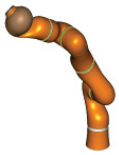
KUKA DLR



The KUKA-DLR Lightweight Robot

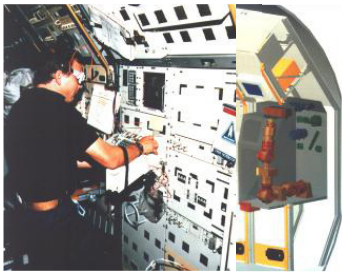
The KUKA-DLR Lightweight Robot – an advanced tool for robotics research, manufacturing and new applications

Winner of the euRobotics Tech-Transfer Award
European Robotics Forum 2011

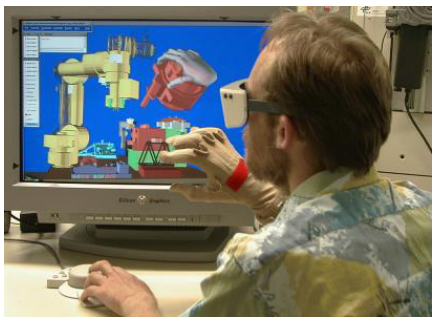
Dr. Ralf Koeppe, Head of R&D, KUKA Laboratories GmbH, Augsburg, Germany
Dr. Alin Albu-Schäffer, Head of the Mechatronics Department, Institute of Robotics and Mechatronics, DLR, Wessling, Germany

The Origins of the Product

ROTEX 1993



GETEX 1999



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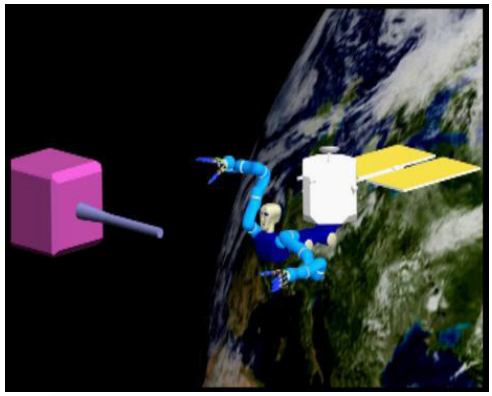
The first robots in space

Space Driven Robot Development at DLR

Change of paradigm:

From large, rigid and position controlled to light-weight, compliant, and adaptable

Therefore we coined the name "Soft Robotics"



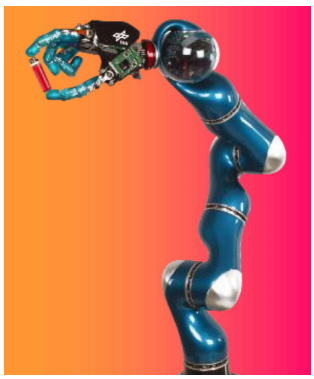
Evolution of the DLR Light-Weight Robots

