IROS 2011 Workshop

European Efforts in Strengthening the Academia-Industry Collaboration

Friday, Sept. 30, 2011
San Francisco, California

Abstract:

Several key projects funded by the European Commission emphasize the need for a tighter cooperation between academia and industry in robotics.

euRobotics is a Coordination Action involving stakeholders of well-known European initiatives, namely EURON and EUROP. euRobotics has two main objectives:

1. Improvement of cooperation between robotics stakeholders in academia and industry
2. Promotion of European robotics

Furthermore, euRobotics aims at strengthening the European robotics community across all robotics sectors (industrial, professional service, domestic service, security and space robotics).

ECHORD (European Clearing House for Open Robotics Development) is an innovative framework aiming at intensifying the collaboration between scientific research and industry in robotics. After the set-up phase, where approx. 50 small projects, so-called experiments were selected based on independently evaluated proposals, this project has the unique opportunity to accompany these projects scientifically by the mechanism of a “structured dialogue” and thus to gain additional knowledge for the whole community. ECHORD is funded by the European Commission within the 7th Framework Programme, Challenge 2: Cognitive Systems, Interaction, Robotics (FP7-ICT-231143, http://www.echord.info).

There has been a long history of outstanding research and development in both robot manufacturers and research institutes. However, finding common ground between manufacturers and the research community, especially when it comes to defining the future direction of robotics research, has proven difficult in the past. This is one of the recurring themes on both sides, and a new level of cooperation is long overdue. The goal of the proposed workshop is to strengthen the exchange of knowledge and experience between scientists and practitioners and to inspire the robotics community to form new types of cooperation.

The workshop will comprise two parts. The first part focuses on an overview of the exisiting European robotics networks EURON and EUROP and projects such as euRobotics with their scientific direction and the activities intended to transfer the knowledge:

- EUROP is an industry-driven framework for the main stakeholders in robotics to strengthen Europe’s competitiveness in robotics R&D and global markets. EUROP is one of several European Technology Platforms (ETPs) supported by the European Commission.

- EURON is a community of more than 220 academic and industrial groups in Europe with a common interest in advanced research in the field of robotics. The network was founded in 2000 and was supported by the European Commission for 8 years.
- The euRobotics Coordination Action targets two main objectives: the improvement of cooperation between industry and academia and the enhancement of public perception of (European) robotics. The euRobotics Coordination Action is funded by the European Commission within the 7th Framework Programme, Challenge 2: Cognitive Systems, Interaction, Robotics (FP7-ICT-244852; 01/2010 – 12/2013).

The second part will use the pool of ECHORD experiments to exemplarily point out ideas and first results in different industrial relevant scenarios: "human-robot co-worker", "hyper-flexible manufacturing cells", and the "cognitive factory". Within these scenarios, different research foci ("human-robot interfacing & safety", "robot hands & complex manipulation", "mobile manipulators & cooperation" and "networked robots") allow to categorize the work and to streamline the “structured dialogue”. A systematic overview of the ECHORD experiments will be given by the coordinating partners of ECHORD (i.e. Alois Knoll and/or Bruno Siciliano), based on a systematic analysis of the experiments with respect to the above mentioned categories and taking further different types of experiments (i.e., Joint enabling technology development by academia and industry, application development, and feasibility demonstration) into account.
In addition to this general overview, selected experiments will have the opportunity to present their results and discuss them with the participants. The main focus of these presentations and discussions will be on practical use of the scientific work and knowledge transfer aspects.

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Economic analysis of new service robot applications and their relevance for robotics development (EFFIROB)

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On behalf of the German Ministry of Education and Research (BMBF), the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) and Fraunhofer Institute for Systems and Innovation Research (ISI) developed some novel service robot applications between December 2009 and November 2010 and analyzed their techno-economic relevance for robotics. In addition to conceptual considerations, the aim was to analyze the technical and economic feasibility of the service robot applications with reference to specific application scenarios. These findings were then used to determine the necessary R&D input for improving the cost/benefit ratios in relation to key technologies, components and system development processes.

For this purpose, a comprehensive method set with associated software tools was developed in order to provide developers and users with a costing-based decision-making tool for their involvement in service robot application areas. The methods focus on practical engineering and business-management techniques – especially axiomatic design (AD) – as well as life cycle cost (LCC) analysis. The combination of these methods guarantees an evaluation of the technical and economic feasibility of the service robot scenarios from the user's viewpoint.

Eleven examples of novel applications from seven target markets were analyzed as service robot scenarios. These differ considerably in terms of technical implementation and business-management evaluation:

- Groundskeeping
- Holding ready of care utensils
- Moving of elderly persons in residential care homes
- Ground-crop harvesting
- Floor cleaning
- Transport of containers in hospitals
- Cleaning of building facades
- Assistance in interior finishing works on buildings
- Sewer inspection
- Dairy farming
- Assistance on production lines

The core messages of the study can be divided into three areas: analysis of market potential, assessment of the components and technologies used as well as assessment of the required research input.

Summary analysis of market potential

- Reducing the initial costs of acquisition is not normally the overriding factor for increasing the economic efficiency of a service robot concept. Only in a few service robot scenarios are the initial costs of acquisition the key cost driver – they usually account for less than 25% of total life cycle costs.
- Exceptions can be found, for example, in the "Groundskeeping" and "Floor cleaning" scenarios. Here, the necessary cost reductions in order to break even compared to how the activity is currently done, of well above 50%, cannot be plausibly justified by economies of scale, at least in the short term.
- Conversely, it follows that reducing the activity costs may offer an easier means of achieving greater economic efficiency, e.g. by means of a more robust, technical solution with lower maintenance and upkeep costs.

There is no evidence that additional qualitative benefits are of decision-making relevance in cases where economic efficiency is poor.

- In all markets, economic efficiency is the primary decision-making criterion. Consequently, qualitative factors cannot outweigh poor economic efficiency.
- There might be exceptions in heavily regulated markets, such as the long-term care market, where additional costs might be absorbed, for example, by health/long-term care insurance institutions.

High economic efficiency does not necessarily mean high exploitation of possible market potential.

- The conducted market structure analyses have shown that, in many of the target markets, despite a positive microeconomic assessment, the macroeconomic financing options might represent a constraint with regard to fast market penetration by the service robot application. Normally, either equity financing or debt financing of a service robot application will enter into consideration only for large companies.
- This is where new business models from robot manufacturers could offer an alternative – especially business models that focus on the performance of the product (pay per service, pay for availability, flat rate). This might help overcome the previously mentioned financing obstacles and thus increase the identified exploitation of market potential.

SUMMARY ASSESSMENT OF THE COMPONENTS AND TECHNOLOGIES USED

On the basis of existing standards, the safety-related design of service robots is complex but realizable.

