Robotizing of small lot production

Challenges and opportunities

1. **Structural changes brings challenges for industry**
2. **Special obstacles for SME**
3. **Vision: Semi automation with robots**
4. **Benefitting from specific skills of robot and human**
    1. Robotic assembly
    2. Robot Human Interaction
    3. Robotic disassembly
    4. Robotic grinding
5. **Summary**

Structural change in Luxembourg

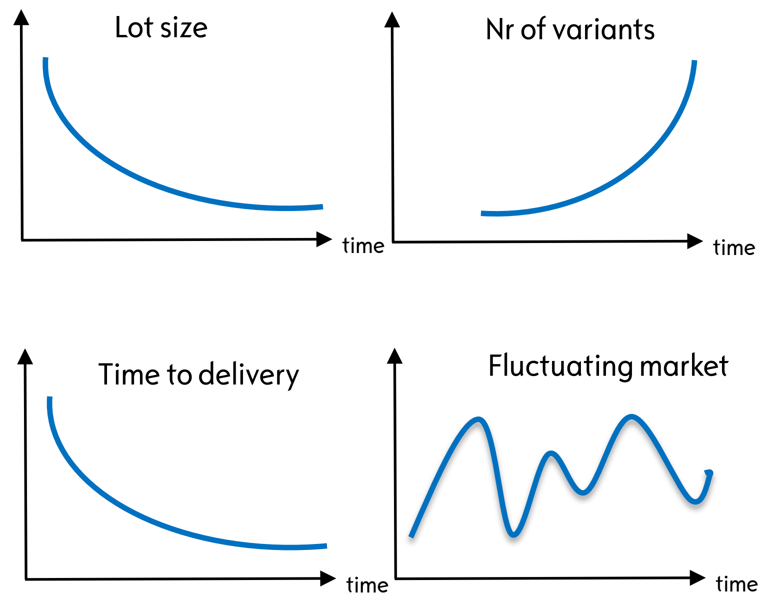
From steel production via finance services to knowledge society

National manufacturing corporations

Luxembourgish manufacturing companies & selection of our project partners

Challenges to manufacturing enterprises

- **Market requires more individualized products at reduced price**
- **Nbr. of variants increases**
  => smaller batches
  =>Enhanced flexibility of machines,
  of operators,
  of processes
- **Reduced lead time (faster time-to-delivery)**
- **Quality expectations remain high or even increase**
- **Ageing employees**
- **Novel technologies needed**



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Especially SMEs face significant challenges

- **Limited inhouse R&D capabilities available** => cooperation w/ universities
- **Customized products** => small lot / low volume production
- **Limited skills for maintenance for "high tech" automation accessible**

  => no over-engineered level of automation
- **Fast response to customer demands is mandatory**