- Three generations of robot arms

1995

1999

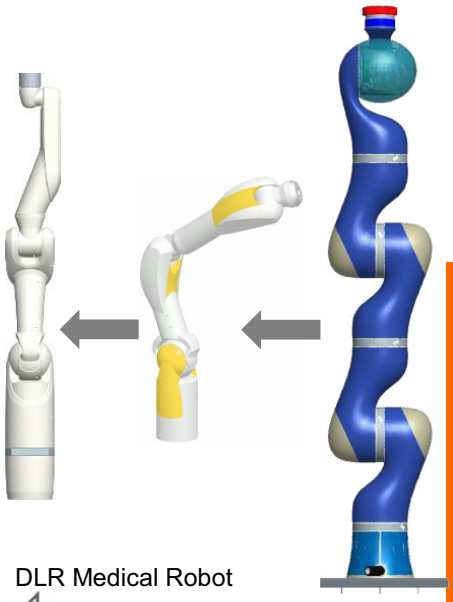
LWRIII



2003

Torque sensing in each joint, after the gear-box

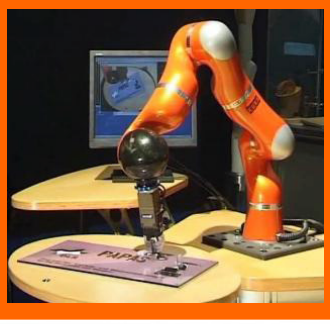
Evolution of the arm since 2003



Justin

DLR Medical Robot

Technology Transfer to KUKA



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"Soft Robotics" Features

torque control, gravity compensation

force and vision

programming by demonstration

safety

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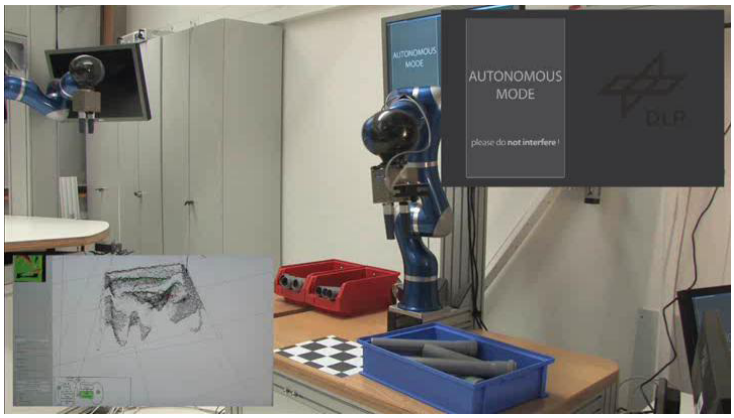
Highlights in research

controlling the LWR
through the brain

LWR as haptic input device
at ILA 2010, Berlin

New Programming Paradigms

- Safe physical human-robot interaction
- Reactive behavior
- Hands-on robot programming



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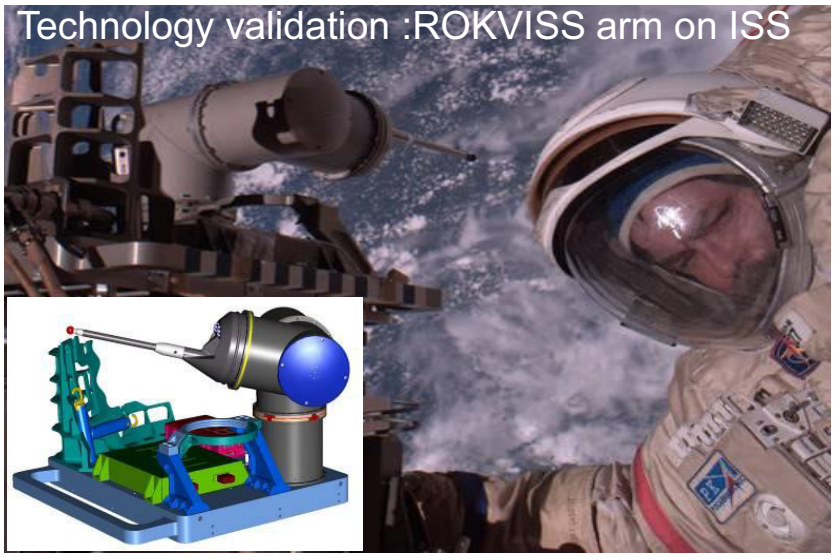
Modularity and light-weight allows the construction of complex robots using the arm joints

Justin **DLR walker**

Technology validation :ROKVISS arm on ISS



Nov. 2004 – Dec.2010

The technology reached the maturity for commercialization

State of the Art

Barrett cable driven arm

Robotics Research Corp. arm

Mitsubishi PA10 arm

Schunk modular arm

Still, there was a strong demand for arms which are

- Anthropomorphic in size and kinematics
- Strong (weight/load ratio 2/1 at 24/7 operation, 1/1 for research)
- precise (as good as industrial robots)
- compliant (for fast assembly and interaction with unknown environments)
- highly sensorised thus reactive
- safe for physical interaction with humans
- modular and scalable
- with open research interfaces (on all levels, including torque)

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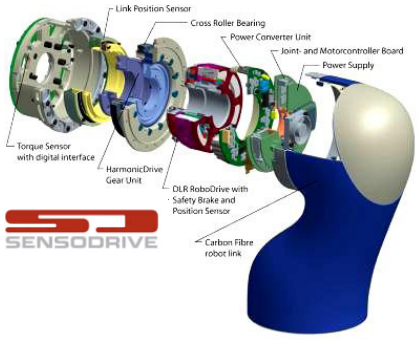
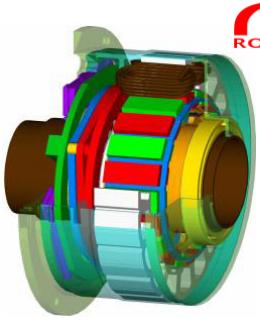
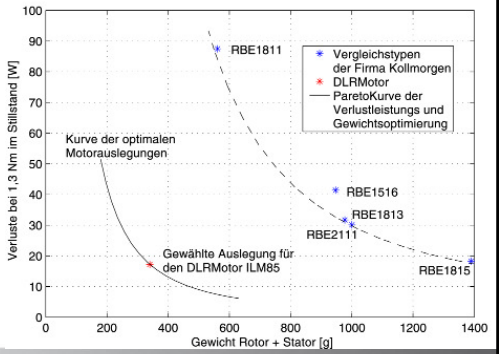
The development of a „robot-optimized“ motor ROBODRIVE was a key step for the the new lightweight arms.