The safety of a service robot is a fundamental prerequisite for its introduction on the market. Risks can be determined on the basis of currently available methods and can be addressed by established measures:

- Existing (and announced) ISO standards already provide a basis for the risk assessment and safety-related design of service robot systems. Additional standards, specifically with a focus on the safety of service robot systems, are currently in preparation.
- The risk assessment and safety-related design of service robot systems calls for an extensive knowledge of complex standards as well as experience of the realization and certification of service robot systems. Standard procedures and examples of best practice, which to a great extent do not exist at present, would be helpful.

A broad range of key mechatronic components is already available for service robots.

The presented service robot applications have already been realized on the basis of a catalogue of mechatronic components. This resulted – almost automatically – in a common-parts strategy across the applications.

- The considered applications require only a few totally new mechatronic components. The – in some cases – very high component prices are an indication of the currently low unit volumes.
- There is a lack of components for simplifying safe interaction between humans and robots.

Significant software development costs demand cross-application reuse of software components.

Developing software results in significant costs for manufacturers and integrators of service robots together with comparatively low annual unit volumes:

- Especially in the case of low to medium unit volumes, cross-application reusable components within standardized system architectures are absolutely essential for keeping software development costs under control.
- To give service robot manufacturers and system integrators greater planning certainty and thus make entry into the market easier, public availability of software components and know-how about service robot software development must be promoted.
- To estimate the costs of software development, it is necessary to develop software engineering tools that help to plan and monitor the use of resources.

Summary assessment of the required research input

Identified research requirements complement existing roadmaps and research initiatives.

Although it was not the purpose of the study to formulate a technology roadmap, the key service robot technologies were identified on the basis of technology taxonomies and glossaries of existing robotics roadmaps and position papers.

- As the investigated scenarios are based on clearly defined tasks with extensively fixed sequences of actions, an analysis of key cognitive robotics technologies (machine learning, reasoning, automatic planning of actions) was for the most part excluded from this study.
- This study focuses on the following four areas of technology: object recognition, navigation, manipulation and human-machine interaction.
- Measures for improving the efficiency and success of the service robot development process, especially from the supplier's viewpoint, have not hitherto been studied in detail in any roadmap.
- This study does not include a timescale or estimate of required resources for achieving the research and development goals.

As expected, object recognition is the key basic technology for industrial service robotics. It is linked to other technologies.

- Improvements in object recognition have widely ramified impacts in other basic robotics technologies. Therefore, research efforts should aim at making it possible in future for objects to be recognized faster, more reliably and in greater number.
- Required service robot availabilities of virtually 100% mean that development should focus on especially robust object recognition processes. Uncertainties in the recognition of objects, environments and individuals can be addressed by "shared autonomy" (i.e. assistance from the human if he or she detects uncertainty or an error condition).
- Metrics and benchmarks for the development and specification of key object recognition technologies should be implemented in the context of test scenarios representative of typical application requirements.

Robustness of key navigation technologies (self-localization, path planning) is seen as a crucial requirement by suppliers and users.

- To assess the navigational robustness of mobile robots, metrics and benchmarks should be established for systematic evaluation and specification of key navigation technologies.
- To improve the navigation of autonomously mobile service robots, the robustness of path planning and self-localization should be improved.

Focus of manipulation is on robust gripping of workpiece spectra and everyday objects.

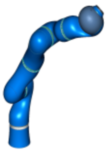
- The capacity of physical interaction with objects (manipulation) is a key technology for opening up new areas of application for service robots. The gripping of objects is a typical performance-determining cross-cutting requirement. An attempt should be made, therefore, to make improvements in gripping speed (gripping planning) and grip variability (number of grippable object forms).
- Gripping uncertainties must be detected and, where possible, interactively addressed by shared autonomy.

Efficient and safe human-machine interaction improves user acceptance and efficiency of use, especially with regard to activity costs.

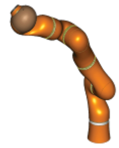
- Reliable speech recognition increases intuitive usability; recognition rates similar to those for neck microphones should be the goal.
- If the robot misperforms or fails in a task, the human must have a simple possibility to return the robot to the desired mode of operation. A possible approach is so-called "shared autonomy", which allows teleoperation of the robot by computer (possibly by a call-center employee) or mobile phone.
- There is a need for safety components that facilitate direct interaction, e.g. contactless emergency shutdown ("virtual bumper" or safety skin, or collision protection by means of a 3D CCD workspace-monitoring camera).

Efficient software engineering is vital for reducing the development costs of service robot applications.

- High costs could be lowered by promoting public software libraries (repositories) with standardized and re-usable components.
- To give service robot manufacturers and system integrators greater planning certainty and thus make entry into the market easier, there is a need for tools and methods for cost estimation and financial controlling of service robot software development.
- Cross-application (re-)use of components requires a thorough specification process to minimize development costs and risks. Systematic experimental evaluation of key functions with reference to test cases based on the requirements of typical scenarios should be a key focus of research.



KUKA DLR



The KUKA-DLR Lightweight Robot

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

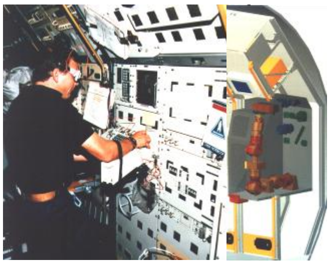
Winner of the euRobotics Tech-Transfer Award

European Robotics Forum 2011

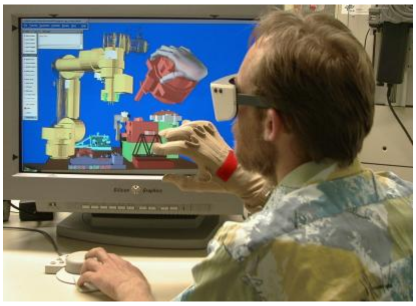
Dr. Ralf Koeppe, Head of R&D, KUKA Laboratories GmbH, Augsburg, Germany
Dr. Alin Albu-Schäffer, Head of the Mechatronics Department, Institute of Robotics and Mechatronics, DLR, Wessling, Germany

The Origins of the Product

ROTEX 1993



GETEX 1999



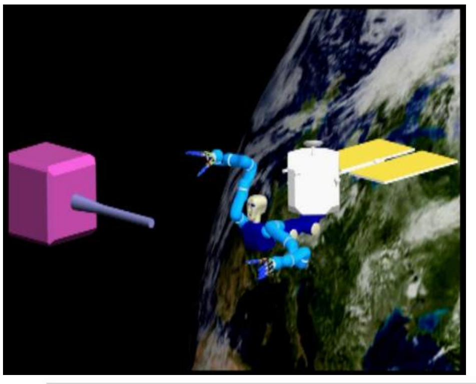
The first robots in space

Space Driven Robot Development at DLR

Change of paradigm:

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

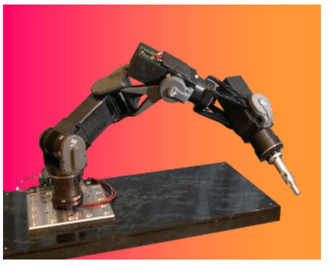
Therefore we coined the name "Soft Robotics"



