Institute of Automation

Towards the designing of sampling based motion planner for manipulators - application to rehabilitation robotics.

MSc Christos Fragkopoulos

Presentation at
National technical University of Athens

Greece2012

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Contents

- Introduction
- Approach
- Experiment Results with Video
- Conclusions

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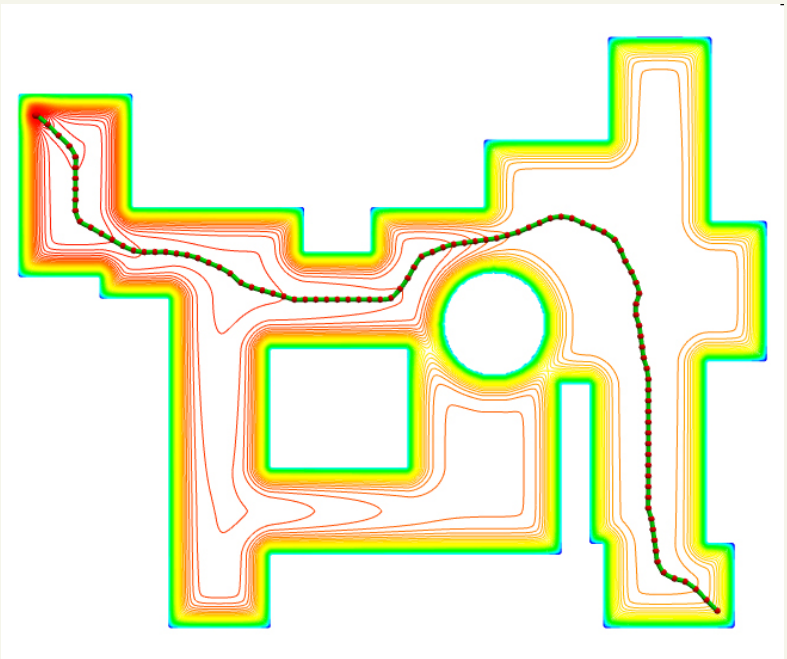
1.Introduction



1. Introduction

- Robot motion planning usually focuses primary on the translations and rotations required to move an object (e.g. example of moving a piano)
- Trajectory planning usually refers to the problem of taking the solution from a robot motion planning algorithm and determining how to move along the solution in a way that respects the mechanical limitations of the robot.
- In recent control theory literature, motion planning sometimes refers to the construction of inputs to a nonlinear dynamical system that drives it from an initial state to a specified goal state

1. Introduction

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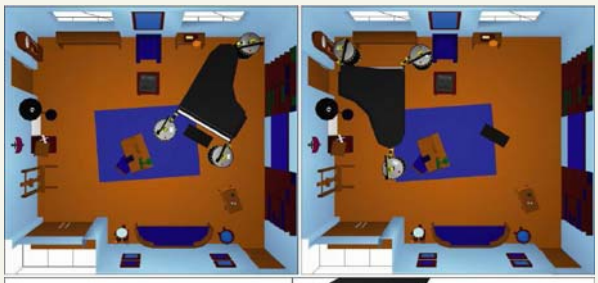
- Example 1

Moving Furniture:

Piano problem



- How to replace and move the piano in a free place ?
- How to move the robots so that the piano will not fall down ?

1. Introduction

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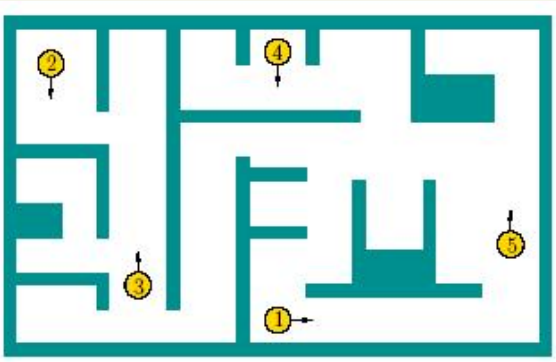
- Example 2

Navigate mobile robots

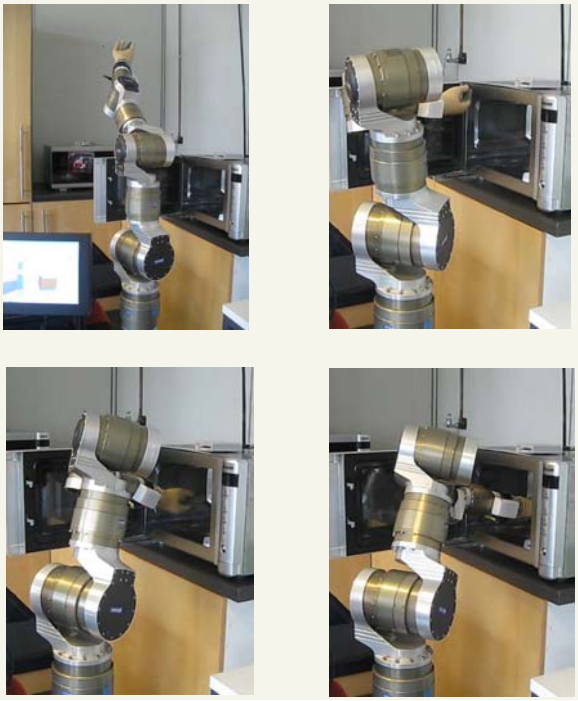
Robots should move without colliding with environment and each other



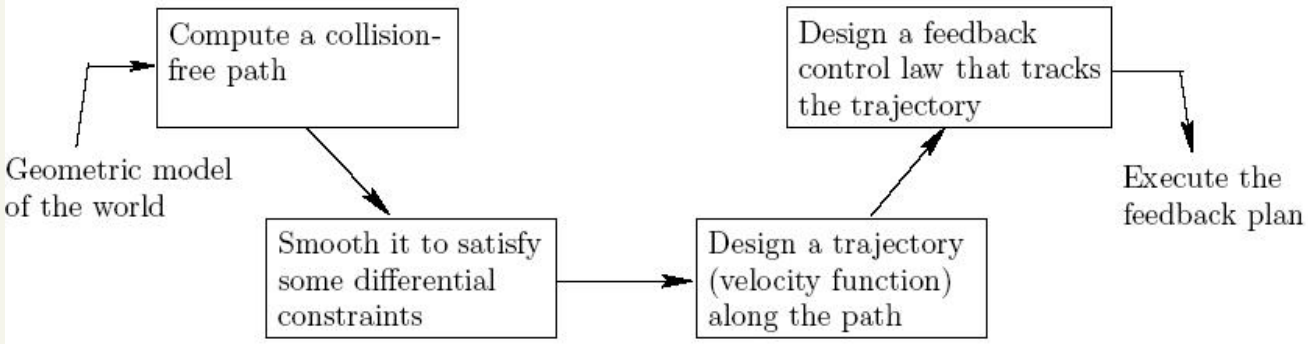
1. Introduction

- Example 3.
  Robot manipulator.

  How to move a robot arm to a target pose without colliding with the environment ?



1. Introduction



1. Introduction

Requirements for Robot arm Motion Planning

- Deliver fast a solution
- Keep Velocity + Acceleration continuation and constraints (during the motion)
- Safety
- Optimality

1.Introduction

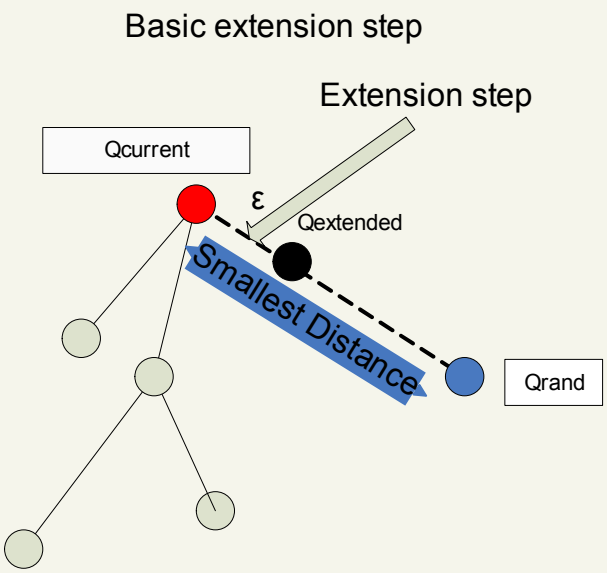
RRTs

Random configuration generated. Expansion with step ε directed to Qrand follows.

Possible metric in order to calculate the smallest distance ?