ROBODRIVE





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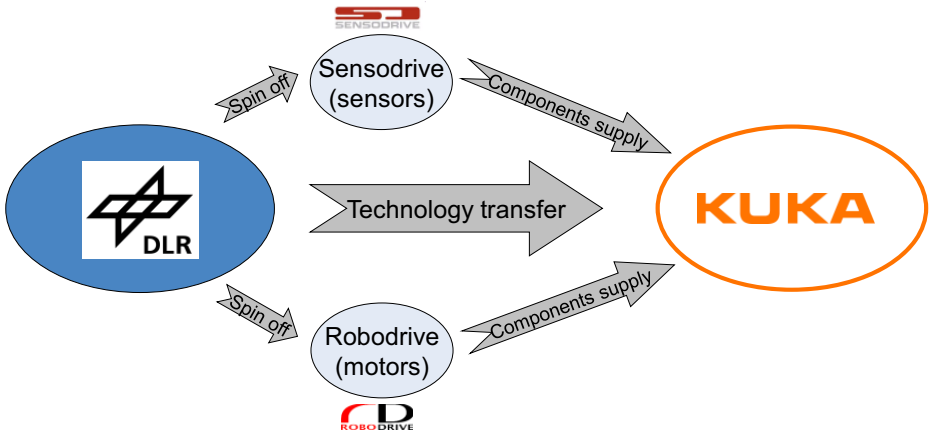
Technology Transfer Between DLR and KUKA

More than 100 high-tech jobs were created by the project



- Initial transfer of technology, patents, and know-how for the first DLR-KUKA robot
- Continuous support in the development of next models and transfer of new results through a strategic partnership

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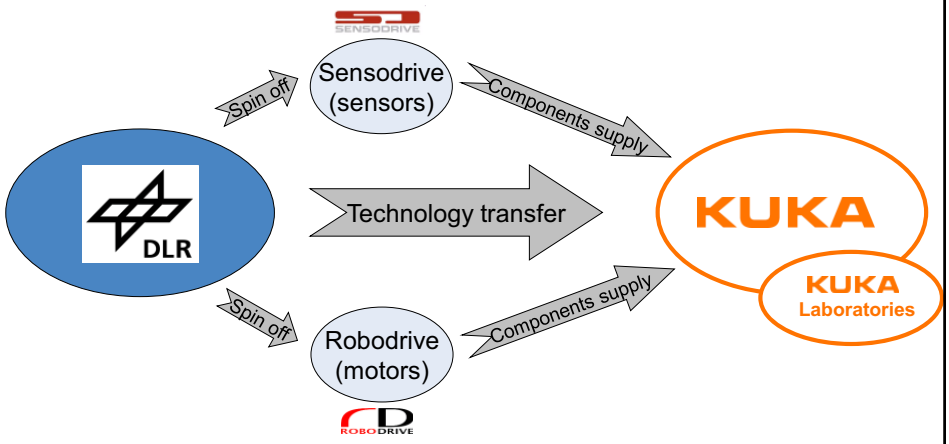
KUKA DLR

Technology Transfer Between DLR and KUKA



More than 100 high-tech jobs were created by the project

Product genesis – technology transfer stage

merging best of both worlds:

- DLR:
  - lightweight robot design
  - compliant control
  - torque measurement in joints
- KUKA:
  - sequence control
  - robot programming language
  - operator interface (KUKA look & feel)
  - I/O interfaces, field buses

DLR basic controller

DLR basic controller
KUKA KRC

Novelty of the product – innovative features

gravity compensation

kinematic redundancy

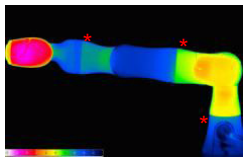
programmable damping

programmable stiffness

Product genesis – from prototype to product

numerous (sometimes “invisible”) improvements along the way:

- revised design for series production and industrial use
  - lowering production and service costs
  - caring for maintainability
  - improving EMC (electromagnetic compatibility) and passing tests
  - assuring norm conformity (e.g. ISO 10218)