Evolution of the DLR Light-Weight Robots

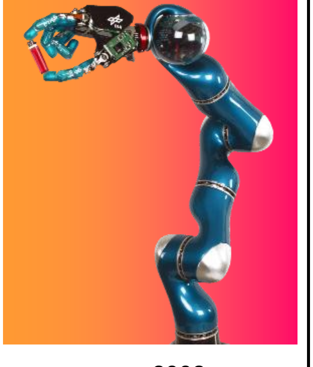
- Three generations of robot arms

1995



1999

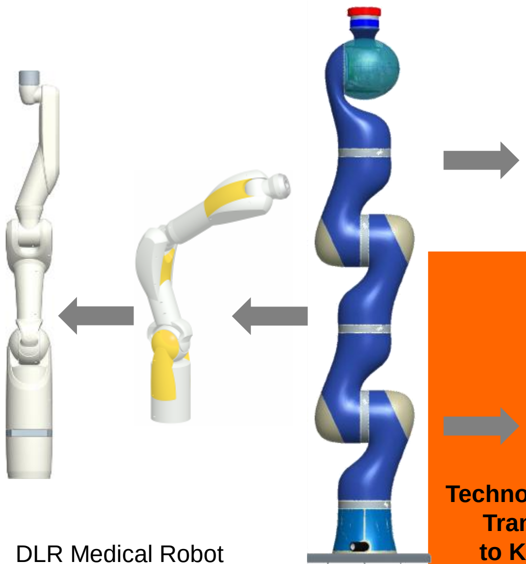
LWRIII



2003

Torque sensing in each joint, after the gear-box

Evolution of the arm since 2003



DLR Medical Robot

Justin

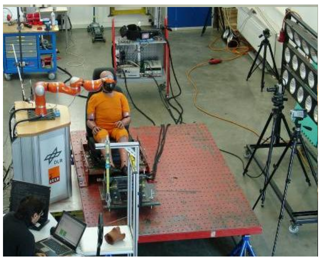
Technology Transfer to KUKA

"Soft Robotics" Features

torque control, gravity compensation

force and vision

programming by demonstration



safety

Highlights in research

controlling the LWR
through the brain

LWR as haptic input device
at ILA 2010, Berlin

New Programming Paradigms

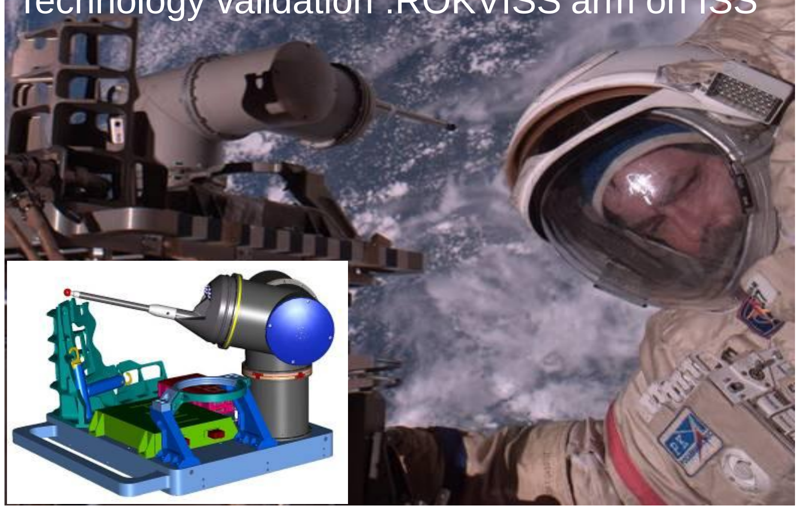
- Safe physical human-robot interaction
- Reactive behavior
- Hands-on robot programming

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

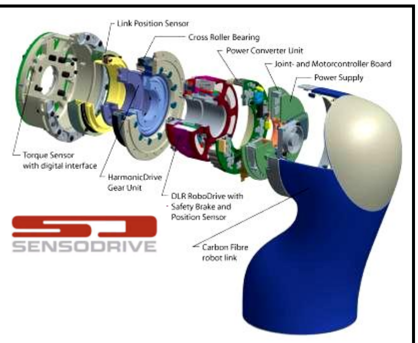
Mitsubishi PA10 arm

Schunk modular arm

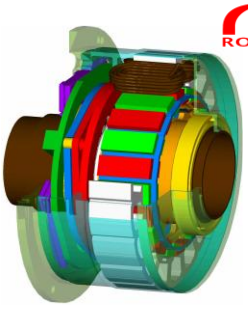
Still, there was a strong demand for arms which are

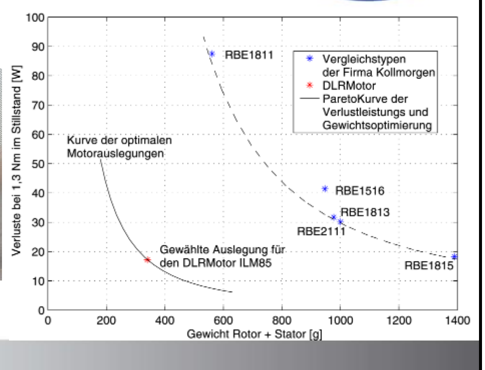
- Anthropomorphic in size and kinematics
- Strong (weight/load ratio 2/1 at 24/7 operation, 1/1 for research)
- precise (as good as industrial robots)
- compliant (for fast assembly and interaction with unknown environments)
- highly sensorised thus reactive
- safe for physical interaction with humans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

