Production Technology Center Berlin

Your partner for applied research,
development and implementation

Future Trends in Robot Based Automation for Manufacturing, Assembly and Inspection

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Fraunhofer IPK
INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY

IWF
INSTITUTE FOR MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN

Fraunhofer Institute for Production Systems and Design Technology (Fraunhofer IPK)

Your partner for applied research, development and implementation

R&D Areas

- Corporate Management
- Virtual Product Creation
- Production Systems
- Joining and Coating Technology
- Automation Technology
- Quality Management
- Medical Technology

Production Technology Center Berlin (PTZ)

Research along the manufacturing process chain

Example: Automobile Production

Company management

Automobile development

Automobile production with innovative manfacturing technologies,

…machines and tools,…

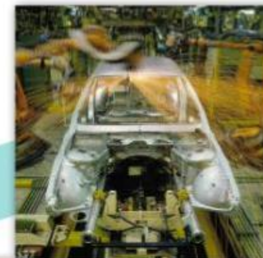
…and automation technologies

MRO

Quality management

The German R&D Innovation Chain

3. Industrial application

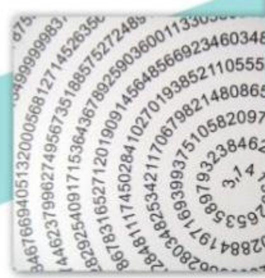


implements application-ready solutions in the **economy**.

2. Application-oriented research

transfers basic innovations to the **application stage** and creates **prototypical solutions.**

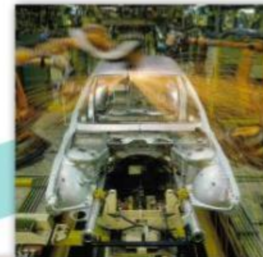
1. Basic research



creates **basic innovations**.

From Idea to Practice : Who stands where?

3. Industrial application
- **Companies**

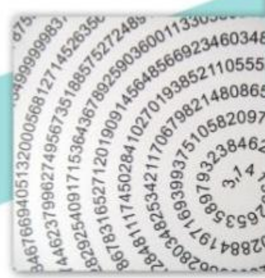


implements application-ready solutions in the **economy**.

2. Application-oriented research
- **Industrial research centers**
- **Fraunhofer Institutes**

transfers basic innovations to the **application stage** and creates **prototypical solutions.**

1. Basic research
- **Universities**
- **Helmholtz Centers**
- **Max-Planck-Institutes**



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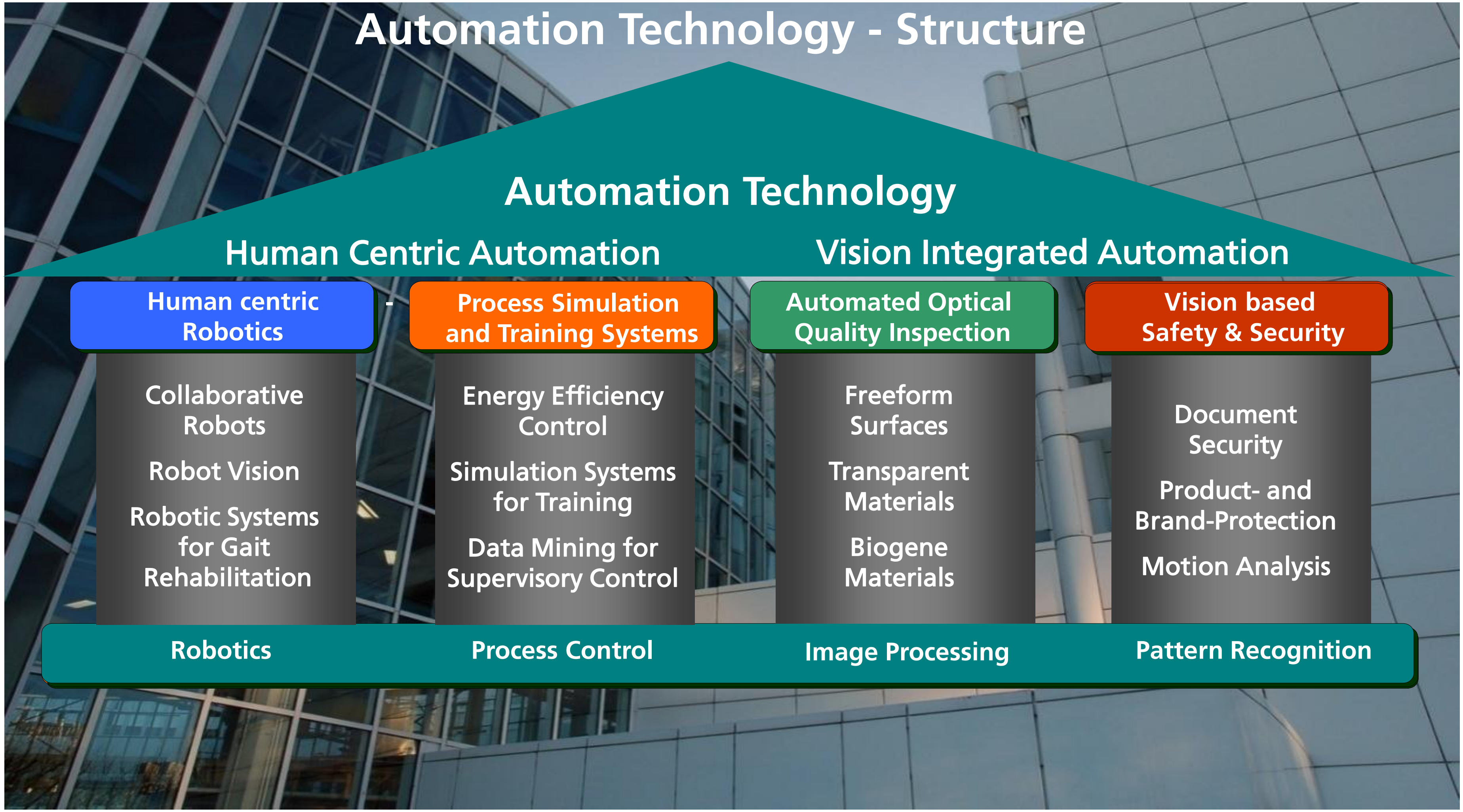
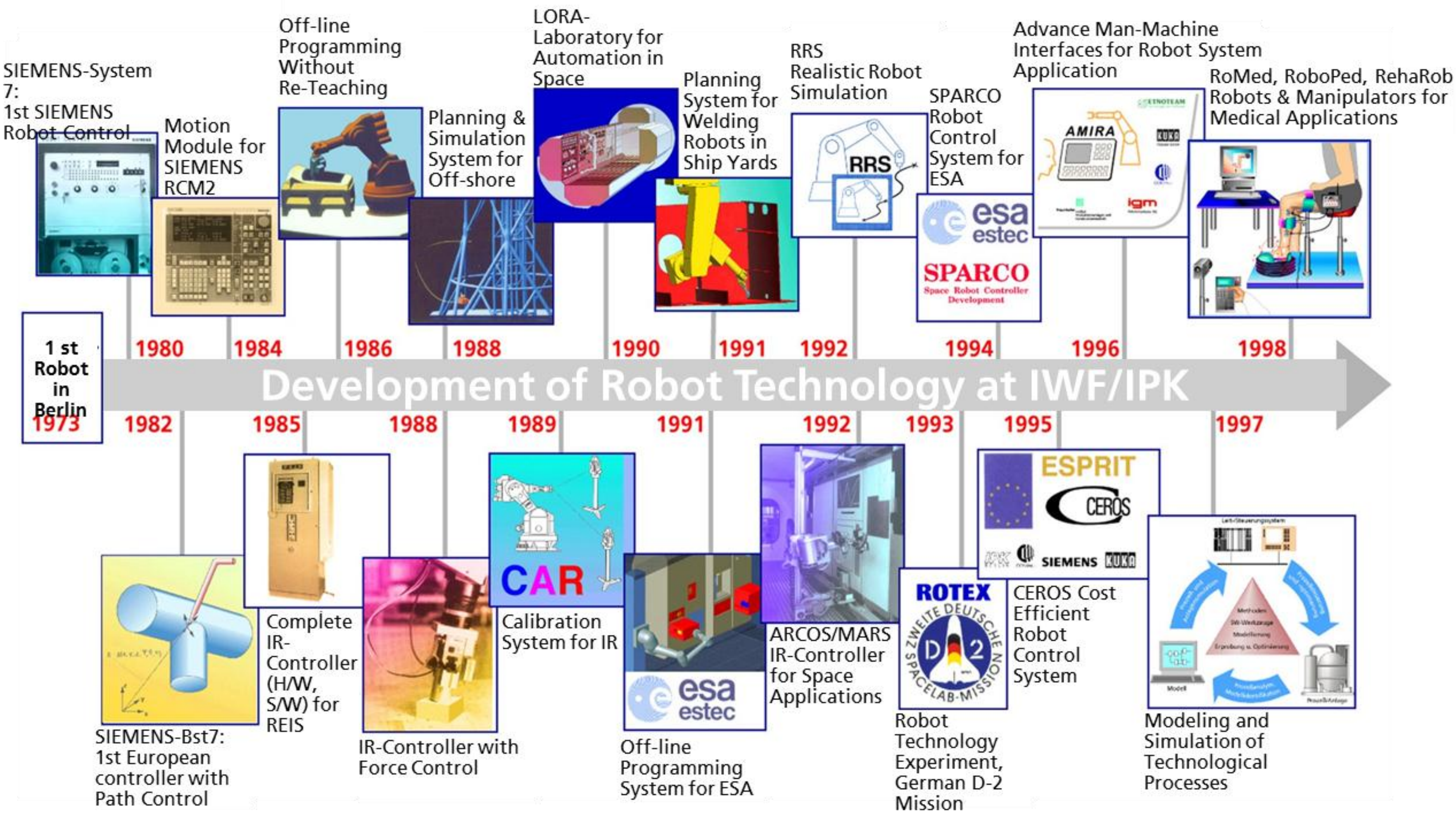