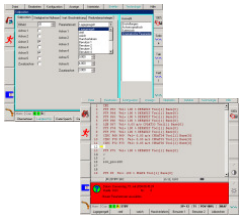


Thermal Management

drive train
gears, drive electronics

aluminum
structure

I/O
connectors



HMI for setup; functionality in KRL; seamless switching of control modes

Product genesis – product development stage

LWR 3 (Dec. 2008)

- prototype robots
- basic development
- no sale
- first application experiments with academic and industrial partners

LWR 4 (July 2010)

- zero series robots
- fundamental product improvements
- sales area: Europe
- sale to research departments
- collect experiences about operational availability
- input for LWR5 specification

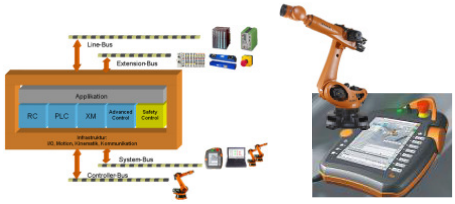
LWR 4+ (2012)

- zero series robots
- further improvements towards industrial use adding KUKA technologies for robot accuracy for exchangeability
- sales area: Europe + USA, Canada
- sale to research departments + key customers
- intended use: behind fences

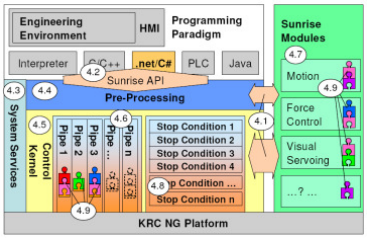
LWR 5

- series robots
- New design
- Safety, Maintainability, Dependability
- sale in large quantities
- sales area: worldwide
- intended use: safe without fences

Towards LWR 5 – The Robot Human Collaborative Robot



KRC Nexxt Controller Architecture / Safety Regulation



KUKA Robot Operating System

Market analysis, economic viability and pathway for commercialization

4 Medical


- Medical robotics: market size > US$1.8bn in diagnosis, surgery and therapy

3 General Industry


- Transfer of high volume automation to lotsize one
- Market twice the volume of automotive

2 Automotive


- Assembly in German automotive industry: only 5% automated, market size 300 million €, > 250.000 employees

1 Research


- New reference platform in robotics research
- Open and fast control interfaces

Ongoing sequential market introduction

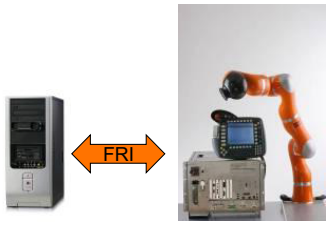
1 Research

KUKA DLR

Example: Fast Research Interface (FRI)

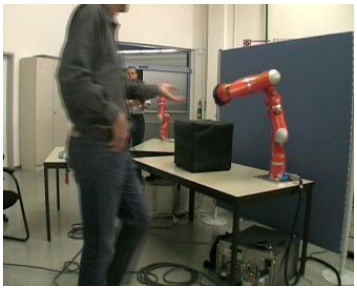
purpose:

- to remotely control the LWR
- to enable researchers to combine their own control algorithms and peripherals with the unique features of the LWR
  (researchers can focus on their research!)
- access at 1 ms



examples:

- DLR: connect LWR to haptic input device
- TUM: mobile dual handed manipulation
- KUL: peer-to-peer haptics



1 Research

KUKA DLR

Impact on research and education

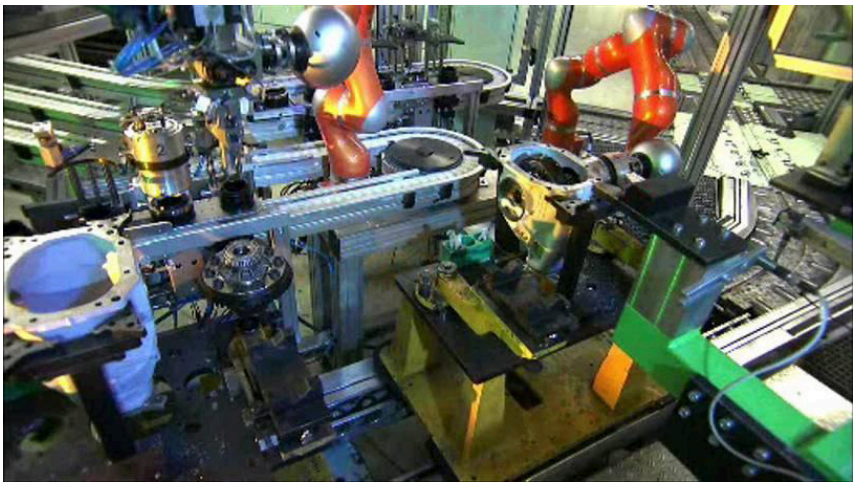





2 Automotive

Example: Daimler pilot plant

- More than 40,000 transmissions have been produced to date!