•Euclidean – cartesian space $\sqrt{\sum_{i=1}^{3} \Delta x_i^2}$

•C-Space $\sqrt{\sum_{i=1}^{N} \Delta q_i^2}$



1. RRTs

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RRT Algorithm

1. $V \leftarrow \{x_{\text{init}}\}$, $E \leftarrow \emptyset$
2. repeat
3. $\quad x_{\text{rand}} \leftarrow \texttt{NewSample}$
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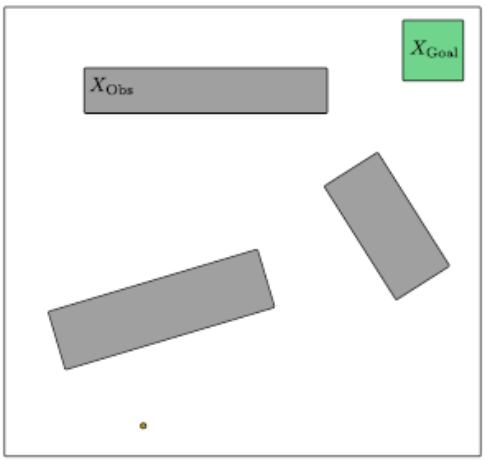

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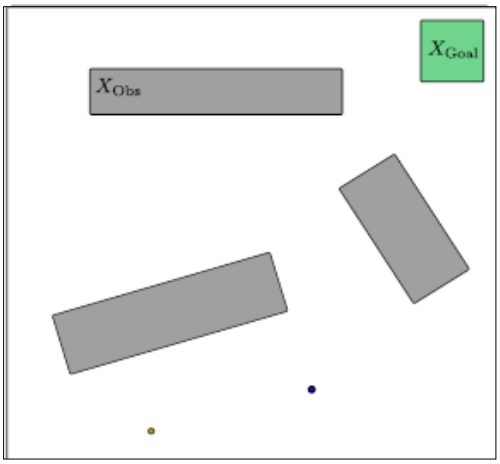

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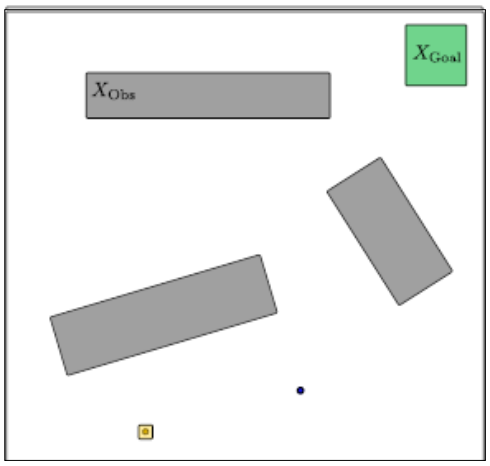

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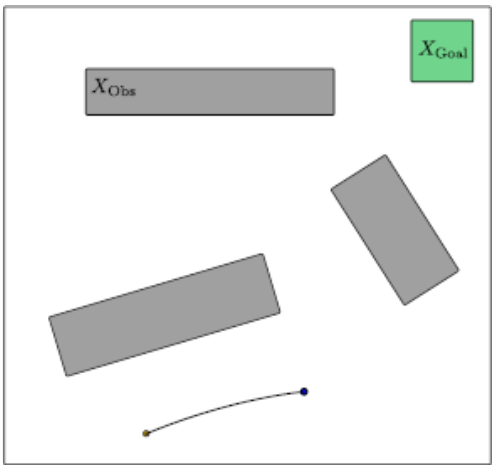

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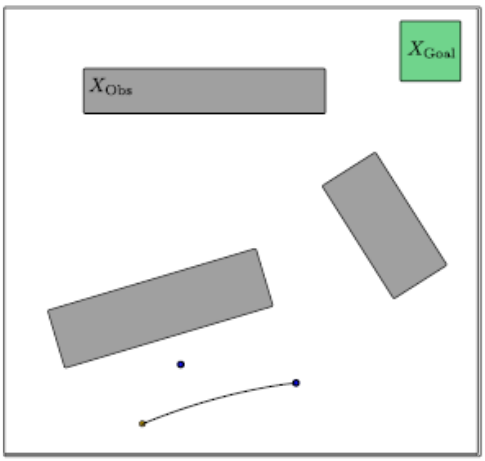

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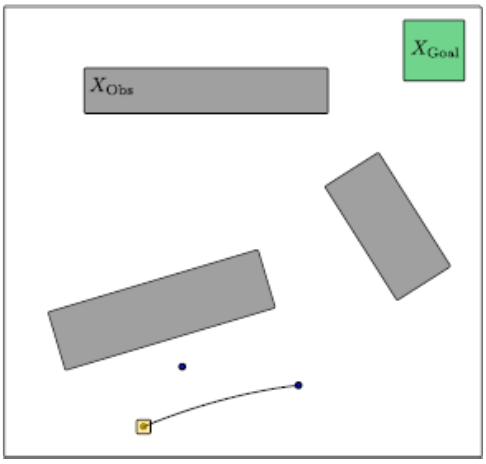

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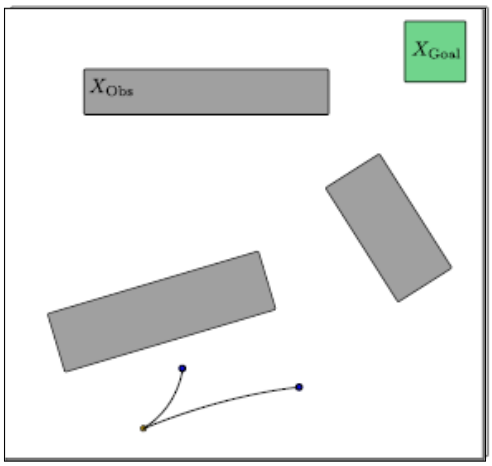

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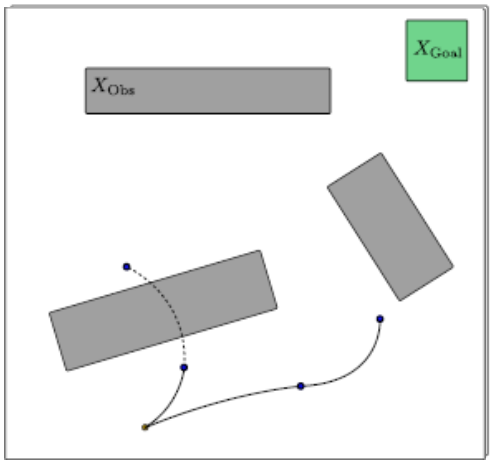

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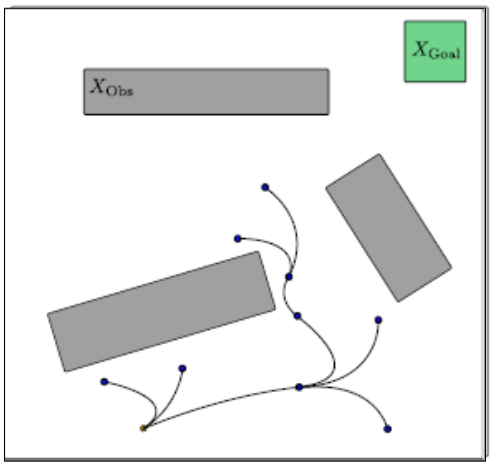

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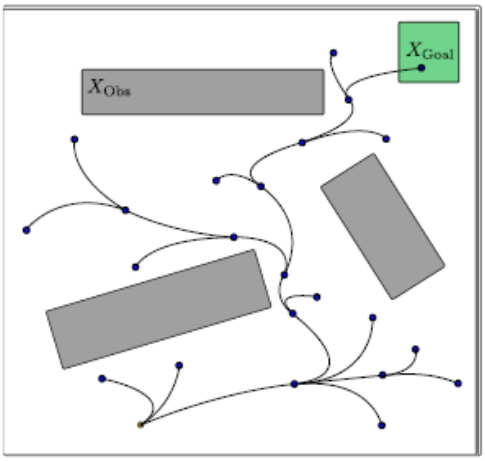

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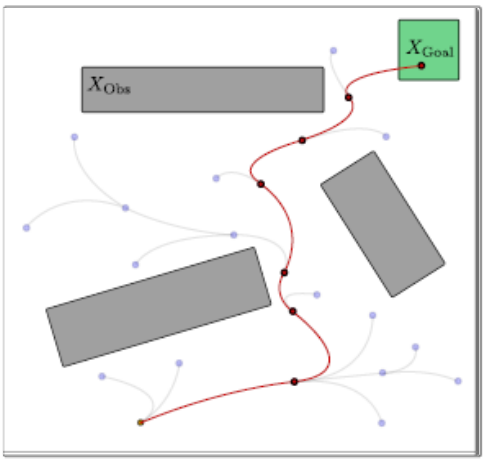

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1.Introduction

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Problems using C-Space (probabilistic)

- Explores extremely the C-space
- Needs lot of time to find a solution
- Not optimal solution for a real time application system
- No constraints

Improvement

- Bi-directional trees.
- Probabilistic exploration
- Position and orientation constraints

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1.Introduction

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Robotarm path planning

- Cartesian space
- Configuration-Joint space

Cartesian space: understandable(3D space), gives nice TCP trajectories (but not in Joint space), it is deterministic. Trajectories need smoothing, during execution may have big joint velocities.

Configuration space: better for a manipulator (control of joint velocities), ***probabilistic behavour (PRM, RRTs)***, refinement is also necessary