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



ROBODRIVE

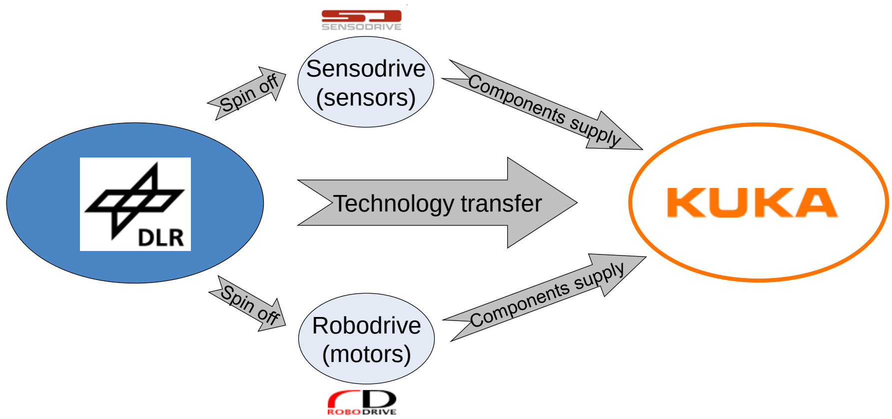




Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

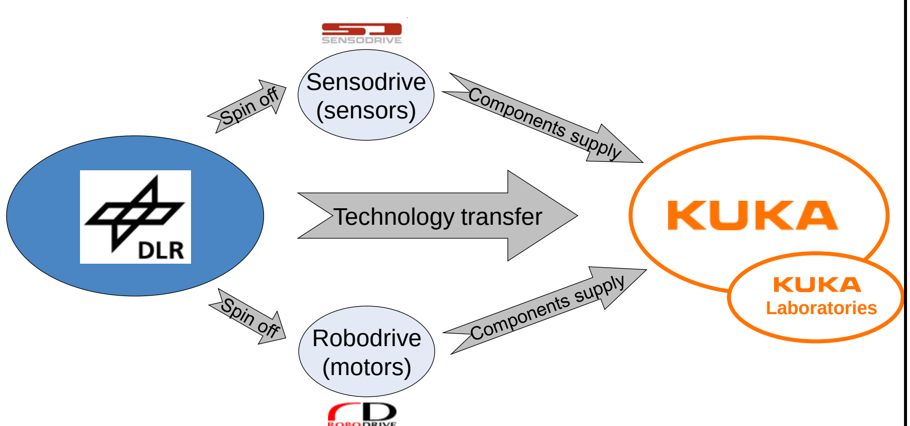
Technology Transfer Between DLR and KUKA

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

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

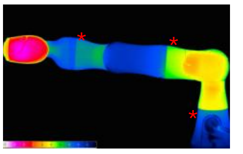
programmable stiffness

KUKA DLR

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)

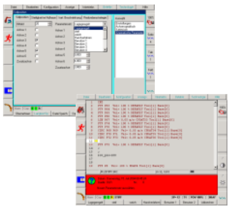


Thermal Management

drive train
gears, drive electronics

aluminum
structure

I/O
connectors



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

KUKA DLR

Product genesis – product development stage

LWR 3	LWR 4 (Dec. 2008)	LWR 4+ (July 2010)	LWR 5 (2012)
▪ prototype robots	▪ zero series robots	▪ zero series robots	▪ series robots

LWR 3

- prototype robots

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

Dec. 2008

LWR 4

- zero series robots

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

July 2010

LWR 4+

- 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

2012

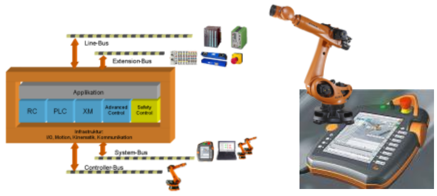
LWR 5

- series robots

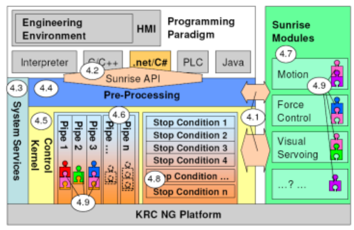
- New design
- Safety, Maintainability, Dependability
- sale in large quantities
- sales area: worldwide
- intended use: safe without fences

KUKA DLR

Towards LWR 5 – The Robot Human Collaborative Robot



KRC Nexxt Controller Architecture / Safety Regulation



KUKA Robot Operating System

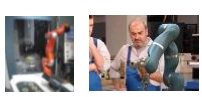
KUKA DLR

Market analysis, economic viability and pathway for commercialization

4 **Medical**

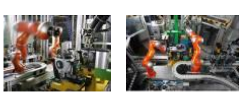
- Medical robotics: market size > US$1.8bn in diagnosis, surgery and therapy

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

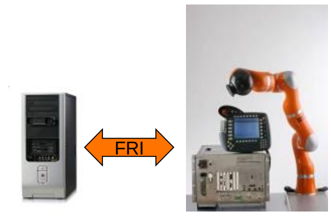
Example: Fast Research Interface (FRI)

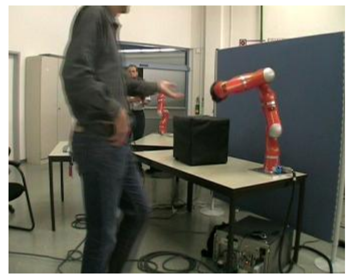
purpose:

- 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





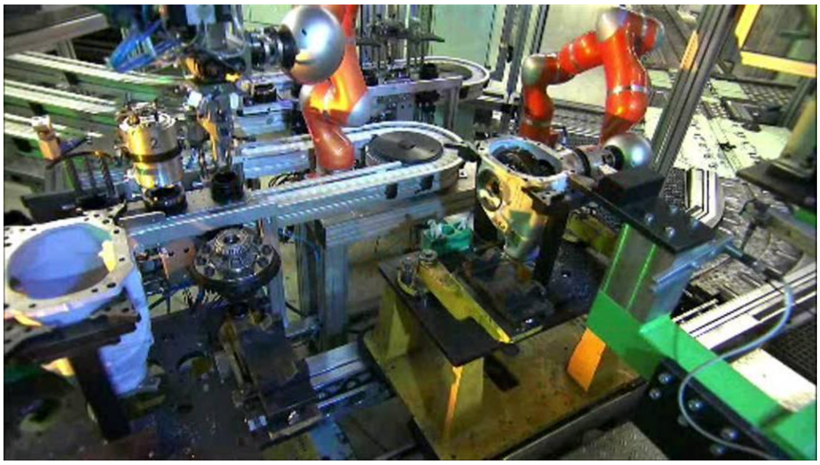
Impact on research and education

2 Automotive

KUKA DLR

Example: Daimler pilot plant

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



2 Automotive 3 General Industry

KUKA DLR

Future impact on and relevance to industry

Gear assembly

Sealing plugs insertion

Flexible part assembly

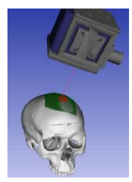
Mechatronic products assembly

4 Medical

KUKA DLR

Future impact on and relevance to industry

Robot Assisted Biopsy
Kalender, University of Erlangen

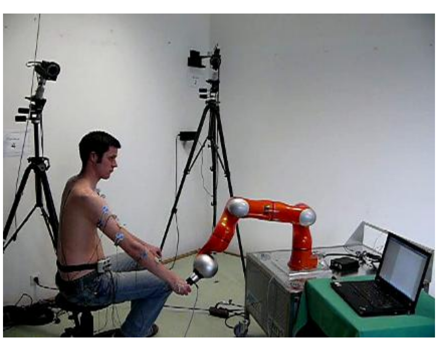


Robot Assisted Laser Bone Cutting
Wörn, Raczkowsky, KIT
EU Project
AccuRobAs:
Accurate Robot Assistant