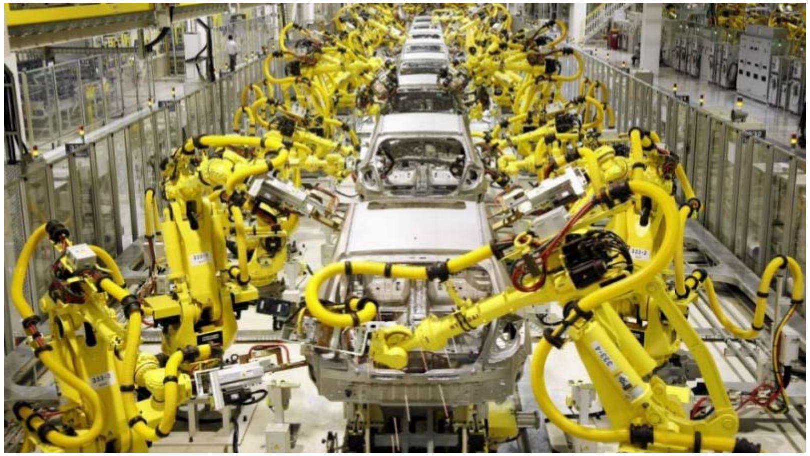
  => versatile automation

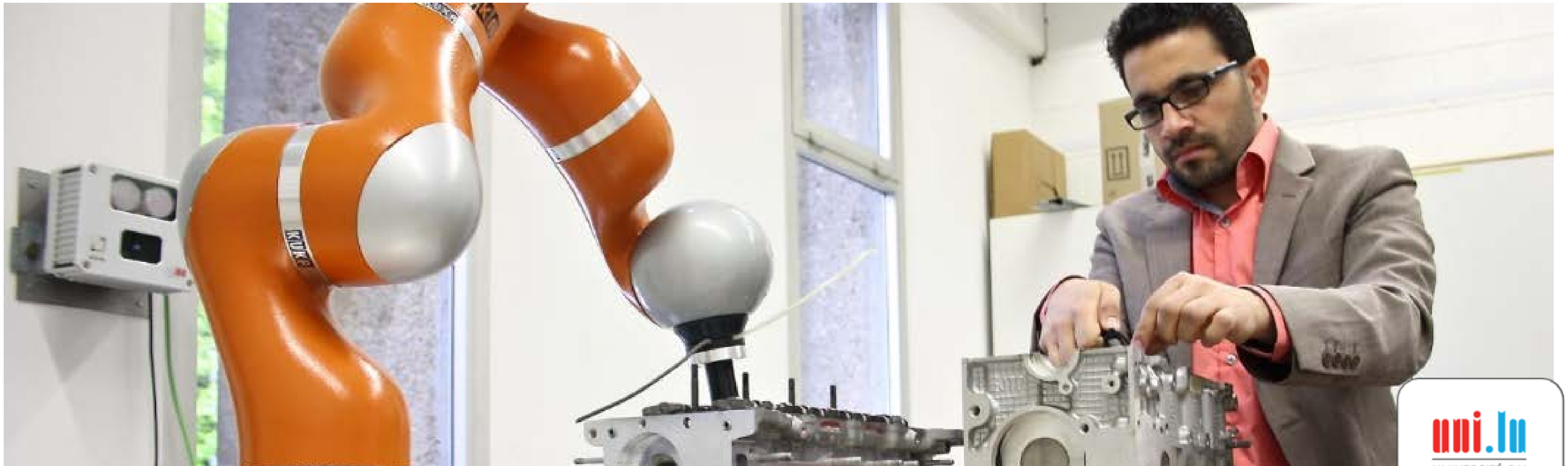
Summarizing:

Full robotic automation may not be the answer for small lot production

Vision of the future: Semi - automation

Robotic automation as enabler





Sources: Uni Luxembourg, http://alliancecomm.biz, Miele AG

Complementary skills of human and robots

- **Strength of robots:**
  - Integrated process control
  - Repetitive accuracy
  - Fatigue-proof
  - Handling of heavy or sharp-edged parts
  - …

- **Weaknesses of robots:**
  - Simple tasks
  - Low flexibility
  - Low decision power
  - …

