Document D-16-01

Proceedings of the RIC Project Day

Workgroups *'Framework & Standardization'* and *'Manipulation & Control'*

Frank Kirchner (Editor)

Thomas M. Roehr, Vinzenz Bargsten, Sankaranarayanan Natarajan (Associate Editors)

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German Research Center for Artificial Intelligence
Deutsches Forschungszentrum für Künstliche Intelligenz

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Prof. Wolfgang Wahlster
Director

Proceedings of the RIC Project Day

Workgroups 'Framework & Standardization' and 'Manipulation & Control'

Frank Kirchner [1,2] (Editor)

Thomas M. Roehr [1], Vinzenz Bargsten [1], Sankaranarayanan Natarajan [1]

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03/2016

Document D-16-01 des

Deutschen Forschungszentrums für Künstliche Intelligenz (DFKI)

Abstract

This document is the current edition of a publication series which records the topics, discussions and efforts of the workgroups at the DFKI Robotics Innovation Center (RIC). Each edition contains presentation slides and posters of a project day which is organized by two workgroups.

Workgroups provide a platform for cross-project communication and knowledge transfer. They are formed by peers dedicated to a specific topic. Each workgroup has one administrator. In 2008, the workgroups started to present their results and efforts in an open presentation format called brown-bag talk. From 2009 onwards, these presentation were held at so-called project days. Since 2014, a project day consists of two main parts: an oral session and a poster session. Both sessions are documented in a proceedings using the DFKI Document format.

Zusammenfassung

Dieses Dokument enthält die aktuelle Ausgabe einer Tagungsbandserie, welche die Themen, Diskussionen und Bemühungen der Arbeitsgruppen am DFKI Robotics Innovation Center (RIC) protokolliert. Jede Ausgabe enthält Vortragsfolien und Poster eines Projekttages, der von je zwei Arbeitsgruppen gestaltet wird.

Arbeitsgruppen widmen sich einem bestimmten Themengebiet und stellen eine Plattform dar, um über Projekte hinaus zu kommunizieren und Wissen zu transferieren. Jede Arbeitsgruppe wird von einem sogenannten Kümmerer administriert. Im Jahr 2008 begannen die Arbeitsgruppen ihre Ergebnisse und Arbeiten in einem offenen Vortragsformat – dem sogenannten 'Brown Bag Talk' – vorzustellen, welches ein Jahr später in die Form von Projekttagen überführt wurde. Seit 2014 besteht ein Projekttag nicht nur aus Vorträgen, sondern beinhaltet zudem Posterpräsentationen. Beide Formate werden seitdem in einem Tagungsband in Form eines 'DFKI Document' festgehalten.

Contents

1 Editorial

This proceedings document records the last year's efforts of two thematic workgroups of the DFKI-RIC.

Workgroups are formed by peers and provide a means for cross-project communication on a deep content level and facilitate knowledge transfer amongst the peers. In 2008 we first started forming workgroups on specific topics around robotics and AI research. Among them were topics as 'system design & engineering', 'machine learning', 'planning & representation' as well as 'frameworks & architectures' and 'man-machine interaction'. These workgroups were established with the intention to provide a platform for interested DFKI-RIC personnel for discussing the state of the art, recent achievements, and future developments in the respective fields.

Over time the workgroups gathered a collection of material in form of presentations, short papers, and posters which were worthwhile to be presented also to the rest of the institute. Due to this development, in 2009, we started to have a project day once every quarter. Each project day provided a platform for two of the workgroups to present their material and to discuss it with the colleagues of the institute. Nowadays, the project day is organized as a half-day workshop with oral presentations, poster sessions, and a free sandwich lunch for everybody who attends.

The current document format compiles the material of the workgroups presented during a project day into a single, citable document of unified format. The future might bring further ideas and changes to enhance the presentation quality of this material.

Frank Kirchner

The project day season of this year has been opened by the two workgroups 'Framework & Standardization' and 'Manipulation & Control'.

The purpose of the workgroup 'Manipulation and Control' is to bring the expertise knowledge in the field of kinematics, dynamics, and control together in order to provide solutions to problems faced in these fields during the course of the projects.

This year the workgroup 'Manipulation & Control' started the project day with an introduction presentation, which gave an overview of the workgroup and the topics discussed in the past year. In the second talk trajectory generation for a synchronous motion in joint space was presented. The next two presentations were focused on Human-Robot-Collaboration: The first one gave an insight about the FourByThree project and the latter one focused on a real time collision avoidance for Human-Robot-Collaboration. The final talk was about the ground adaptation control for a four legged robot.

The focus of the workgroup 'Framework & Standardization' remains with the continuous improvement of the software development, but is extending with respect to the special use case of robotic software development.

This year's introductory presentation of the workgroup 'Framework & Standardization' provides an insight to the the main topics of the past year: the Robot Construction Kit (Rock) is the main robotics software framework in use in this institute and it is subject of constant maintenance and improvements, e.g. further continued development to provide Debian-Packages for Rock has led to the first testing phase, which has been announced during this project day.

The first presentations of the workgroup 'Framework & Standardization' outline new developments in the area of framework extension and maintenance: opaque type generation within the Rock framework, the introduction of a plugin management system that relies on the existing class loader library, and an approach to embed a general nameservice into Orocos Realtime Toolkit (RTT). The two final presentations deal with two framework independent topics, and describe the space related activities in the project SARGON and the the setup of a fully distributed multi-robot communication system based on existing meshing technology.

Thomas M. Roehr, Vinzenz Bargsten, Sankaranarayanan Natarajan

2 ‘Framework & Standardization’

2.1 ‘Introduction to AG Framework and Standardization’ (FW-T-01)

Thomas M Roehr[(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany
(2) Universität Bremen, Arbeitsgruppe Robotik, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: thomas.roehr@dfki.de

Abstract

This introductory talk gives inside about the ongoing discussion within the AG Framework and Standardization. Apart from the discussion this talk highlight relevant work examples, e.g., such as the construction of Debian packages for the Robot Construction Kit (Rock).

Project Day 2016
AG Framework and Standardization

Introduction by ‚Kümmerer' Thomas M. Roehr

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Outline

DFKI GmbH Robotics Innovation Center

Projectday 17 March 2016

AG Manipulation & Control and AG Framework and Standardization

Start	End	Title	Presenter	Duration
09:30	09:40	Introduction to AG Manipulation and Control	Sankar or Vinzenz	00:10
09:40	10:00	Trajectory Generation for Synchronous Motion in Joint Space	Rohit Menon	00:20
10:00	10:20	Project FourByThree - Human-Robot-Collaboration in the Industry 4.0	José de Gea Fernández	00:20
10:20	10:40	Real Time Collision Avoidance for Human-Robot Collaboration	Dennis Mronga	00:20
10:40	11:00	Ground Adaption Process for SherpaTT	Ajish Babu	00:20
11:00	11:10	*Pause*		00:10
11:10	11:20	Introduction to AG Framework and Standardization	Thomas Röhr	00:10
11:20	11:35	Opaque autogeneration / ClassLoader-based plugin manager	Sascha Arnold	00:15
11:35	12:00	Orocos RTT: 3rd party NameServices and TaskContexts	Bernd Langpap	00:25
12:00	12:15	Activities with SARGON - Space Automation & Robotics General cOntroller	Javier Hidalgo	00:15
12:15	12:35	Multi-robot communication using meshing (or B.A.T.M.A.N. begins)	Thomas Röhr	00:20
12:35	12:45	Cleanup of presentation room		00:10
12:45	13:15	Postersession	ALL	00:30
		Snack at Empore		

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Past year recap

- Organizational
  - Meeting schedule changed
    - Alternation of general topic meeting and Rock-specific topic meeting (see RIC Calender of Team 8)
  - Mapping (maintenance) responsibilities to people
- Topics
  - Changes in typelib
    - GCCXML support has been stopped for gcc 5
    - Alternative CastXML has been embedded (by now from Sylvain)
  - OpenSceneGraph Serialization and synchronization by Steffen
  - ROS 2.0 ahead

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Debian Packaging

- Motivation
  - Remove need for compilation on target system
    - especially for embedded devices (such as Gumstix)
  - Allow for verifiable and reproducable Rock installations
  - Verification of dependency chain before deployment (unfortuneately that is limited to non-ruby packages)

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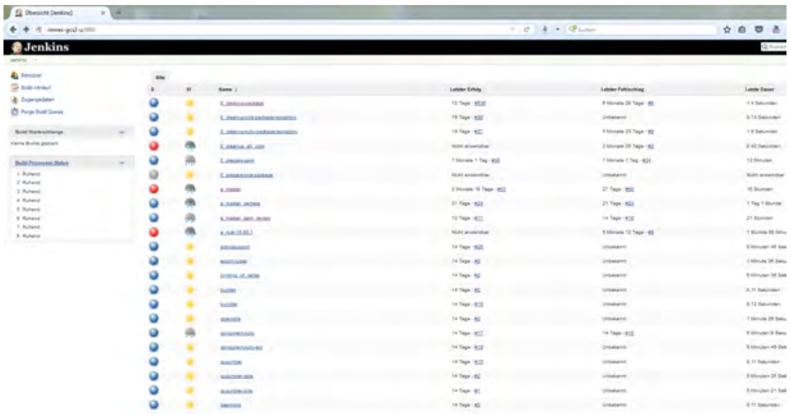
Revisioned after first test phase

- Jenkins based build infrastructure
  - Conversion of packages via Common Debian Build System (CDBS)
  - Conversion of Ruby packages via Debian tool *gem2deb*



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Looking for early adopters

- Support for
  - Rock packages of rock.core package_set and master branch
- Package built for
  - Ubuntu 14.04, Ubuntu 15.04: arm64, i386
  - Debian Jessie: arm64, i386, armhf, arm
- Two main testcases
  - rock-display
    - validation that Ruby gems are installed properly
  - drivers/orogen/camera_usb on Gumstix
    - cross compilation for ARM Platform
    - deployment on embedded system

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Current limitations

- Support for one flavor only (currently master)
- Gem are installed into system-folders and might conflict when using with a parallel custom Rock installation

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Further ongoing activities

- Modularization of systems management
  - First basic prototype available
- Opening up RTT for extension (see talk by Bernd)
- Revision of EnviRe (see talk by Sascha)
- Fully distributed robot communication (see talk by Thomas)

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2.2 'Opaque type auto-generation & ClassLoader based plugin management' (FW-T-02)

Sascha Arnold[(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: `sascha.arnold@dfki.de`

Abstract

This talk gives an overview of two components that have been developed in the context of the new environment representation (EnviRe). An orogen plugin that allows automatic opaque type generation based on boost serialization and a plugin management front-end which uses the ClassLoader library as back-end. Both components are potentially interesting in other contexts and for other projects with equal requirements.

Opaque type auto-generation &
ClassLoader based plugin management

Sascha Arnold

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Opaque type auto-generation

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AG Framework
16. März 2016

2/16

Opaque type auto-generation

What are opaques types

- An opaque type is an intermediate type that typelib and therefore oroGen can understand and holds the data the real type holds.
- Due to the limitations of typelib it can be necessary to write an opaque type and the corresponding conversions.
- Known limitations of typelib:
  - header file must be parseable by gccxml
  - pointers are unsupported
  - private members are not allowed
  - unsupported types (char, short, 64-bit integers, float, std::map, std::list)

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Opaque type auto-generation

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Opaque type auto-generation

Our requirements

- Requirements for EnviRe:
  - Independent from the framework
  - Serialization available on library level
  - Ideally use an existing solution for type serialization
  - Be able to send data through Orocos tasks
- Idea: Auto-generate opaque type and conversions methods based on boost serialization.

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Opaque type auto-generation

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Opaque type auto-generation

How to use

Registration the .orogen file:

```
typekit do
    opaque_autogen '/your_lib/SomeClass',
                   :includes => 'your_lib/SomeClass.hpp',
                   :type => :boost_serialization

    export_types '/your_lib/SomeClass'
end
```

Usage:

```
task_context 'Task' do
    property 'config', '/your_lib/SomeClass'
    output_port 'data', '/your_lib/SomeClass'
end
```


Opaque type auto-generation

How does it work

- For a type 'your_lib::SomeClass' an opaque type named 'your_lib::SomeClass_w' and the conversion methods are generated.
- To support boost serialization a method

```
template<class Archive>
void serialize(Archive & ar,
               your_lib::SomeClass & c,
               const unsigned int version) {}
```

needs to be defined inside or outside of the class.

Opaque type auto-generation

How does it work

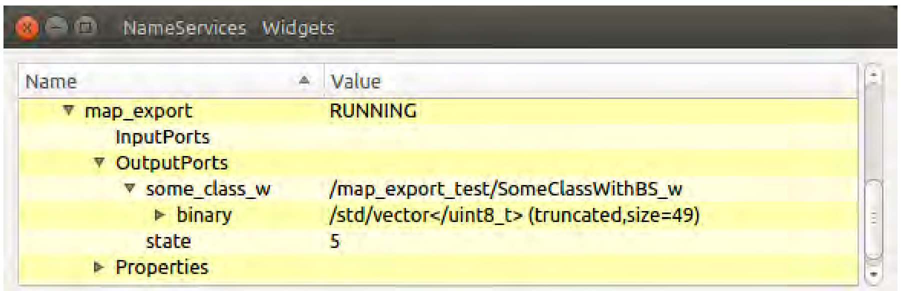

Abbildung : The auto generated opaque type in ruby

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Opaque type auto-generation

Conclusion

- Drawbacks: No introspection in ruby (also task inspector and log replay)
- Benefits: Send arbitrary 'complex' structures through Orocos tasks, especially interesting if serialization on library level is already a requirement
- This orogen plugin is currently exported by the package envire/orogen/envire_core (github.com/envire/envire-package_set)

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Opaque type auto-generation

Conclusion

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ClassLoader based plugin management

Plugin management

Requirements

- Allow more than one base class
- Gather informations about available plugins without loading all shared libraries
- Be able to model associations to other plugins or types
- Singleton instance support

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Plugin management

Implementation

- Use ClassLoader to export plugin classes and load instances
- Use XML files to export meta informations about the plugins

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Plugin management

XML based plugin registration

```
<library path="envire_octomap">
  <class class_name="envire::octomap::OcTree"
         base_class_name="envire::core::ItemBase">
    <description>Octomap OcTree plugin</description>
    <associations>
      <class class_name="octomap::AbstractOcTree"></class>
      <class class_name="octomap::OcTree"></class>
    </associations>
    <singleton>false</singleton>
  </class>
</library>
```

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Plugin management

XML based plugin registration

- CMake macro to help install XML files:

  ```
  install_plugin_info(envire_octomap)
  ```

- XML files are installed in a subfolder of LD_LIBRARY_PATH

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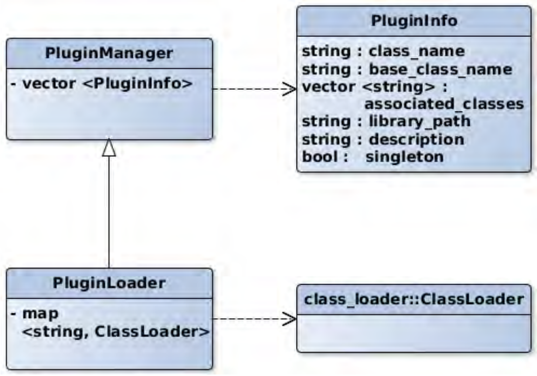
Plugin management

Class diagram

- The PluginManager parses the XML files and provides informations about the available plugins
- The PluginLoader uses ClassLoader to instantiate classes



Plugin management

Conclusion

- The plugins are raw ClassLoader plugins
- The implementation is very close to the ROS pluginlib, but framework independent and supports associations and singletons
- First version of the library (tools/plugin_manager) is finished and can be used
- Currently available through the EnviRe package set (github.com/envire/envire-package_set)

Thanks for your attention!
Questions and suggestions?

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16. März 2016 16/16

2.3 'Orocos RTT: 3rd party NameServices and TaskContexts' (FW-T-03)

Bernd Langpap [(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: `bernd.langpap@dfki.de`

Abstract

In the current status the wrapping of a task, which is an elementary execution instance within the Rock framework, into a task context server and its registration at a name service is done implicitly. The advantage of an efficient integration is quickly depleted by the drawbacks of this solution, i.e. a low level of maintainability and flexibility, etc. The proposed approach introduces an additional layer promoting the object oriented design principles of high-cohesion and low-coupling. Therefore, an abstract factory is added, capable of generating the needed task context server and name service objects on demand. Additionally, the usage of interfaces and a plug-in mechanism facilitates maintenance and extensibility.