2.CellBiRRT

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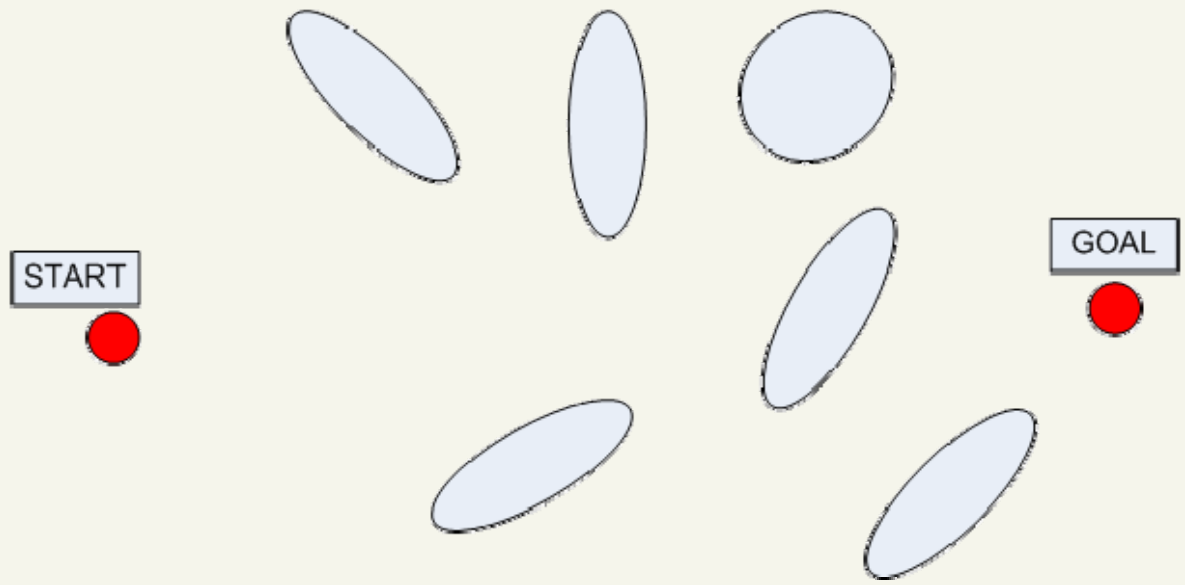
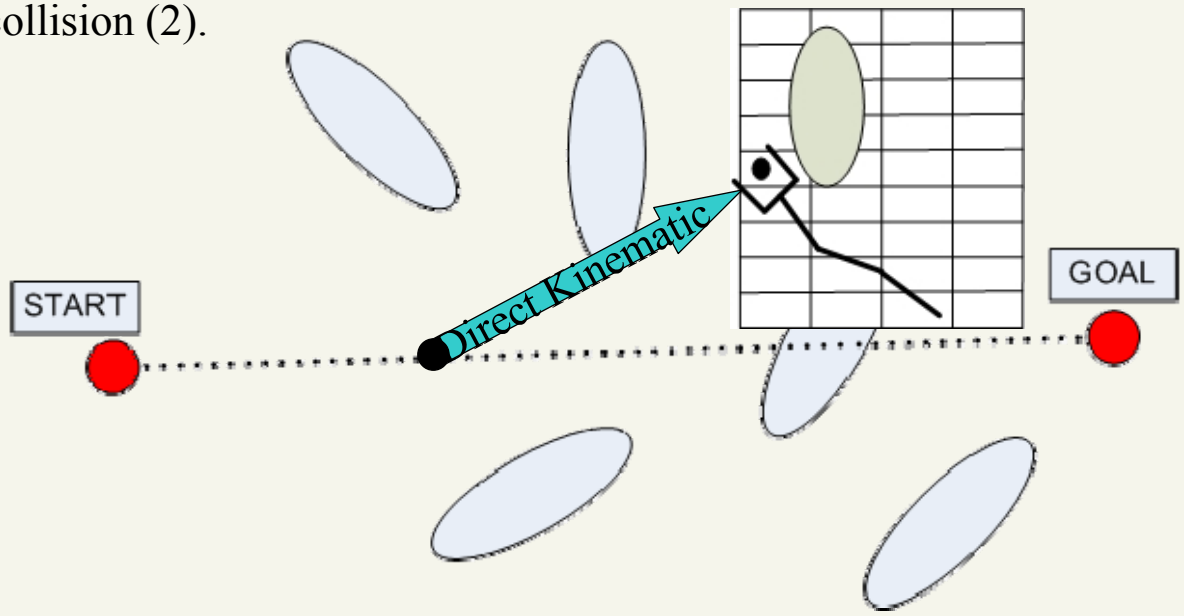
Forward Tree



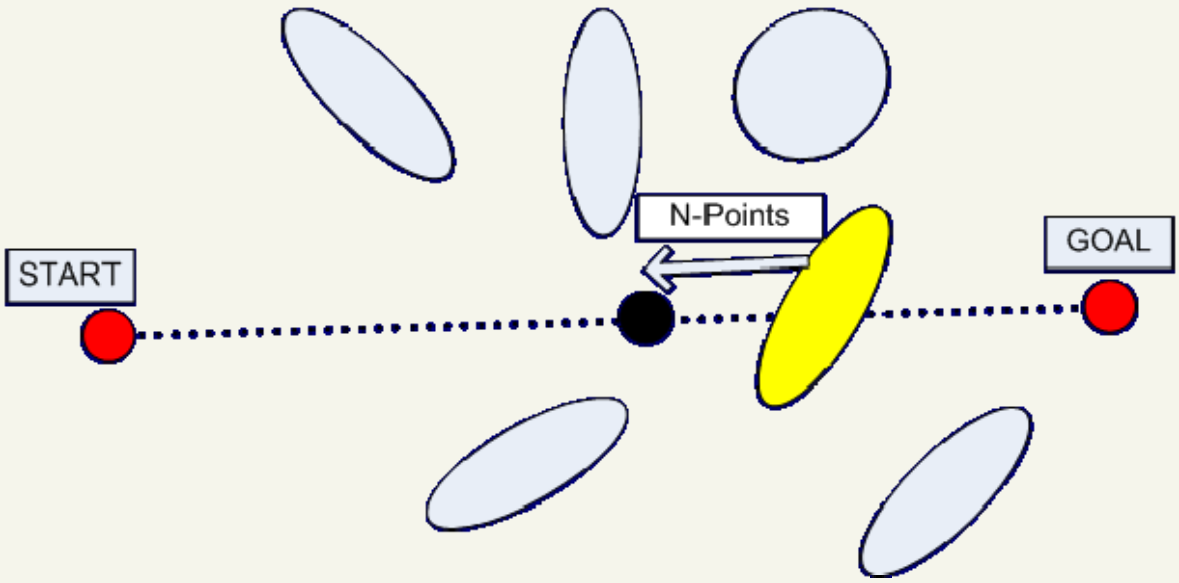
2.CellBiRRT

Probabilistic parameter controls repeatability. Direct line is **sampled**, and each sample is checked for constraints (1) and for collision (2).



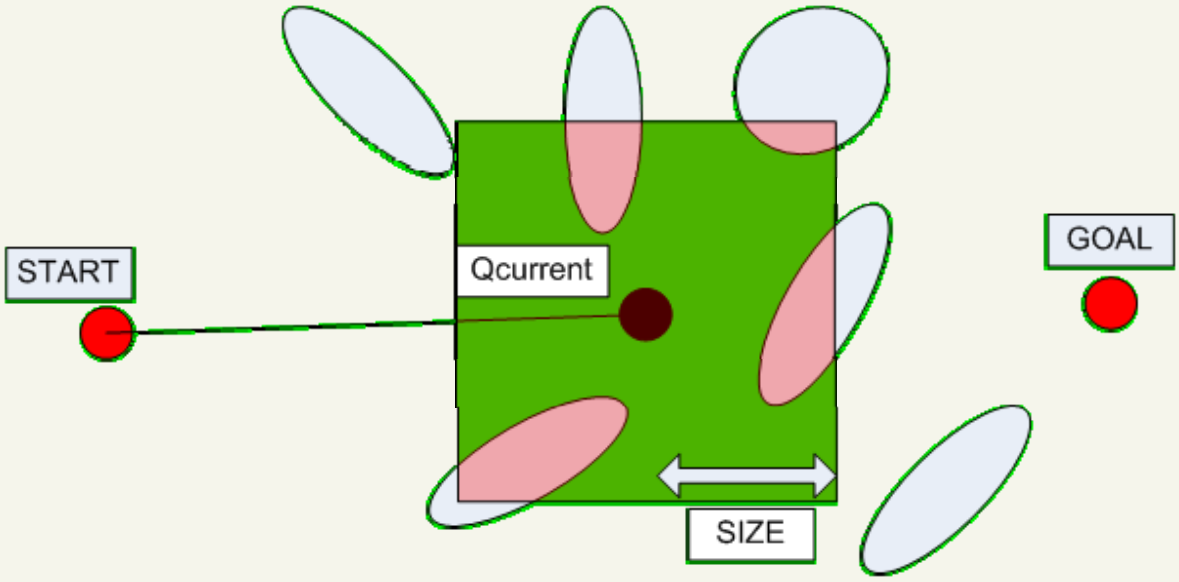
2.CellBiRRT

N-Points before an invalid configuration, a free-configuration is added to the tree.



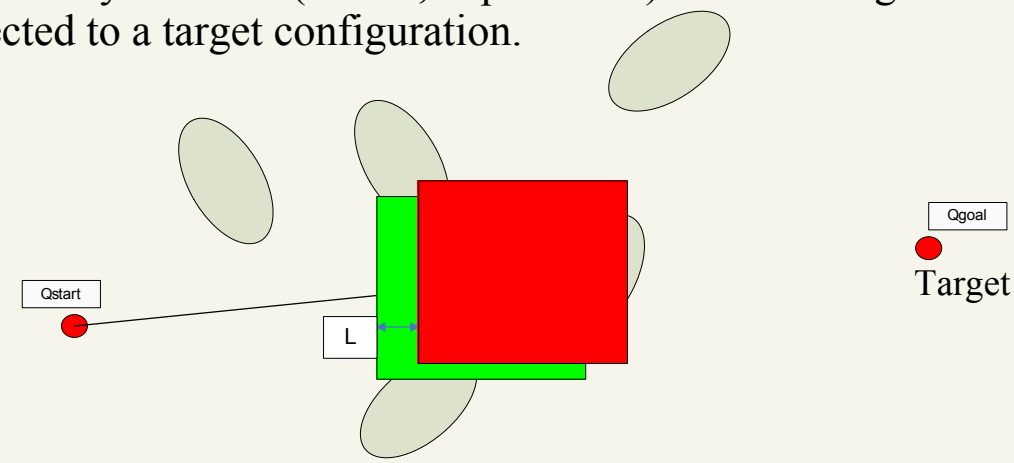
2.CellBiRRT

The current configuration generates an N dimension cuboid („N-cuboid“) in C-Spacewith a specific size. Reduce unnecessary space.