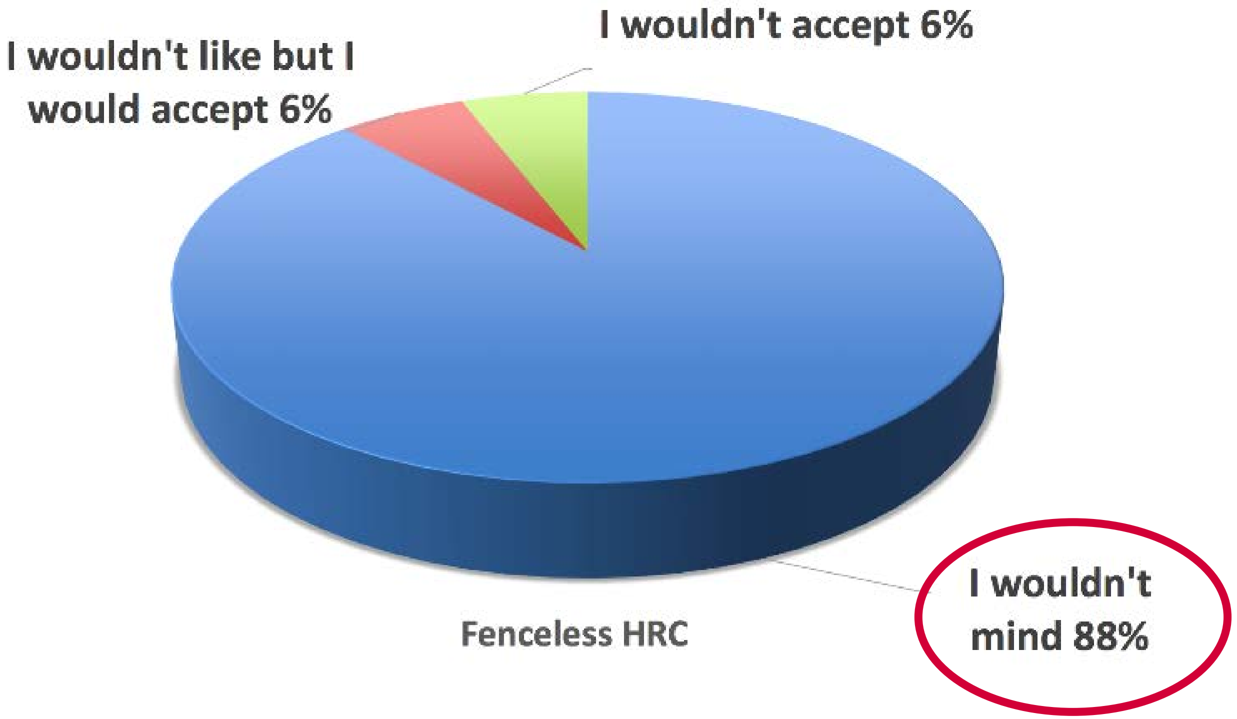
- **Weaknesses of human:**
  - Low repeatability
  - Variability of positioning
  - Limited force/ lifting capability
  - Exhaustion
  - …

- **Strength of human:**
  - High availability
  - Complex tasks, self adaptive
  - Handling of filigree parts
  - Accurate and fast positioning
  - …

Sources: http://alliancecomm.biz, Miele AG

Would you work alongside with an industrial robot?

Survey during EU project “fourbythree ”



http://fourbythree.eu/

HRC: Human Robot collaboration

Area of action for this vision / Robotic research topics

- **Assembly:**

- Manipulation of filigree parts
- Detect contact
- Compliant, flexible components
- Position inaccuracy
- Handle Heavy modules
- Consider unknown geometry
- Partial automation
- Safe interaction robot / worker

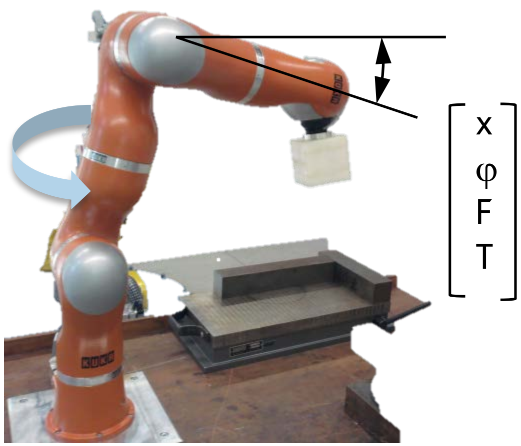
Sources: www.fotokonzepte.com; www.beisansystems.com/; www.make-ag.ch/images/; www.mercedes-seite.de/

Example 1: Robotic assembly of Product

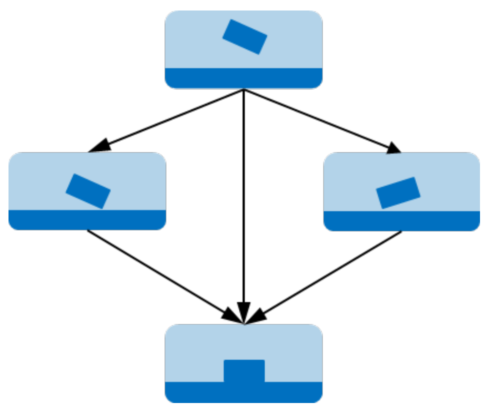
a) Detect discrete contact states

- **Robotic assembly**
- **„Peg-in-hole problem“**
- **Use of robot internal force and torque sensor signals**
- **Detect contact state**