Orocos RTT: 3rd party NameServices and TaskContexts

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Agenda

1. Introduction / Motivation
2. Current State
3. Proposed Solution
4. Implementation Details
5. Conclusion

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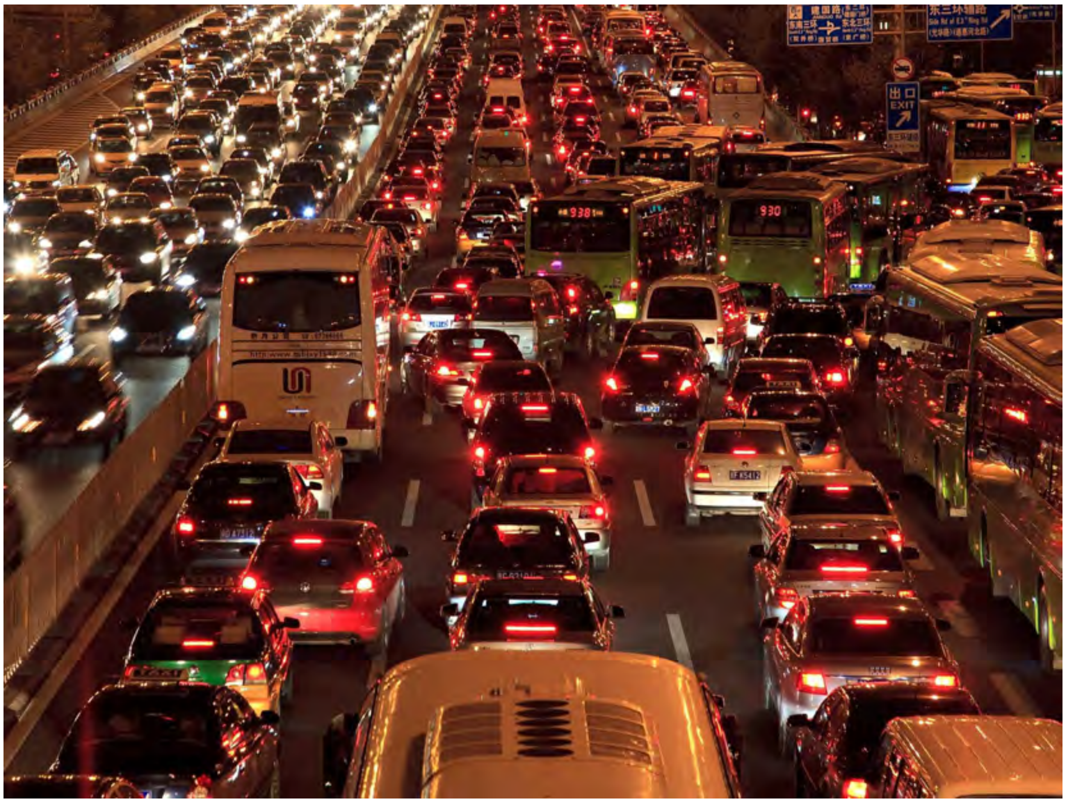
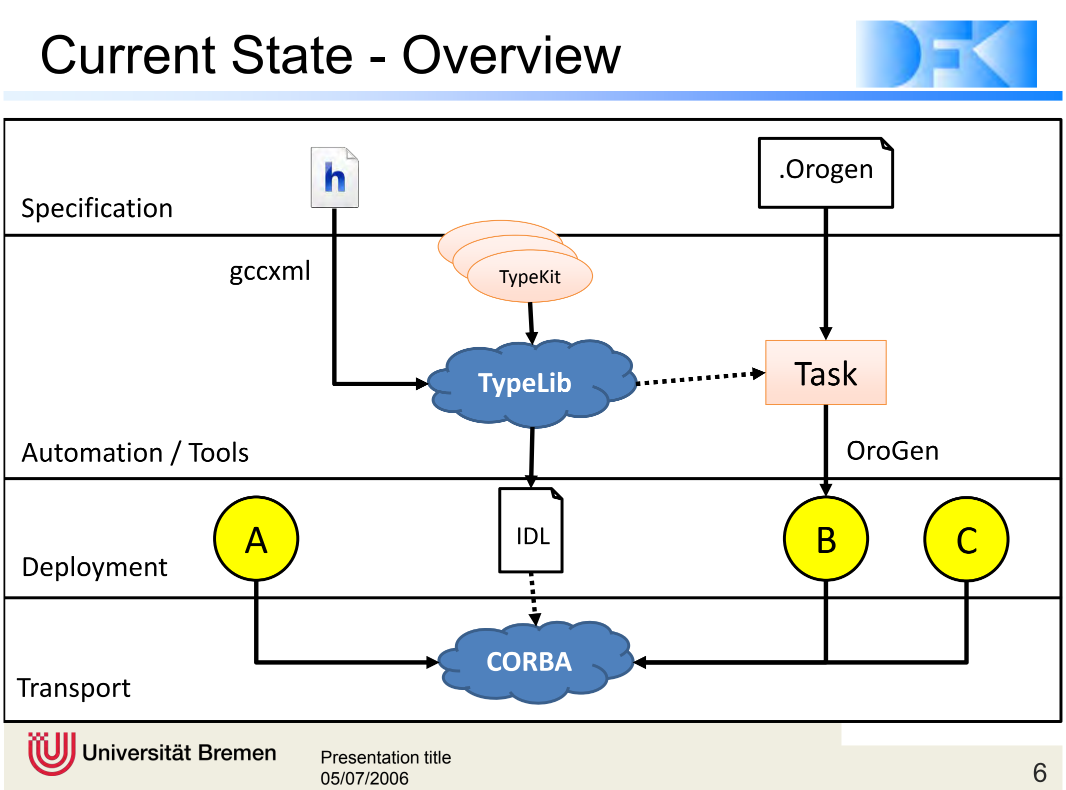



Flexibility
Maintainability
Exchangeability


Current State
Presentation title
05/07/2006


Current State - Overview
Specification
.Orogen
gccxml
TypeKit
TypeLib
Task
Automation / Tools
OroGen
A
IDL
B
C
Deployment
CORBA
Transport
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Presentation title
05/07/2006
6

Current State

- Rock: Usage of OmniORB as Corba implementation

Pro	Cons
Maturity	Regarded as complicated
Open Standard	Problem with Firewalls
Wide Platform and Language Support	Locations Transparency
Efficiency	Reconnect Mechanism
Scalability	

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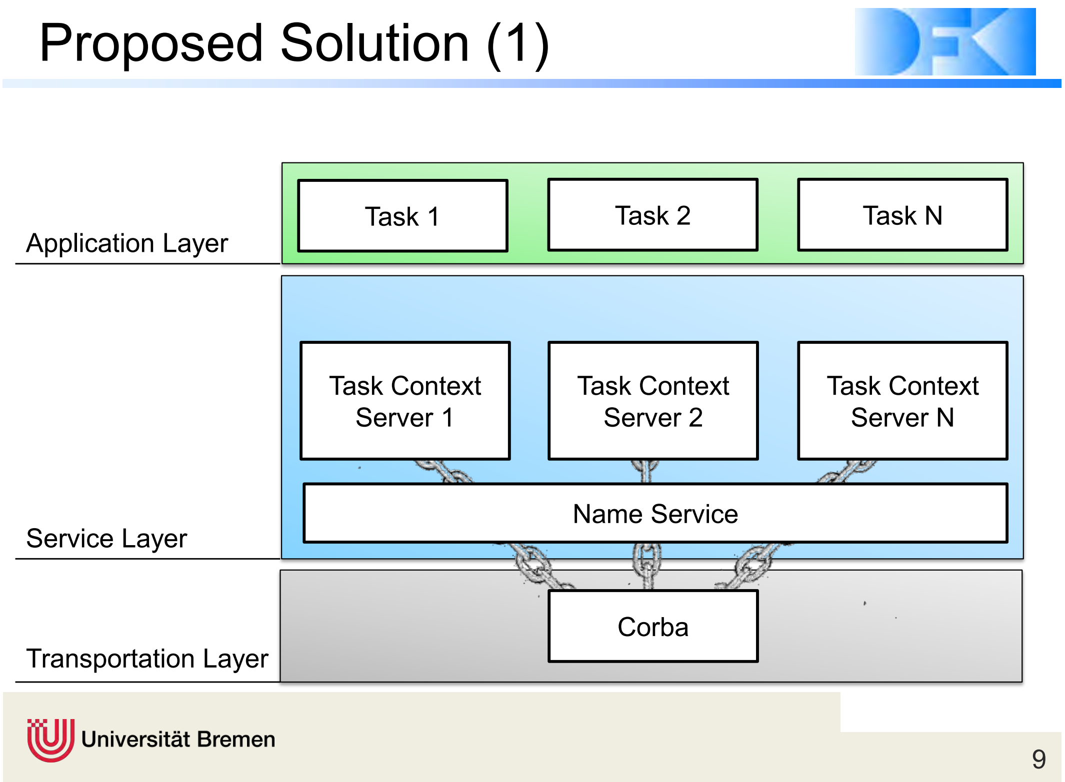
Presentation title
05/07/2006

7

Proposed Solution

Presentation title
05/07/2006


Proposed Solution (1)
Application Layer
Task 1
Task 2
Task N
Task Context Server 1
Task Context Server 2
Task Context Server N
Name Service
Service Layer
Corba
Transportation Layer
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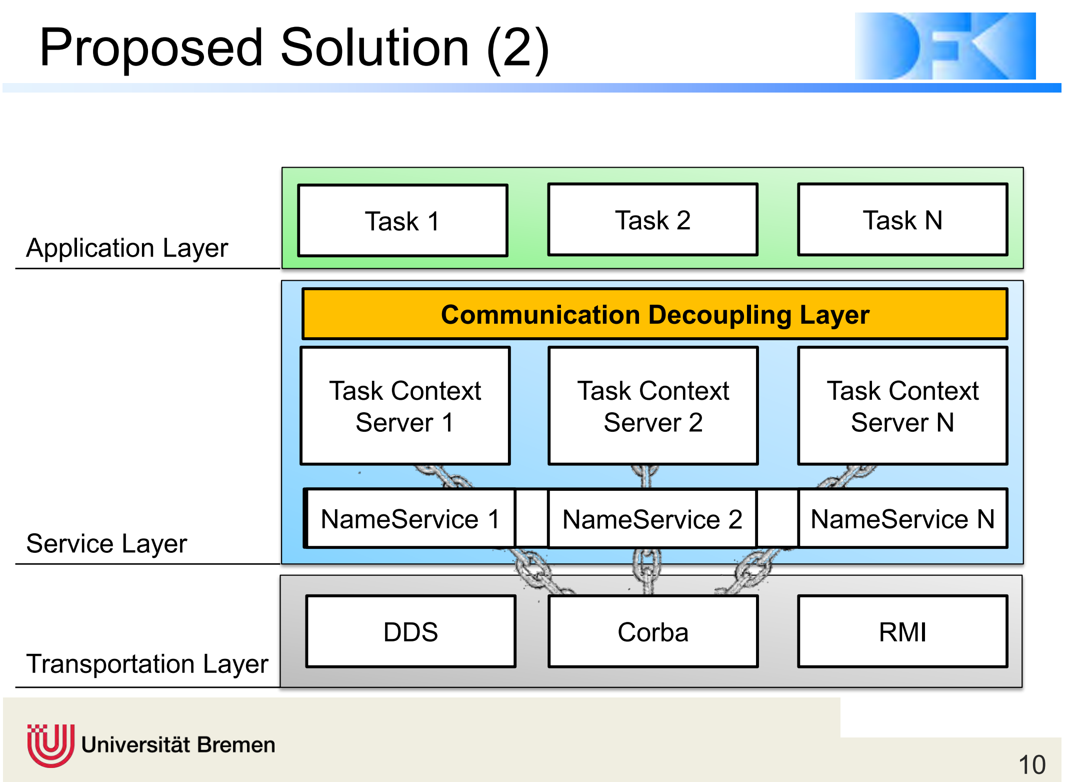
Proposed Solution (2)
Application Layer
Task 1
Task 2
Task N
Communication Decoupling Layer
Task Context Server 1
Task Context Server 2
Task Context Server N
NameService 1
NameService 2
NameService N
Service Layer
DDS
Corba
RMI
Transportation Layer
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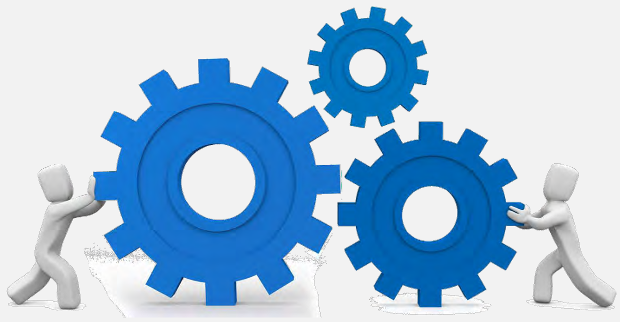

Implementation Details

Presentation title
05/07/2006

Abstract Factory (1)

Usage: „Provide an interface for creating families of related or dependent objects without specifying their concrete classes."

- Provides simple creational interface for a complex family of classes
- "Family" of objects is created at runtime
- Client unaware of concrete implementation details, i.e. concrete classes can be changed without affecting the clients

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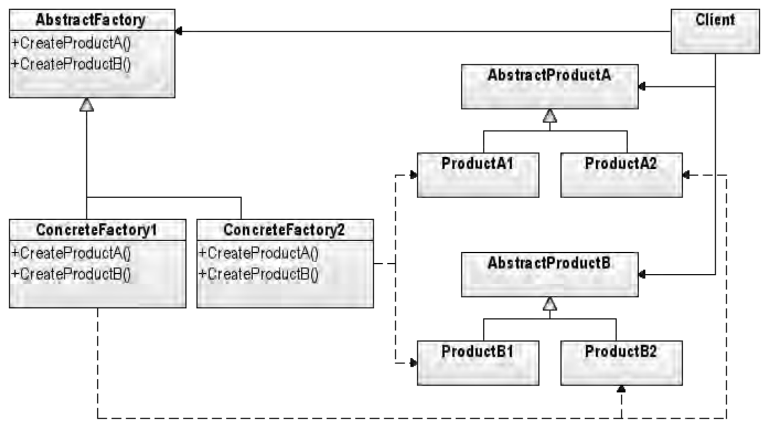
Abstract Factory (2)



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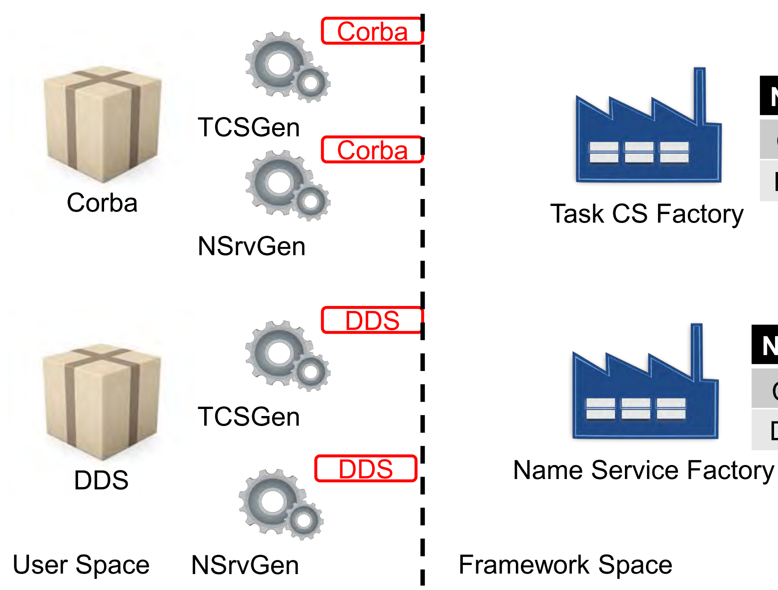
Implementation Details (1)



Name	ITCSG
Corba	pTCS
DDS	pTCS

Name	INSG
Corba	pNSG
DDS	pNSG

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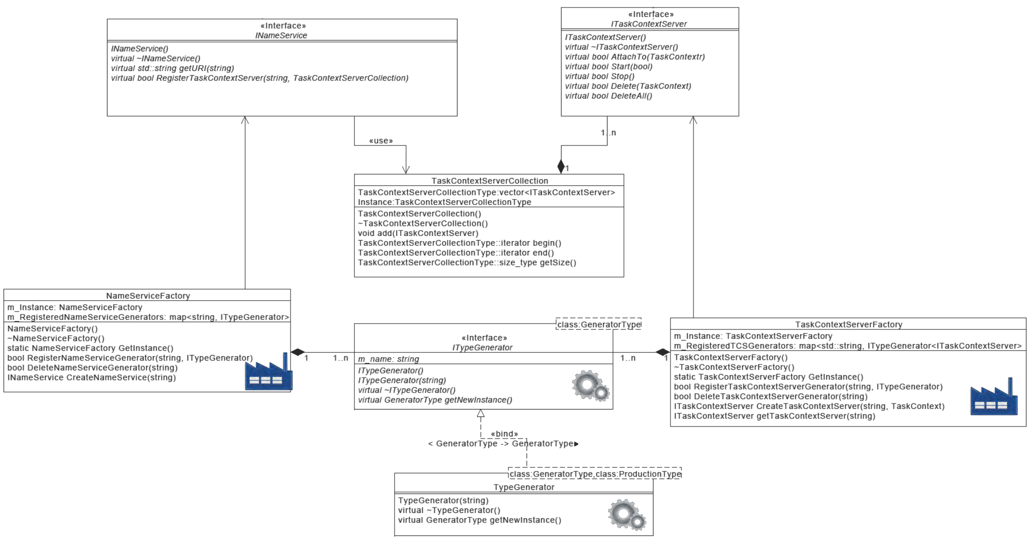
Implementation Details (2)



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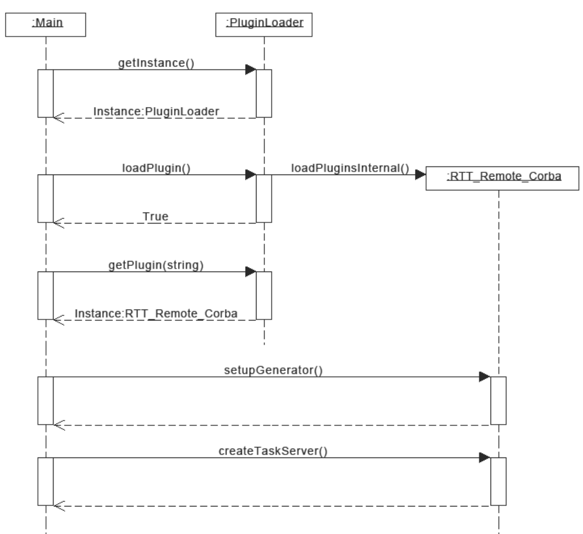
Implementation Details (3)



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Conclusion

- Strict framework setup imposes a flexible yet more complex architecture
- Transparent change to existing framework (downward compatibility)
- Decoupling of application (Task) and communication (Corba) layer
- Support of new transportation mechanisms
- Finalizing implementation and testing – only minor changes expected

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2.4 'Activities within SARGON - Space Automation & Robotics General cONtroller' (FW-T-04)

Javier Hidalgo Carrió [(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

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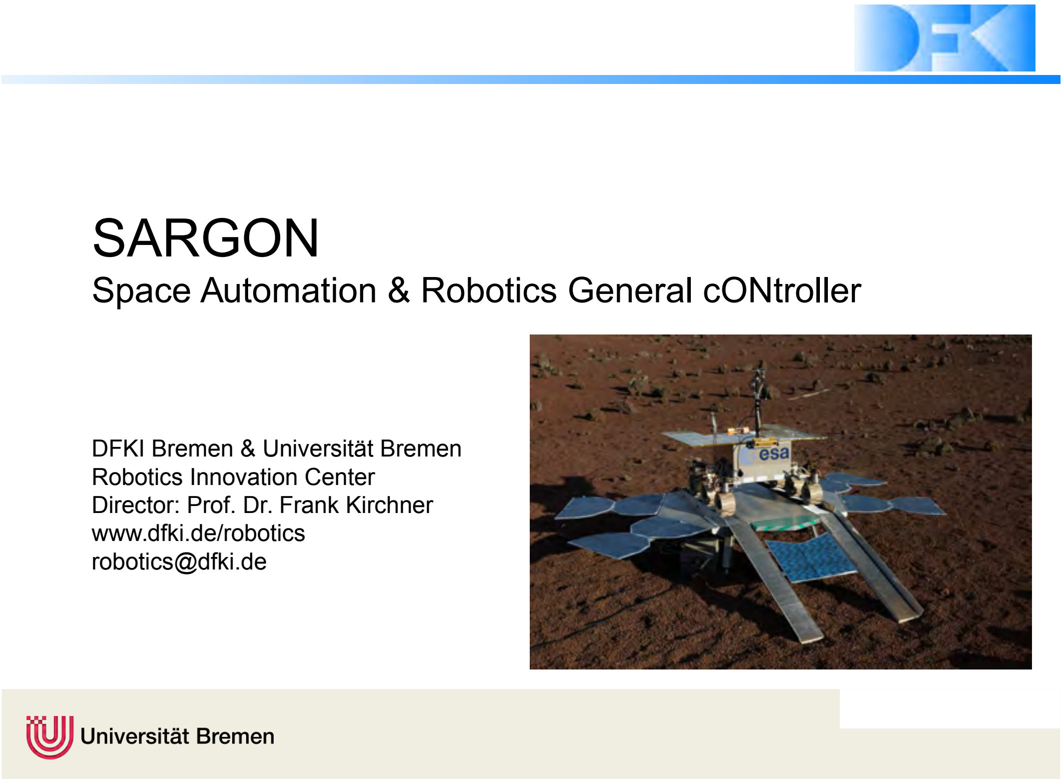
Abstract

This talk gives an overview of the framework activities within SARGON. SARGON is founded by ESA towards a Space Automation & Robotics General cONtroller. SARGON would bring a model-driven approach into the Rock framework based on AADL, SDL and ASN.1. The orchestration mechanism is given by TASTE. TASTE - The ASSERT Set of Tools for Engineering is a developing ecosystem implemented by an ESA consortium. TASTE focuses on Real-Time, mission critical and embedded systems. This presentation gives the implementation details, trade-offs and issues which the software design is currently dealing with.