2.CellBiRRT

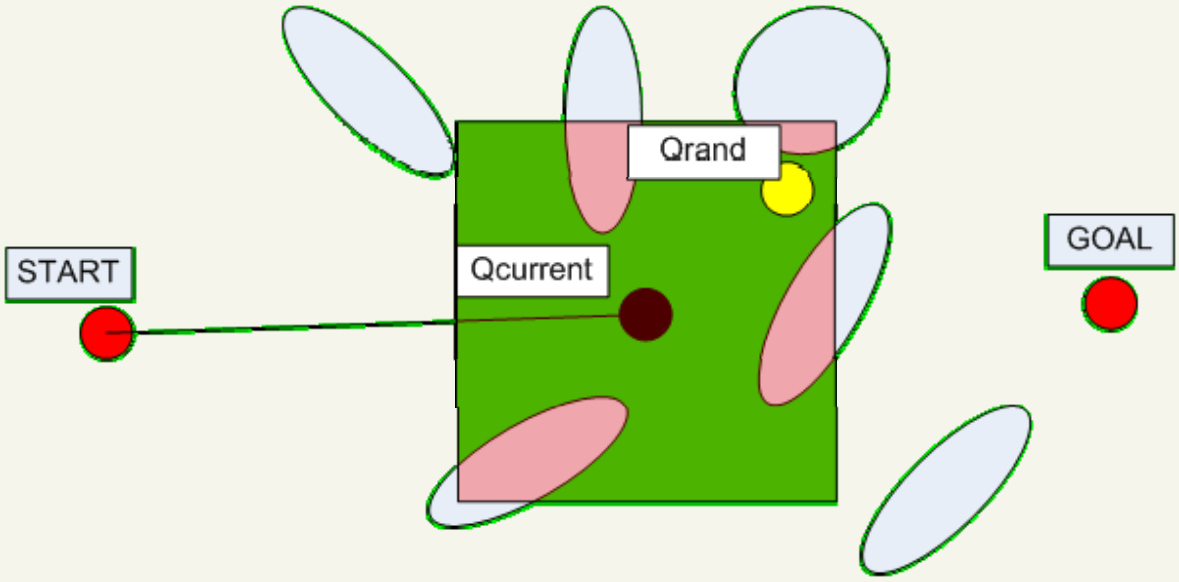
Start -> Goal . The N-cuboid can be shifted by L. the shifting can be any function (linear , exponential). The shifting is done, directed to a target configuration.



Linear: $L_i = a * \Delta q_i / \Delta q_{max}$ Exp : $L_i = 1 - \exp(- a * |\Delta qi / \Delta qmax|)$

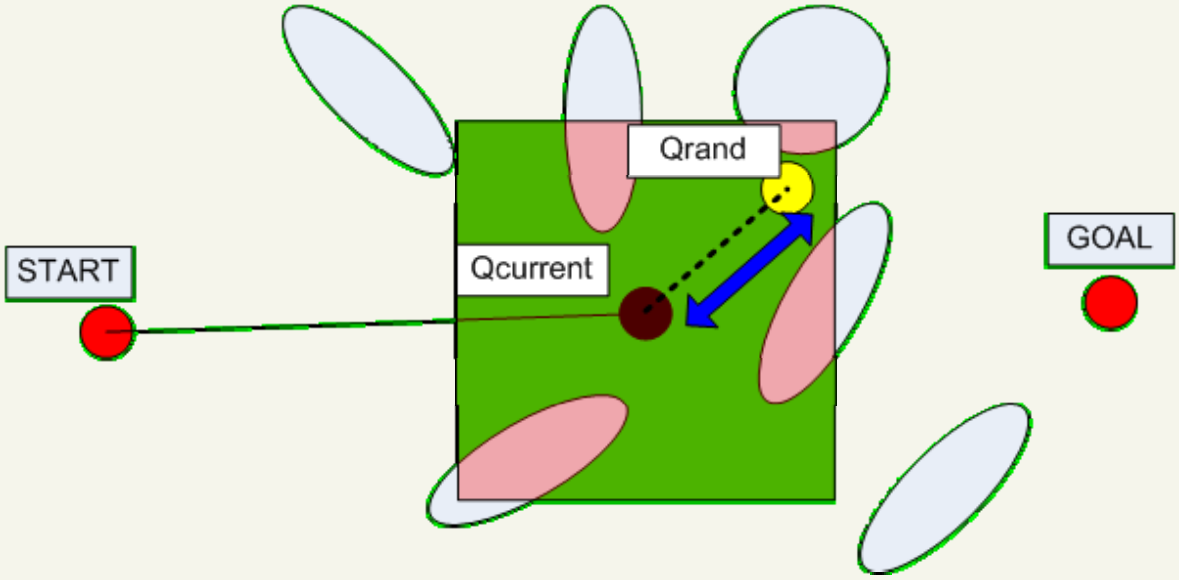
2.CellBiRRT

Random configuration(Qrand) is generated inside the cuboid.



2.CellBiRRT

Find nearest neighbour (C-Space Metric)and tries to connect to the random configuration. If M trials fail, the Qcurrent is set as „not active“



2.CellBiRRT

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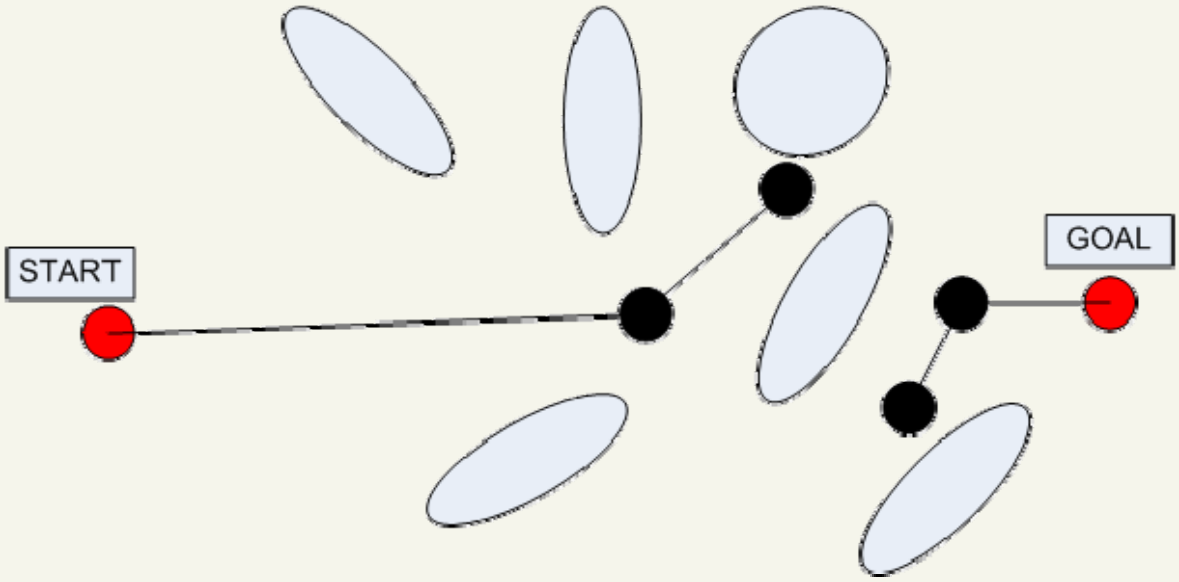
Algorithm repeats again for backward tree



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2.CellBiRRT

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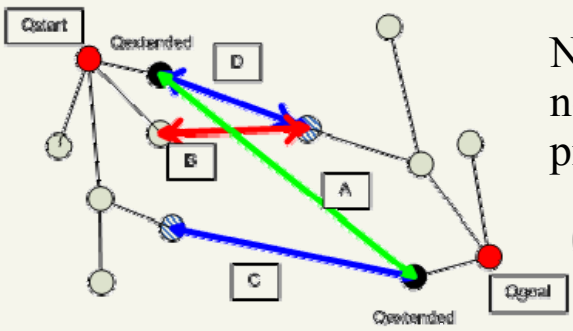
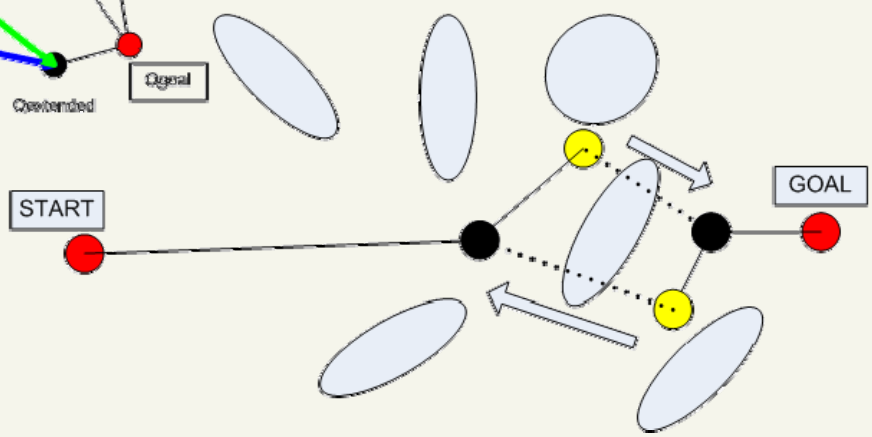
Trees connection

Nearest neighbor from last expanded node of each tree gives bigger probability to connect the trees