Robot Control
Internal force, torque and pose signals

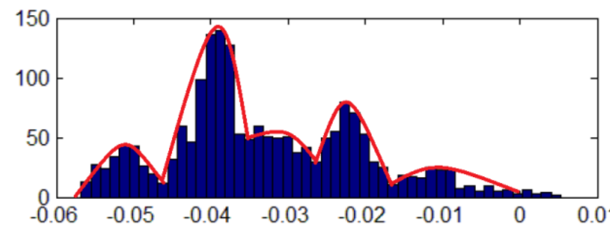


Method
Contact state recognition



Expectation Maximation Gaussian Mixed Models

$$p(x_k|c_i;\theta) = \sum_{q=1}^{M} \omega_q \mathbb{N}_q(x_k|c_i;\mu_q,\Sigma_q)$$



Published in Jasim, I.; Plapper, P.
Contact-state Recognition of Compliant Motion Robots Using Expectation Maximization –Based Gaussian Mixtures
Conference ISR Robotics 2014 pp 65 ff

Example 1: Robotic assembly of Product

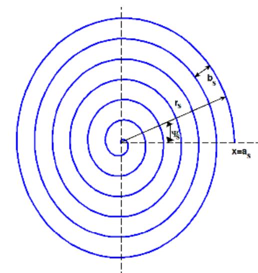
b) Search Algorithm

- **Self adaptive control for not precisely located parts**

- **Requirements:**

- Simple implementation
- Large Position Uncertainty
- High Success Rate
- Reduced Assembly Time

- **Results:**



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- Localization Success Rate

  92.5% (74/80) rigid peg

  90.0% (72/80) compliant peg

As reference: other literature (only rigid parts.):

- Particle Filtering resulted in LSR of 73.75% (59/80).
- Shape Recognition resulted in LSR of 66.25% (53/80).

Published in Jasim, I.; Plapper, P.; Voos, H.
Position Identification in Force-Guided Robotic Peg-in-Hole Assembly Tasks; Procedia CIRP 23 (2014) 217 -222

Example 1: Robotic assembly of Product

c) Industrial Application

- **Camshaft Cap Assembly**
- **Multiple peg-in-hole**
- **Archimedean spiral search**
- **Accommodates targeted variation**

Published in Jasim, I.; Plapper, P.:
Contact-State Monitoring of Force-Guided Robotic Assembly Tasks Using Expectation Maximization-Based Gaussian Mixtures Models International Journal of Advanced Manufacturing Technology, JAMT 7/ 2104 , DOI: 10.1007/s00170-014-5803-x, Springer, 2014