SARGON
Space Automation & Robotics General cONtroller
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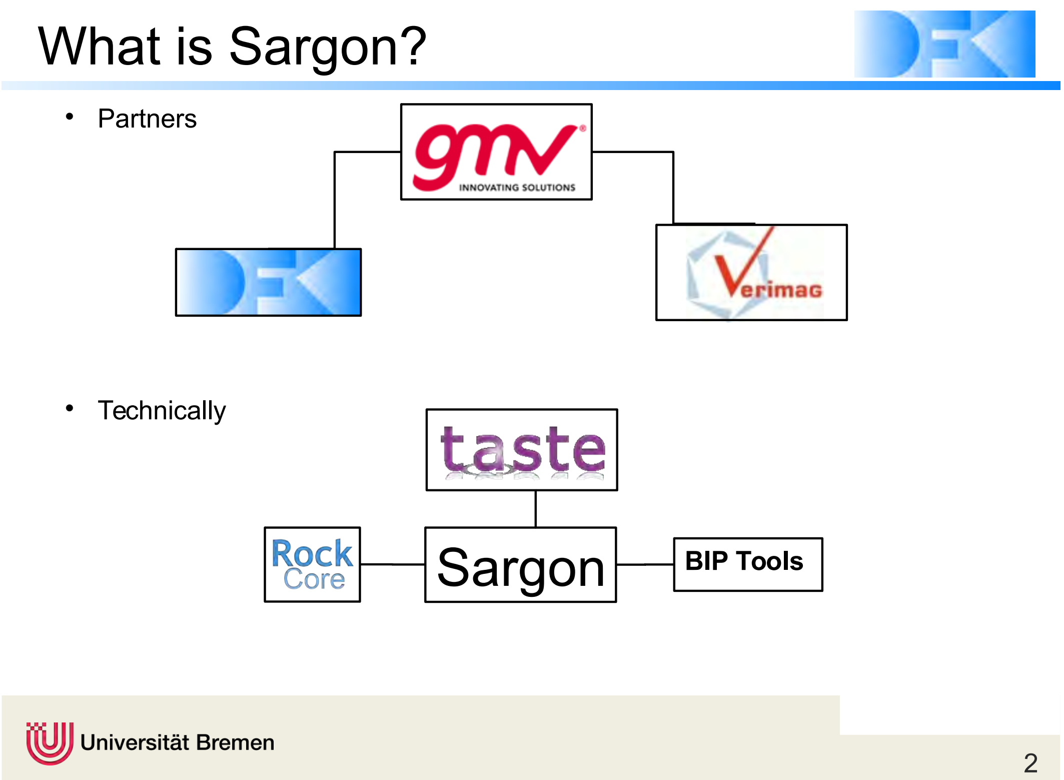
What is Sargon?
Partners
gmv
INNOVATING SOLUTIONS
Verimag
Technically
taste
Rock Core
Sargon
BIP Tools
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Sargon with Rock - General

1. Sargon brings a model-driven approach to Rock

- Architecture Analysis & Design Language (AADL)
- SDL to model the behavior of an RTT state machine
- ASN.1 data types definition

2. Avoid languages with weak semantic or syntax

3. Sargon brings software criticality levels into Rock

- Space software criticality levels are defined
- The code is generated depending on the hardware&partitioning

4. Sargon brings a model checker into Rock

- Behavior, Interaction and Priority (BIP) models the interaction among components and expresses scheduling policies.

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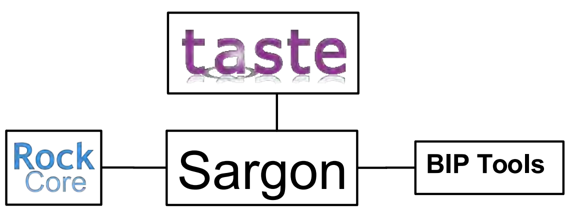
What is Sargon?

- Partners

- Technically



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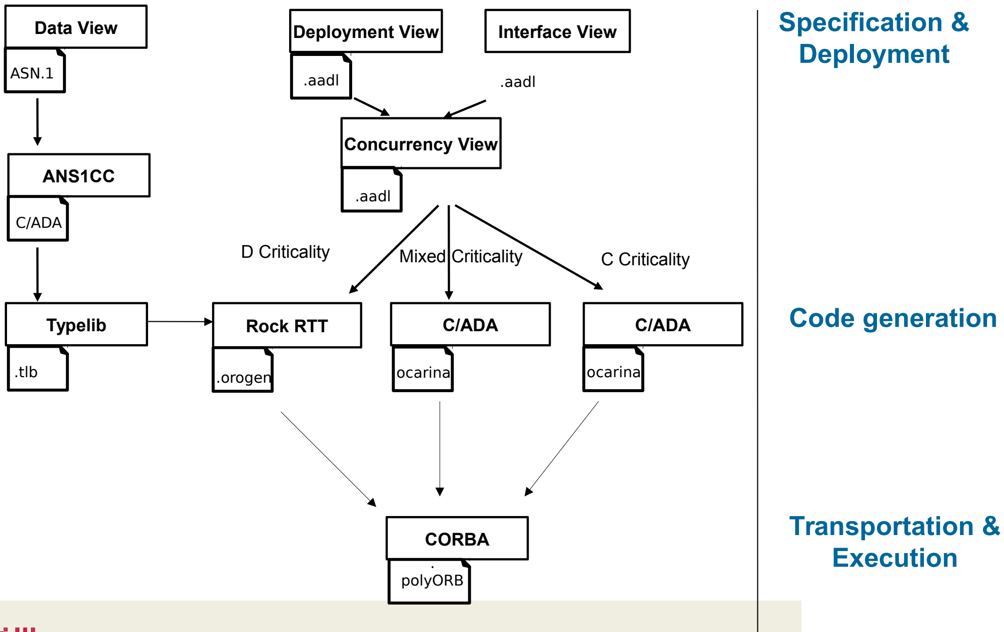
Sargon with Rock – Impl.



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Sargon with Rock – Open

- Directly generate RTT C++ Code from AADL
  - Pros: we don't need orogen and therefore ruby
  - Cons: we don't have orogen
- Conflict between typelib serialization and Taste serialization
  - Typelib within orocos.cpp development
  - Typelib with D-Rock development
- RTT Corba transport layer working with polyORB instead omniORB

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Thank you!

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2.5 ‘Multi-robot communication using meshing (or B.A.T.M.A.N begins)’ (FW-T-05)

Thomas M Roehr[(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: thomas.roehr@dfki.de

Abstract

In order to take advantage of multi-robot systems decentralized elements should be avoided. As such, this presentation illustrates how to realize a mult-robot communication system, which supports fully decentralized systems and even supports relaying between robotic systems. The solution relies on the installation of specially prepared access points into the robots, that are capable of running the meshing protocol B.A.T.M.A.N and allow to publish their endpoint using Avahi. Eventually this result in a fully distribution communication system that relies on FIPA-Messages for communication.

Multi-robot communication using meshing (or B.A.T.M.A.N begins)

by Thomas M. Roehr

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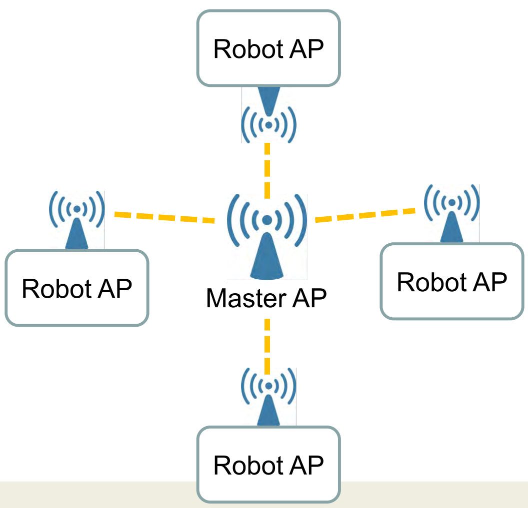
Main motivation

- Avoid the classic **centralized** setup of communication which has a single point of failure



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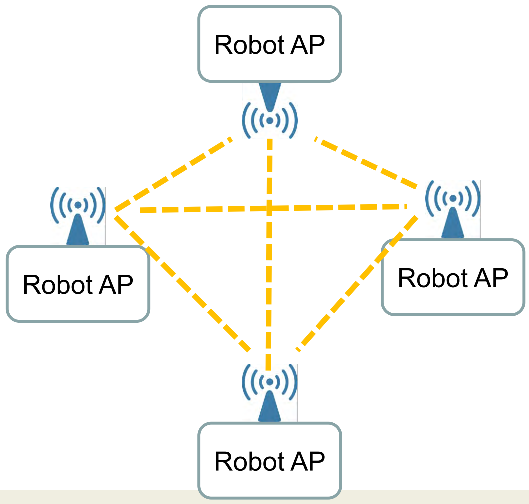
Main motivation

- Move to a fully distributed communication infrastructure and dynamic creation of a communication network



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Potential benefits

- Solution avoids
  - a central access point as single point of failure
  - dependency on external infrastructure i.e. (apart from the robots themselves)
- Solution allows
  - autonomy by direct robot-2-robot communication
  - allow for relaying and thus a larger operational range of the multi-robot system

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Solution – up to Layer 2 (ISO/OSI)

OM2P Router

+ OpenWrt Wireless Freedom

Open Router Operating System
(release: Chaos Calmer)

+ Open-Mesh

B.A.T.M.A.N. advanced
(release: 2015.2)

= Distributed communication infrastructure with routing and relaying at the level of MAC Addresses

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Meshing with B.A.T.M.A.N advanced

- B.A.T.M.A.N = Better Approach To Mesh Area Networks

Open-Mesh

- Identifies all communication nodes in the network (even across multiple hops)
- Provides user-space tools to communicate and ping (at MAC level)

```
root@gumstix:/home/gumstix# batctl o
[B.A.T.M.A.N. adv 2014.3.0, MainIF/MAC: wlan0/00:19:88:3e:86:bf (bat0 BATMAN_IV)]
  Originator      last-seen (#/255)           Nexthop [outgoingIF]:   Potential nexthops ...
d8:50:e6:aa:a2:c2    0.398s   (251) d8:50:e6:aa:a2:c2 [     wlan0]: 00:24:d7:17:cf:78 (205) d8:50:e6:aa:a2:c2 (251)
00:24:d7:17:cf:78    0.429s   (232) 00:24:d7:17:cf:78 [     wlan0]: d8:50:e6:aa:a2:c2 (185) 00:24:d7:17:cf:78 (232)
```

```
root@gumstix:/home/gumstix# batctl ping d8:50:e6:aa:a2:c2
PING d8:50:e6:aa:a2:c2 (d8:50:e6:aa:a2:c2) 20(48) bytes of data
20 bytes from d8:50:e6:aa:a2:c2 icmp_seq=1 ttl=50 time=2.32 ms
^C--- d8:50:e6:aa:a2:c2 ping statistics ---
1 packets transmitted, 1 received, 0% packet loss
rtt min/avg/max/mdev = 2.319/2.319/2.319/0.000 ms
```

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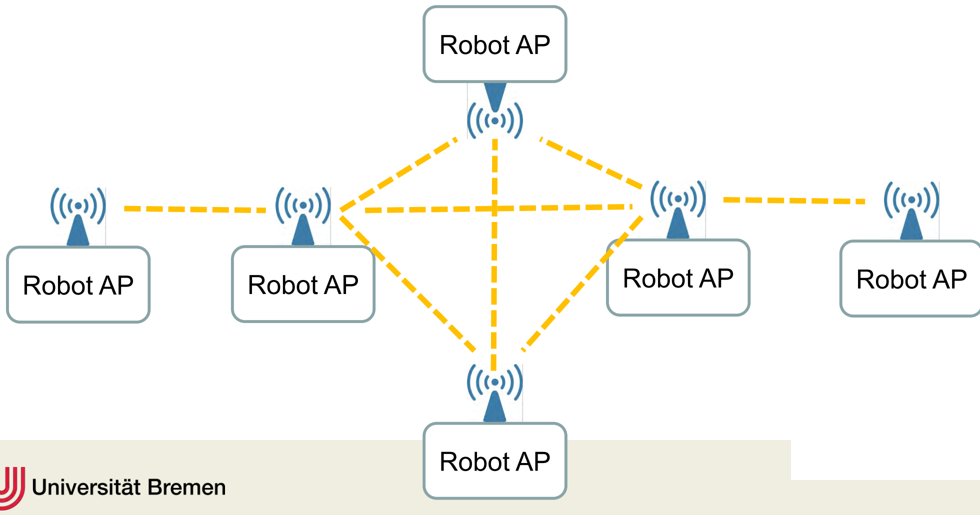
Benefits

- Routing across a fully distributed system is possible through meshing



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Drawbacks

- The technical solution is based on creating on AdHoc network where all nodes can participate
  - same frequency is used for all nodes
- Some features are incompatible with running this solution in the standard infrastructure:
  - Distributed APR Table
    - Intention: reproduce ARP reponses to speed up the finding of nodes
    - Drawback: switches assume that the originator sending the package sits behind the port that response packages come across
    - Solution (easy when identified): disable this feature

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OpenWrt

- Allows to setup router with
  - B.A.T.M.A.N. advanced
  - avahi-daemon
    - Required to support the FIPA-based communication infrastructure that has been developed in RIMRES and revised in TransTerrA

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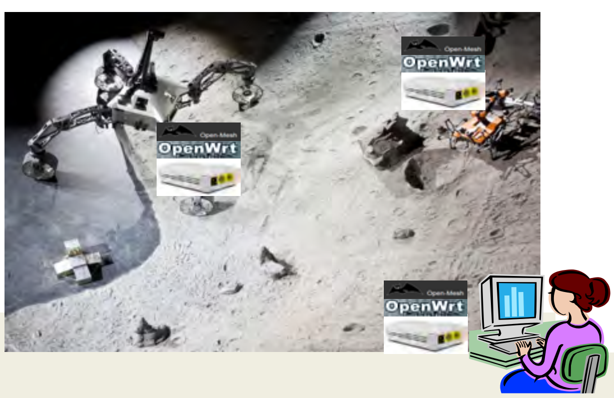
Validation

- The current solution is being applied in the project TransTerrA
  - each robot has one pre-configured OM2P access point
  - access to the communication infrastructure through a additional access node (same router)
    - embeds into the DFKI network



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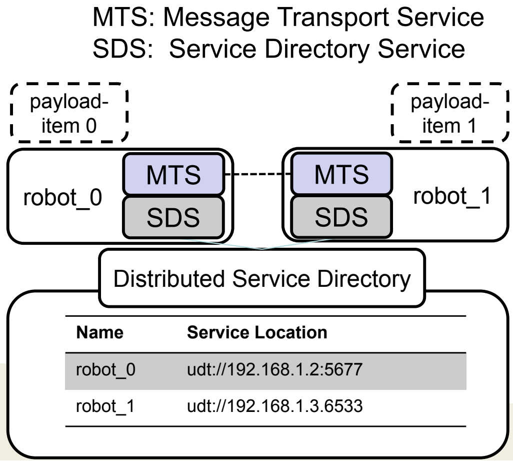
Validation

- Additional application of
  - a Distributed Service Directory (based on Avahi)
  - and FIPA-based messaging
    - see Rock multiagent/orogen/fipa_services



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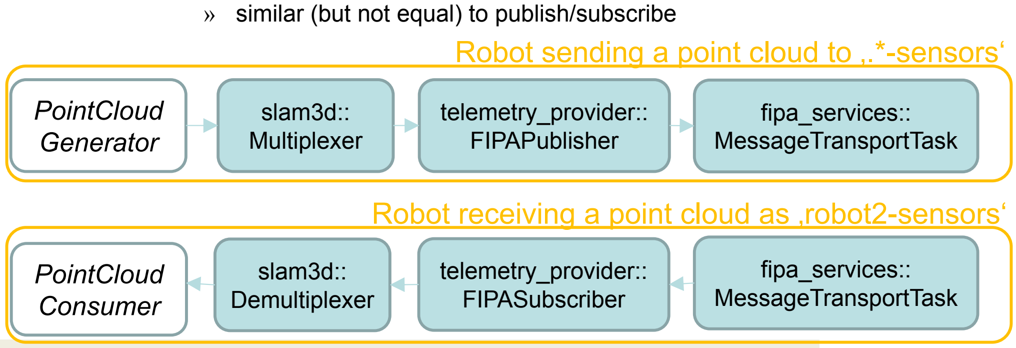
Validation

- Usage for distributed mapping
  - Distribution of PointCloud measurements from one robot to all other robots (even if previously unknown)
    - based on a multi-cast like sending of messages
      - minimal configuration need for robots that what to receive measurements
      - similar (but not equal) to publish/subscribe



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Observations

- Instability problems with Asus 330gN
  → Consistent deployment of OM2P accesspoints
- Bandwidth of up to 50 Mbit/s
  - measured using *iperf*
- APs should not be positioned very close to each other
  - otherwise we see a significant bandwidth drop to about 4 Mbit/s
- Isolate the network using a VLAN (not just an IP subrange)
  - Use subnet and access to main infrastructure through a dedicated router (gateway)
  - Setting the gateway on all(!) participating routers is required

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? or !