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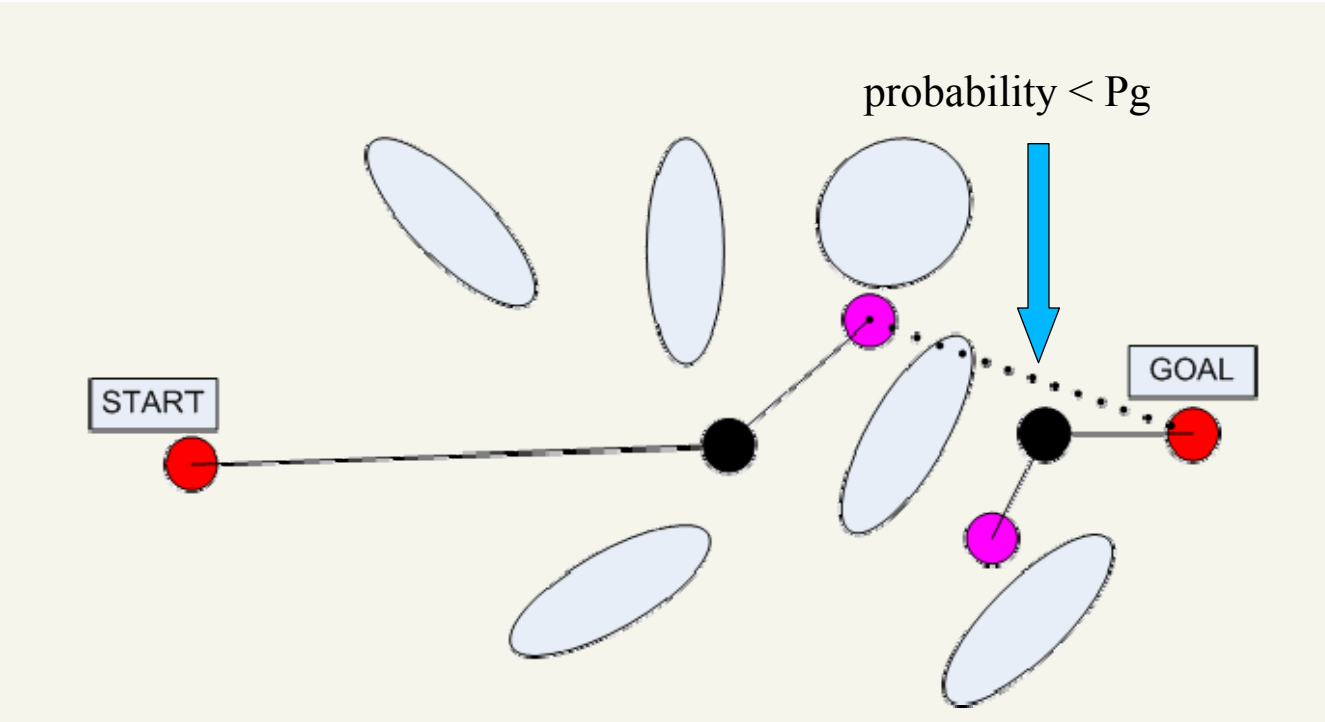
2.CellBiRRT



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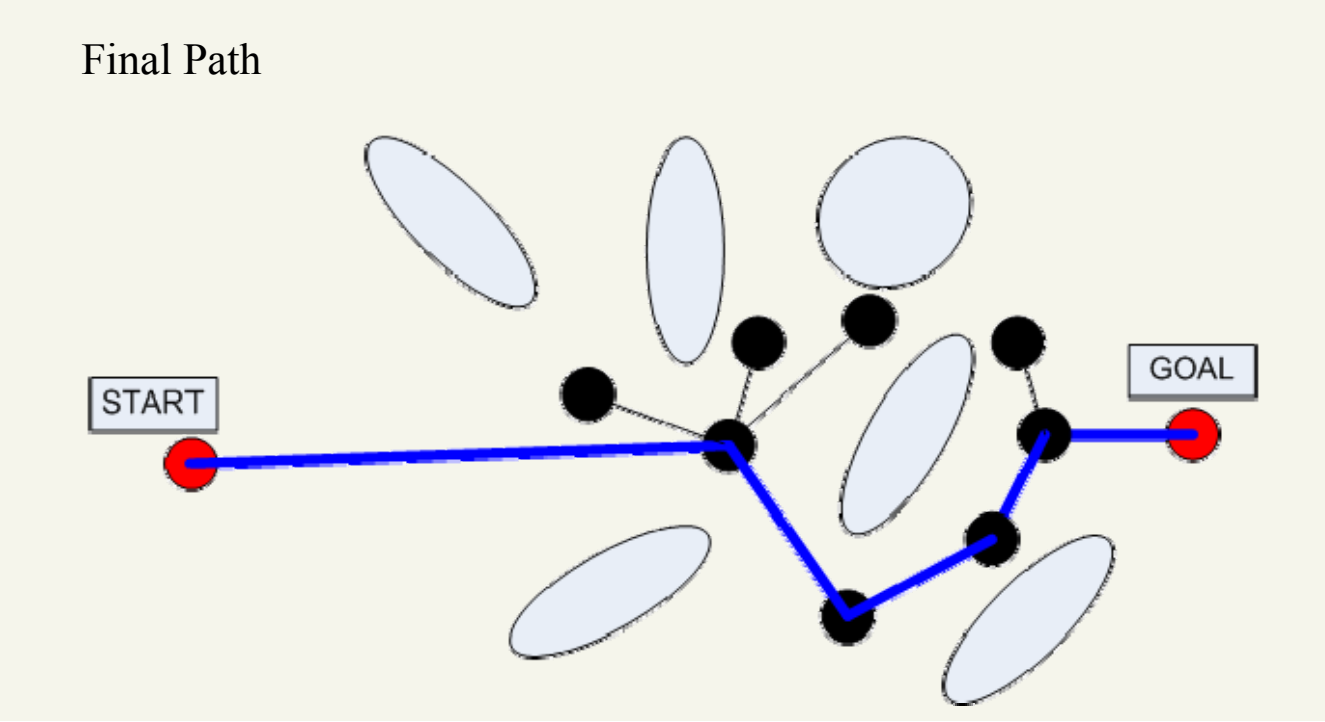

2.CellBiRRT

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Main Problem :

No extra criterion for constraints in orientation and position

Can solve also problems with constraint orientation , but the excecution time is high.

Possible Solution:

The space is divided into cells, and for each extended node the algorithm searches all the neighbour cells. The best one is selected and a posed is calculated. This is the centre configuration for the N-cuboid.

2. Proposed Approach Cell based Bi-directional RRT (CellBiRRT)

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- Extra Constraints

$$C = \begin{pmatrix} X_{max} & X_{min} \\ Y_{max} & Y_{min} \\ Z_{max} & Z_{min} \\ RotX_{max} & RotX_{min} \\ RotY_{max} & RotY_{min} \\ RotZ_{max} & RotZ_{min} \end{pmatrix}$$

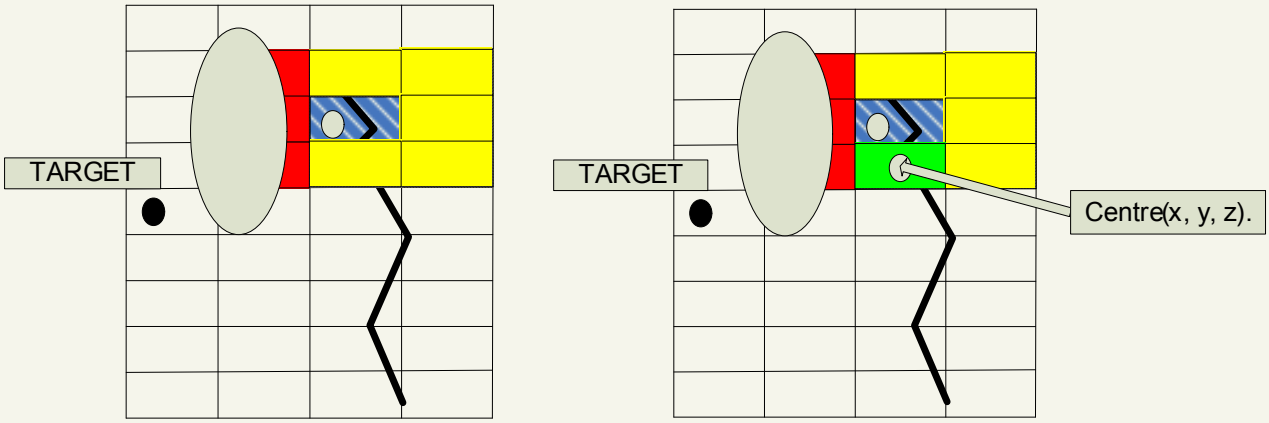
2.CellBiRRT

Institute of Automation

Red cells are rejected cells.

Yellow cells are „free“ cells and can be used. The green one is selected. Same cells cannot be visited many times.