Automation Technology - Structure
Automation Technology
Human Centric Automation
Vision Integrated Automation
Human centric Robotics
Process Simulation and Training Systems
Automated Optical Quality Inspection
Vision based Safety & Security
Collaborative Robots
Robot Vision
Robotic Systems for Gait Rehabilitation
Energy Efficiency Control
Simulation Systems for Training
Data Mining for Supervisory Control
Freeform Surfaces
Transparent Materials
Biogene Materials
Document Security
Product- and Brand-Protection
Motion Analysis
Robotics
Process Control
Image Processing
Pattern Recognition

Development of Robotics at IWF/IPK 1980 - 2000



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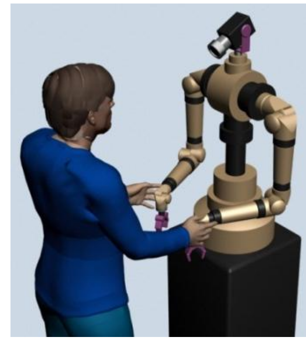
Future Trends in Robot Based Automation for Manufacturing, Assembly and Inspection



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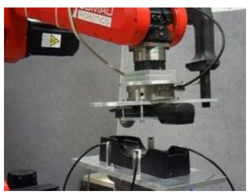
2000 2010 2020

Depending on

- Drivers for Automation
- Developments in Robotics
- …

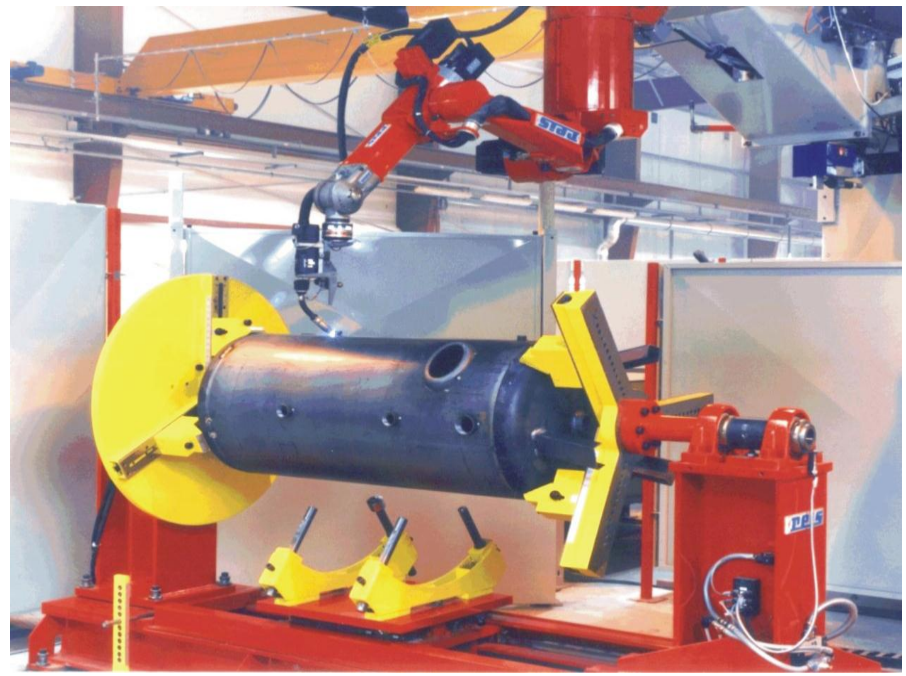
Drivers for Automation

Main drivers

- Cost
- Time (reduction of cycle times)
- Quality (reproducibility)
- Flexibility (react on changes)

Further aspects

- Work conditions
- Shortage of skilled labors
- Environmental aspects
- Energy efficiency



Work conditions - humanization of work

- Avoid dangerous & dirty working places
- Protect people from work load
- Improve ergonomics
- Aging society / older employees