2 Automotive 3 General Industry

Future impact on and relevance to industry

Gear assembly

Sealing plugs insertion

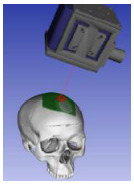
Flexible part assembly

Mechatronic products assembly

4 Medical

Future impact on and relevance to industry

Robot Assisted Biopsy
Kalender, University of Erlangen

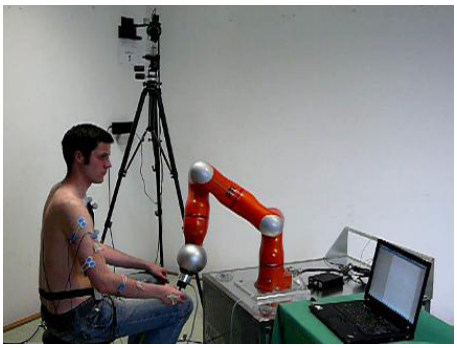


Robot Assisted Laser Bone Cutting
Wörn, Raczkowsky, KIT
EU Project
AccuRobAs:
Accurate Robot Assistant

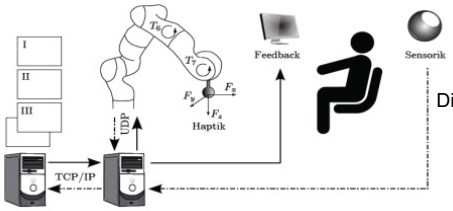
4 Medical

LWR in Medical Rehabilitation – KUKA driven research at RWTH Aachen

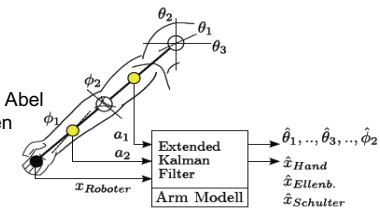
Shoulder flex motion



Hand to mouth motion



Disselhorst-Klug, Abel
RWTH Aachen



Sustained competitive advantage

- KUKA's advantage:
  first mover in actively compliant robot arms and applications:
  - intuitively programmed and high motion performance
  - very relevant to the manufacturing industries, but also beyond
- KUKA's competitive advantage is sustainable because of
  - the intensive and exclusive collaboration with DLR
  - the expert know-how needed to parameterize and fine-tune low-level control algorithms
  - filed strategic patents on LWR technology
- The LWR generates great business opportunities in known and new markets.

Conclusion:

From intention (1991) to invention (1998-2003) to zero series product (2008):

The KUKA-DLR Lightweight Robot
has become a historic milestone in robotics.

Acknowledgement

- **KUKA Laboratories GmbH:** Bernd Liepert, Dr. Ralf Koeppe, Dr. Johannes Kurth, Dr. Günter Schreiber, Dr. Rainer Bischoff, Florian Hofmann, Wilhelm Müller, Michael Gerung, Achim Heinze, Dr. Matthias Kurze **former DLR members**
- **DLR:** Prof. Dr. Gerd Hirzinger, Dr. Alin Albu-Schäffer, Alexander Beyer, Oliver Eiberger, Dr. Gerhard Grunwald, Sami Haddadin, Georg Plank, Andreas Stemmer
  - *RoboDrive GmbH:* Manfred Schedel
  - *Sensodrive GmbH:* Norbert Sporer
- **Sponsors:**
  - Bavarian government: Bayerische Forschungsstiftung, Bayern Innovativ
  - German government: NEUROS, LISSY, DIROKOL, MORPHA, PAPAS, and DESIRE
  - European Commission: PHRIENDS, SMErobot, BRICS
  - KUKA and DLR are very grateful for these contributions.

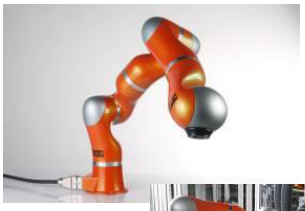
Thank you very much for your attention

LWR 1

LWR 2

LWR 3

LWR 4
Research Applications



LWR4+ Industrial
Evaluation Projects