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3 ‘Manipulation & Control’

3.1 ‘Introduction to AG Manipulation and Control’ (MC-T-01)

Sankaranarayanan Natarajan [(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: sankara.natarajan@dfki.de

Abstract

This introductory talk brief about the focus about workgroup AG Manipulation and control. Later an insight about topics discussed during the past year were briefed.

Introduction to AG Manipulation and Control

Project Day

17.03.2016

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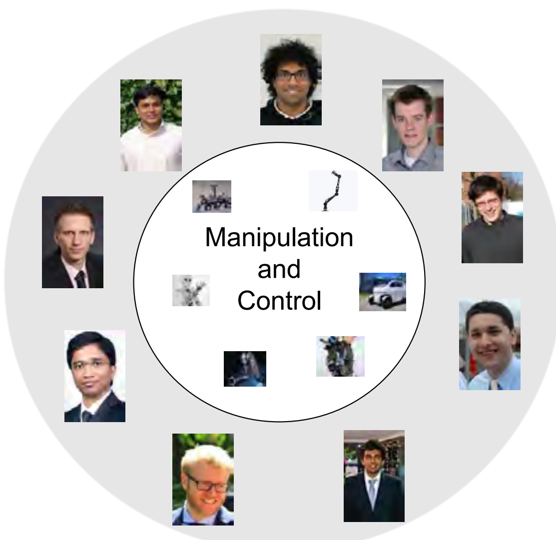

Members of AG Manipulation and Control

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Focus of AG Manipulation and Control

- To elaborate the state of the art – manipulation and control field.
- To discuss current activities – manipulation & control – DFKI .
- Ideas and suggestion – manipulation & control related problems – different projects.
- Share the work – not to reinvent the wheel.
- Wiki: *https://svn.hb.dfki.de/trac/Workgroups/wiki/Manipulation*
- SVN: *https://svn.hb.dfki.de/Workgroups/AG_manip_motion_ctrl/*

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Outline since 2015

- Smith Predictor controller for an underwater vehicle.
- Adaptove parameter identification for an underwater vehicle.
- Generalised Newton-Euler Equation
- Port Hamiltonian based modelling – Human robot cooperation
- Shared control for grasping – offline grasp database.
- Biped model – IMU sensor
- Coyote III Manipulator – system overview
- Spacebot gripper – manipulation
- Trajectory planner based on Bezier curves

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Agenda

Block I – AG Manipulation & Control

09:30 09:40 Introduction to AG Manipulation and Control (Sankaranarayanan Natarajan)
09:40 10:00 Trajectory Generation for Synchronous Motion in Joint Space (Rohit Menon)
10:00 10:20 Project FourByThree - Human-Robot-Collaboration in the Industry 4.0 (José de Gea Fernández)
10:20 10:40 Real Time Collision Avoidance for Human-Robot Collaboration (Dennis Mronga)
10:40 11:00 Ground Adaption Process for SherpaTT (Ajish Babu)

11:00 11:10 Coffe Break

Block II – AG Framework and Standardization

11:10 11:20 Introduction to AG Framework and Standardization (Thomas Röhr)
11:20 11:35 Opaque autogeneration / ClassLoader-based plugin manager (Sascha Arnold)
11:35 12:00 Orocos RTT: 3rd party NameServices and TaskContexts (Bernd Langpap)
12:00 12:15 Activities with SARGON - Space Automation & Robotics General Controller (Javier Hidalgo)
12:15 12:35 Multi-robot communication using meshing (or B.A.T.M.A.N. begins) (Thomas Röhr)

12:35 12:45 Cleanup of presentation room

Block III – Posters section - Foyer

12:45 13:15 Postersession ALL

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3.2 'Trajectory Generation for Synchronous Motion in Joint-Space' (MC-T-01)

Rohit Menon[(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: `rohit.menon@dfki.de`

Abstract

In this talk we give a brief overview of the existing trajectory interpolation methods and thereafter present our library which attempts to mitigate the challenges encountered with respect to multiple waypoints, synchronous motion in joint space and jerk limited motion

Trajectory Generation for Synchronous Motion in Joint Space

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Background and Motivation

- Trajectory types
  - Workspace Trajectories
  - Joint space Trajectories
- Generally, robot needs to travel through several waypoints rather than continuous path
- Joint space trajectories computationally efficient
- How do we generate such trajectories in joint space?

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Joint Space Trajectory

- Robotic manipulators with multiple DoF
- Multiple joints-> multiple optimal time joint trajectory durations
  - Shorter trajectories- already completed
  - Longer ones- still moving
- No additional time saved
- However unnecessary stresses on joints

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Problem Statement

- Convert N sparse path points to dense interpolated points
- Ensure joint synchronisation
- Ensure compliance of motion with position, velocity and acceleration constraints
- Jerk Limitation

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Types of Trajectory Interpolation

- Straight line interpolation- No C^2 (or even C^1) continuity
- Trapezoidal path- Point to Point Motion.
- Polynomials- Cubic or Higher Order for waypoint interpolation
- Polynomial of N-1th order for N points
- Interpolating Splines- Bezier Curves

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Bezier Curves

- Parametric Curve that uses the Bernstein polynomial as a basis
- Bezier Curve of degree n (order n+1)
  $C(t) = \sum_{i=0}^{n} \binom{n}{i} b_i * t^i (1-t)^{n-i}$
- Bezier Curve of degree n has C^{n-1} continuity
- As we need jerk limited motion, we need velocity and accleration profiles to have continuity i.e. C^1 Tangent and C^2 curvature continuity
- => Cubic Bezier splines for trajectory interpolation
- $C(t) = b_0 * (1-t)^3 + b_1 * t * (1-t)^2 + b_2 * t^2 * (1-t) + b^3 * t^3$

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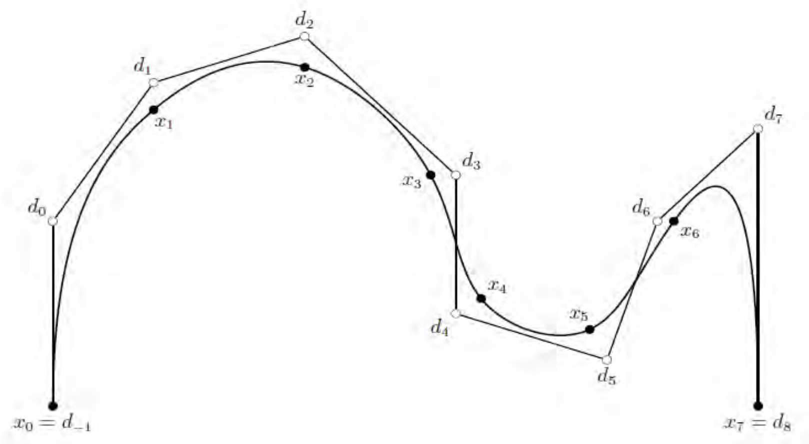
Interpolating curve through points



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deBoor Control Points

- Find N +3 auxiliary points d_{-1} to d_{N+1} called deBoor points
- $d_{-1} = x_0$, $d_{N+1} = x_N$
- N-1 equations for N Bezier curves, hence d_0 *and* d_N chosen arbitrarily
- End Conditions:
  - Natural: $C''_1(0) = 0, C''_N(0) = 0$ (Zero Acceleration)
  - Other conditions can also be specified by user

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Implementation

- Curves can be of M dimensions
  - Cartesian Space: M=3 for 3D curves
  - Joint Space: M= Number of Joints
- In joint space, synhcronisation of joint movements
  - For every ith Bezier curve section and jth joint,

    $tmax_i = \max(t_j)$ where t_j is the minimum time for jth joint in ith section taking velocity and acceleration constraints into consideration
- $C(t) = b_0 * \left(1 - \frac{t}{T}\right)^3 + b_1 * \frac{t}{T} * \left(1 - \frac{t}{T}\right)^2 + b_2 * \left(\frac{t}{T}\right)^2 * \left(1 - \frac{t}{T}\right) + b^3 * \left(\frac{t}{T}\right)^3$
- Time optimisation using recursive time scaling

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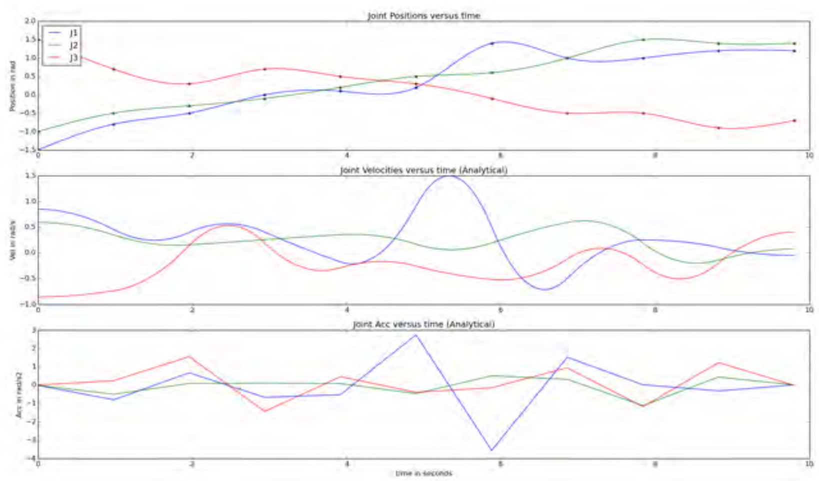
Curves without time reduction



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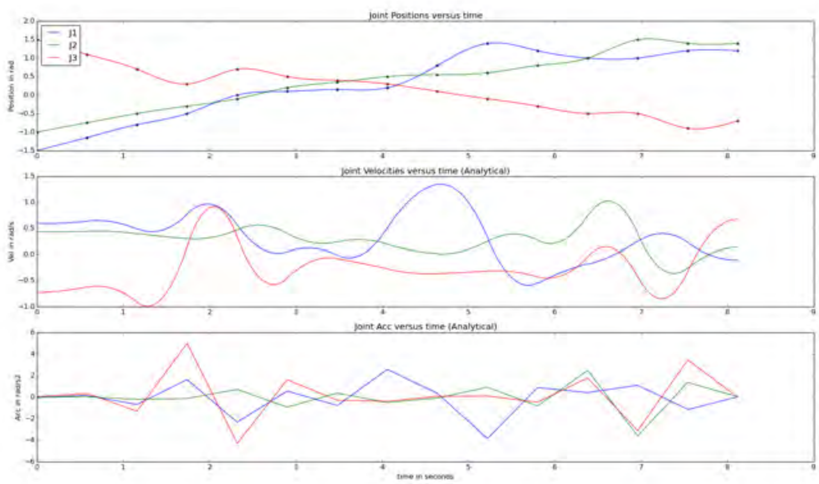
Curves with time reduction



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kuka_lbr.mp4

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Next Steps

- Test and verify the trajectories on actual hardware
- Incorporate additional constraints viz. dynamic
- Reduce computation time for time optimisation of trajectory generation

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3.3 'Project FourByThree - Human-Robot-Collaboration in the Industry 4.0' (MC-T-02)

José de Gea Fernández[(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: jose.de_gea_fernandez@dfki.de

Abstract

Human-robot collaboration is a key element in the Industry 4.0. There are currently many commercially-available examples of a new generation of robots which are designed for this purpose. One is the robot Baxter (and Sawyer), whose motors incorporate in series a mechanical spring which ensures that even in case of power failure, the robot remains always 'soft' to external contacts. Another example are the robots developed by Universal Robots which are certifiable for most human-robot collaborative tasks. Those robots include several safety measures, including limitation of maximum forces. Probably the most well-known example of lightweight robots for human-robot collaboration are the KUKA LBR iiwa robots. Those include joint torque sensors which enable the possibility of accurate dynamic control and, additionally, collision detection. In the current European project FourByThree, the aim is to combine two of the previous concepts: the combination of active and passive compliance in a modular elastic actuator.

Project FourByThree

- Human-Robot-Collaboration in the Industry 4.0 -

Dr.-Ing. José de Gea Fernández

German Research Center for Artificial Intelligence (DFKI)
- Robotics Innovation Center -

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Industry 4.0

Digitalisation of the factory

An interconnected factory in which machines and products permanently exchange information

- intelligent machines coordinate autonomously production processes
- intelligent robots cooperate with humans on assembly tasks

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Human-Centered Robotics

- Involves robotics applications where there is close interaction between robotic manipulation systems and human beings

- Traditional measures of robot performance:
  - Bandwidth (~ speed)
  - Maximum force and torque
  - Reachable workspace
- Human-centered robotics needs to consider an additional measure:
  - SAFETY

Challenge: Blend together safety and performance

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Human-Centered Robotics

- Traditional robot manipulator design: „Stiffer is better“
  - Precise position control
  - High forces from small joint displacements

- Stiff robot → heavy links → large forces
  - Electrical motors + high gear ratios
  - Gears increase reflected inertia and can cause injuries on impacts

Stiff Robots Are Not Good for Force Control and Dangerous for Human-Robot Interaction
- Humans are good at force control
  - Humans have low (adjustable) stiffness

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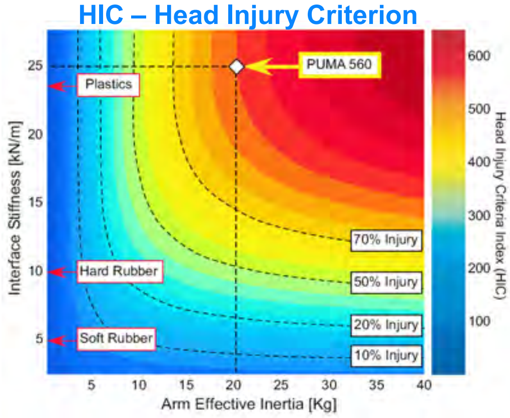
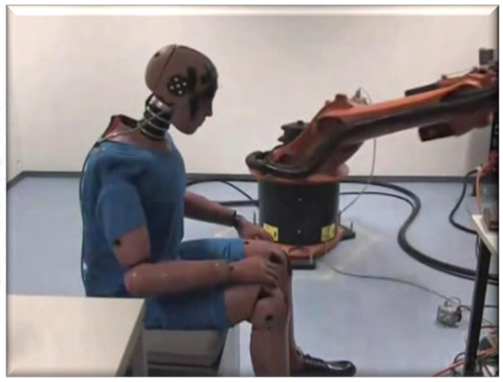
Human-Centered Robotics

- Most serious hazard:
  → potential for large impact loads which can result in serious injury or death

HIC – Head Injury Criterion





Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., *"Playing It Safe – A New Actuation Concept for Human Friendly Robot Design"*, IEEE Robotics and Automation Magazine, Vol. 11, No. 2 June 2004

Haddadin, S., Albu-Schäffer, A., et al., *"The DLR Crash Report"*, DLR – German Aerospace Center, Institute of Robotics and Mechatronics

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Human-Centered Robotics

- Compliant covering can reduce impact loading
  - Problems:
    - the amount of compliant material required to reduce impact loads to a safe level can be substantial and impractical
    - Does not tackle the root of the problem → the large effective inertia of most robotic arms

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Human-Centered Robotics

- Intermediate solution:
  - Mitigate the hazard by using software and sensor architectures which monitor and interrupt anomalies

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Human-Centered Robotics

- Ultimate solution:
  - Reduce effective impedance → lightweight, low-inertia manipulators