Industrial robots today

- Available from many manufacturer in a big range of payload and work space
- Lower costs in last years / decades
- Accepted as a standard automation component
- Most installations in
  - Automotive industry
  - Electrical / electronics industry

Predominant conventional mass production applications

Robotics in the future
Product visions & application scenarios[1)]

- **Robotic Workers**
  Robots performing tasks autonomously
- **Robotic Co-Workers**
  Robots working directly with and for humans
- **Logistics robots**
  Robots moving goods and people
- **Robots for surveillance & intervention**
  Robots protecting citizens against security threats
- **Robots for exploration & inspection**
  Robots in unknown or dangerous environments
- **Edutainment robots**
  Robots educating and entertaining humans

1) Robotics visions to 2020 and beyond.
The Strategic Research Agenda for Robotics in Europe, 07/2009

Robotics in the future
Product visions & application scenarios[1)]

- **Robotic Workers**
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Direct relation to production industry

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Benefit from used technologies

1) Robotics visions to 2020 and beyond.
The Strategic Research Agenda for Robotics in Europe, 07/2009

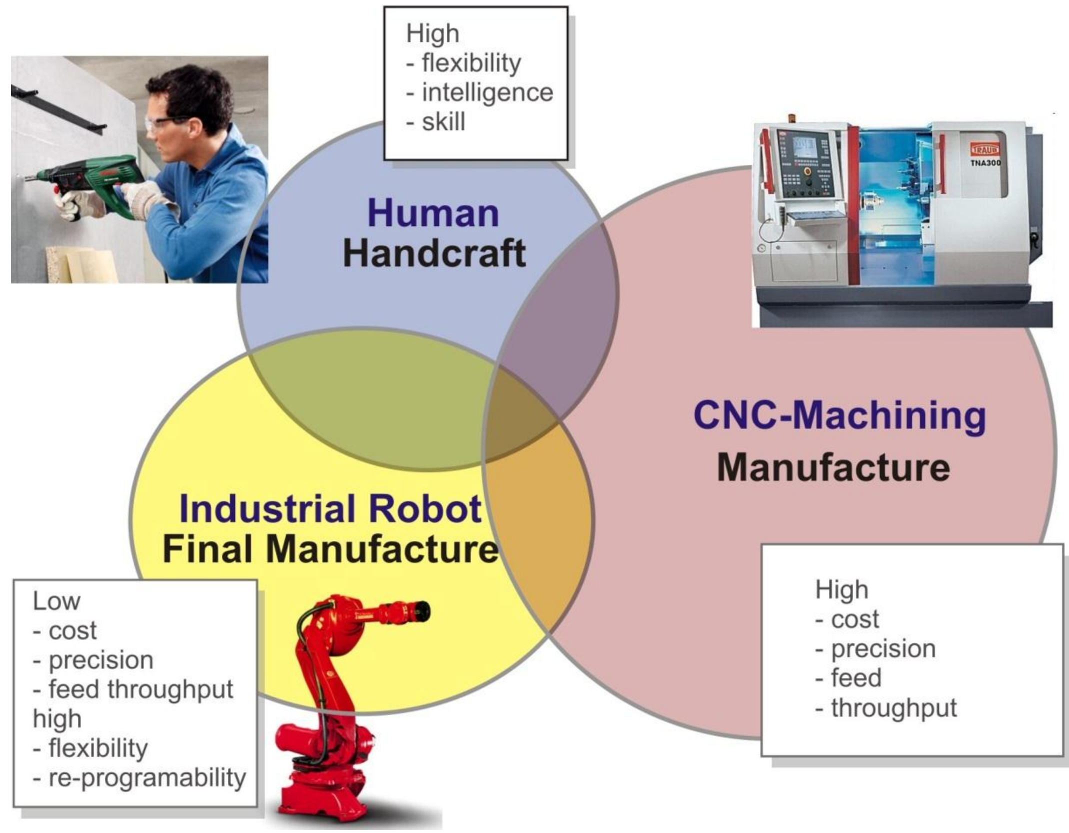
Machining with industrial robots

Machining with industrial robots - feasibility and limits

In comparison to CNC machines

- Benefits
  - Scalable workspace and considerably price reduction (1/5-1/3)
  - ...

- Hurdles/Challenges
  - low precision, stiffness (1/100)
  - ...



Machining with industrial robots

- Increased demands of leading industry sectors (automotive, aerospace) for introduction of industrial robot machining processes (milling, grinding, polishing, drilling etc.)
- Robotics based flexible material removal is considered as an ideal solution for its programmability , adaptivity, flexibility and relatively low cost.
- Tools and solutions for robot machining of soft material (Molded plastics, wood, aluminum, cast steel) are more and more available on the market.
- Robotic machining of hard material (Inconel alloys, titanium etc.) is still a topic more research and development is needed.

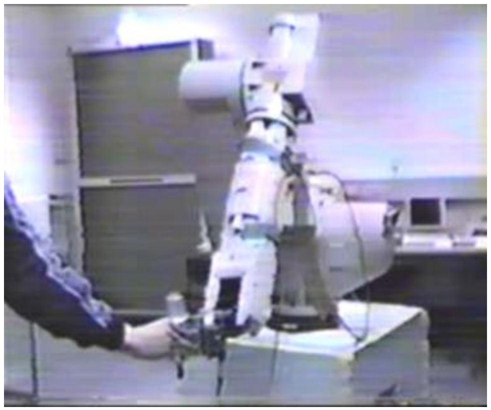
Robotic machining of hard material
Challenges and hurdles

- The flexible robotic machining, such as milling, grinding and polishing of hard metals and materials is still a challenging problem
- Hard machining is a recent technology focusing on materials in constant use by automotive, aerospace, biomedical and other advanced industries.
- Insufficient rigidity and accuracy have been widely identified as major obstacle of widespread use of robots for metal-removal jobs, making robotic machining of hard materials quite difficult.
- Specific robotic systems adapted for machining are considerably more expensive in comparison to standard industrial robots.
- The CAM packages include considerably knowledge of process technology and tooling, but didn't consider specific performance and limitations in robotic system kinematics, dynamics and control.