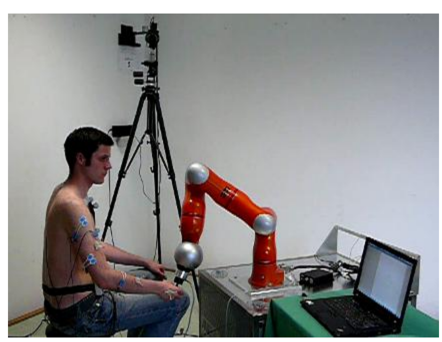
4 Medical

KUKA DLR

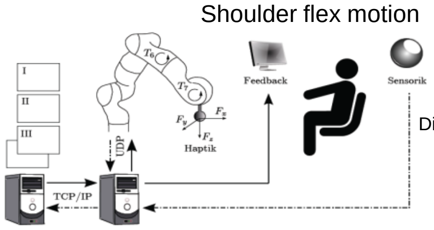
LWR in Medical Rehabilitation – KUKA driven research at RWTH Aachen



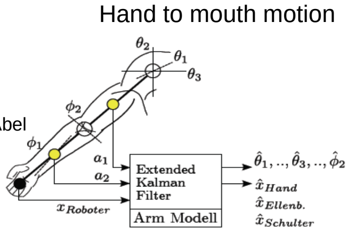
Shoulder flex motion



Hand to mouth motion



Disselhorst-Klug, Abel
RWTH Aachen



KUKA DLR

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.

KUKA DLR

Acknowledgement

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  - *Sensodrive GmbH:* Norbert Sporer
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  - 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

Industry-Academia Collaboration through Open Source

Jan Becker

Bosch Research and Technology Center, Palo Alto, CA

The Bosch Research and Technology Center in Palo Alto is the North American research arm of the Bosch Group. The center has offices in Palo Alto, CA, Pittsburgh, PA and Cambridge, MA and is working in close collaboration with the leading US universities and cutting-edge industry partners. Among the various tasks of the center is technology scouting and transfer of expertise from the academia into the company. Often a significant gap has to be bridged from cutting-edge research to industrialization.

The Robotics group in Palo Alto is an active participant in the Willow Garage PR2 Beta Program. Bosch is the only corporate research organization among 10 academic institutes to receive a PR2. As part of our engagement in the PR2 Beta Program, we develop and publish open source software and collaborate with Willow Garage, the PR2 community and the ROS community.

Collaboration with academia on the basis of open source has been very successful and has led to increased exchange of expertise and to improved repeatability of results.

This talk focuses on the challenges involved in academia-industry collaboration from the perspective of a corporate research lab.

HANDS.DVI@ECHORD
An abstraction layer for robotic hands based on postural synergies of human hands

Department of Information Engineering, University of Siena,
Centro "E. Piaggio", University of Pisa and
Advanced Robotics Lab, Italian Institute of Technology

Project Coordinator: Domenico Prattichizzo

People involved in HANDS.DVI at the University of Siena: Monica Malvezzi, Gionata Salvietti and Guido Gioioso and D. Prattichizzo; at the University of Pisa: M. Gabiccini, E. Farnioli and A. Bicchi and at the Italian Institute of Technology: N. Tsagarakis, I. Sarakoglou and D. Caldwell.

I. Introduction

Robotic hands have many degrees of freedom (DoFs) distributed among several kinematic chains: the fingers. The complexity of the mechanical design is needed to adapt hands to the many kinds of tasks required in unstructured environments, such as surgical rooms, food industry, house, space and other domains, where robotic grasping and manipulation have become crucial.

One of the main issues in designing and controlling robotic hands is that a large number of motors is needed to fully actuate the DoFs. This makes both the mechanical and the control system design of robotic hands dramatically more complex when compared to simple grippers often used in industrial applications [3]. Fig. 1 pictorially represents this aspect: the larger is the number of DoFs, the lower is the number of possible applications of the robotic hands in industries. This is one of the major limitations to the use of advanced robotic hands in flexible automation.

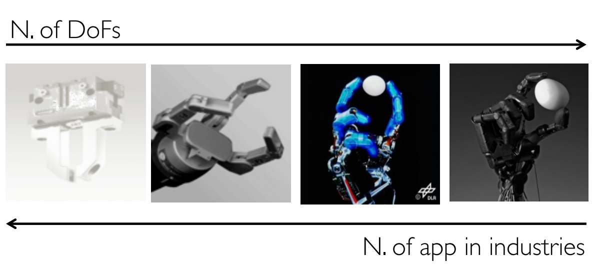


Fig. 1. Nowadays, the larger is the number of DoFs of the device, the lower is the number of industrial problems where these complex devices are used.

As far as control is concerned, it is our belief that the development of a unified framework for programming and controlling of robotic hands will allow to extend the use of these devices in many areas. Borrowing the terminology of software engineering, we believe that there is a need for middleware solutions for manipulation and grasping tasks to seamlessly integrate robotic hands in flexible cells and in service robot applications.

The goal of the ECHORD experiment: HANDS.DVI is to develop a unified framework for programming and controlling robotic hands based on a number of fundamental primitives, and abstracting, to the extent possible, from the specifics of their kinematics and mechanical construction.

HANDS.DVI is inspired and supported by recent advancements in neuroscience which have shown that the description of how the human hand moves during grasping is dominated by trajectories in a configuration space of much smaller dimension than the kinematic structure would suggest. Such configuration space is referred to as the space of postural synergies. Santello et al. [13] investigated this hypothesis by collecting a large set of data containing grasping poses from subjects that were asked to shape their hands in order to mime grasps for a large set $(N = 57)$ of familiar objects. Principal Components Analysis (PCA) of this data revealed that the first two principal components account for more than 80% of the variance, suggesting that a satisfying characterization of the recorded data can be obtained using a much lower-dimensional subspace of the hand DoF space. These and similar results seem to suggest that, out of the more than 20 DoFs of a human hand, only two or three combinations can be used to shape the hand for basic grasps used in everyday life. These ideas can be brought to use in robotics, since they suggest a new and principled way of simplifying the design and analysis of hands different from other more empirical, sometimes arbitrary design attempts, which has been the main roadblock for research in artificial hands in the past [3].

This work presents the recent results developed in HANDS.DVI. In particular we will present the study of a mapping function between the postural synergies of the human hand and synergistic control action in robotic devices. This mapping leads to an interesting scenario, where control algorithms are designed considering a paradigmatic hand model, and without referring to the kinematic of the specific robotic hand.

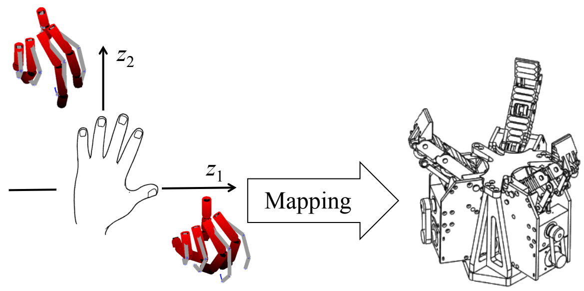


Fig. 2. Mapping between human synergies and robotic hands.