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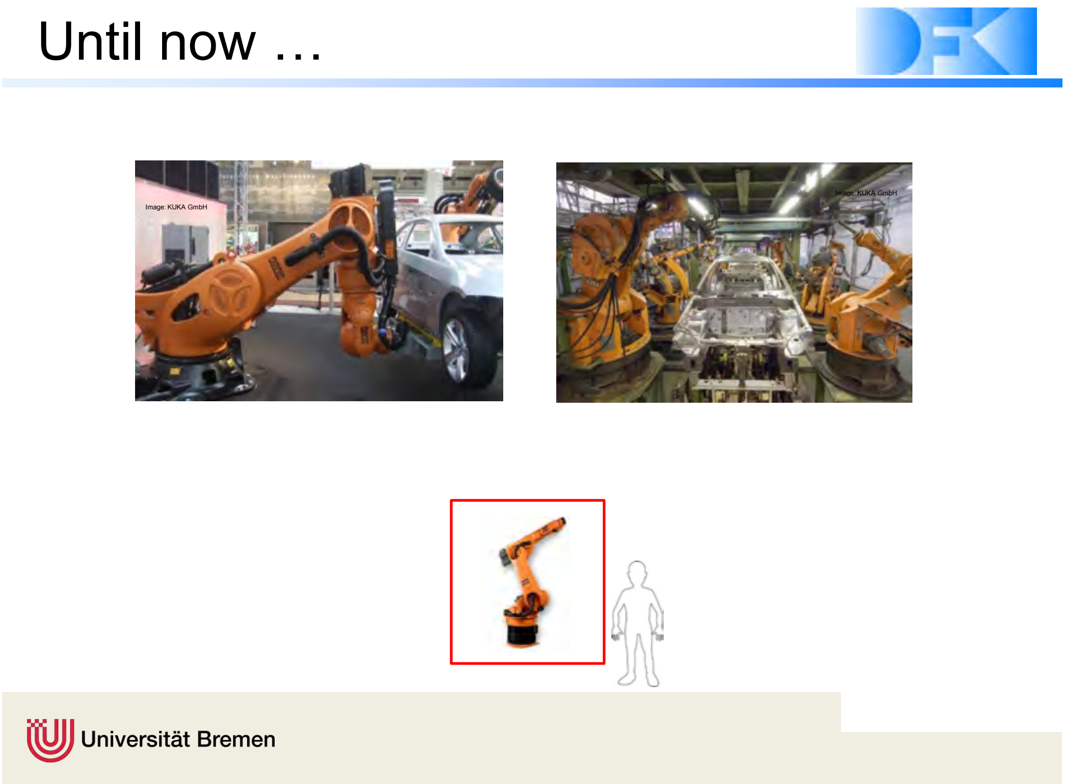
Until now …
Image: KUKA GmbH
Image: KUKA GmbH
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Currently happening …
Image: KUKA GmbH
Image: Universal Robots
Image: DFKI
Image: ABB
Image: Rethink Robotics
Image: KUKA GmbH
Redeploying Baxter now just takes a few minutes
Introducing the UR3
UNIVERSAL ROBOTS
Operates off standard household current
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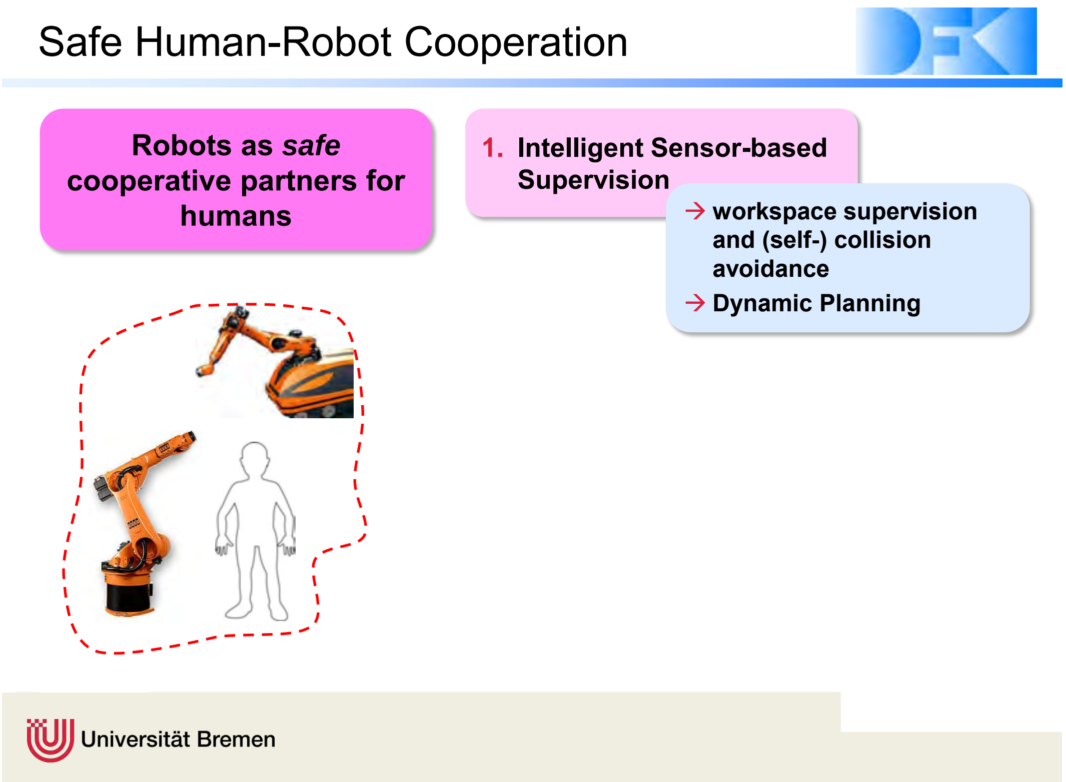
Safe Human-Robot Cooperation
Robots as *safe* cooperative partners for humans
1. Intelligent Sensor-based Supervision
→ workspace supervision and (self-) collision avoidance
→ Dynamic Planning
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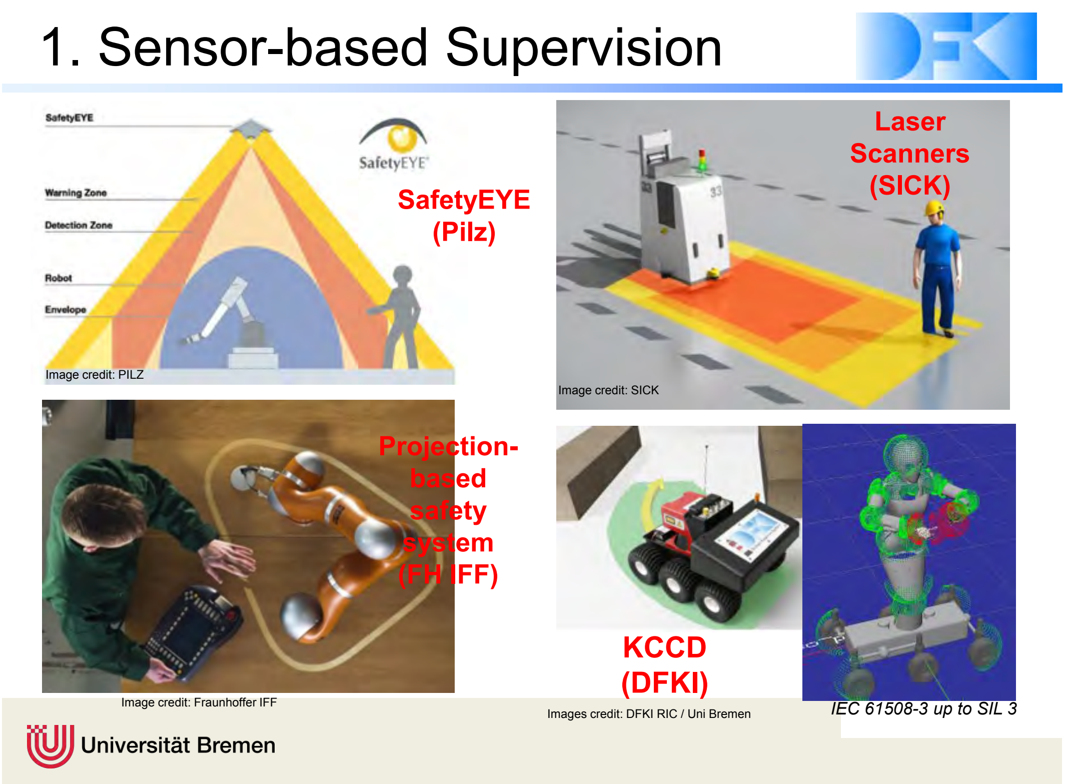
1. Sensor-based Supervision
SafetyEYE
Warning Zone
Detection Zone
Robot
Envelope
SafetyEYE (Pilz)
Image credit: PILZ
Laser Scanners (SICK)
Image credit: SICK
Projection-based safety system (FH IFF)
Image credit: Fraunhoffer IFF
KCCD (DFKI)
Images credit: DFKI RIC / Uni Bremen
IEC 61508-3 up to SIL 3
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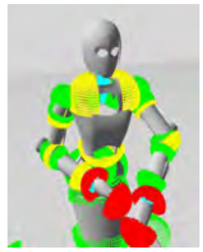
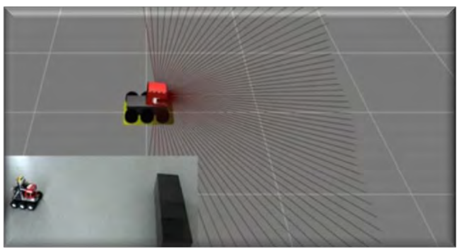
(Self-)Collision avoidance

- DFKI KCCD Software Library
  - Robot self-collision avoidance (manipulators) and calculation safety zone (moving autonomous vehicle) depending on current state
    - Certified according to **IEC 61508-3** (*Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems*) up to **SIL** (Safety Integrity Level) **3**
    - Patent submitted





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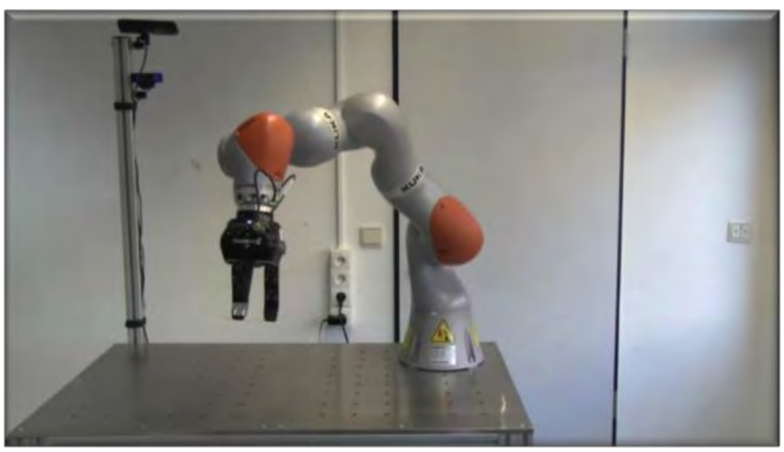
Images credit: DFKI RIC / Uni Bremen

(External) Collision avoidance

- DFKI KCCD Software Library
  - Reactive collision avoidance with external objects



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Images credit: DFKI RIC / Uni Bremen

Safe Human-Robot Cooperation

Robots as *safe* cooperative partners for humans

2. Robot design

- → **Inherent safety by design**
- → **e.g. series-elastic actuators, low-inertia, compliant covering …**

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2. Safety via Design

Series Elastic Actuation

- Baxter
  - Payload: 2.2kg (including Gripper)

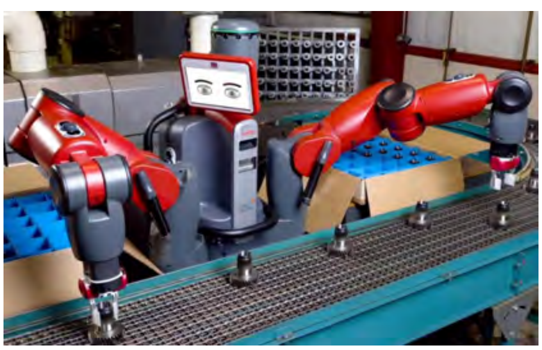

Image: Rethink Robotics

- Sawyer
  - Payload: 4kg

Image: Rethink Robotics

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Image credit: Rethink Robotics

Safe Human-Robot Cooperation

Robots as *safe* cooperative partners for humans

3. Dynamics & Control

- → **Safety via control software**
- → **E.g. active compliance**

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3. Safety via Control Software

Joint Torque Control

- Use of torque sensors on each joint to enable
  - Compliance

  and

  - Collision detection

- New KUKA iiwa
  - 7kg and 14kg Payload

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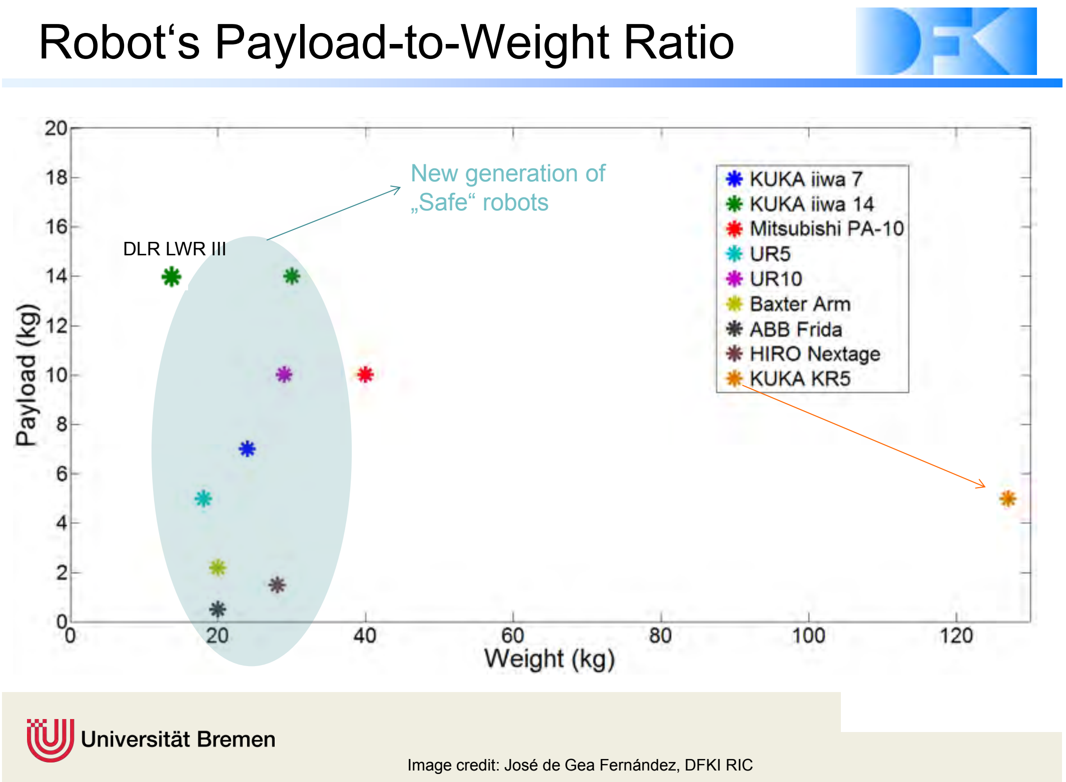
Robot's Payload-to-Weight Ratio
Payload (kg)
Weight (kg)
DLR LWR III
New generation of „Safe" robots
KUKA iiwa 7
KUKA iiwa 14
Mitsubishi PA-10
UR5
UR10
Baxter Arm
ABB Frida
HIRO Nextage
KUKA KR5
Universität Bremen
Image credit: José de Gea Fernández, DFKI RIC

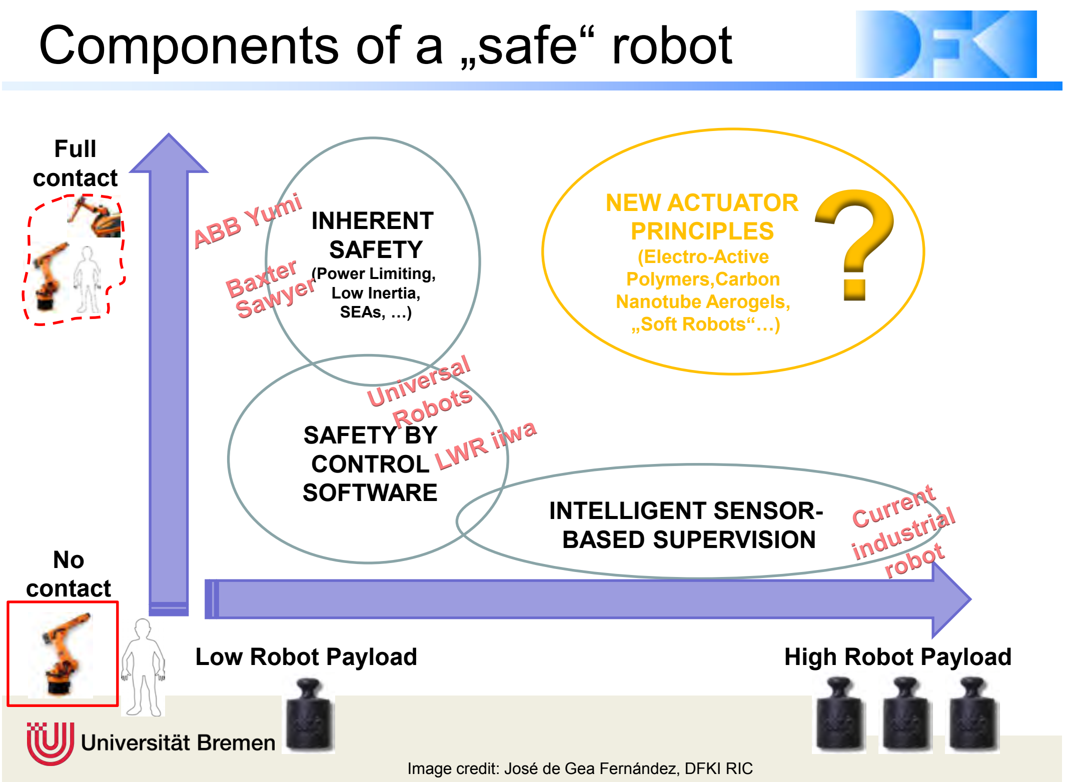
Components of a „safe" robot
Full contact
No contact
ABB Yumi
Baxter
Sawyer
INHERENT SAFETY
(Power Limiting, Low Inertia, SEAs, ...)
NEW ACTUATOR PRINCIPLES
(Electro-Active Polymers,Carbon Nanotube Aerogels, „Soft Robots"...)
Universal Robots
LWR iiwa
SAFETY BY CONTROL SOFTWARE
INTELLIGENT SENSOR-BASED SUPERVISION
Current industrial robot
Low Robot Payload
High Robot Payload
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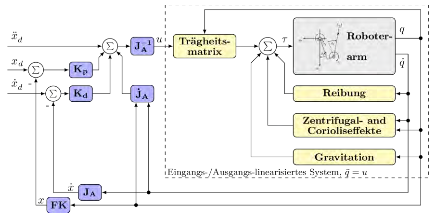
Image credit: José de Gea Fernández, DFKI RIC

Safety via Control Software – COMPI 6-DOF arm

- Torque control based on motor currents and inverse dynamic model
  - Joint mechatronics
    - Harmonic drive gears (1:100)
    - Robodrive BLDC motors
    - Onboard joint electronics (FPGA)



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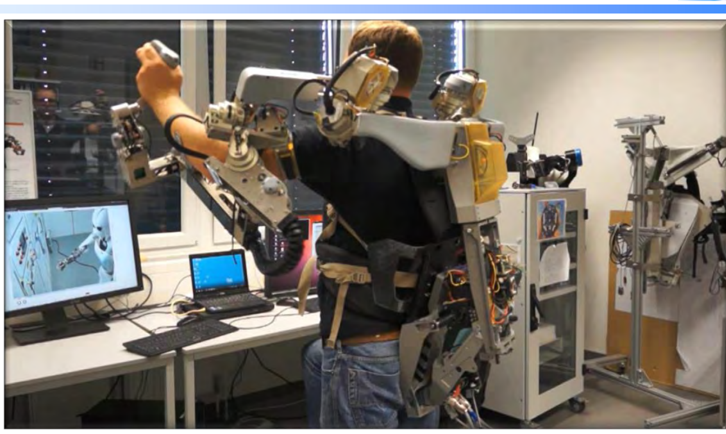
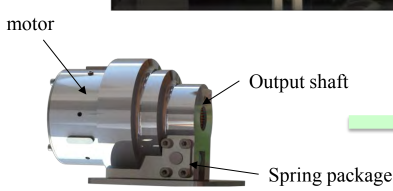
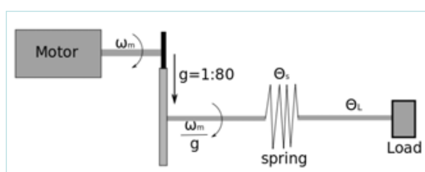
Vinzenz Bargsten, José de Gea Fernández, *„COMPI: Development of a 6-DOF Compliant Robot Arm for Human-Robot Cooperation",* In Proceedings of the 8th International Workshop on Human-Friendly Robotics, (HFR-2015),