Robotic machining of hard material
Approach followed at Fraunhofer IPK

- Using conventional robots and open robot control systems
- Performing contact tasks without additional passive/active impedance devices
- Advanced position based impedance and force control (6DOF F/T sensor)
- Specific planning and control toolbox for robot machining
- Adapt process parameters to specific robot features (robot signature)
- Development of robot friendly machining processes and process chains

Contact Task Applications by Force / Impedance Control



IPK Pioneering work in force and compliance control

Approach

- Standard industrial robot arm
- Normal processing tools
- 6DOF F/T Sensor at robot tool interface
- Advanced force / impedance control (**SW solution**)

Benefit

- High flexibility concerning process design and task execution

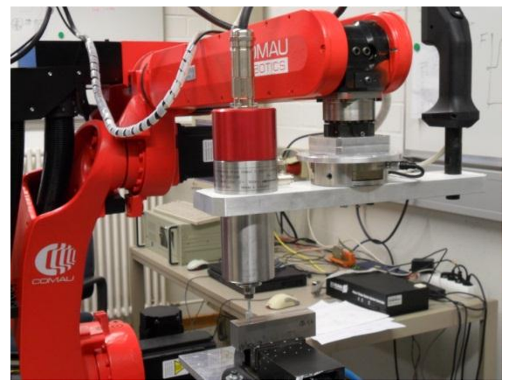
Challenges

- Stability, performance, robustness

Experimental set-ups at Fraunhofer IPK
Robotic cells for milling, grinding and polishing

Applied Comau robots with C4GOPEN Controllers:

- NH3-220
  (left)
- NJ-370
  (upper-right)
- SMART-SIX
  (down-right)



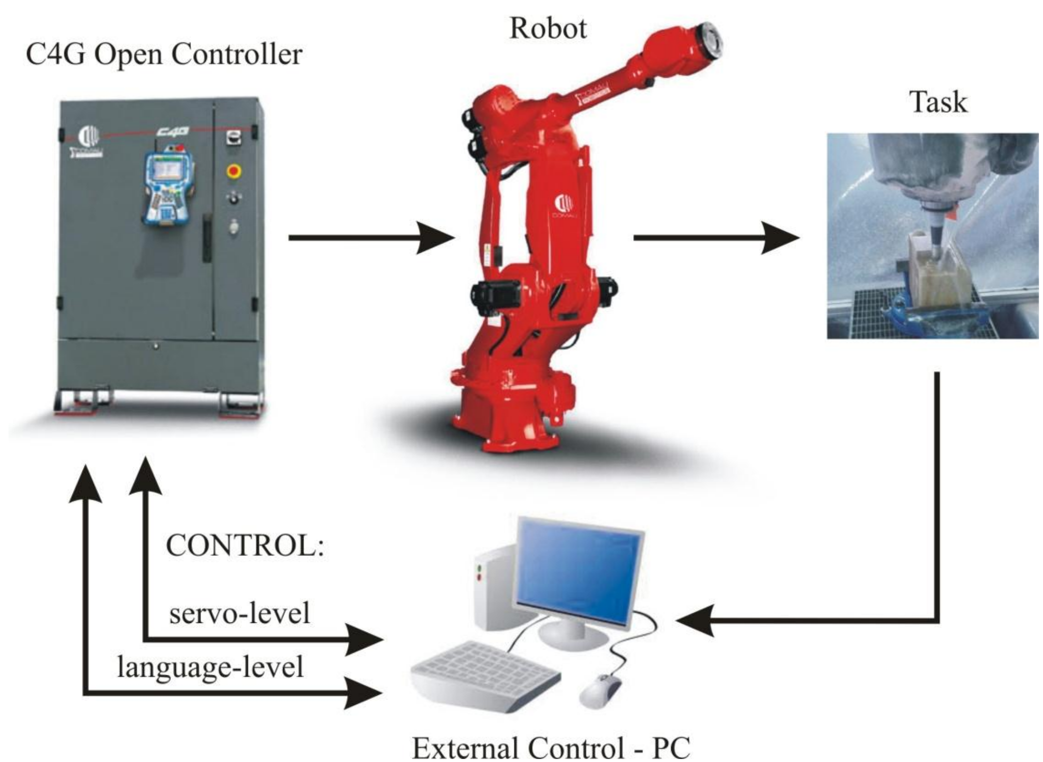
Experimental set-ups at Fraunhofer IPK
Open control platform

C4GOpen control system with real time interfaces at

- Servo-level
- Language-level

External control PC (RT Linux) with advanced control algorithms

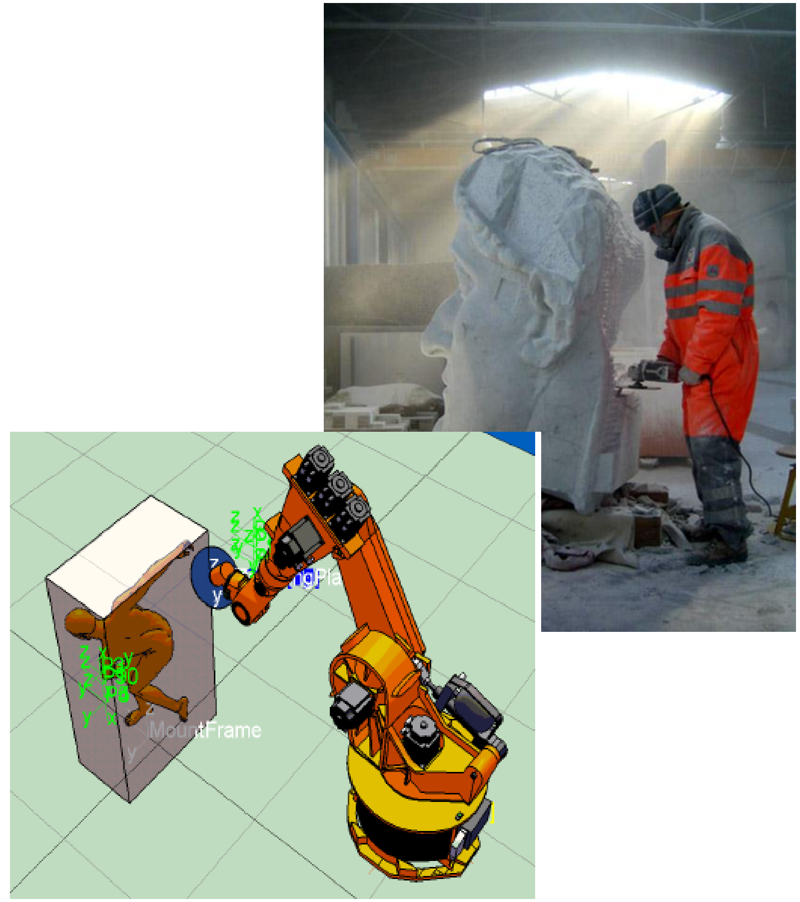
- force control
- impedance control
- path governor



Application - stone sculptures milling

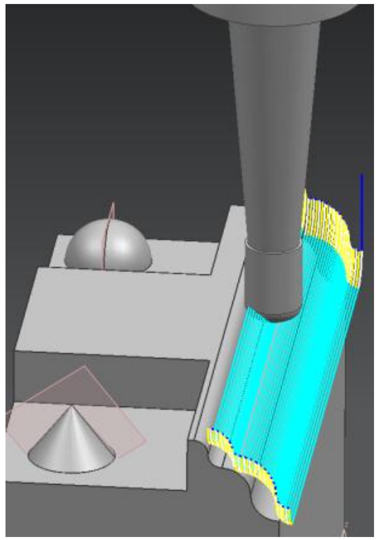
Objectives

- Automatic pre-shaping of sculptures
- To assist the artists (sculptor) for the routine sculpturing with robots
- Decrease sculpturing time and costs
- Processing of free-form surfaces

