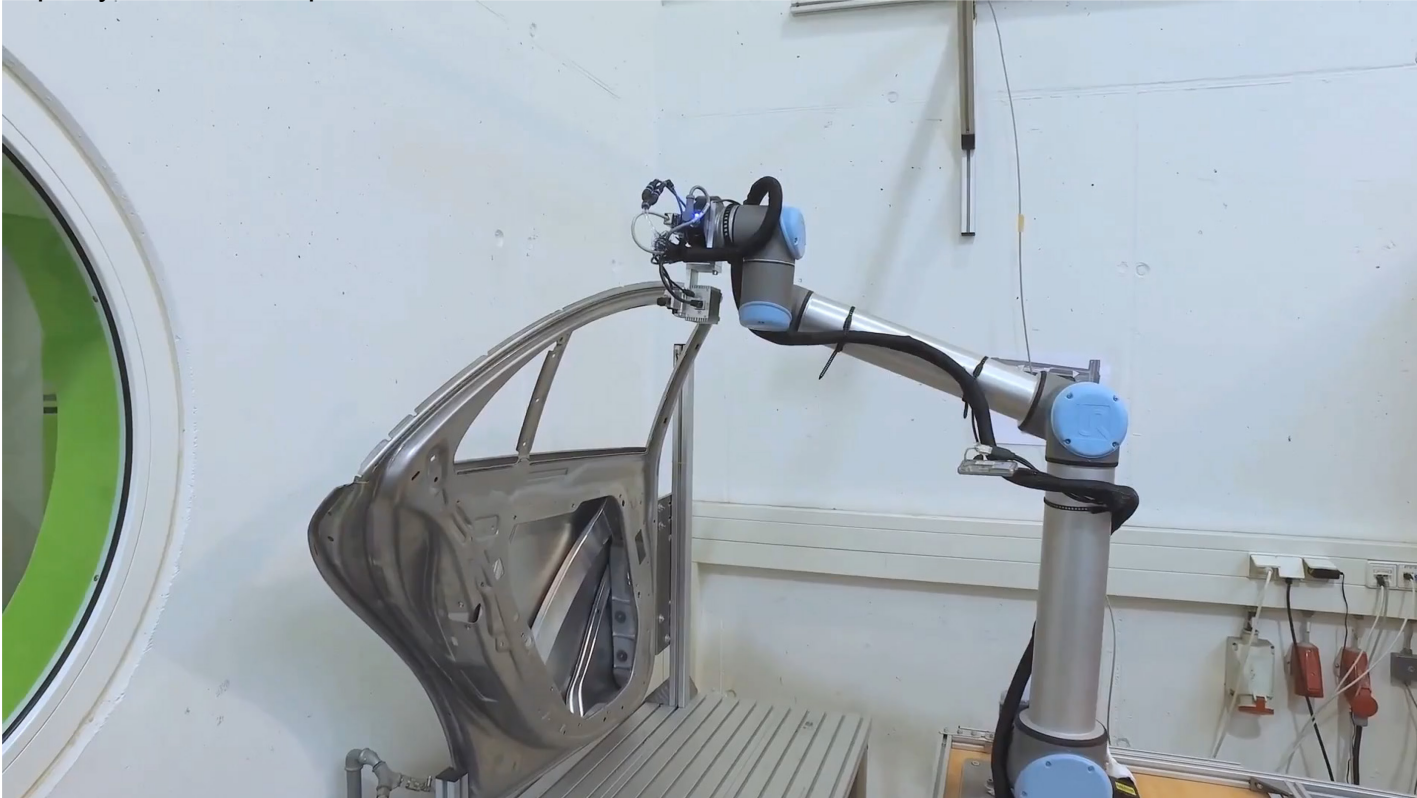
Freestyle – Intuitive Teach-In & Adaptation

- Intuitive graphical trajectory teach-in
  - Trajectory is generated by drawing it onto a 3D model
  - Automatic adaption 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
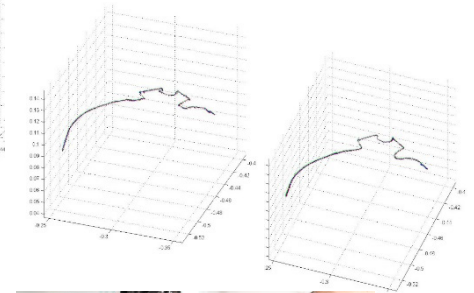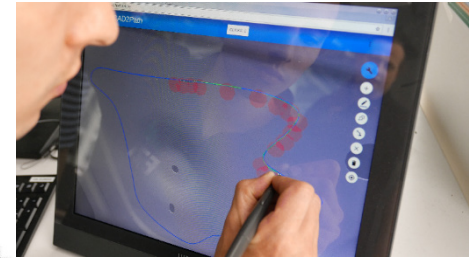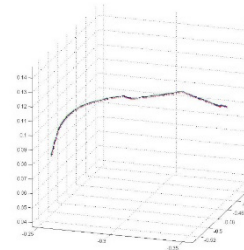
Freestyle – Intuitive Teach-In & Adaptation