Safety via Design – CAPIO series-elastic actuator







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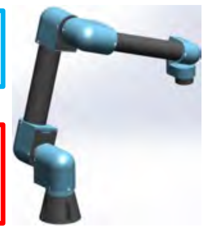
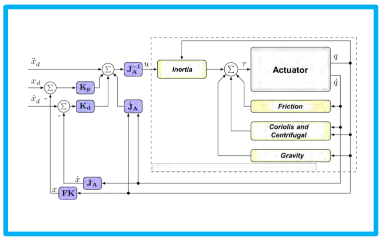
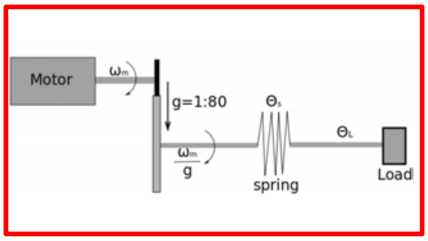
Martin Mallwitz, Luis Manuel Vaca Benitez, Bertold Bongardt, Niels Will, *„The CAPIO Active Upper Body Exoskeleton",* In Workshop Proceedings of the IEEE International Conference on Robotics and Automation 2014, (ICRA-2014)

Safety via Control/Design – FourByThree SEA

- Combination
  - Safety via control software
    - Joint torque estimation via motor currents and dynamic model
  - Safety via design
    - Series-elastic actuator
    - Redundant joint torque estimation via spring deflection







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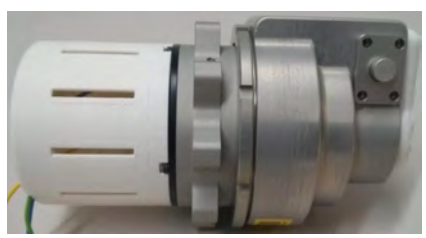
Actuator 28Nm

Features

- Lightweight BLDC-motor TQ-Systems
  - 0.28 Nm, 130 W, 48 V
- HarmonicDrive Gear ratio 100:1
- Three off-axis absolute position encoders, 19 bit resolution
- Max. 5° deflection
- Overall weight 600 g
- Variable springs sets (Stiffness 175 Nm/rad)
- 38 rpm, peak torque ~50 Nm



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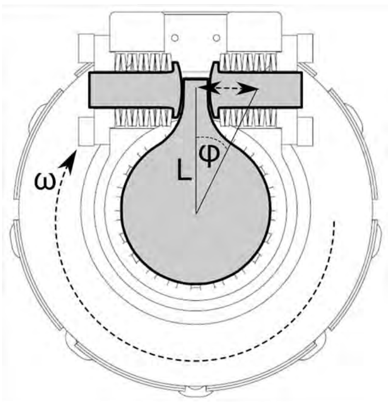
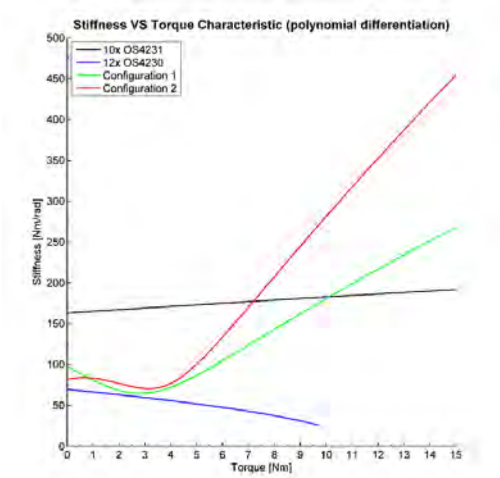
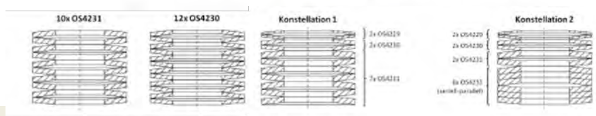
Actuator 28Nm







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Actuator 50Nm

Features

- Lightweight BLDC-motor TQ-Systems
  - 0.5 Nm, 145 W, 48 V
- HarmonicDrive Gear ratio 120:1
- Three off-axis-absolute position encoders (19 bit resolution)
- Max. +- 5° deflection
- Stiffness ~ 520 Nm/rad
- Overall weight 2500 g
- 22 rpm, peak torque ~85 Nm

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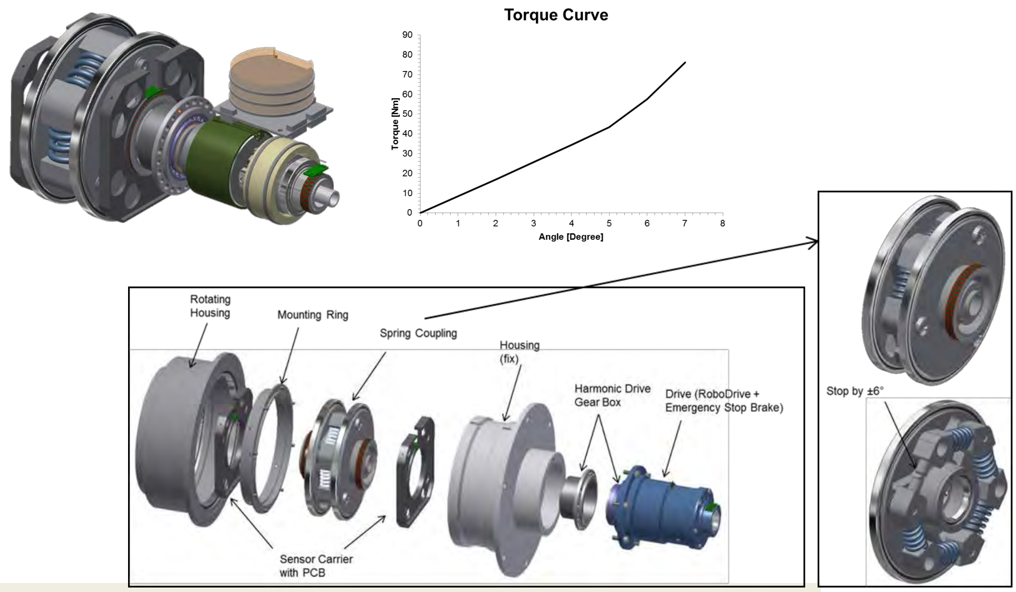
Actuator 50Nm



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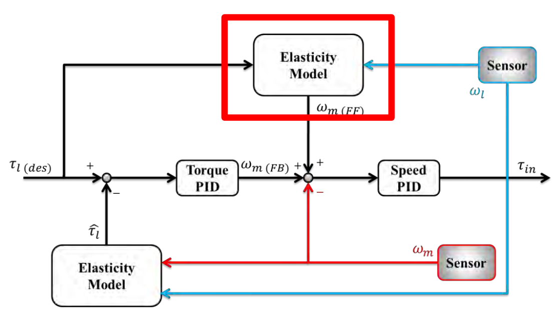
Actuator Control (FPGA)

- Computed Torque control
  - Friction compensantion
  - Adaption to different spring stiffness
- Two-channel torque estimation
  - Motor current based
  - Spring deflection
- Low-level safety features
  - Max. torques, currents, position limits, watchdogs, …
- Input:
  - Reference/s: torque (velocity) values
  - Configuration: single joint PD values on-the-fly, control mode, joint limits (motor current, position, velocity…)
- Outputs:
  - Status: motor currents, positions (motor side, link side, deflection), PD values, status, etc…

Velocity-sourced torque control
- Improved position accuracy
- Feedforward elastic model



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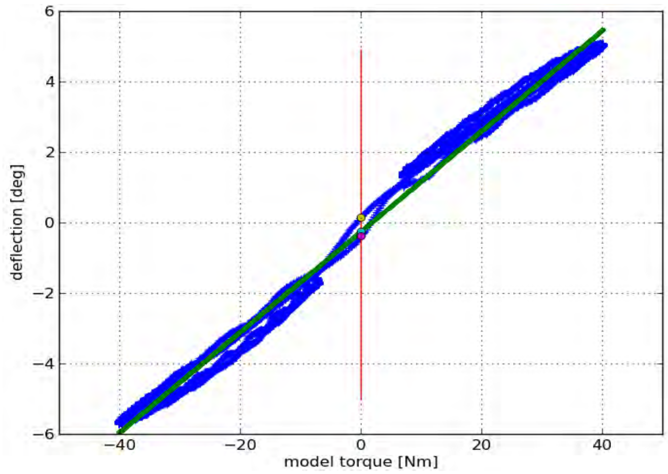
Elasticity – Torque vs Deflection - Linear Model



Torque-spring deflection curves with 10 different load positions

A fitted linear regression model (green) : **τ=a*θs+b** is used for representing the torque-spring deflection curve, where **τ** is the motor torque and **θs** is the deflection of the spring.

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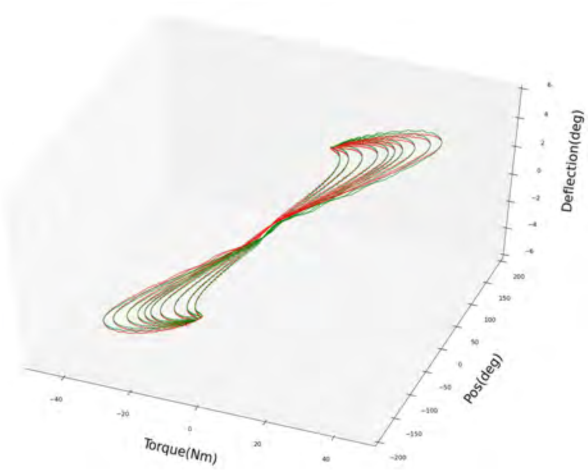
Elasticity – Torque vs Deflection with third dimension



DGMM Model

- Joint Probability Distribution (JPD)
- JPD is represented by a mixture of Gaussians
- P[τ,θ,θs,sign(v)]
- Estimation from JPD:
- E[τ*|θ,θs,sign(v)]

Torque-spring deflection curves with 10 different load positions

The motor rotating position is used as the third dimension for training the **DGMM** model.

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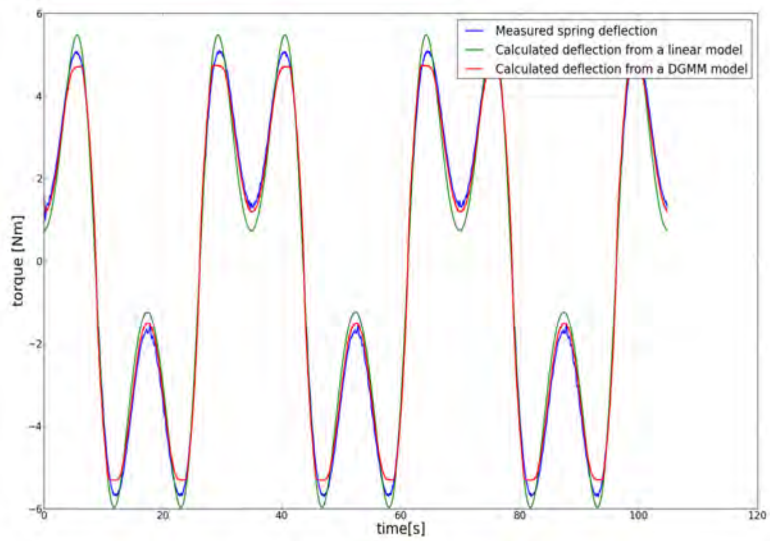
Elasticity – Comparision Predicted Torques using Linear vs DGMM Model (offline data)



The parameters of the models are calculated by the data from nine experiments and the results are evaluated by using the data from the tenth experiment

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Thank your for your attention!

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3.4 ‘Real-Time-collision-Avoidance for Human-Robot-Collaboration’ (MC-T-03)

Dennis Mronga [(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: dennis.mronga@dfki.de

Abstract

Production lines in which hybrid teams of robots and humans are working in collaboration are focussed in the context of industry 4.0. Regarding overlapping workspaces and tasks where robots and humans are working closely together, the aspect of safety is becoming a major issue. Apart from techniques for workspace monitoring and compliant control, we require sophisticated collision avoidance approaches that allow the robot to avoid contact with obstacles where it is undesired. In the Bilateral project we developed an approach for reactive collision avoidance based on RGB-D camera data. The approach can be applied in real-time and works on arbitrary obstacles that enter the workspace of the robot. It is integratable with other operational space controllers using the WBC (Whole Body Control) framework. This talk gives an overview on the methodology and first results.

Real Time Collision Avoidance for Human-Robot Collaboration

Dennis Mronga

DFKI Bremen & Universität Bremen
Robotics Innovation Center
Director: Prof. Dr. Frank Kirchner
www.dfki.de/robotics
robotics@dfki.de

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Introduction

www.pcworld.com

http://blog.robotiq.com

- Establish hybrid teams of robots and humans in an industrial context
  - Overlapping workspaces
  - Collaborative tasks
  - *Safety of the worker*

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Introduction


www.pcworld.com


http://blog.robotiq.com

- Mechanical barriers
- Light curtains
- Safety stops

- Workspace monitoring
- Collision avoidance
- Compliance, contact monitoring

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Introduction


www.pcworld.com


http://blog.robotiq.com

- Mechanical barriers
- Light curtains
- Safety stops

- Workspace monitoring
- Collision avoidance
- Compliance, contact monitoring

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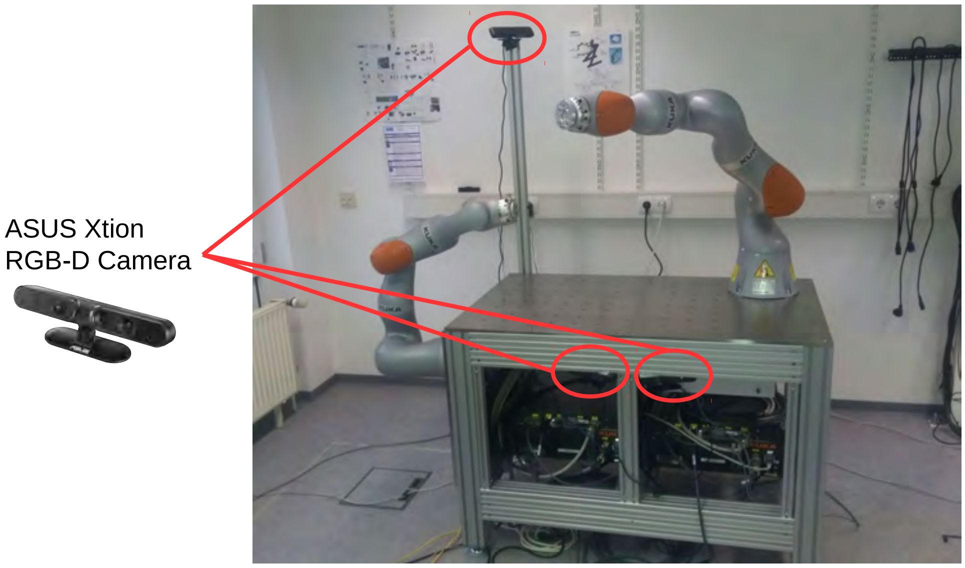
Demonstrator



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Reactive Collision Avoidance

Reactively avoid collisions with arbitrary obstacles in a high-frequency control loop using 3D camera data

1. Sensor Processing
2. Collision computation
3. Collision avoidance control

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Reactive Collision Avoidance

Reactively avoid collisions with arbitrary obstacles in a high-frequency control loop using 3D camera data

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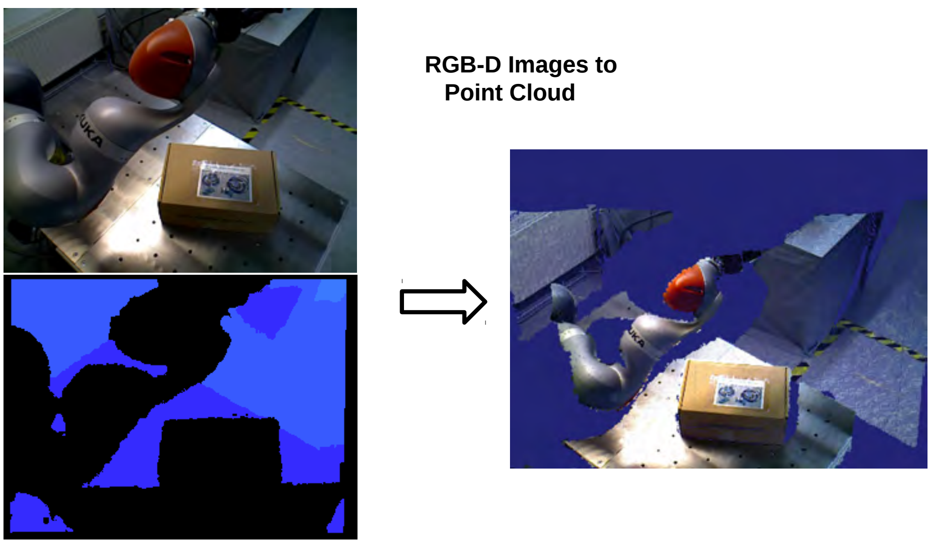
Sensor Processing



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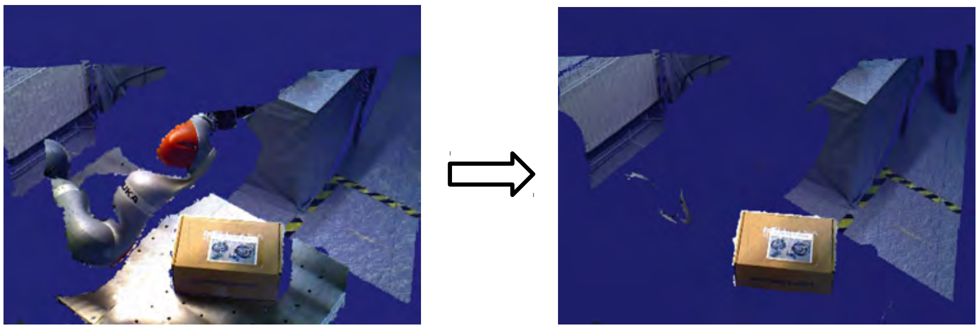
Sensor Processing

Robot Self Filter



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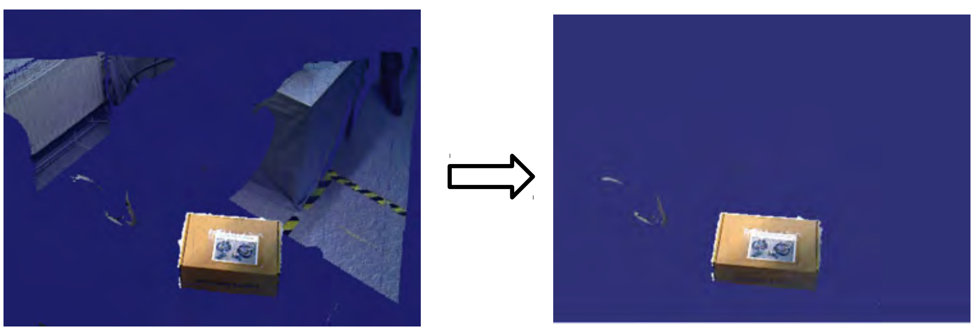
Sensor Processing