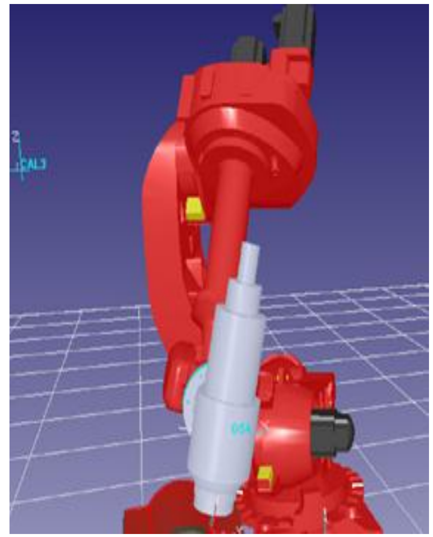


Machining off-line planning
Planning and programming chain

3D-scanners (ViALUX)



CAM G-code generation (NX)

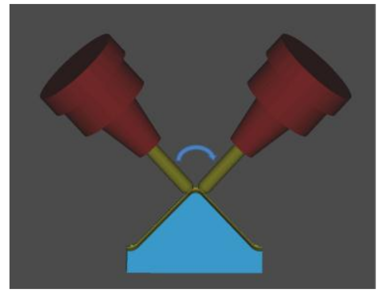


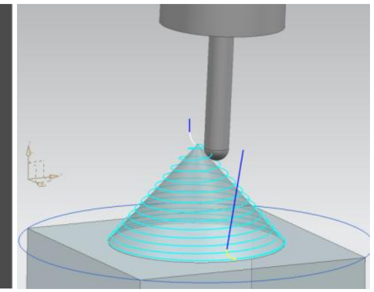
Testing, Optimization and Robot Program Generation (Easy-Rob)

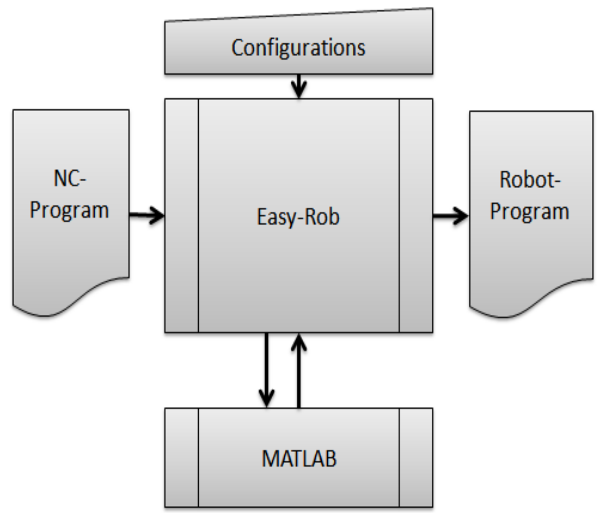
Realization (Comau C4GOpen)

Machining off-line planning
Robot specific program generation needed (off-line optimization)

- Need for improvement of initial NC-programs (G-code)
- Detection and avoidance of collisions, singular configuration, restricted work space, bad manipulability
- Use Redundancy of IRs - Reconfiguring
- Improvement - nominal motion profiles (path velocity, i.e. tool feed rates)
- Adjustment of velocity profiles for IRs dependent on the real path
- Consideration of robot dynamics and control limitations

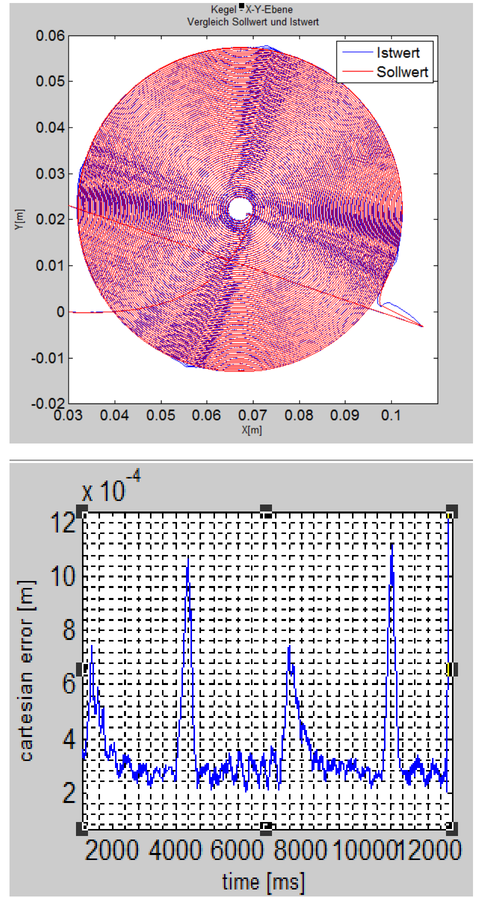






Machining on-line optimization e.g. Path Governor

- Despite careful off-line planning, experiments with standardized parts demonstrate higher position errors at specific robot configurations.
- e.g. Coulomb stiction/friction in main robot joints, during direction changes the specific axes remain jammed for a time period and other axes achieve maximum speed.
- Real-time error monitoring and reducing implemented using on-line algorithm referred to as real-time velocity path governor.



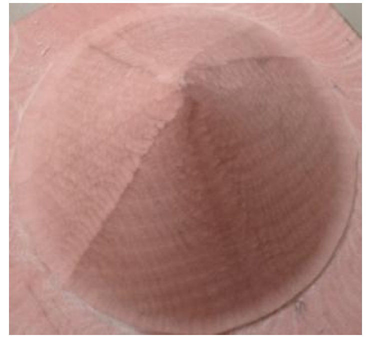
Periodical real-time position errors picks during milling a cone part

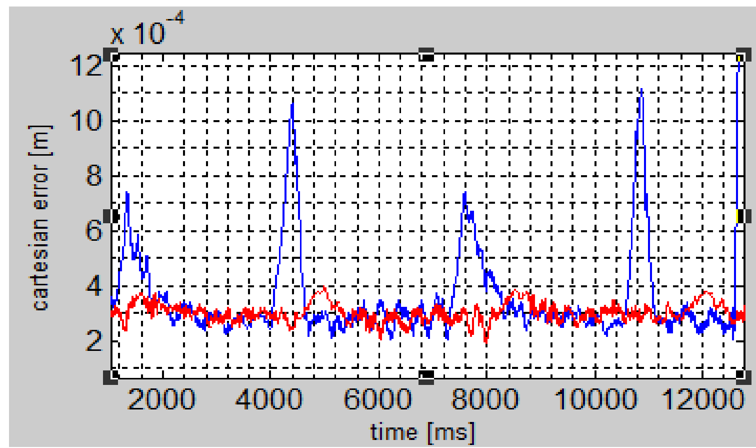
Machining on-line optimization
e.g. Path Governor

- Path governor adjust (slow-down) the nominal robot velocity dependent on the real position errors by controlling the robot override.