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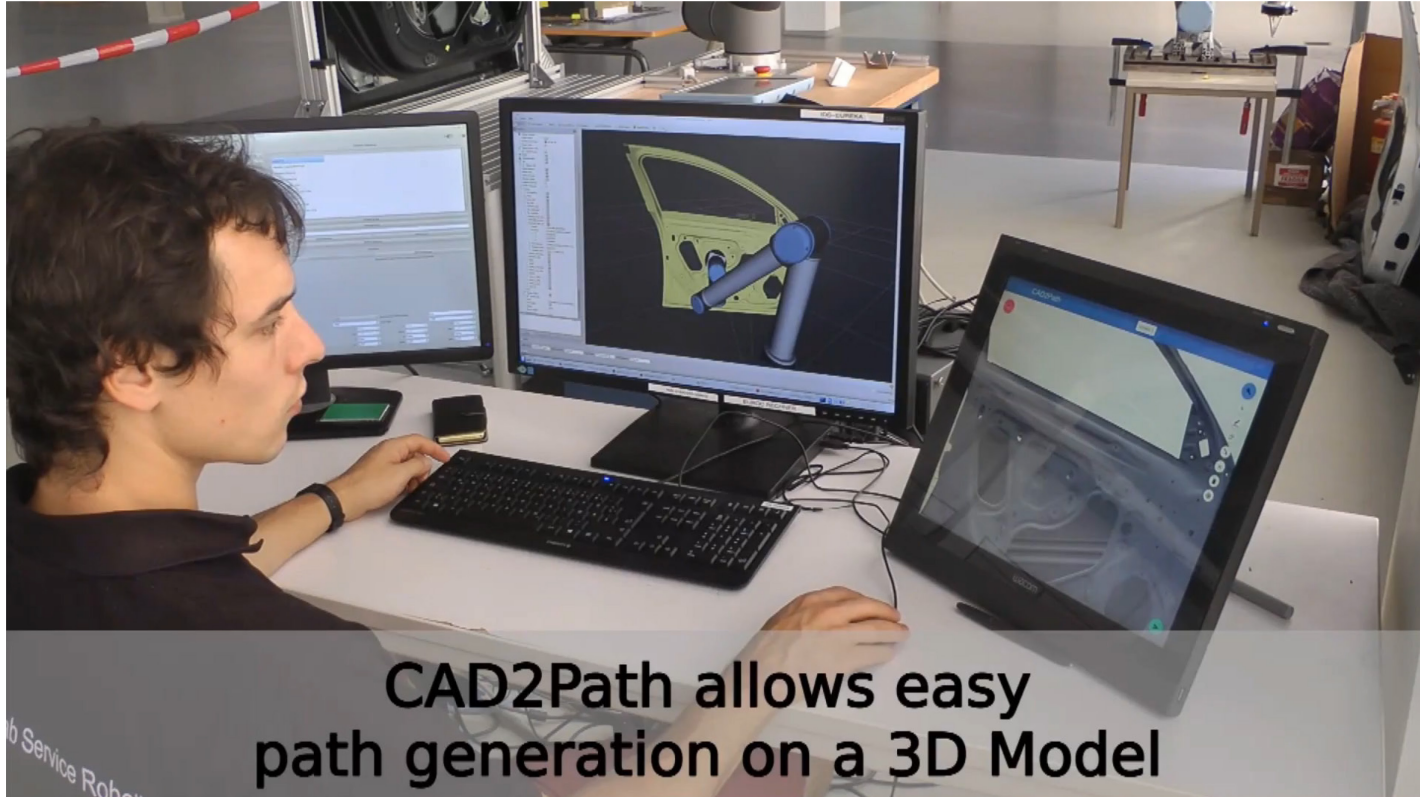
CAD2Path allows easy
path generation on a 3D Model

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  - Large door & human workspace
   - **Safe industrial robot required**