Background Subtraction



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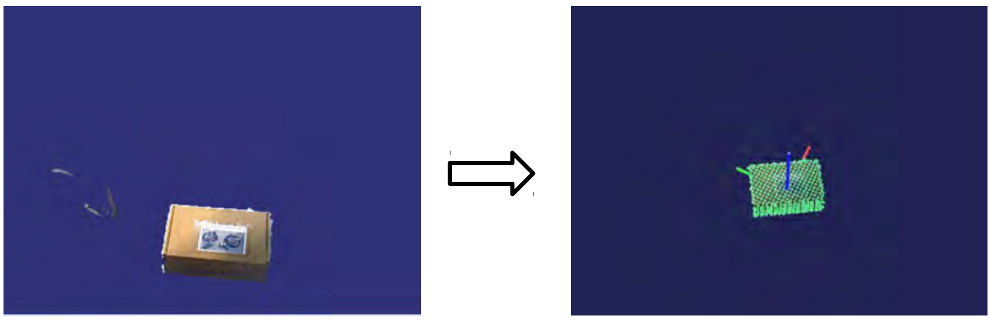
Sensor Processing

Clustering, Tracking



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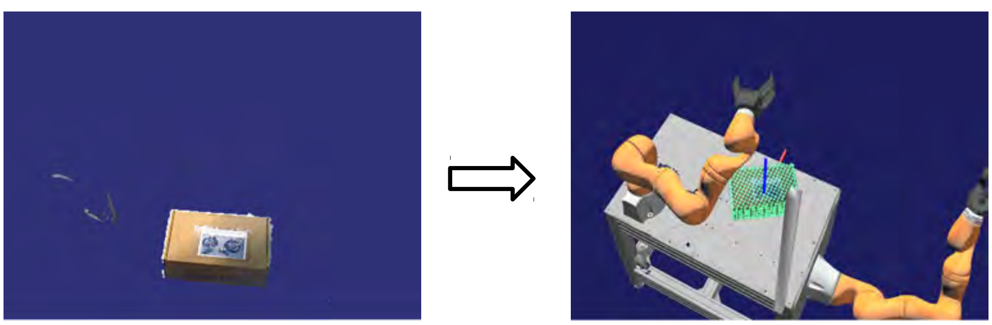
Sensor Processing

Clustering, Tracking



- One point cloud (cluster) for each external object
- Position, velocity and id's of the clusters

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Reactive Collision Avoidance

Reactively avoid collisions with arbitrary obstacles in a high-frequency control loop using 3D camera data

1. Sensor Processing
2. Collision computation
3. Collision avoidance control

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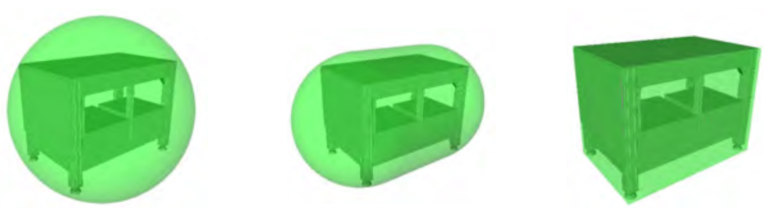
Collision Computation

- Use of KCCD (Kinematic Continuous Collision Detection) Library
- Rigid bodies are represented as convex hulls
- A hull is represented of a finite set of n points and a radius



n=1 n=2 n=8

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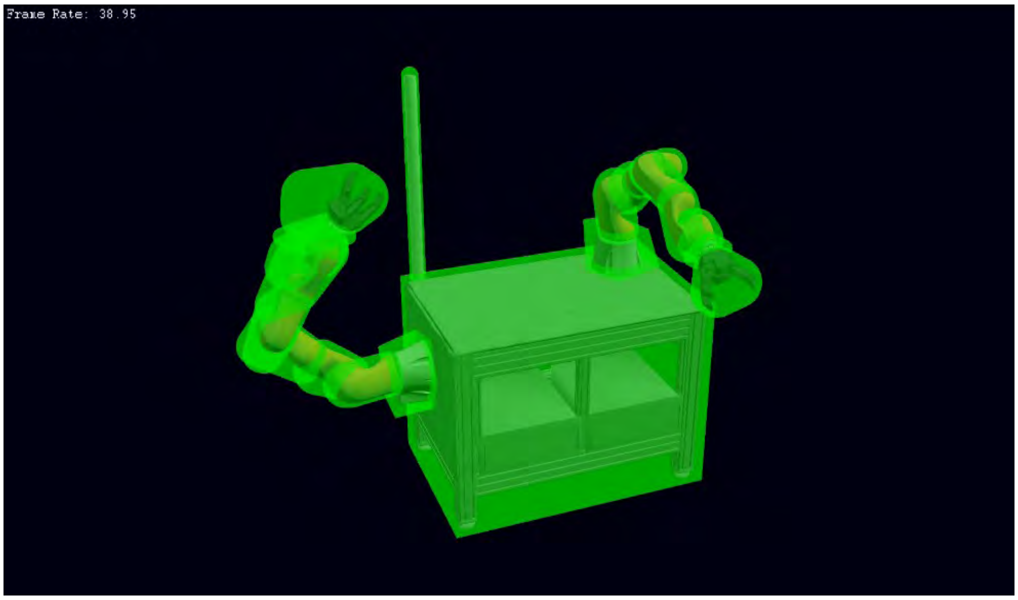
Collision Computation



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Collision Computation

- KCCD model is defined through a kinematic and a collision volume description
- Fixed at runtime

Extension to external objects:

- Add a fixed number of external objects to the KCCD model
- Assign each tracked object id to an external object in KCCD model
- For each point cloud ...
  - For each point, add a point to KCCD Volume
  - Remove a KCCD point and check if the volume still covers the point cloud
  - If the number of KCCD points is bigger than max. number of points, increase the radius and check again

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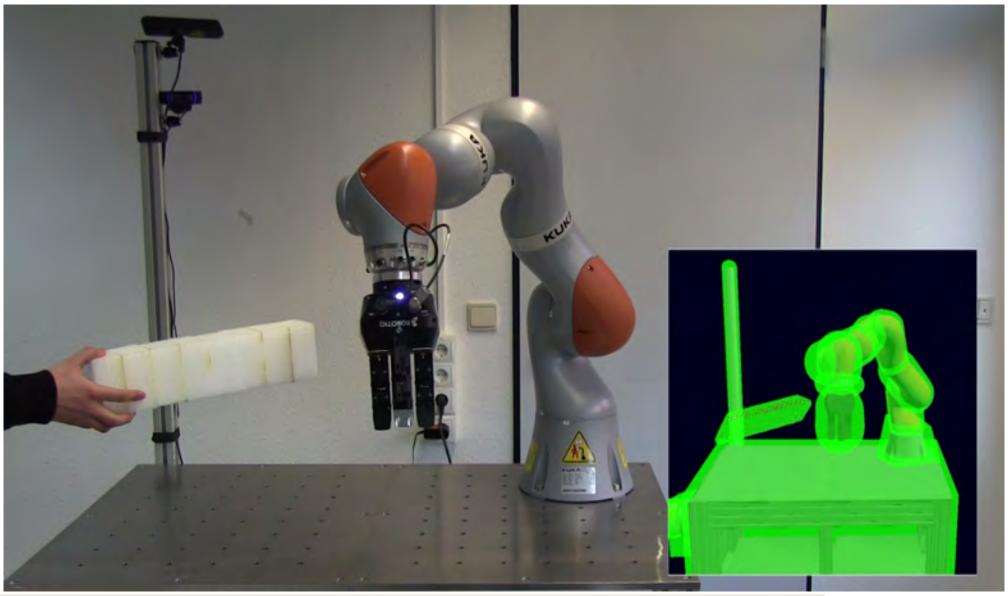
Collision Computation



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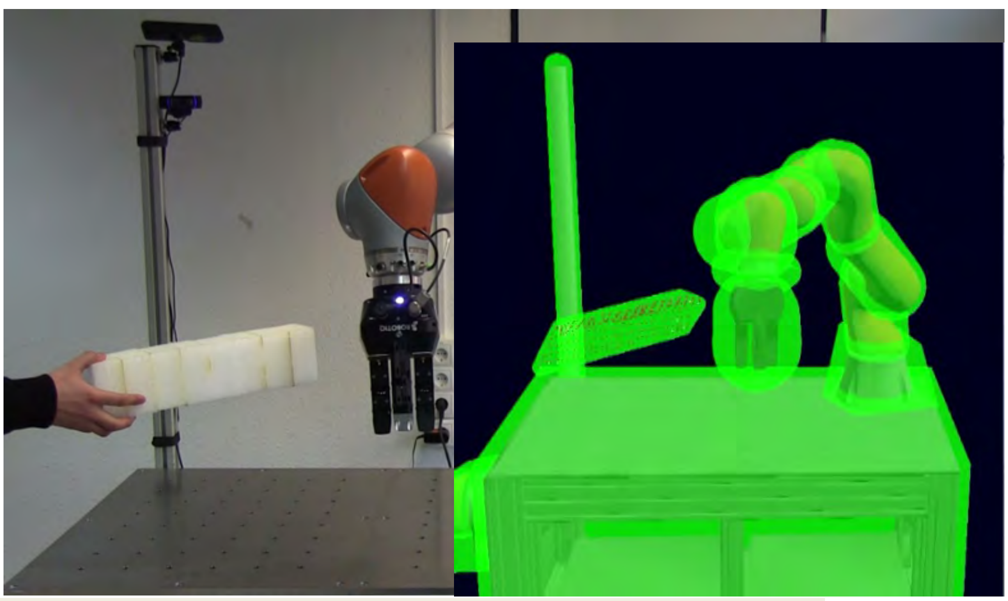
Collision Computation



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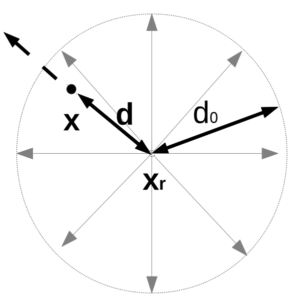
Reactive Collision Avoidance

Reactively avoid collisions with arbitrary obstacles in a high-frequency control loop using 3D camera data

1. Sensor Processing
2. Collision computation
3. Collision avoidance control

Collision Avoidance Control

- Avoidance behaviors are implemented as *radial repulsive potential fields*:

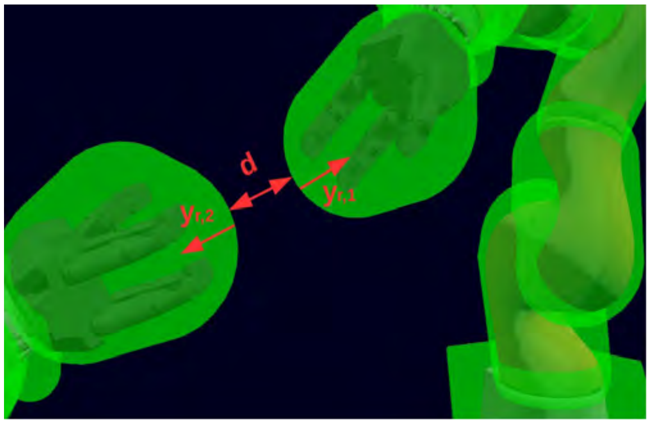


$$y_r = \begin{cases} k_p \frac{x - x_r}{d^2}, & d < d_0,\ d = |x - x_r| \\ 0, & \text{otherwise} \end{cases}$$

$\mathbf{y_r}$ control output
$\mathbf{K_p}$ proportional gain
$\mathbf{x}$ link position
$\mathbf{x_r}$ closest collision point
d distance
d_0 max. influence distance

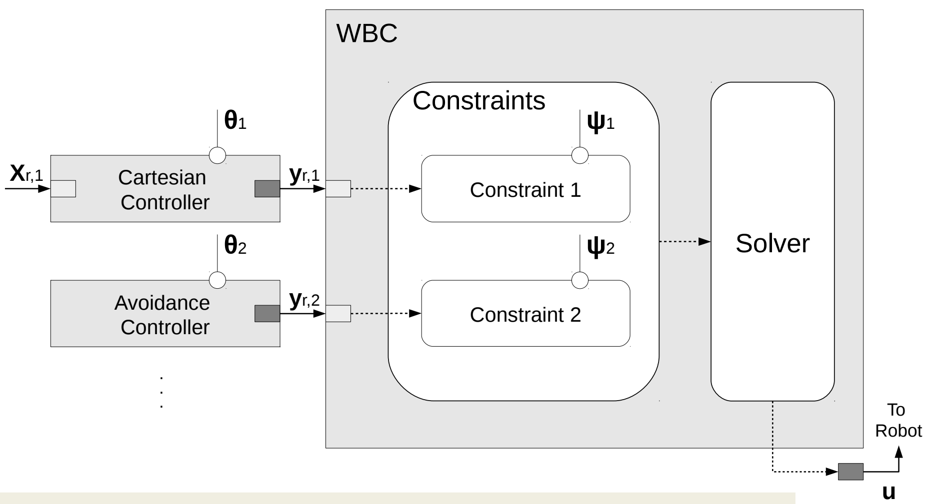
Collision Avoidance Control

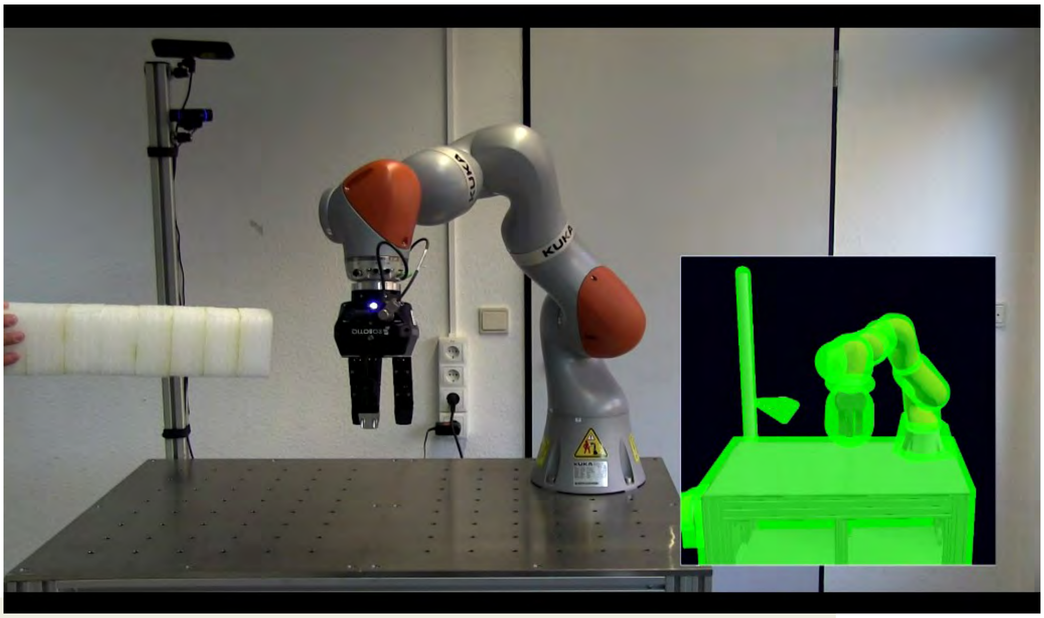
- Avoidance behaviors are implemented as *radial repulsive potential fields*:



Collision Avoidance Control

- Combine with other behaviors, e.g. Cartesian Control. Using whole body control





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Thank you!

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3.5 'Ground Adaption Process for SherpaTT' (MC-T-04)

Ajish Babu [(1)]

(1) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: ajish.babu@dfki.de

Abstract

The presentation shows the initial results from the Ground Adaption Process (GAP) for the planetary rover SherpaTT with active suspension. The GAP process makes use of the sensory outputs from force-torque sensors attached to each wheel and the Inertial Measurement Unit. The process satisfies the two primary objectives of maintaining a desired roll and pitch of the body of the rover and distributing the forces evenly on all wheels. The experiments produced good results with roll and pitch errors within 0.5deg and force deviation within 100N.