- Implemented in the C4GOpen robot control system on the external PC in C++ and using language control interface

- The algorithm is running at 10 ms and is adjusting programmed real-time override within range 5-100% of the nominal speed.





blue- without path-governor, red-with path-governor control

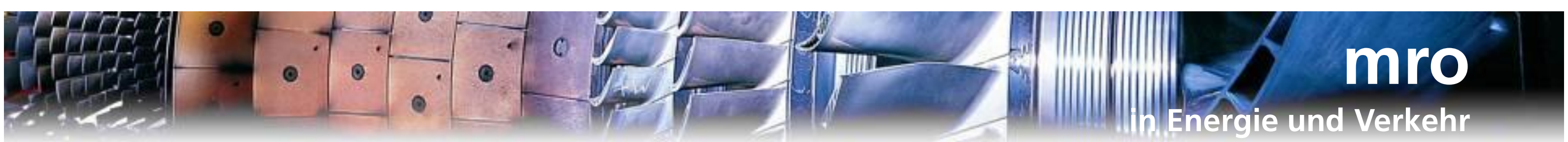
=> Video: Robot Cone Milling

Stone milling - final benchmark designed by the sculptor

Application – automation of repair tasks (MRO: Maintenance repair and overhaul in energy and traffic)

Objectives

- Increasing the level of automation for repairing of used parts
- Individual parts with complex shape, lot size one
- Hard material like Titanium, Inconel
- Process chains combining several manufacturing and machining operations
- Validation of robot-based repair procedures

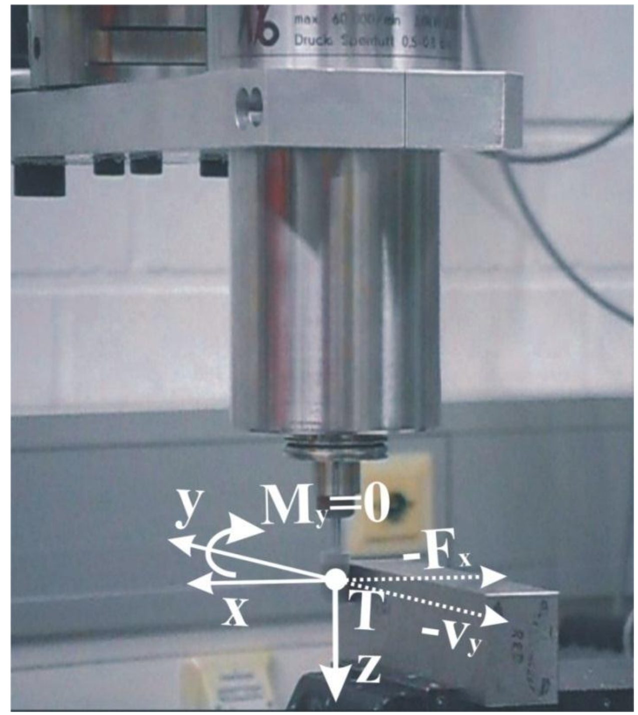


High precision grinding / polishing
Force and impedance control approach

Grinding and polishing operations requires precision to achieve a good quality of surfaces, which is beyond robot positioning accuracy.

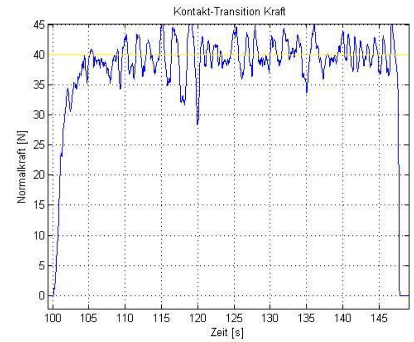
Applied approach:

- Force control in the surface normal direction
- Torque control to adjust the tool to the surface tangents
- Impedance control to cope with tolerances and inaccuracies



High precision grinding / polishing
Experiments with complex test parts

- Polishing of free-form surface with controlled constant pressure force
- Feasibility and reliability of the applied approach is shown
- Ongoing research focuses the optimization of the force/feed rate control based on the process knowledge

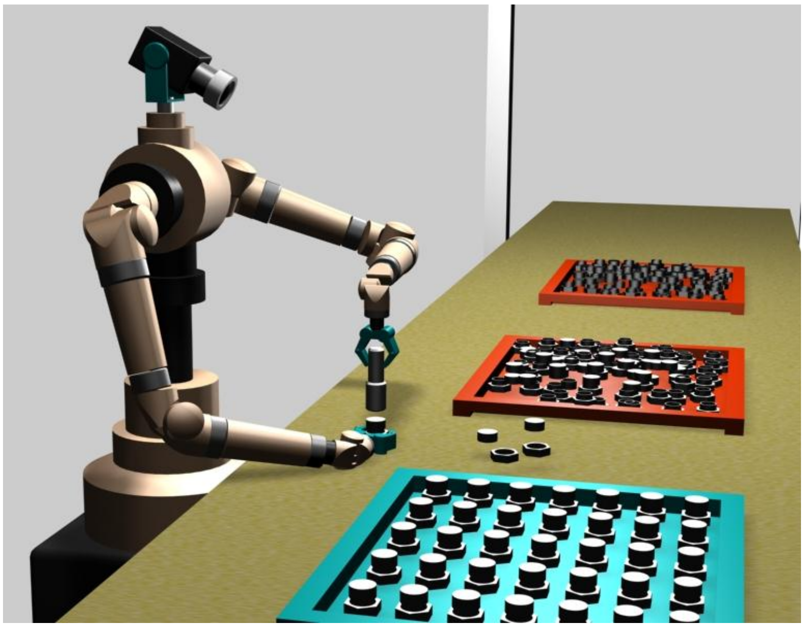


=> Video: Robot Polishing

Robot based automation in assembly and inspection

Robot based automation in assembly and inspection

In future?



Source: Fraunhofer IPK

Today

Source: PISA Project

Next Generation of Flexible Assembly Systems and Processes

- Research Area of the finalized sixth framework programme for research and technological development of the European Commission (EC)
- EC Integrated Project PISA:
  Flexible Assembly Systems through Workplace-Sharing and Time-Sharing Human-Machine Cooperation

PISA

- PISA integrates three different branches
  - Aircraft Industry
  - Automotive Industry
  - Household Appliances Industry

  This Includes OEM´s and Suppliers

- The overall goal of PISA is to keep human workers in the loop but to support them with powerful tools

Source: PISA Project

PISA: Flexible Assembly Systems through Workplace-Sharing and Time-Sharing Human-Machine Cooperation

Novel Intelligent Assist System IAS	Planning Tools for their Integration	Reconfigurability and Reusability of Assembly Equipment