Example 1 – b : Robotic assembly of Product

c) Industrial Application

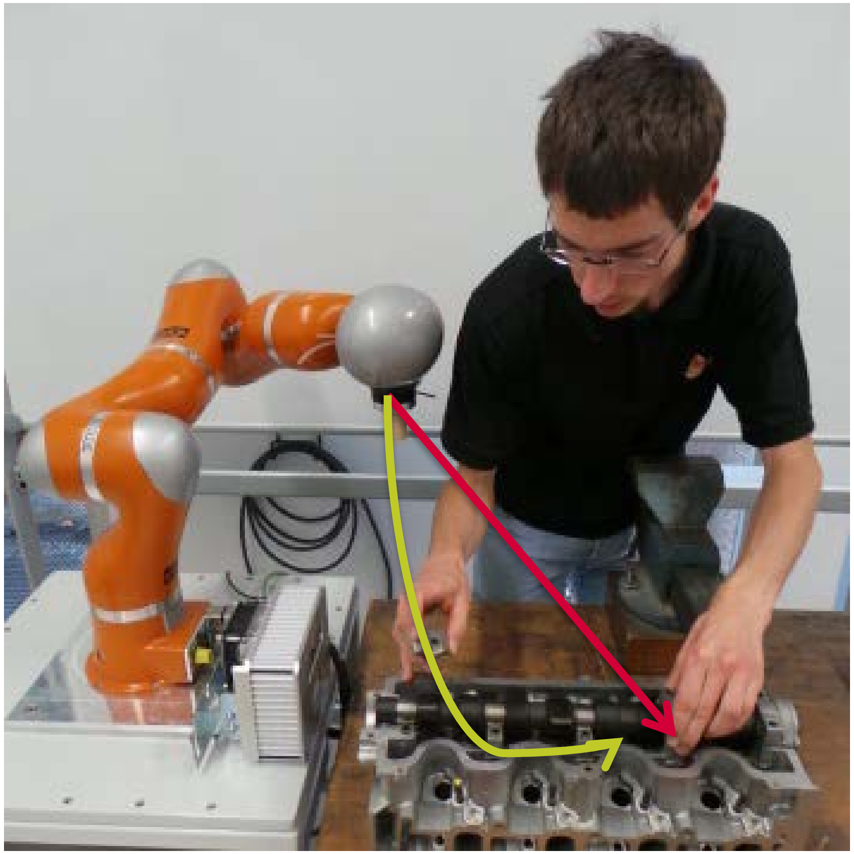
- **Manipulating of compliant parts**
- **Assembly of O-rings**
- **Automation of manual process**

Source: ABB / national industry

Example 2: HRC Human - Robot - collaboration

Safe working environment

Human Robot Cooperation for assembly



- Target: semi-automated assembly
- Human and robot interact in same working zone
- Safe detection of human required
- Dynamic environment => fast and real-time path planners are needed

Source: University of Luxembourg

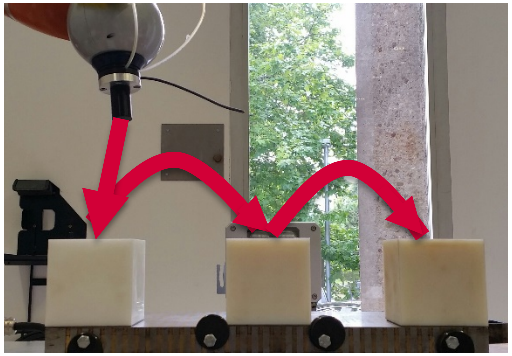
UNIVERSITÉ DU LUXEMBOURG

Example 2: HRC Human - Robot – collaboration (continued)

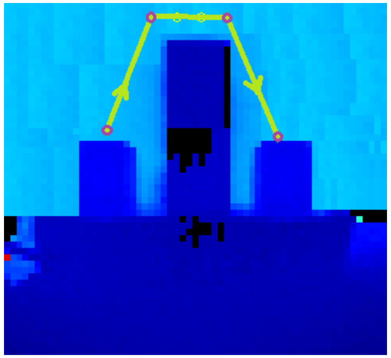
Collision avoidance - static

- 3D time-of-flight (T.o.F.) camera detects obstacles
- Path planning algorithm computes detour of obstacles