Ground Adaption Process for SherpaTT

Ajish Babu & Dipl.-Ing Florian Cordes
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28359 Bremen, Germany

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Ajish Babu & Florian Cordes 1

System

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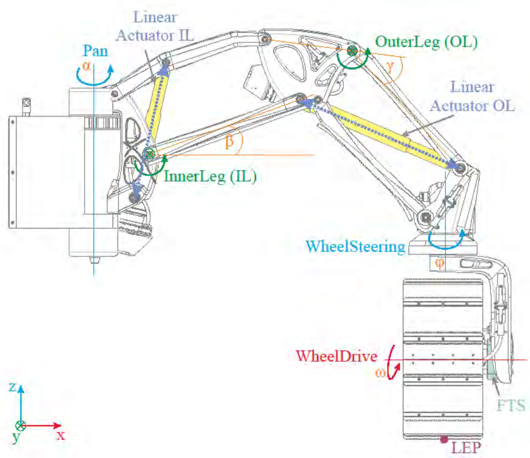
Ajish Babu & Florian Cordes 2

SherpaTT

- Legs with wheels at end
- Manipulator
- Sensors (IMU, FTS)



- Active Adaption
  - Avoid tip over
  - Distribute load over wheels
  - Maintain desired orientation

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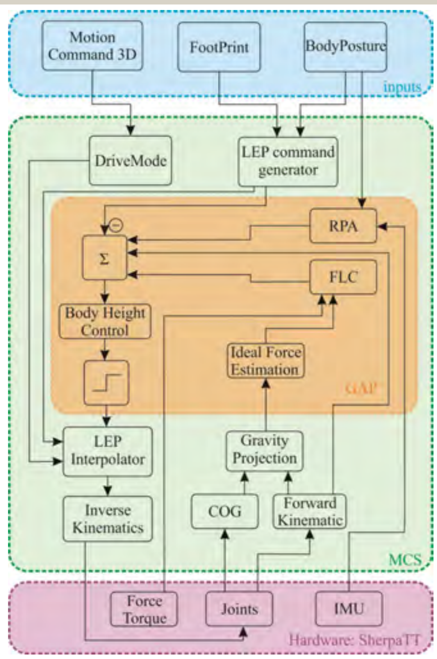
The Motion Control System MCS

- Inputs from
  - User via GUI
  - High-Level (Trajectory Follower)
- GAP is a component of the MCS
- Main Components of GAP
  - Roll/Pitch Adaption RPA
  - Force Leveling Control FLC

1. Each GAP-component writes offsets for each wheel
2. Current command is subtracted, actual LEP is added -> results in final offset
3. Check if all offsets same sign
4. Limit the output



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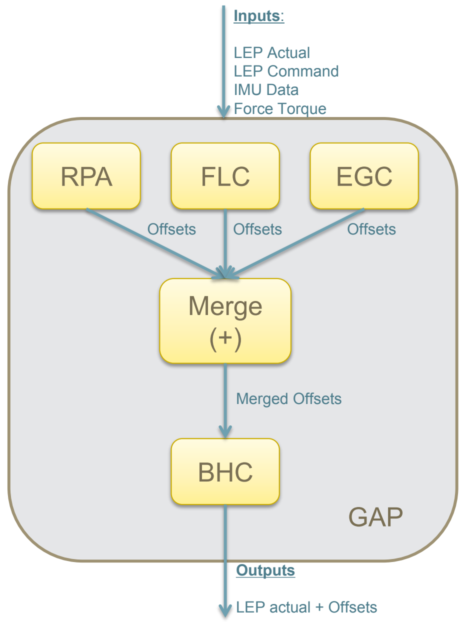
Controller Components

- Force Leveling Controller FLC
  - Ensures ground contact
  - Maintains force distribution
  - Proportional controller
  - Ideal force distribution
    - Static equilibrium
    - Project onto gravity perpendicular plane
- Roll Pitch Adaption RPA
  - Maintains orientation w.r.t world
  - Offset computation
  - Proportional controller
  - Angle axis error representation



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Setup

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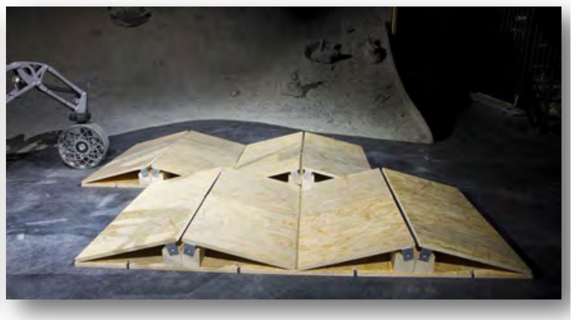
Wooden Obstacle Course

- Two boards with 1.2m x 2.4m
- Roll-Pitch Triangles (h=0.2m)
- One sided obstacle for SherpaTT
  - On left side of robot
- Both sides with offset ¼ obstacle



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Results

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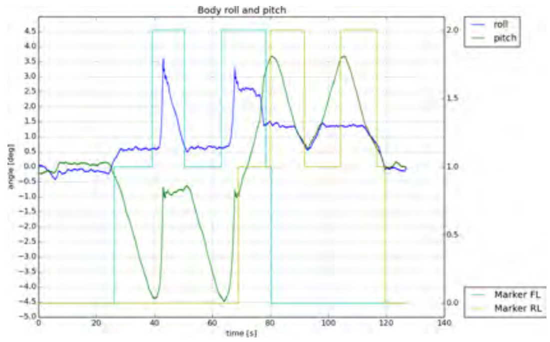
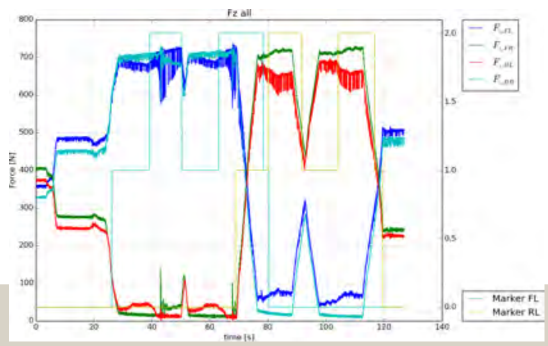
Ajish Babu & Florian Cordes 8

No Adaption

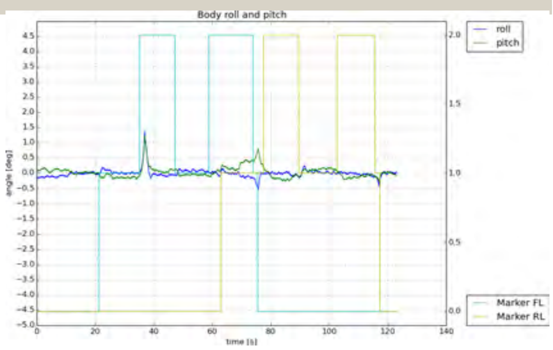
- Two wheels have basically no grip/ground contact most of the time
- Forces show high deviations from reference (ref is ~370N)
- Pitch follows more or less the obstacle
  - Tipping over shifts pitch to roll

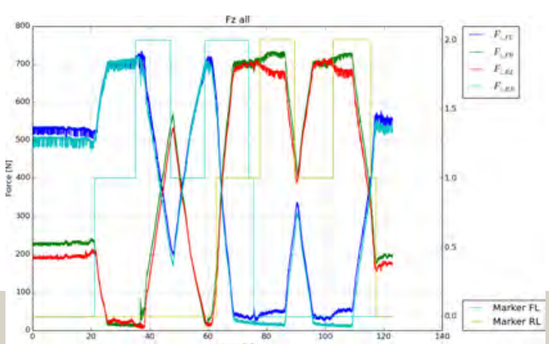




RPA active

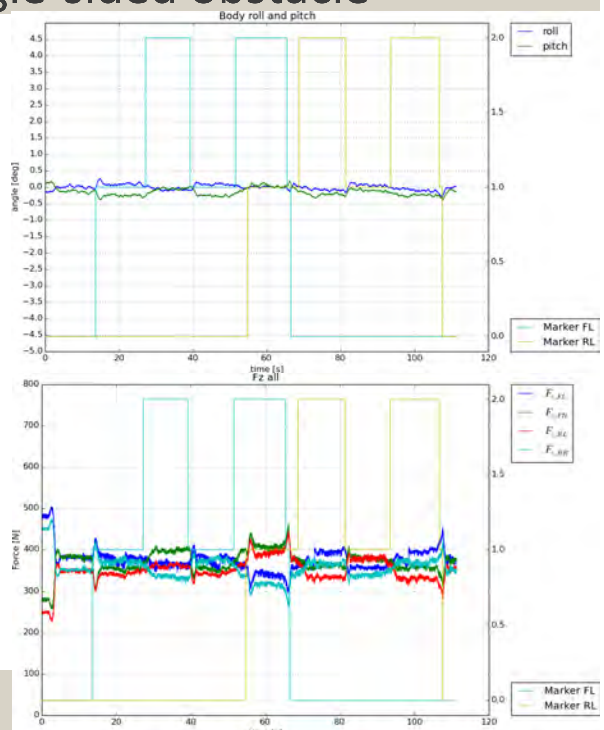
- Forces still deviate (no force control active!)
- Roll and pitch quite nicely limited
  - Pitch peaks when tipping over
  - Roll the same





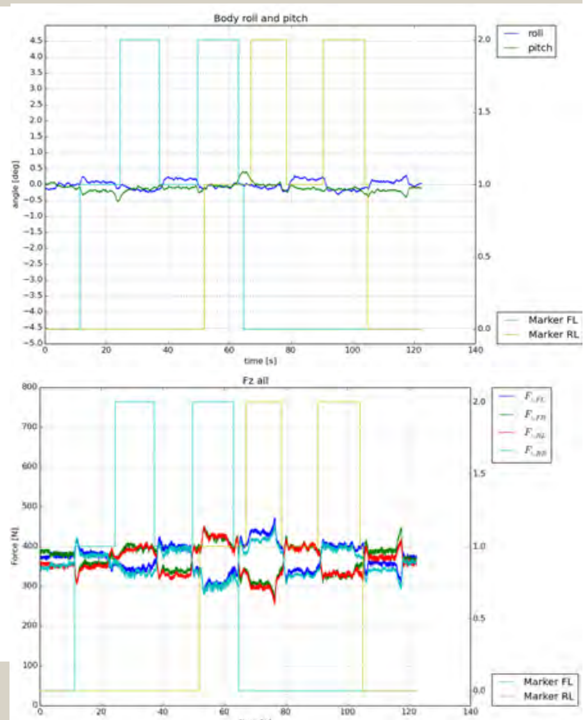
RPA and FLC on single-sided obstacle

- All wheels keep ground contact
- Forces deviation occur when wheels enter or leave the obstacle
- Roll and Pitch mostly in range +/-0.5deg
- Force variation within 150 N



RPA and FLC on double-sided obstacle

- Similar results



Videos

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3.6 'Sensor-less Collision Detection and Isolation' (MC-P-01)

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Abstract

Safety is becoming an important issue as the next generation of robots will be working closely with the humans possibly without any physical safety cages. To increase the safety, the robot must be able to detect and react to collisions possibly using only the robot's internal sensors (e.g. joint position and joint velocity). This poster presents the theory of sensor-less collision detection and isolation using residual energy and residual momentum approaches from the literature and its implementation on the COMPI robot platform. The implementation does not require any torque sensing or external sensors and hence, it is sensor-less. Additionally, a roadmap to safer physical human robot interaction is presented in the form a collision event pipeline which uses these two approaches to identify, classify and react towards different collisions. In the future work, the collision event pipeline will be implemented and extended.

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Sensorless Collision Detection & Isolation

Towards safer physical Human Robot Interaction (pHRI) - Shivesh Kumar

Motivation

Industrial robotics research is gradually shifting its focus from robots that can *replace* humans to robots that can *work with* humans because this can augment the abilities of human workers and increase overall productivity. Thus, safety becomes a key issue in next generation of robots.

To increase the safety, the robot must be able to detect and react to collisions possibly using only the robot's internal sensors (e.g. joint position and joint velocity).

Theory of Sensorless Collision Detection and Isolation (CDI)

If $\boldsymbol{F}_c$ is the external force acting during a collision at point ($\boldsymbol{q}_c$), the dynamics of the overall system becomes:

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} + \boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} + \boldsymbol{G}(\boldsymbol{q}) + \boldsymbol{\tau}_f = \boldsymbol{\tau}_m + \boldsymbol{\tau}_c = \boldsymbol{\tau}_m + \boldsymbol{J}^T(\boldsymbol{q}_c)\boldsymbol{F}_c$$

Sensor-less Collision Detection deals with detection of collision with the robot without the use of any external sensors. The collisions can be detected by observing a disturbance in total energy of the robot $E(t)$.[De Luca et al, 2006]

$$\sigma(t) = K_\sigma\left[E(t) - \int_0^t \left(\dot{\boldsymbol{q}}^T(\boldsymbol{\tau}_m - \boldsymbol{\tau}_f) + \sigma(t)\right)dt - E(0)\right]$$

Commanded Total Power

This leads to a first order stable linear filter driven by work performed by the joint torques due to collision:

$$\dot{\sigma} = -K_\sigma\sigma + K_\sigma\dot{\boldsymbol{q}}^T\boldsymbol{\tau}_c$$

Collision Isolation deals with identification of contact link where the collision occurs. Collision can be isolated using momentum $\boldsymbol{p}(t)$ based residual disturbance observer.[De Luca et al, 2006]

$$\boldsymbol{r}(t) = \boldsymbol{K}_r\left[\boldsymbol{p}(t) - \int_0^t \left((\boldsymbol{\tau}_m - \boldsymbol{\tau}_f) + \boldsymbol{C}^T(\boldsymbol{q},\dot{\boldsymbol{q}})\dot{\boldsymbol{q}} - \boldsymbol{G}(\boldsymbol{q}) + \boldsymbol{r}\right)dt - \boldsymbol{p}(0)\right]$$

Commanded Torque

This also leads to a first order linear filter driven by external torques:

$$\dot{r} = -K_r r + K_r\boldsymbol{\tau}_c$$

When there is a collision with i^{th} link, r will take the form:

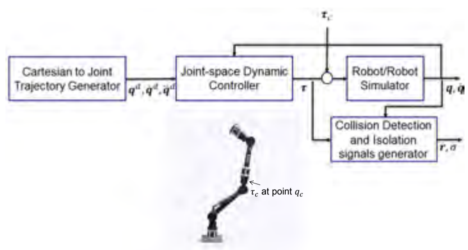
$$\boldsymbol{r} = [r_1 \quad r_2 \quad \cdots \quad r_i \quad 0 \quad 0]$$

Remarks:

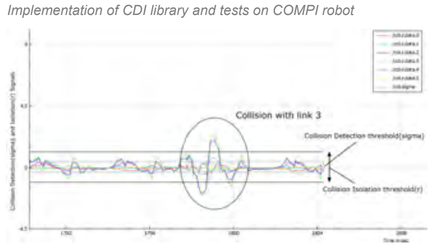
- $\boldsymbol{r}(t)$ and $\sigma(t)$ are ideally zero during the free motion of the robot and become non-zero as soon as there is a collision. In reality, a collision is detected and isolated using threshold values which depends on the noise characteristics of the system.
- $\sigma(t)$ is insensitive to collisions when robot is at rest ($\dot{\boldsymbol{q}} = \boldsymbol{0}$) or when Cartesian velocity at the contact point is perpendicular to the collision force ($\boldsymbol{V}_c \perp \boldsymbol{F}_c$).
- Theoretically, for infinite observer gains($\boldsymbol{K}_r \longrightarrow \infty$), $r_i \cong \tau_{c,i}$. Practically, observer gains must be chosen as high as possible keeping in mind the noise characteristics of the system.

Results and Discussions

- Development of RoCK software library named CDI
- Inputs for CDI library: Dynamic model, Robot joint position ($\boldsymbol{q}$) and velocity ($\dot{\boldsymbol{q}}$), Commanded Torque.
- Output: Collision Detection(σ) and Isolation ($\boldsymbol{r}$) signals
- No torque sensing at joints or external sensors are needed to detect collisions – Sensorless.



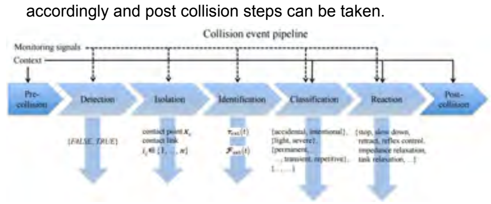
Implementation of CDI library and tests on COMPI robot



Collision Detection and Isolation signals – collision with link 3

Future work

- Residual momentum signal can be used to calculate external torque/forces and hence perform collision identification.
- Intention of the collisions can be classified based on the magnitude and frequency response of external torque.
- Several reactive strategies for the robot can be defined accordingly and post collision steps can be taken.



Collision Event Pipeline (Prof. De Luca, ICRA Keynote 2015)

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3.7 'Identification of Robot Motion Dynamics' (MC-P-02)

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Abstract

This poster gives an overview of the procedure carried out to identify a model of the robot motion dynamics. Those models relate actuation torques or forces with the corresponding robot motion. It is useful to include the model knowledge into the control problem as then controllers can work with much lower gains, thus allowing compliance in contact situations.

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Identification of Robot Motion Dynamics

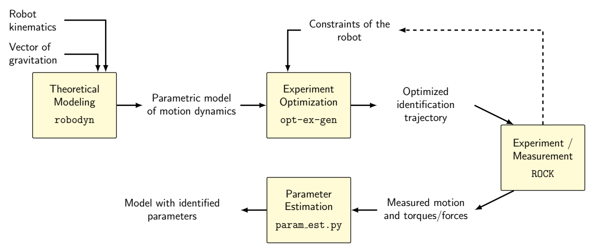
An Overview of Identification through Experiments

Vinzenz Bargsten, Yohannes Kassahun

Introduction

- Robot Motion Dynamics
  - relates actuator torques/forces with the resulting motion
  - often highly coupled and non-linear system
  - data from CAD model can be incomplete

⇒ linear controllers require high gains to compensate for unmodelled dynamics



Current toolchain for the experimental identification based on rigid-body physics

Motivation

- Taking the robot dynamics into account in the control system
  - simplifies control problem
  - allows more *compliant* control schemes instead of stiff position control
- Detection of collisions and contact forces
- Simulation of motion dynamics

⇒ Require computation of the dynamic robot model, $\tau = f(q, \dot{q}, \ddot{q})$

Identification Procedure

1. Modeling
   - theoretical model from physical insight into Rigid-Body-Dynamics
   - choice of appropriate coordinate systems yields a model of the form

$$\tau(t) = \mathbf{Y}\left(q(t), \dot{q}(t), \ddot{q}(t)\right)\,\theta \qquad (1)$$

   - with constant parameter vector $\theta \in \mathbb{R}^{12n}$

$$\theta_i = \left(m_i\; m_i c_{x,i}\; m_i c_{y,i}\; m_i c_{z,i}\; I_{xx,i}\; I_{xy,i}\; I_{xz,i}\; I_{yy,i}\; I_{yz,i}\; I_{zz,i}\; F_{c,i}\; F_{v,i}\right)^T$$

2. Experiment Generation by Optimization
   - sampling the theoretical model for a reference trajectory gives the identification matrix:

$$\Phi = \begin{pmatrix} \mathbf{Y}\left(q(T_s), \dot{q}(T_s), \ddot{q}(T_s)\right) \\ \cdots \\ \mathbf{Y}\left(q(kT_s), \dot{q}(kT_s), \ddot{q}(kT_s)\right) \\ \cdots \\ \mathbf{Y}\left(q(KT_s), \dot{q}(KT_s), \ddot{q}(KT_s)\right) \end{pmatrix} \qquad (2)$$

   - the reference trajectory is then optimized to meet the robot's constraints and to generate a *rich* measurement (*d-optimality criterion*)

3. Estimation
   - motion and according actuation torques are measured
   - parameter vector $\hat{\theta}$ is estimated by minimizing the error between measured torque and torque computed by the model

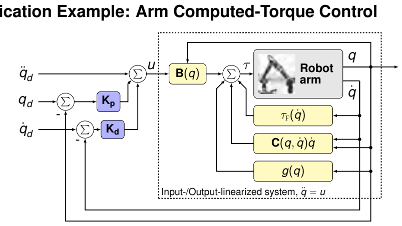
$$\min_{\hat{\theta}} \left(\Phi\hat{\theta} - \tau_{msr}\right)^T \left(\Phi\hat{\theta} - \tau_{msr}\right) \qquad (3)$$

   - constraints are used to ensure a physical consistency of the parameters: positive mass and friction parameters, positive definite inertia tensor

Non-Parametric Models

- alternatively the estimation is carried out by e.g. training neural networks
- learns the input-output relationship
- no detailed knowledge of the system required
- less generalisation over unexplored workspace, but no assumption of rigid-bodies

Application Example: Arm Computed-Torque Control



Structure of Computed-Torque-Control

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