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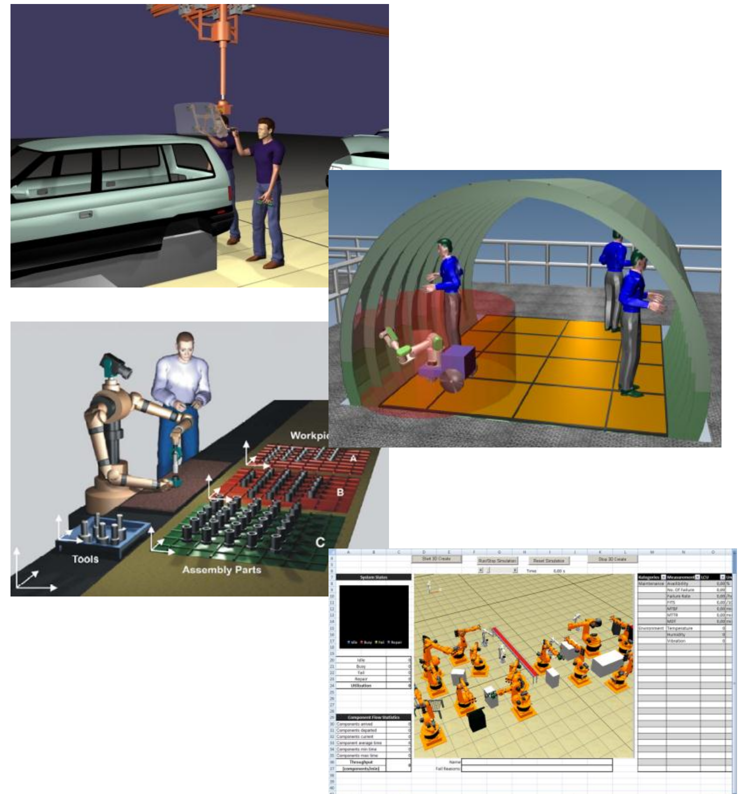
Source: PISA Project

PISA Research Topics

PISA

- Human-Integrated Assembly Automation (Intelligent Assist Systems)
  - Collaboration of human workers and programmable, passive robotic systems (Cobots)
  - Time-sharing robot applicable at a workplace designed for humans
  - Cooperation of human workers and industrial robots in a common workplace
- Planning tools for intelligent assist systems
- Methods and tools enabling reconfiguration and reuse of assembly equipment



Source: PISA Project

PISA Demonstration Scenarios

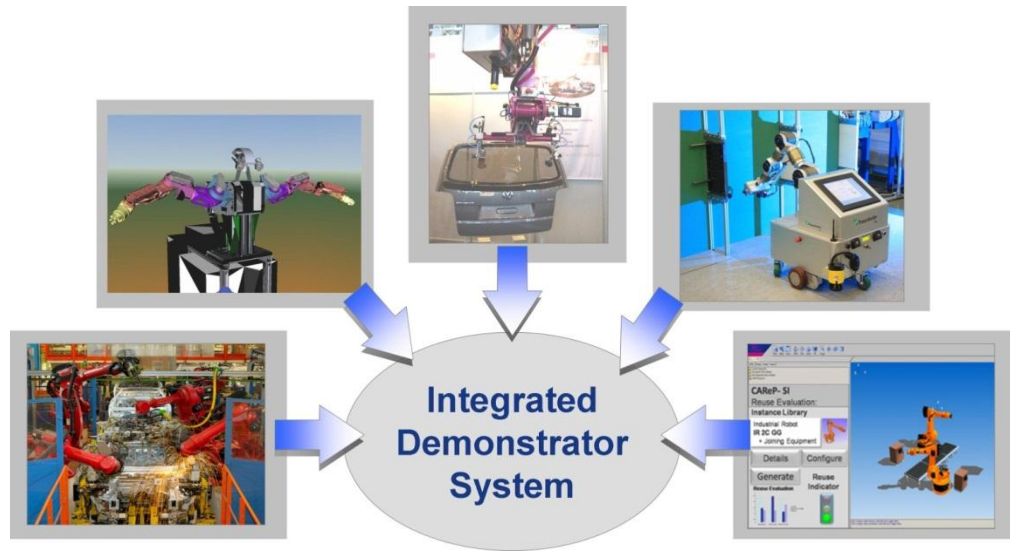
PISA

Realized Demonstrator Systems (Industrial Prototypes)

- Power Assist System (Cobot)
- Dual Arm Robot
- Robot Arm on Mobile Platform
- Software Tools
  (Simulation, Planning and Reusability)
- Distributed Control

With Use Cases in

- Aircraft Industry
- Automotive Industry
- White Goods Industry

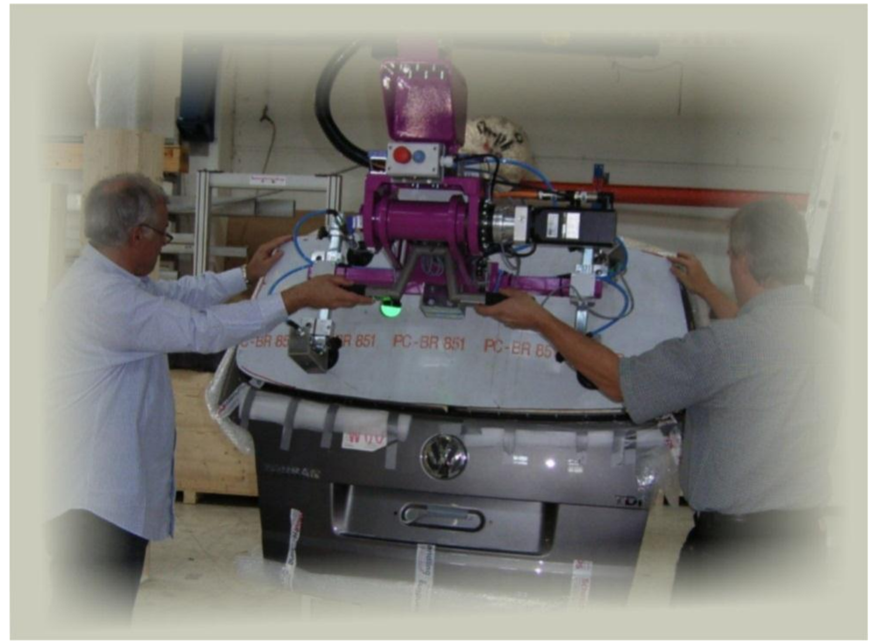


Source: PISA Project

Human centered semi-automatic windscreen assembly with cooperative robots (Cobot)

COBOT - Approach

- Power assist system supporting the worker in part handling tasks
- Manual motion controlled by force input of the worker
- Intelligent additional functions
  - Path guidance / virtual walls
  - Teach-in function for positioning in automatic mode
  - Conveyor synchronization