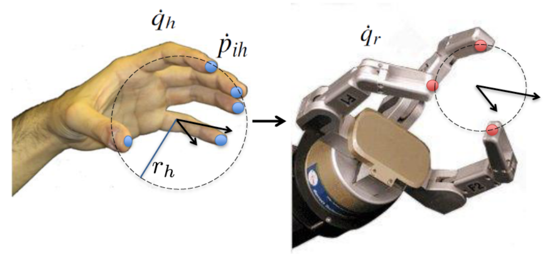


Fig. 3. Mapping synergies from the human (paradigmatic) to the robotic hand: the fingertip positions of the paradigmatic hand allows to define the virtual sphere. Activating the human hand synergies, the sphere is moved and strained; the same motion and strain is imposed to the virtual sphere defined for the robotic hand.

A. Algorithm description

The proposed algorithm maps human synergies onto robotic hands as shown in Fig. 2, by using a virtual object method. In particular, the mapping tries to reproduce, on the robotic hand, the movements and deformations that the human reference hand would perform on a virtual object whose geometry is step by step defined by the hand posture itself. The main idea is to reproduce movements and deformations exerted by the paradigmatic human-like hand, controlled by synergies, on a virtual object, namely a sphere, computed as the minimum sphere containing the hand reference points. The *paradigmatic hand* [1], [5], [7] is a model inspired by the human hand that does not closely copy the kinematical and dynamical properties of the human hand, but rather represents a trade-off between the complexity of the human hand model, accounting for the synergistic organization of the sensorimotor system, and the simplicity and accessibility of the models of the robotic available hands.

The proposed algorithm is not specific for a given task but can be used for most of the manipulation tasks. Such a generality is gained considering that the most important actions in manipulation by robotic hands is to guarantee the stability of the grasp and to move the grasped object along planned trajectories.

Two virtual spheres are used, one for the paradigmatic hand and the other for the robotic hand. These are defined by the hands' posture and change during the task. The main idea is to reproduce movements and deformations exerted by the paradigmatic human-like hand, controlled by synergies, on a virtual object, namely a sphere, computed as the minimum sphere containing the hand reference points (see Fig. 3).

For more detail the reader is addressed to [8], [11], [12].

II. Results

The proposed mapping strategy for synergies between hands with dissimilar kinematics was validated on a fully-actuated robotic hand model. This hand has three finger and eight DoFs. Each finger has two joints. One of the fingers, is fixed, while the other two can spread independently up to 180 degrees about the palm.

In the numerical simulations presented in the following, we supposed to control independently each joint of the robotic hand.

In order to validate the mapping algorithm, joint-to-joint mapping [4] and the fingertip-mapping [10] methods were compared with the proposed algorithm. Other mapping methods [9], [14] were not taken into account since they can not be easily extended to kinematic structures that differ from those proposed in the relative papers. The grasp of two different objects was considered: a sphere and a cube. Algorithm performances were evaluated comparing the grasp quality and the motion of the grasped objects. Grasp quality evaluation was performed using both qualitative and quantitative metrics in order to evaluate the force-closure properties of the grasp. The qualitative metric returns a boolean value that shows if the obtained grasp is *force-closure*. The quantitative aspect of the grasp quality is expressed using a penalty function. The resulting index represents the inverse of the *distance* of the grasp from violating contact constraints. All details of the used indexes can be found in [2], [6].

In the first simulation, the spherical object is considered.

The reference points, both for the human and robotic hand, are chosen on their fingertips, three for the robotic hand and five for the paradigmatic human-like hand.

The resulting synergy mapping on the robotic hand has been tested for a grasping configuration similar to those considered to design the mapping. In particular the robotic hand is assumed to grasp the sphere with contacts at the fingertips which in this case correspond to the reference points of the mapping.

Note that choosing reference points as contact points is not mandatory but it is highly recommended when possible.

To test the validity of the mapping we compared the grasp quality and the object motion between the robotic hand grasping a sphere and the paradigmatic hand grasping a sphere with the fingertips of the thumb, index and ring fingers. The paradigmatic and robot hand grasps that were analysed are shown in Fig. 4.

The obtained results are summarized in table I. Each row corresponds to the case of controlling hands with one synergy or combinations of synergies. This analysis was carried out considering the first three synergies and their combinations.

The second column shows the grasp quality indexes for the human-like hand controlled with synergies, while the third one reports those of the robotic hand controlled with the synergies

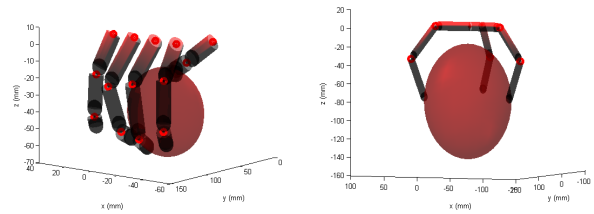


Fig. 4. The paradigmatic human-like hand (left) and the robotic hand (right) grasping a sphere with three contacts in the reference configurations.

obtained with the proposed virtual-sphere mapping. The fourth and the fifth columns refer to the joint-to-joint mapping and to the fingertip mapping [4], [10].

TABLE I
GRASP QUALITY EVALUATION FOR THE SPHERICAL OBJECT

Synergies	Human H	Virtual Sphere	Joint-to-joint	Fingertip
Syn 1	0.2 [1]	0.12 [1]	26.48 [1]	0.37 [1]
Syn 2	– [0]	– [0]	0.09 [1]	– [0]
Syn 3	– [0]	0.36 [1]	– [0]	– [0]
Syn [1-2]	0.14 [1]	0.08 [1]	0.09 [1]	0.11 [1]
Syn [1-3]	0.09 [1]	0.08 [1]	0.08 [1]	0.07 [1]

The performance is expressed by the value of the cost function measuring the grasp quality (lower values are better) and by $[x]$, which is 1 or 0 if the grasp is force closure or not, respectively.

The same quality indexes were evaluated considering the grasp of a different shape object: a cube, the obtained results are summarized in table II.

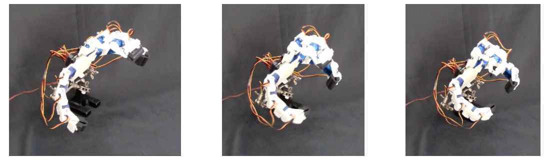
TABLE II
GRASP QUALITY EVALUATION FOR THE CUBIC OBJECT

Synergies	Human H	Virtual Sphere	Joint-to-joint	Fingertip
Syn 1	0.2 [1]	0.12 [1]	26.48 [1]	– [0]
Syn 2	– [0]	– [0]	0.10 [1]	– [0]
Syn 3	– [0]	0.37 [1]	– [0]	– [0]
Syn [1-2]	0.20 [1]	0.08 [1]	0.09 [1]	– [0]
Syn [1-3]	0.14 [1]	0.08 [1]	0.08 [1]	0.08 [1]

In both cases, when only the first synergy is considered, the joint-to-joint approach achieves a force-closure grasp but it exhibits a very high value of the cost function when compared to the virtual sphere mapping proposed in this paper. Concerning the fingertip mapping, we observe that it reaches satisfying performances in the case of sphere manipulation, but with the cubic object it guarantees force closure only when a combination of the three synergies is considered.