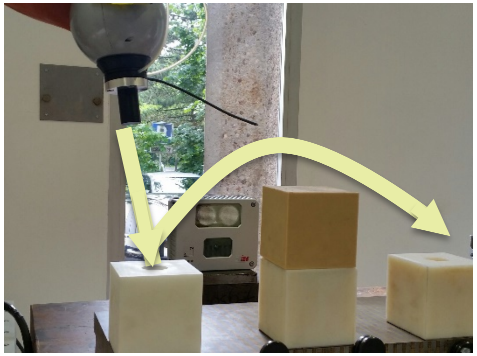
Initial planning
- Peg-in-hole process



3D-Time-of-flight sensor
- Scene information



Result
- Safe path applied by the robot

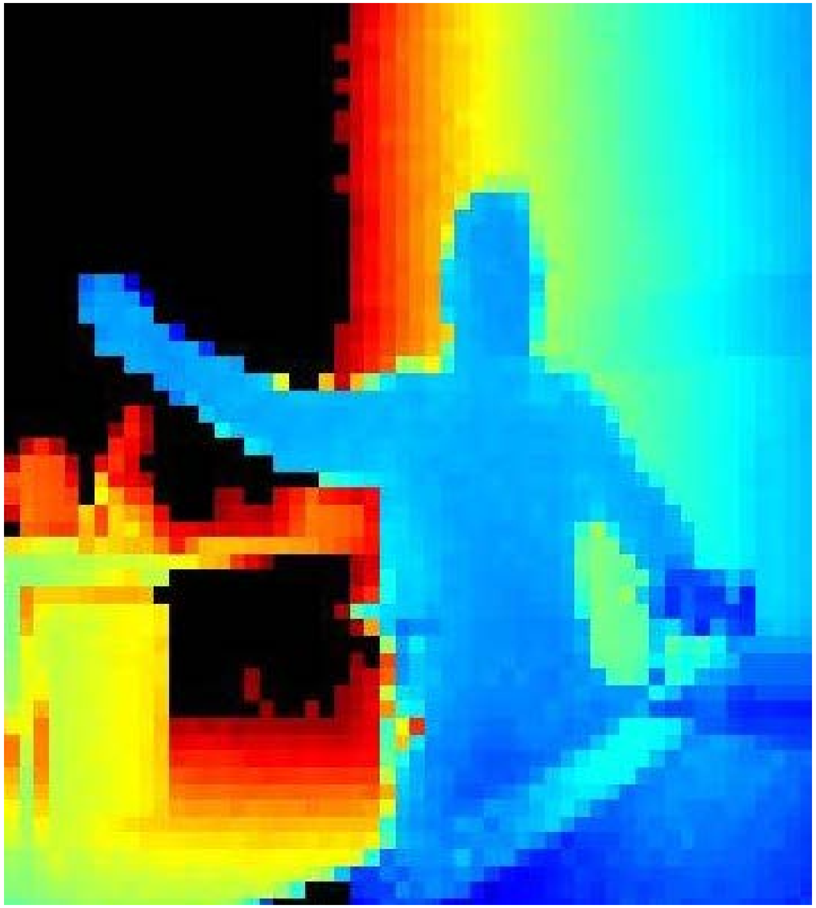


- Flexible assembly – considering unknown, un programmed obstacles
- Static environment

Published in R. Ahmad, P. Plapper:
Safe and Automated Assembly Process using Vision assisted Robot Manipulator,
Journal of CIRP Procedia, Presented in: 48th CIRP Conference on Manufacturing Systems, Ischia (Naples), Italy, June 2015

Example 2: HRC Human - Robot – collaboration (continued)

Collision avoidance- dynamic



Published in P. Plapper:
Semi-automated assembly using human-robot interaction
Business Meets Research, bmr, Luxembourg (2014)

- Robot & worker interact in the same area
- Optical 3D detection of moving obstacles
- Collision avoidance
- Intelligent decision
- Fast real time re-routing of robot path
- Dynamic distribution of labor content