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

Add single points
Automatic spline interpolation in between

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

Industrial gripper PG+70 Pneumatic cylinder
Piston
Optical fiber
Preguidance system
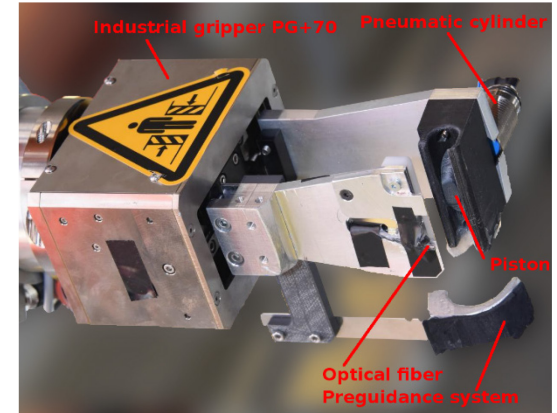
Feeling the Pin

- 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**
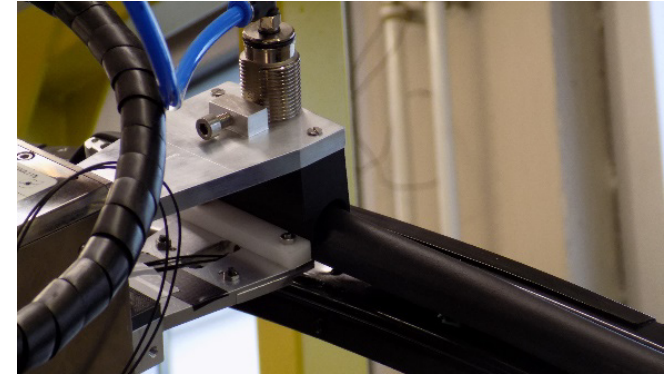
[Forward Dynamics Compliance Control (FDCC): A new Approach to Cartesian Compliance for Robotic Manipulators, Scherzinger et al, IEEE IROS 2017]

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"
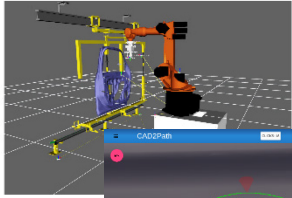 - Hard PLC safety triggers emergency stop if robot is not fast enough

Safe human robot collaboration with no impact on the process

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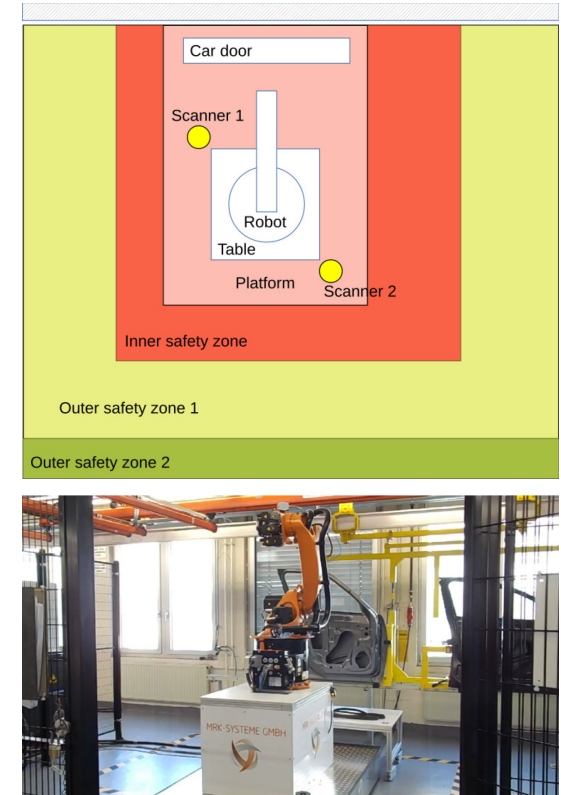
Using ROS-Industrial on the Shop Floor