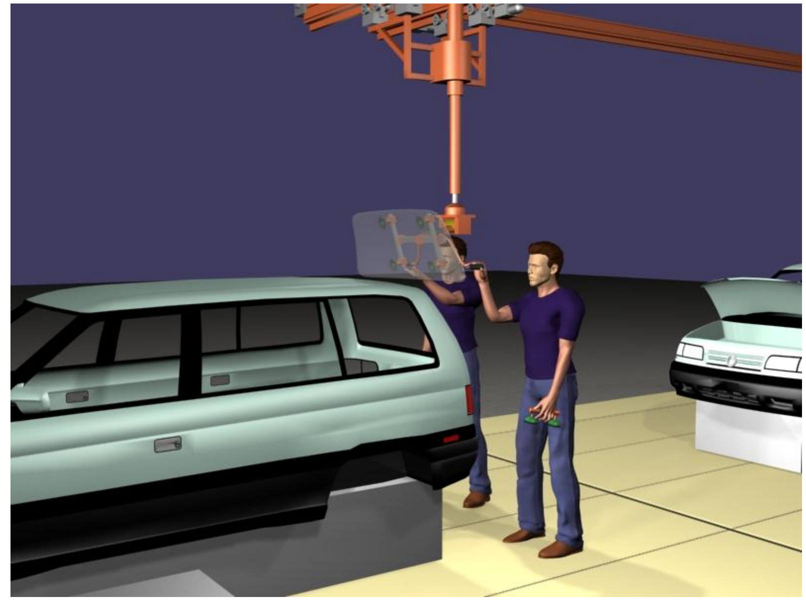


Source: Fa. Schmidt Handling

Human centered semi-automatic windscreen assembly with cooperative robots (Cobot)

COBOT - Advantage

- High flexibility by direct human integration
- Intuitive (force based) interaction
- Configurable system behavior adapted to manual assembly processes
- Automatic functions for screen feeding and return to home / storage position
- Cost-efficient overall system solution
- Improvement of work conditions



=> Video: Simulation of Assembly Scenario

Source: Fraunhofer IPK

Human centered semi-automatic windscreen assembly with cooperative robots (Cobot)

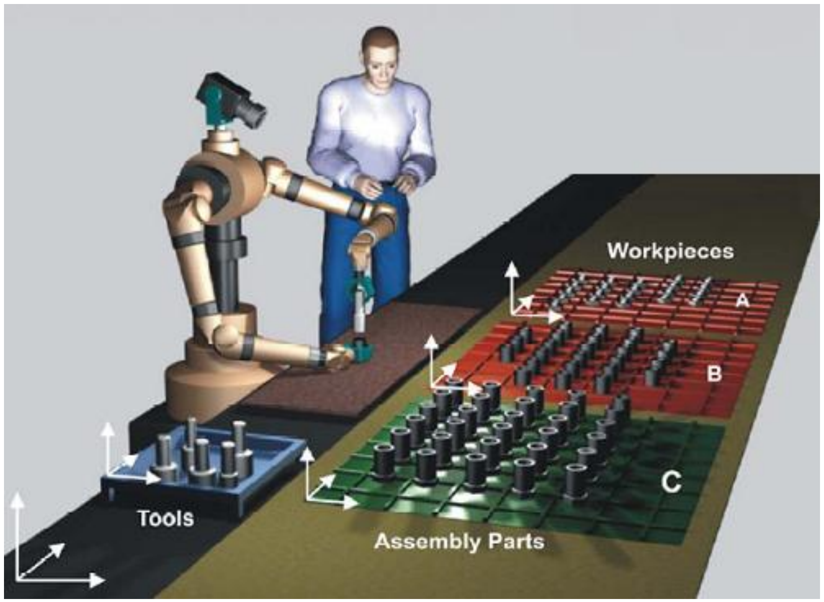
COBOT – Technology

- Modular basic kinematic structure
- End-effector with integrated sensor system
- Motion control for mixed manual und automatic system operation
- Closed-loop-control for the interaction of human – Cobot – environment
- Configurable force intensification adapted to specific assembly task
- Integrated safety functions

=> Video: PISA Demonstrator 1

Source: Fraunhofer IPK

Dual Arm Robot



Basic concept

- Humanoid Service Robot applicable on a workplace designed for humans (e.g. additional work-shift for product volume peaks)

Source: PISA Project

Dual Arm Robot

=> Video: PISA Demonstrator 2

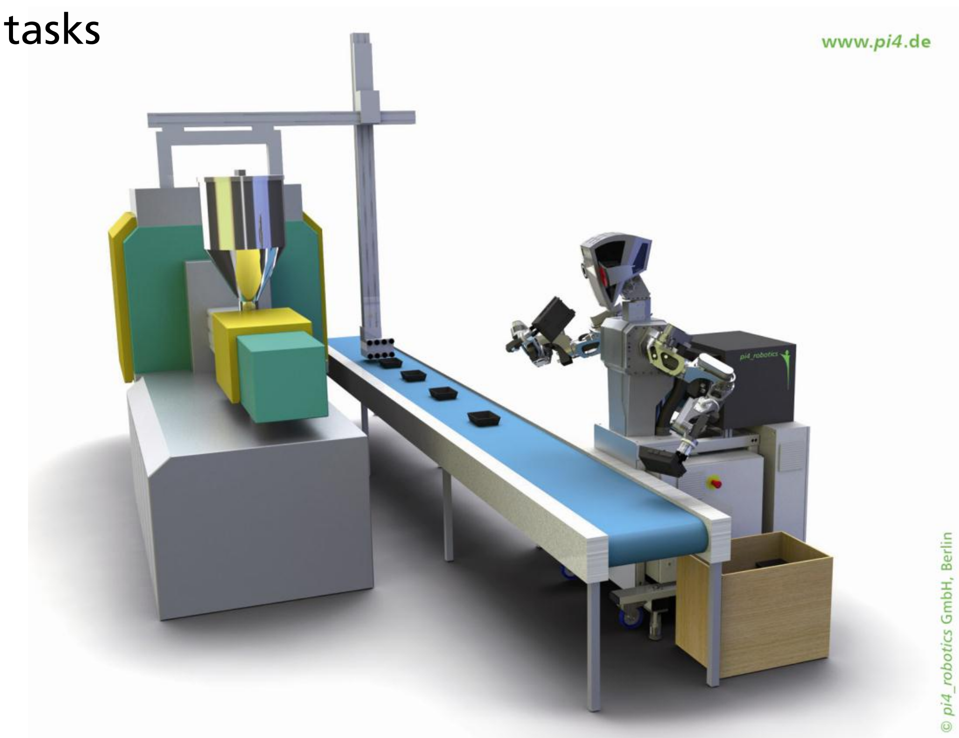
Main issues of the prototype "workerbot":

- fast setup
- reduced environment modifications
- easy reconfigurable safety tools
- skilled robot (impedance, task programming)
- small part manipulation

Dual Arm Robot

Application

- Assembly tasks
- Inspection tasks



Conclusion and Outlook

- Today industrial robots are flexible and low cost automation components
- Feasibility and limits of application needs o be assessed in each case
- Ongoing R&D in robotics will enable further application domains
- Open control platforms and software based solutions are promising approaches
- Force and impedance control solutions offer high flexibility and adaptivity
- Adapted planning and real-time control methodologies enable an efficient application of industrial robots for automated machining
- Intelligent Assist Systems are enablers for human-integrated assembly automation
- Robotic Co-workers will be widespread in near future

Thank you for

your kind attention

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