Criteria: minimum dCost = dB * CostCome+(1-dB)*CostGo and maximum obstacle distance.Target is the last expanded node of the opposite tree



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2.CellBiRRT

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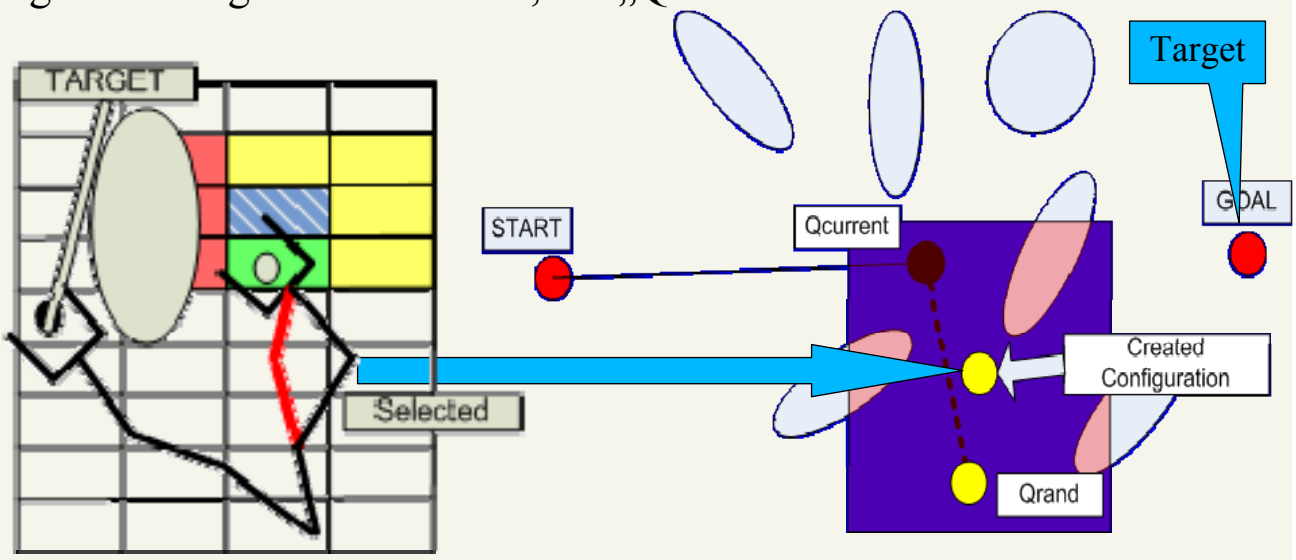
The inverse kinematics find a suitable free configuration within the constraint limts. This one is the basis for generating the N-Cuboid region. If IK gives no solution, the „Qcurrent“ is used.



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2.CellBiRRT

Alternative IK approaches instead of analytical solutions -> Approximate solutions with Jacobian.

$$\dot{x} = J \cdot \dot{\theta} \Rightarrow d\theta = J^{-1} \cdot dx$$ Motion Rate Control

For redundant manipulator

$$\dot{\theta} = J^{+} \cdot \dot{x} + (I - J^{+} \cdot J)^{-1} \cdot \phi$$

$$\boxed{\dot{\theta} = J^{+} \cdot \dot{x} + k \cdot (I - J^{+} \cdot J)^{-1} \cdot \nabla H}$$

H is a performance criterion function.

$$\boxed{\dot{\theta} = W^{-1} J^{T} \cdot (J \cdot W^{-1} \cdot J^{T})^{-1} \cdot \dot{x}}$$

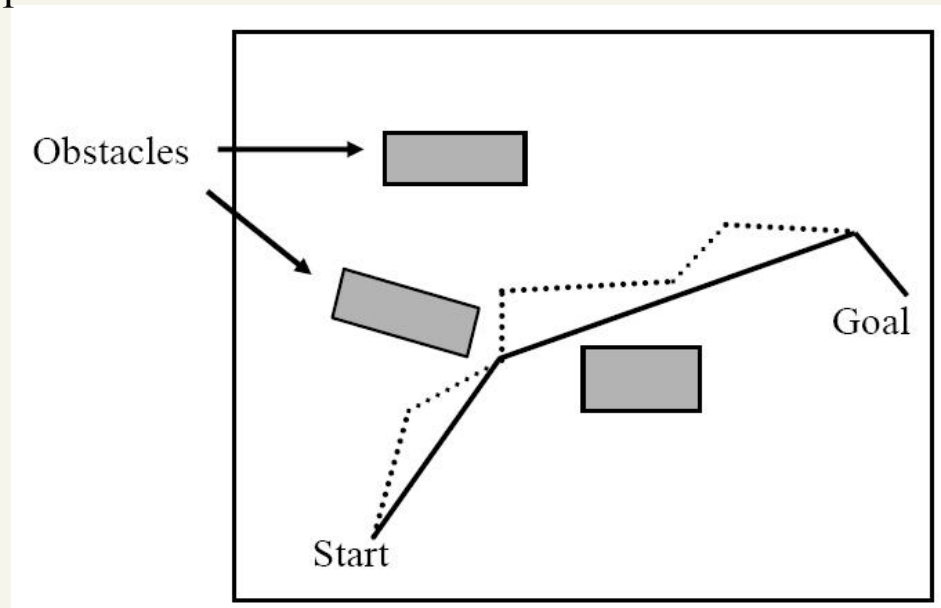
Weighted Least Norm method

$$\boxed{\dot{\theta} = J^{T} \cdot (J \cdot J^{T} + k^{2} \cdot I)^{-1} \cdot \dot{x}}$$

Damped Least Square method (only aroud singularities !!!)

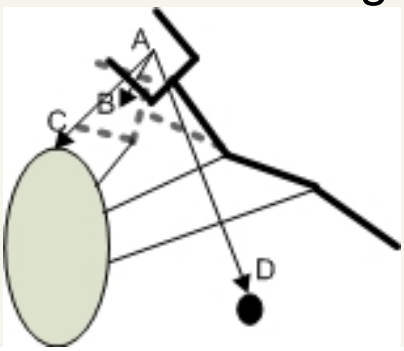
2.CellBiRRT - Refinement

Pruning procedure



2.Motion Planning - Safety

- Video
- Extra expansion criterion – Danger Factor
- Cells extra generation criterion – cells are selected based on the distance from the user
- Online velocities calculation – linear degration of velocities ($v = \frac{D_{user}}{D_{\max}} \cdot v_{\max}$)



3. Experimental Results

Service robotic wheelchair systems (like FRIEND - **F**unctional **R**obot arm with user-fr**IEN**dly interface for **D**isabled people) are focused normally in execution of different scenarios like serving a drink or meal, picking up objects e.t.c. The main problem of these systems till nowadays is the lack of complete autonomous execution of these scenarios.

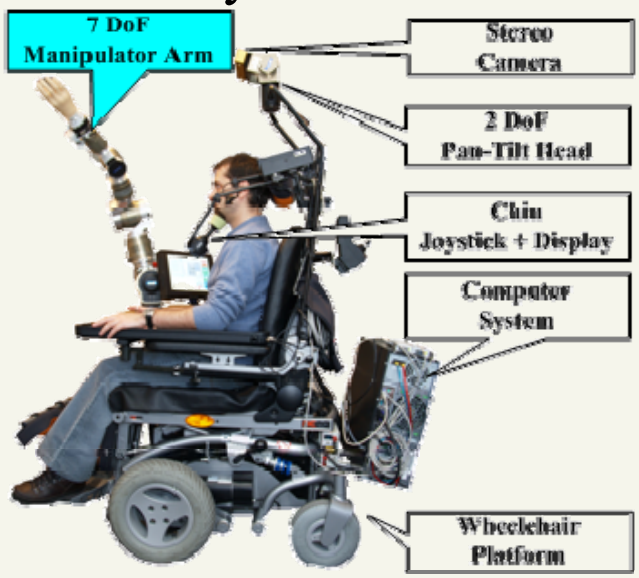
Motion planning and intelligent manipulative skills are necessary.

3.Experiment Results

Institute of Automation

Application to Rehabilitation System FRIEND

- Video – Complete(2min)
- Video – Medium(1min)
- Video – Small (30sec)
- Library
- Library2
- Library3



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4.Conclusion

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- The approach provides a nice framework for handling position and orientation constraints
- It is fast and it is applied to FRIEND system (solution less than 2 sec for nowadays cpus)
- Can solve difficult path-planning tasks
- Plans in C-Space producing user –friendly trajectories.
- Can be used in multi-processing systems(3 different threads will improve the speed)

5. Further Research

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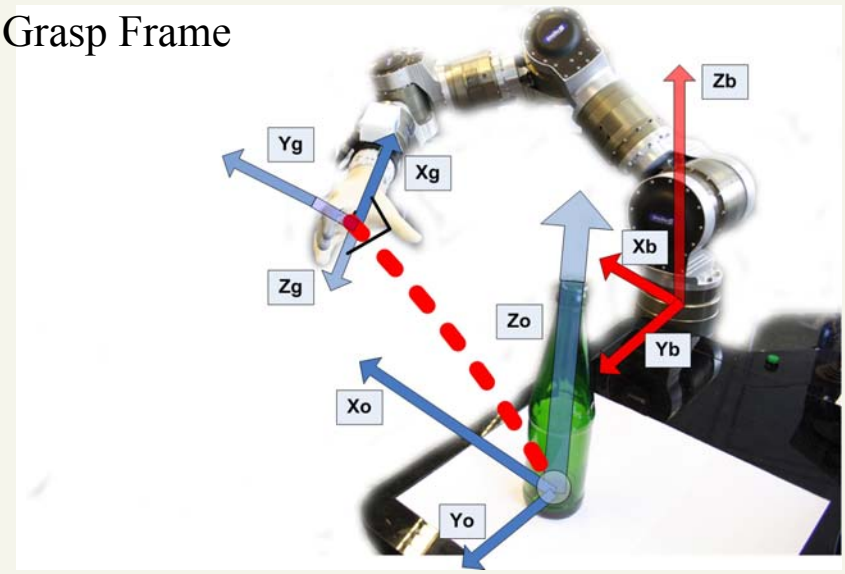
- Development of intelligent manipulative skills for grasping and manipulating objects.
- Improvement of the speed and convergence ratio
- Improves the random creation of nodes with extra criteria
- Use the above algorithm in dynamic environment
- Safe motion planning (planning with extra criteria e.g. avoid being close to the user)