Tools for visualization & available drivers speed up development

Robot independent developments such as force control & intuitive teach in
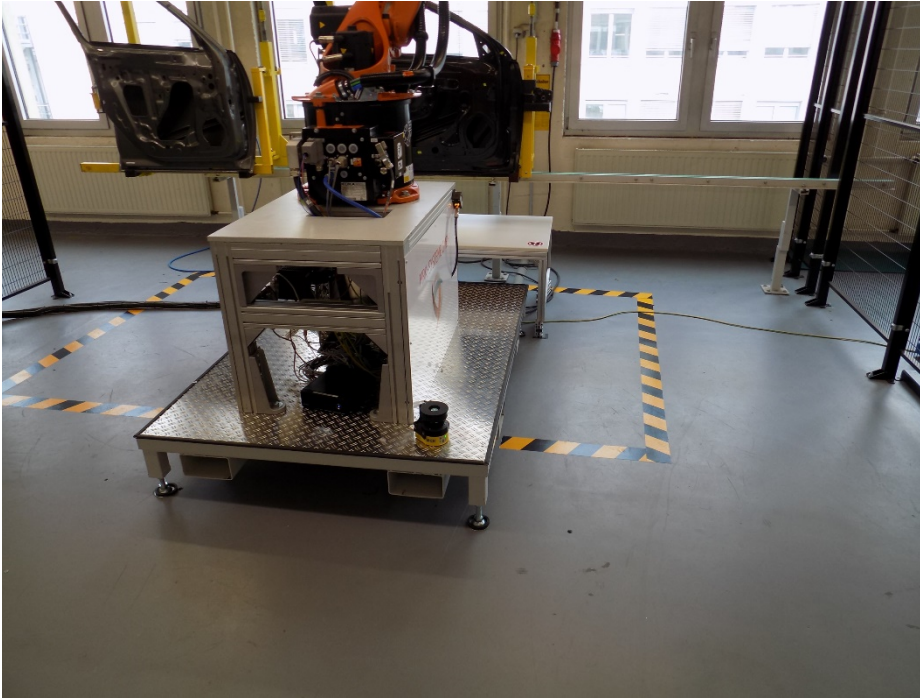
Easy prototyping speeds up development and integration of new hardware
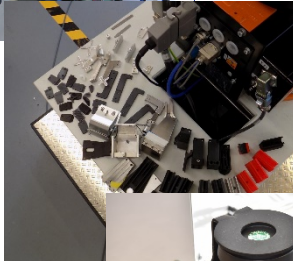
Combining proven safety & adaptive approaches enables a certified safety system with ROS

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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
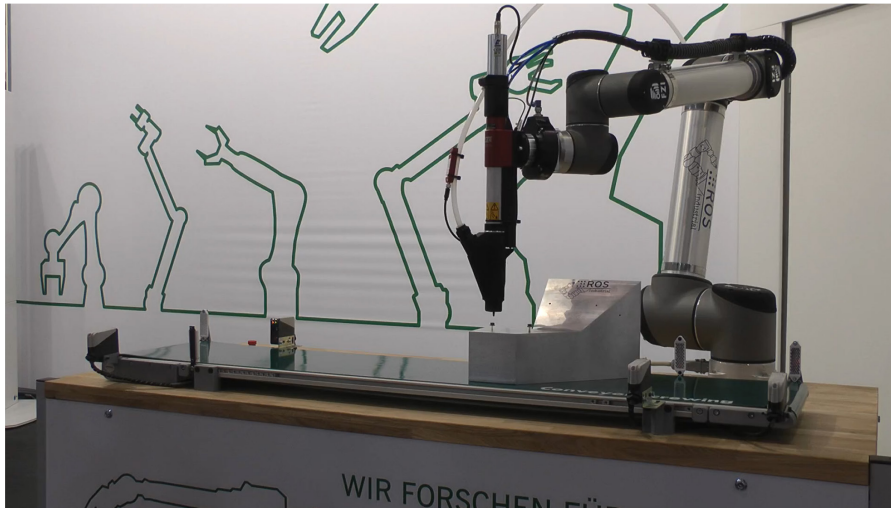
Transferability for Other Applications

- 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
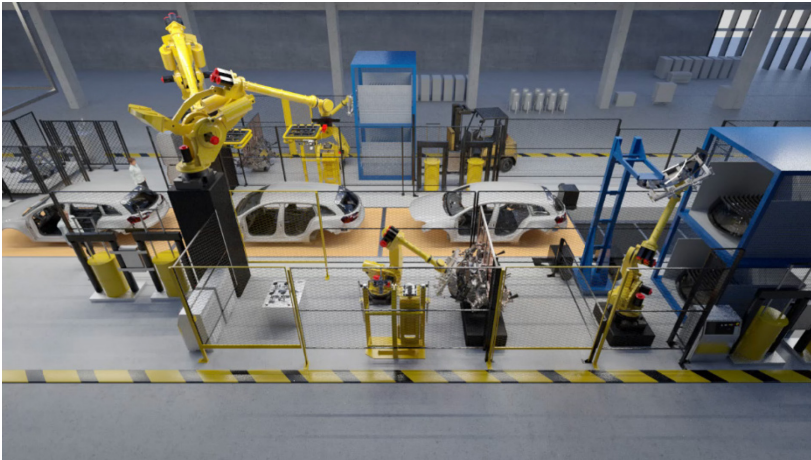
Transferability for Other Applications