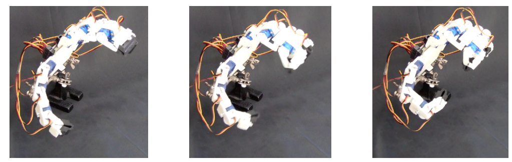
We can conclude that, concerning the grasp quality index, the virtual-sphere mapping for both the spherical and cubic objects gets closer to the human-like grasp behaviour in all the simulated cases.

The proposed mapping procedure has been also validated by some experiments performed with a fully-actuated robotic hand with a modular structure developed at the University of Siena.



(a) (b) (c)

Fig. 5. The first synergy mapped onto the modular hand: (a) starting position, (b) middle position, (c) end position.



(a) (b) (c)

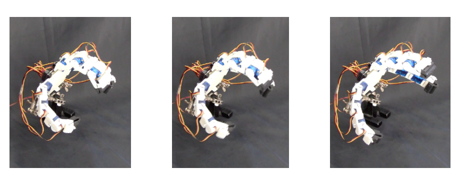
Fig. 6. The second synergy mapped onto the modular hand: (a) starting position, (b) middle position, (c) end position.

The first three synergies of the paradigmatic hand, mapped on the modular robotic hand are shown in Fig. 5, 6 and 7. Videos of the proposed mapping are available at http://tinyurl.com/sirslabmapping.

Although the used device represents a simple example of robotic hand, the complexity and the high number to DoFs to control are, in our opinion, a possible benchmark to validate our approach. Furthermore its kinematic structure is significantly different from the paradigmatic hand one, so it could be useful to test how the proposed mapping method behaves with very dissimilar hand structures.

III. CONCLUSION AND FUTURE WORKS

This extended abstract presents recent results developed within the ECHORD HANDS.DVI experiment whose aim is that of designing an abstraction layer for robotic hands based on postural synergies of human hands modeled here with a so called paradigmatic hand. Designing synergy-based control strategies in the paradigmatic hand domain can dramatically reduce the dimensionality of the grasping and manipulation problems for robotic hands. However, an efficient mapping is



(a) (b) (c)

Fig. 7. The third synergy mapped onto the modular hand: (a) starting position, (b) middle position, (c) end position.

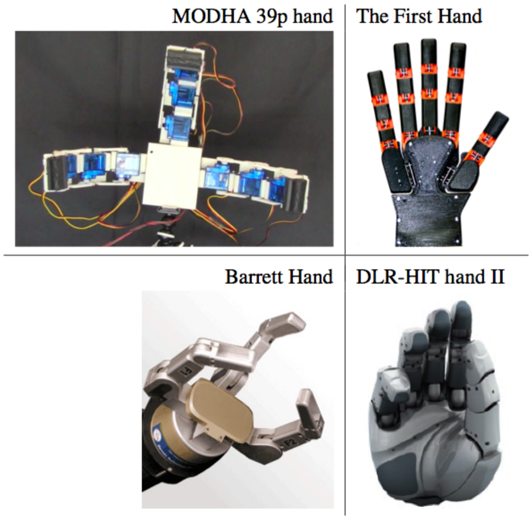


Fig. 8. The four hands to be used for the experimental setups: MODHA 39p hand (Univ. of Siena), The First Hand (Univ. of Pisa), the Barrett Hand and the DLR-HIT Hand II.

needed to deal with robotic hands with dissimilar kinematics. We proposed a method for mapping synergy matrices that, using a virtual object, allows to specify the mappings directly in the task space. Work is in progress to implement the synergy based control language for robotic hands with dissimilar kinematics. The approach will be tested on four different robotic hands

Acknowledgments

This work is supported by the European Commission with the Collaborative Project "European Clearing House for Open Robotics Development" (ECHORD), Grant Agreement n. 231143, Experiment"A DeVice-Independent programming and control framework for robotic HANDS" (HANDS-DVI).

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Hubrina - master-slave navigation in agriculture

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Abstract

The objective of this research is to demonstrate master-slave navigation for agricultural operations on the main field area. A human operator drives a master tractor which is followed by an autonomous slave tractor that performs the same operation in the next tramline. The research includes the design of the hardware and software architecture, the design of a path planning method for a master-slave system, implementation of an algorithm for path following control and design of an algorithm for control of the distance between the master and the slave. Before going into the field, to test and improve the system, we use an approach of pure software simulation as well as hardware in the loop simulation that, eventually, even includes the slave tractor in the loop. The results up till now show that path following control in simulation is successful and give confidence that the final objective of master-slave navigation in a field will be met. The research is supported by the EU FP7 ECHORD project and by CLAAS.

Interactive Mobile Manipulators for Advanced Industrial Diagnostics

Florian Weißhardt

Fraunhofer Institute for Manufacturing Engineering and Automation

The most followed goal in the manufacturing industry of the XXI century is the fulfillment of a productive process with no defects to satisfy the highest expectations of the final customer. For this reason, in the last years test and diagnosis systems have had a very important growth. Today it is possible to say that no production line having one or more quality test systems is meant to exist as well as no technologically evolved product whose development has not been supported by accelerated life tests in laboratories.

The innovation proposed in the ECHORD InterAID experiment considers a diagnosis and testing station not as a fixed system but as a flexible one, based on mobile robots with sensory and diagnostic skills as well as manipulation capabilities.

The application case is a reliability lab of a washing machine factory. In this scenario, the mobile robot moves in a laboratory where hundreds of washing machines are located and under test. The robot is able to inspect, but also interact with the washing. During the test some quantities are measured, such as energy and water consumption, number of cycles performed, check if the led are working or listen if the machine has a higher level of noise. The robot is working in an environment where also the human operator has to perform some tasks and therefore collision free operation of the robot is required. In particular, when the robot is in front of the washing machine, it has to push buttons and to turn knobs in order operate the washing machine as well as to bring some specific sensors, such as microphones and cameras, as close as possible to the machine for acquiring test data.

To solve the above mentioned scenario, the robot shown in Figure 1 is equipped with sensors (laser scanners, color cameras, 3D cameras, microphone, laser vibrometer, force torque and tactile sensors) to acquire data from the washing machine and the environment as well as an 7-DOF arm and a Gripper to operate the washing machine. The 3D and color camera sensors are used to detect the washing machine and the buttons as well as to supervise the movements of the arm in order to avoid collisions with the environment. Figure 3 shows the environment modeling. Additional 3D sensors for the base ensure a safe navigation in an unstructured environment. The microphone and laser vibromenter are used to detect failures in the operation of the washing machine, e.g.