The end

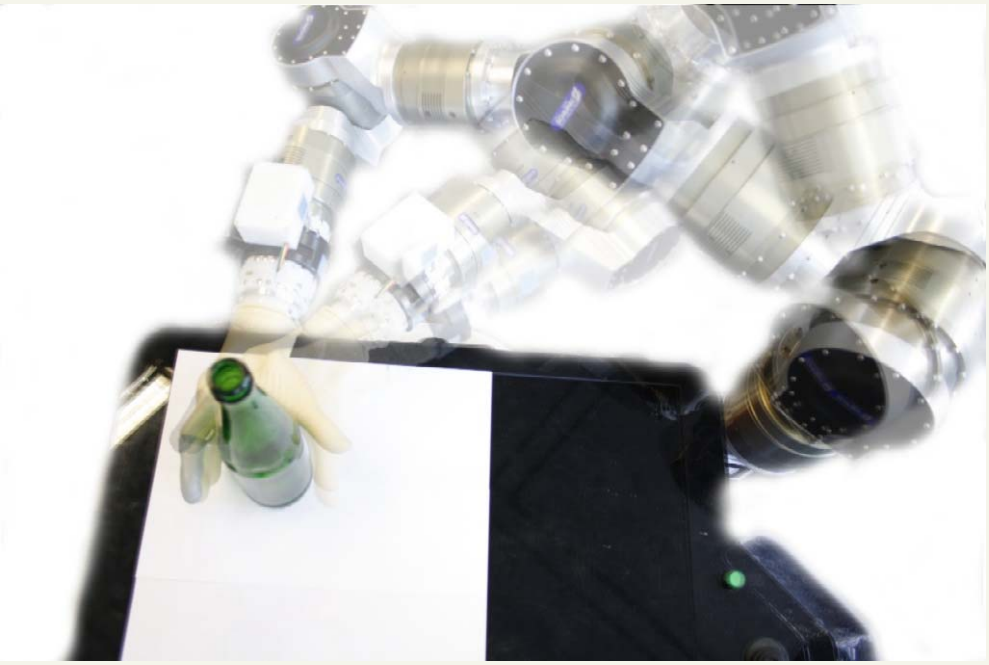
Thank you for your attention

Concept of Grasping

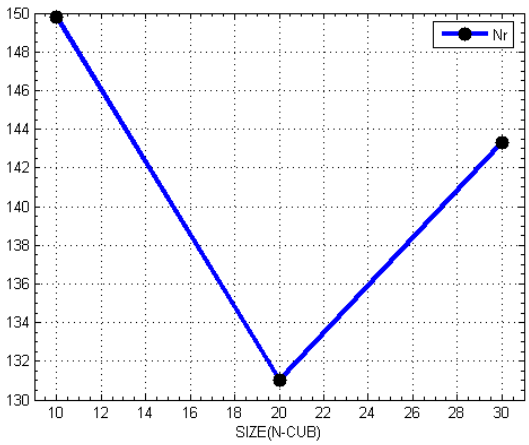
- Teach system where and how to grasp the object (done once)
- Store the relative frame $T_G^O = (T_O^B)^{-1} \cdot T_G^B$
- Find Pre - Grasp Frame

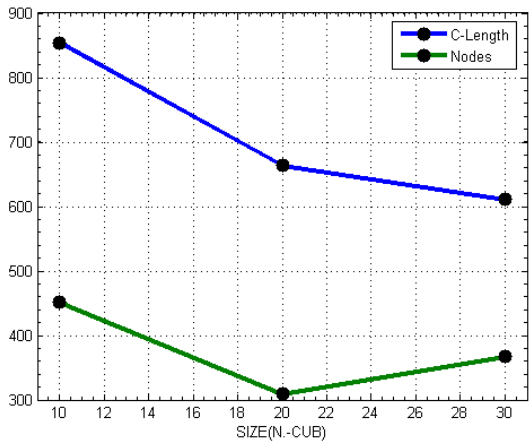


Concept of Grasping



Extra Experiment results





More Information?

Institute of Automation

Contact the international office of the University of Bremen:

io@uni-bremen.de

Contact us:

www.iat.uni-bremen.de

Contact me:

cfragkopoulos@iat.uni-bremen.de

You are very welcome to Bremen. We hope to see you!

Institute of Automation

Institute of Automation (IAT)

University of Bremen, Germany

Host Institution in the ERASMUS Exchange Programme

MSc Christos Fragkopoulos

Presentation at

Department of Electrical Engineering

National Technical University of Greece

Athens/Greece, 2012

Overview

Institute of Automation

- The University of Bremen
- The Institute of Automation (IAT)
  - Fields of research
  - Possible fields for your final projects

- ERASMUS / SOCRATES programme
- Steps to become an ERASMUS exchange student at IAT
- The city of Bremen

About myself

Institute of Automation

1982	Born in Thessaloniki , Greece
2000	„Abitur“ – Greek school leaving examination and university entrance qualification
2000 – 2004	Study at Aristoteles University in Greece. Subject: Physics
2005 – 2007	Study at the University of Bremen *Subject:* Information and Automation Engineering
Since 03/2008	PhD student at the Institute of Automation (IAT) of the University of Bremen *Fields of Research:* Motion planning, direct cartesian control of a robot arm.

University of Bremen

Institute of Automation

The University of Bremen

The science centre of North West Germany

In 1971 the University was founded

- ca. 20,000 Students
- ca. 1,600 Scientists from Germany and 126 other countries

Faculties

1. Physics / Electrical Engineering
2. Biology / Chemistry
3. Mathematics / Computer Science
4. Production Engineering and Technology
5. Geo Sciences
6. Law
7. Economics
8. Social Sciences
9. Cultural Studies
10. Language and Literary Studies
11. Human and Health Studies
12. Pedagogy and Educational Sciences