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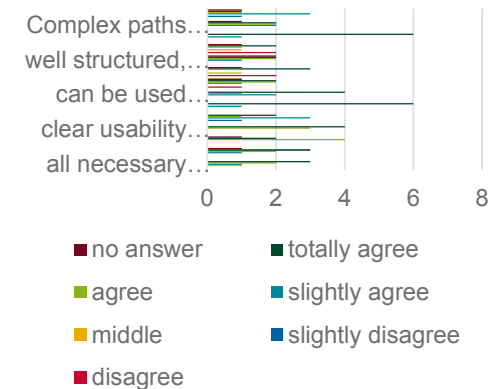
Transferability for Other Applications

- 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
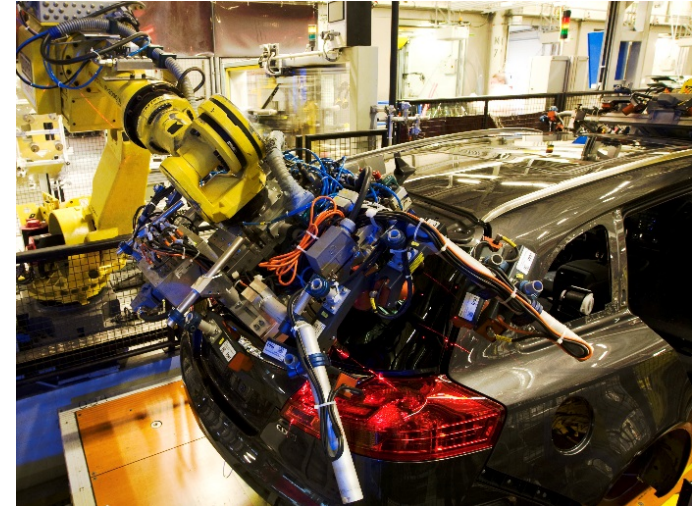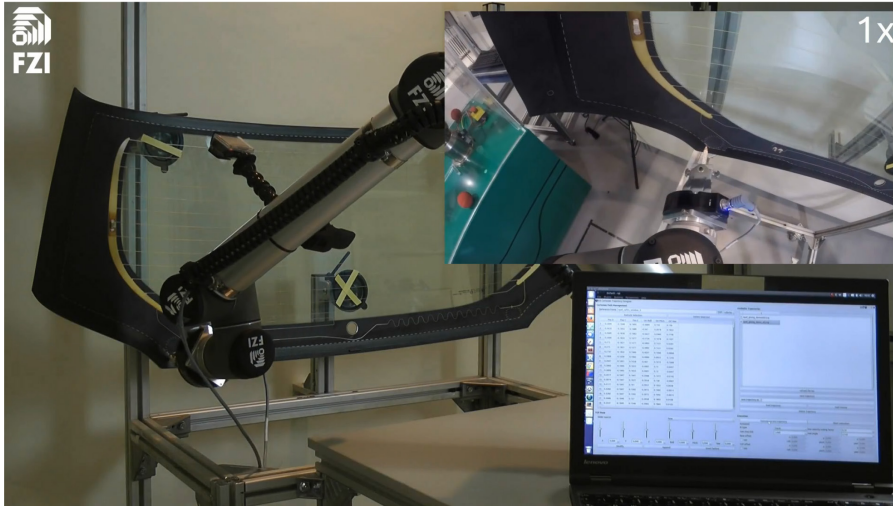
End User Feedback

- 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!**

Complex paths...
well structured,..
can be used...
clear usability...
all necessary...

| no answer | totally agree |
agree	slightly agree
middle	slightly disagree
disagree	

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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
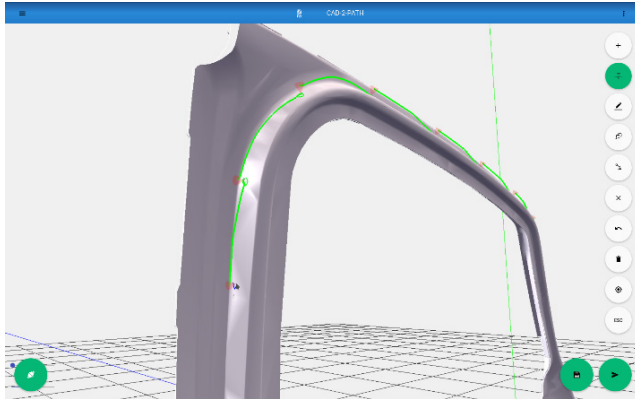
Thanks for you attention!

Questions?

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More At:

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

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