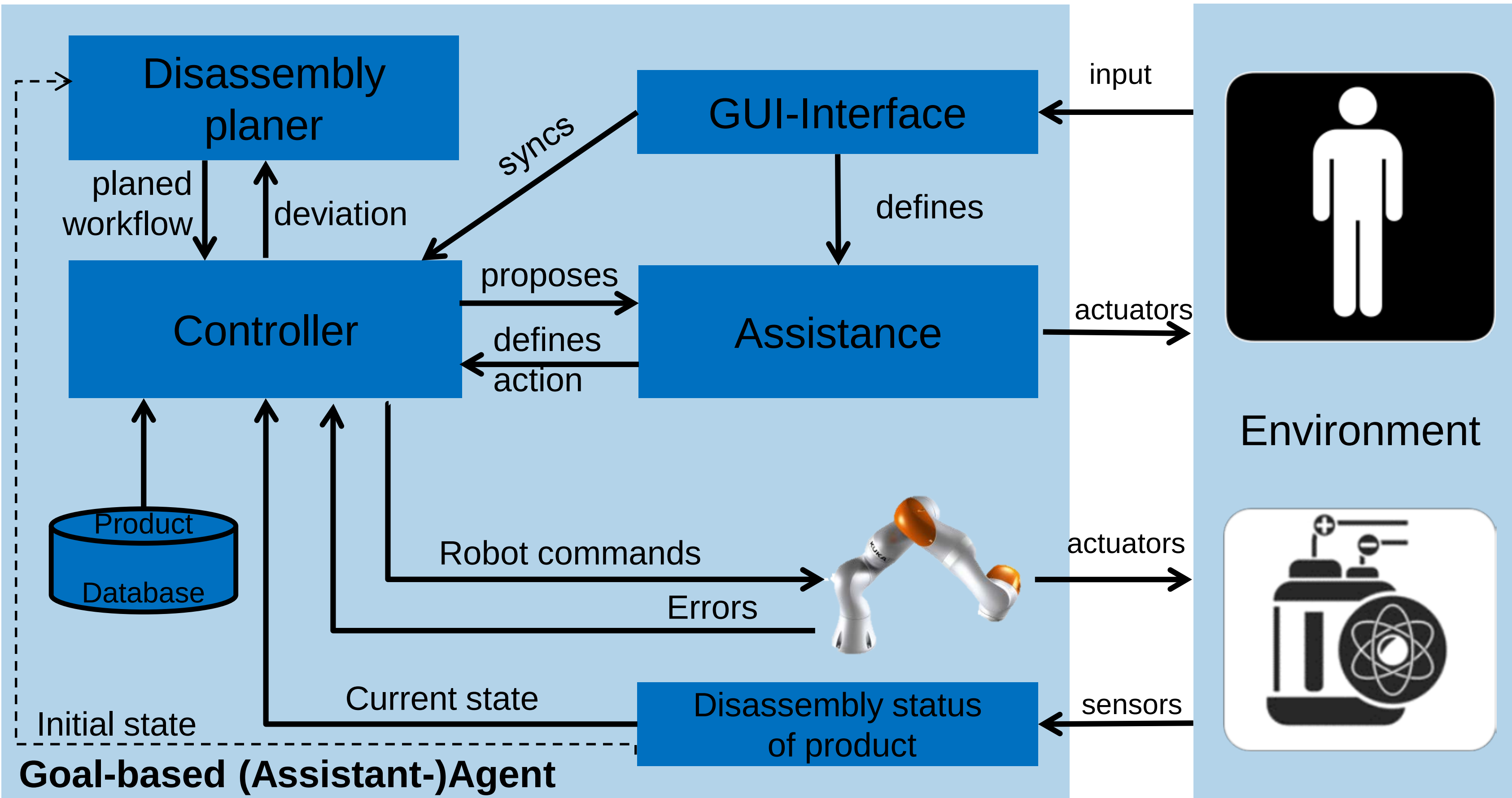
Example 3: HRC Human - Robot – collaboration

Disassembly

- Circular flow economy
- Partial automation
- Robot & worker share disassembly tasks
- No automatic decision about distribution of disassembly tasks available
- Planning tool for disassembly required
- Worker requests specific tasks as assistance from robot
- Distribution of labor content