Figure 1: Mobile Inspection robot equipped with sensors and a manipulator to interact with a washing machine

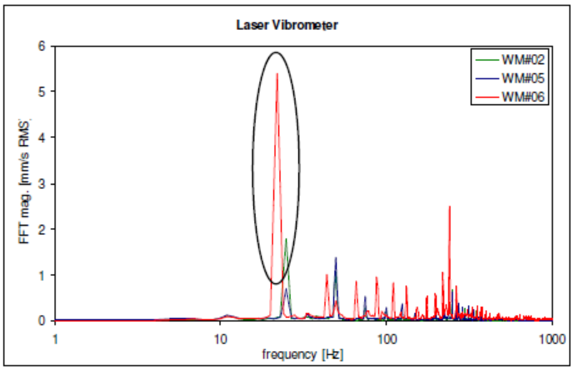

Figure 2: Vibrometer spectra

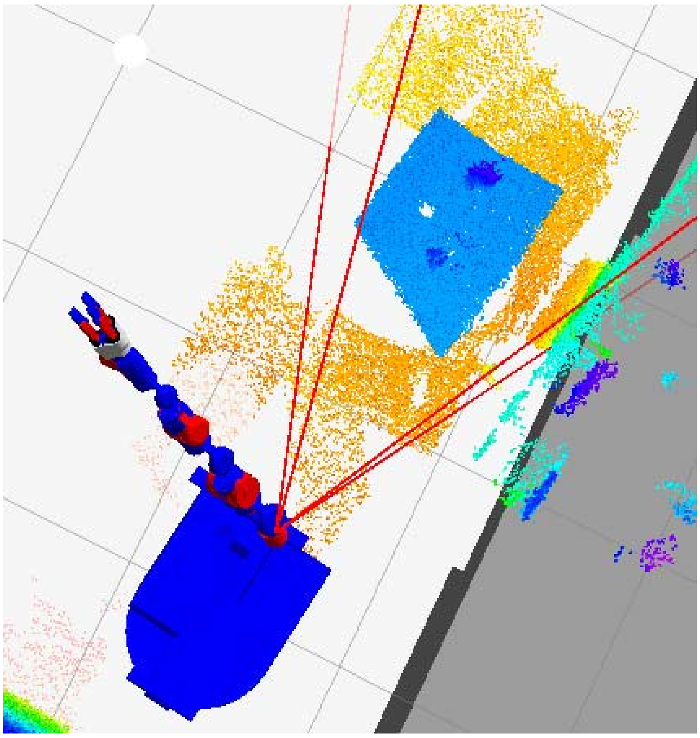

Figure 3: Environment model for collision avoidance

Traffic Control of AGVs in Automatic Warehouses: the TRAFCON Experiment

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Automatic warehouses need to guarantee a higher and higher delivery rate (e.g. for loading trucks timely) and, in order to avoid congestion of goods in entrance and/or in exit, they need to never stop during working hours. For these reasons, the number of AGVs that need to be used is growing more and more and their motion need to be controlled in such a way that each AGV reaches its destination as quickly as possible and that the system never stops, even in case a fault on a vehicle or other unexpected events take place. Thus, traffic management is one of the main issues to be addressed in automatic warehouses.

In then current industrial practice, AGVs are coordinated using manually designed traffic rules that need to be adapted on the installation site for considering unexpected issues. Thus the design of a traffic control algorithm that is collision- and deadlock-free requires a lot of engineer time and it needs to be heavily re-adapted when installing the AGV system in another warehouse. Furthermore, unexpected obstacles (e.g. manual forklifts the AGVs need to share the environment with) and/or faults often require to stop the system for manual recovery. This leads to a decrease of performance and to a bad impact on the customer perception of the system.

In the TRAFCON experiment a global provider of AGV systems for automatic warehouses and an academic institution will cooperate for developing an efficient, fault-tolerant traffic control strategy that can be successfully applied in AGV systems for automatic warehouses. The main objective of the experiment is to make the traffic management of the AGVs automatic and efficient. No tuning depending on the topology of the warehouse needs to be done and good performance have to be guaranteed also in presence of faults and mobile obstacles as human guided forklifts. This will drastically reduce the engineer time required for each installation and the number of required stops of the system leading to better performance, to a significant reduction of installation costs and to an increase of customers satisfaction.

The traffic control strategy will be based on a route planning module and a coordination module interacting in order to keep the efficiency of the traffic management as high as possible. The coordination module will be based on an extended version of the coordination diagram tool which will allow to consider the structure and the problems of an industrial AGV system. An efficiency measure of the system will be developed and it will be used for deciding when to re-plan the paths of the vehicles in order to keep the efficiency of the system as high as possible. The traffic control strategy will be tested and characterized in the arena, namely a small scale AGV system that will be built during the experiment, where all the problems and constraints arising in a real AGV system can be reproduced. Furthermore, a comparative analysis with the traffic control strategy currently used by the industrial partner will be done.

In this Workshop, the coordination strategy based on the coordination diagrams will be illustrated. A fast and efficient method for building the coordination diagram will be shown and a computationally efficient greedy strategy for coordinating the AGVs will be also presented. A comparative evaluation over real automatic warehouses highlights the advantages of the TRAFCON's coordination strategy with respect to the coordinator currently used by Elettric80.

euRobotics coordination action

Dr. Tim Guhl (KUKA Laboratories GmbH)

"European Efforts in Strengthening Academia-Industry Collaboration"
Workshop at IROS 2011, San Francisco, 30/09/2011

Introduction of this session

KUKA

- Goal of this session: Exchange experiences on how to strengthen academia-industry collaboration
- Step 1: Brief summary of what has been discussed today
  - Potential benefits of collaboration
  - Approaches from Europe and elsewhere
  - Lessons learned
- Step 2: Moderated discussion on various related topics
  - What can be done to improve academia-industry collaboration?
  - Discussion of approaches discussed and others you know about
  - How can funding support this process?
  - What is best practice?
  - At which Technology Readiness Level (TRL) should TT happen?

Potential benefits of close collaboration

KUKA

- Better understanding of
  - The needs of industry
  - The offerings of academia
- This can result in
  - Research more industrially relevant
  - Technology transfer from academia to industry
    - More money for research
    - More advanced products
    - Imp. aspects: “how to manage the knowledge transfer” & “people transfer”
  - Less duplication of work
  - More Spin-offs / start-ups

Summary of European approach

KUKA

- Steps taken in euRobotics
  - Identify gaps of understanding & initiate measures to overcome them
  - Maintain and implement Strategic Research Agenda
  - Training for industry
  - Fostering entrepreneurship
- ECHORD
  - Small scale projects (→experiments) involving industry & academia
- FP7 / National funding
  - Calls partially based on roadmaps from industry and academia
  - Frequent consultations of representatives from both comunities
  - Encouragement of industrial participation often with end user