Example 3: HRC Human - Robot – collaboration

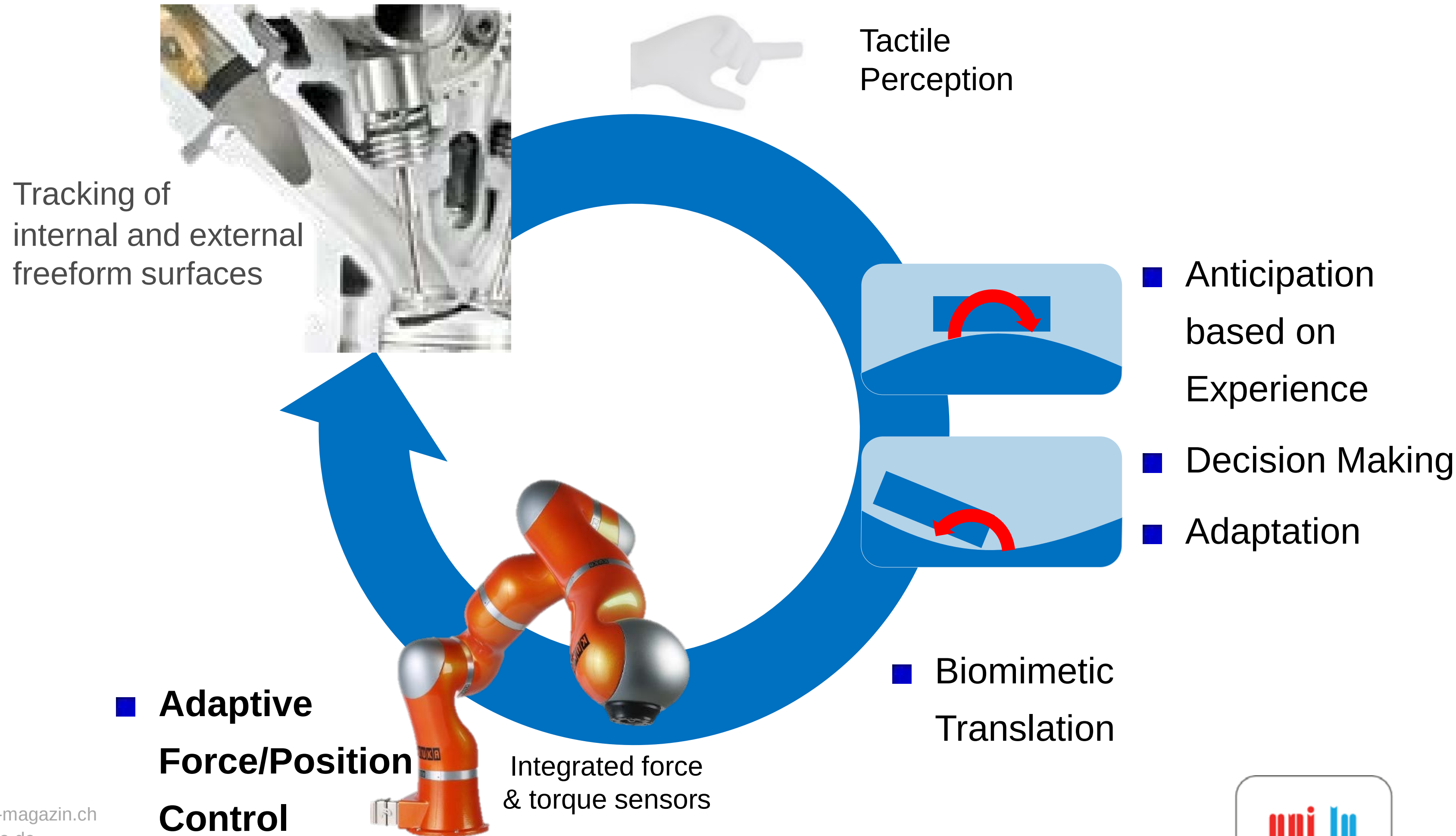
Disassembly



Accepted for publication in Jungbuth, J. Gerke, W, Plapper, P.:
Demontage von Elektroantrieben mit Assistenzrobotern zum wirtschaftlichen Recycling.
Angewandte Automatisierungstechnik; AALE 2016; Lübeck, 2016

Example 4: Robotic grinding

Path-tracking of 3 dimensional freeform surfaces



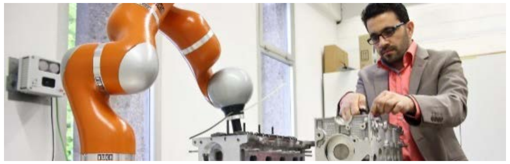
Sources:
www.toeff-magazin.ch
www.fotolia.de
http://www.metal-supply.com/announcement/view/7193/kuka_roboter_is_presenting_a_new_robot_generation_at_automatica_2010#.Vgkr5RvouUk (28.09.2015)

Summary

Robotizing of small lot production

- **Challenges due structural change**

- **Complementary skills of human and robots**



- **Examples:**
  - Robotic assembly of rigid and compliant parts
  - Robot and human interact in same work space
  - Disassembly assistance by robots
  - 3D free form grinding