The University of Bremen

iat Institute of Automation

Lecture hall

Laboratories

Bremen Drop Tower

Universität Bremen

The University of Bremen

iat Institute of Automation

Sport

Mensa

Life in Campus

Transport links

Accommodation

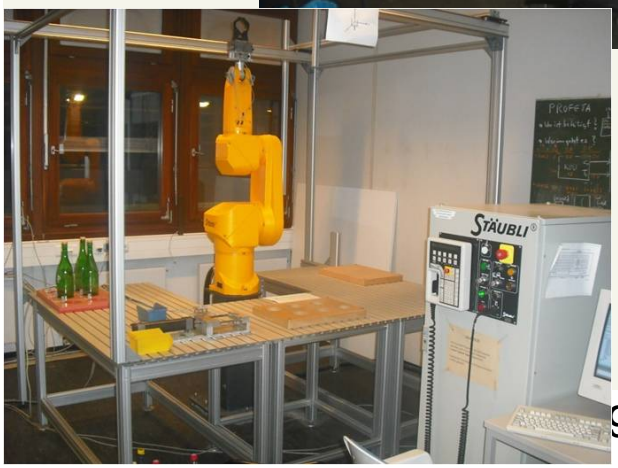
Cultural events

Universität Bremen

The University of Bremen

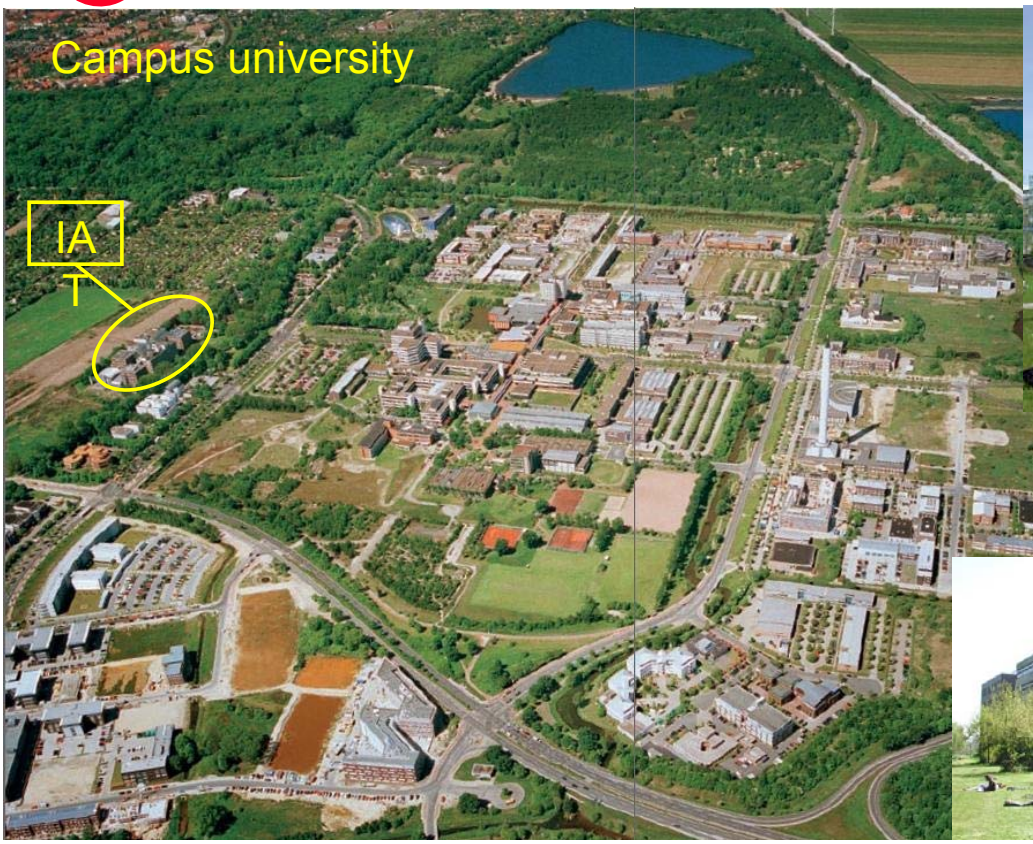
iat Institute of Automation

Laboratories



The University of Bremen

iat Institute of Automation



Pure nature

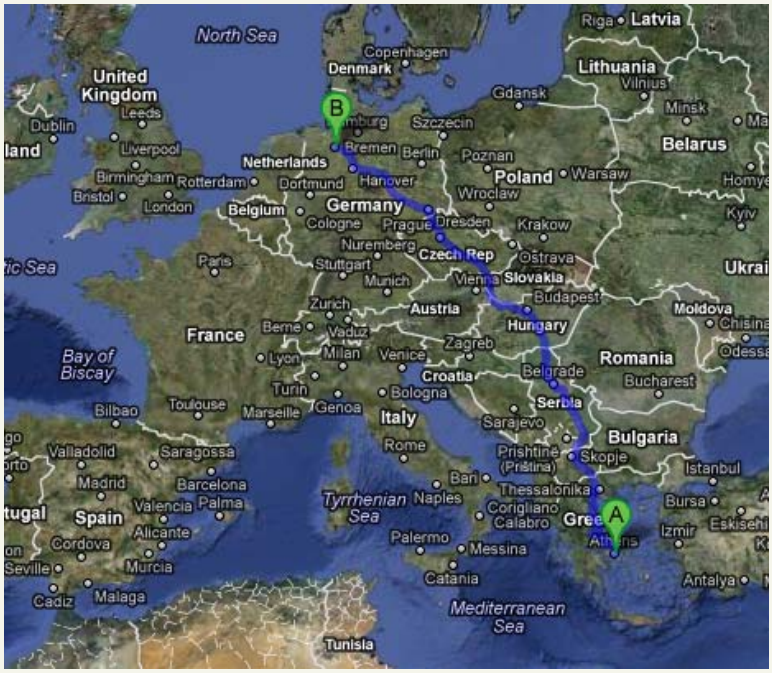
The Institute of Automation (IAT)

Institute of Automation

Geographical Information

Institute of Automation
University of Bremen
NW1/ FB1
Otto-Hahn-Allee 1
28359 Bremen

Phone: +49 (0) 421 218 62445
Fax: +49 (0) 421 218 9862445
email: info@iat.uni-bremen.de
www.iat.uni-bremen.de



Universität Bremen

The Institute of Automation (IAT)

Institute of Automation

Robotics and Process Automation Research Group

Head: Prof. Dr.-Ing. Axel Gräser

ag@iat.uni-bremen.de

Universität Bremen

The Institute of Automation (IAT)

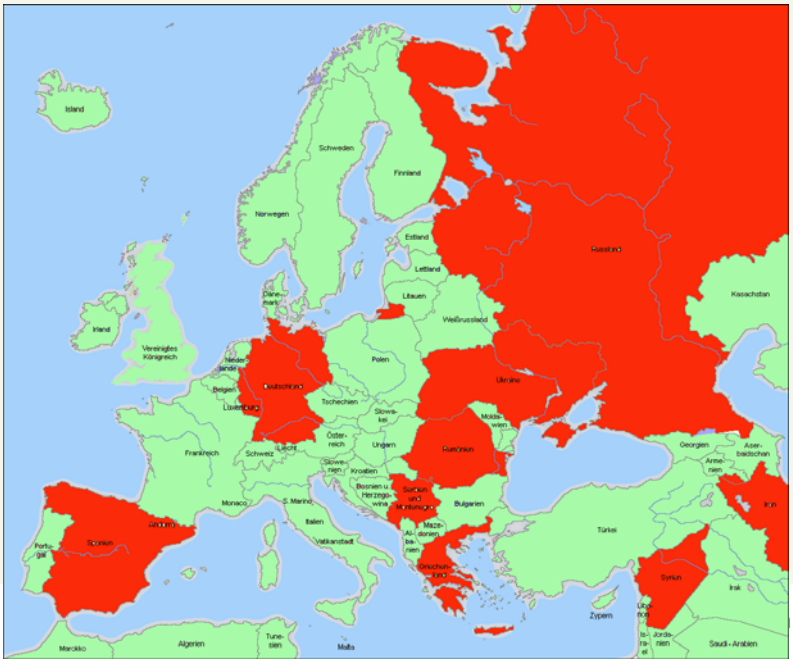
Institute of Automation

3 Professors
29 Researchers from 12 different countries
12–15 Students

Secretary: 2
Technical staff: 4

- Germany
- Greece
- Romania
- Russia
- Serbia
- Spain
- Ukraine

- China
- Columbia
- India
- Iran
- Syria



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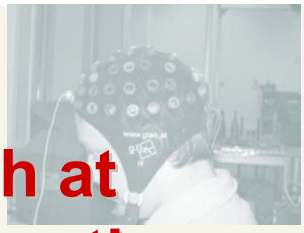
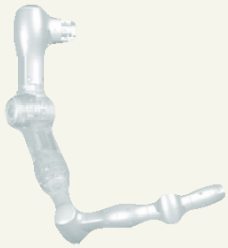


Fields of Research at the Institute of Automation - Possible Student Projects

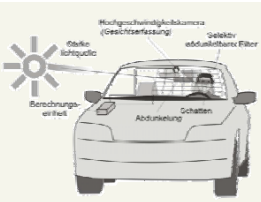


Universität Bremen

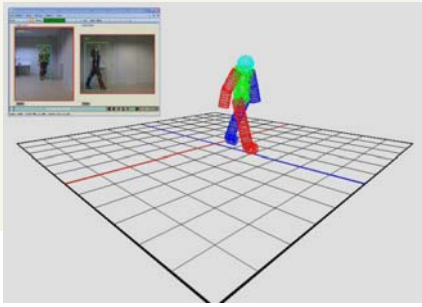
Research Projects IAT

Institut für Automatisierungstechnik

- Service / Rehabilitation Robots
  - FRIEND III
  - ReIntegraRob
  - RoboWalker
  - LeRoS-F / KoBS R
  - PORTASOR
  - …



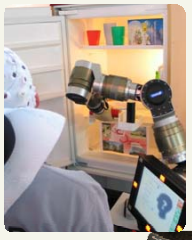
- Image Processing
  - Feedback structures
  - Image-based gait analysis
  - HiSpe3D
  - Shade Vision – driver

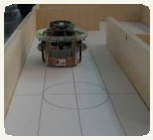


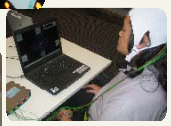
Research Projects IAT

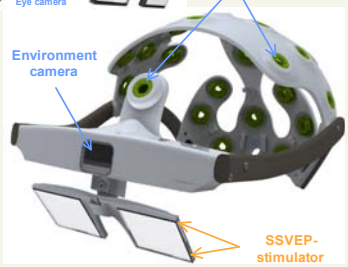
Institut für Automatisierungstechnik

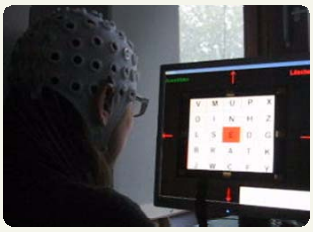
- Brain Computer Interface
  - BRAIN-Robot
  - BRAIN
  - sBCI



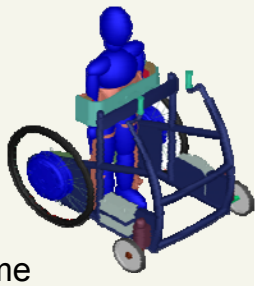


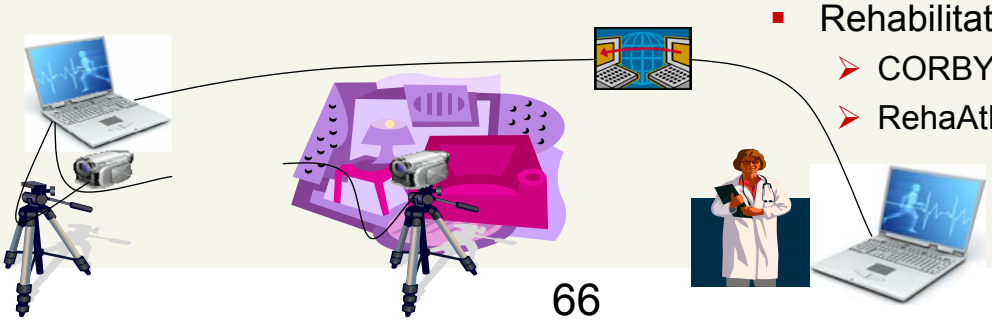






- Rehabilitation
  - CORBYS
  - RehaAtHome



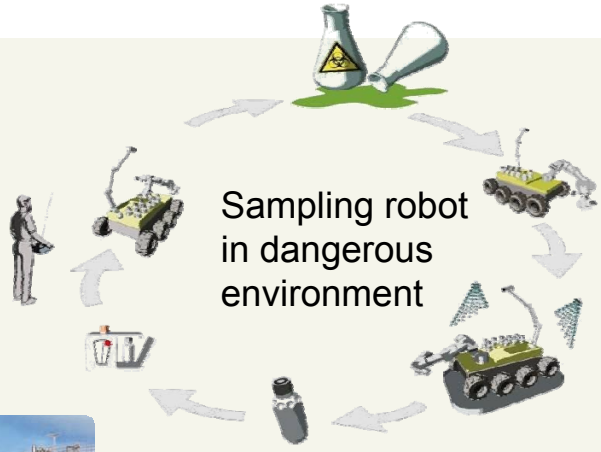


en

Research Projects IAT

Institute of Automation

Process control
in a steel plant



Sampling robot
in dangerous
environment

Optimization of the control of a
waste water treatment plant,
optimization of wind parks

Research Projects IAT

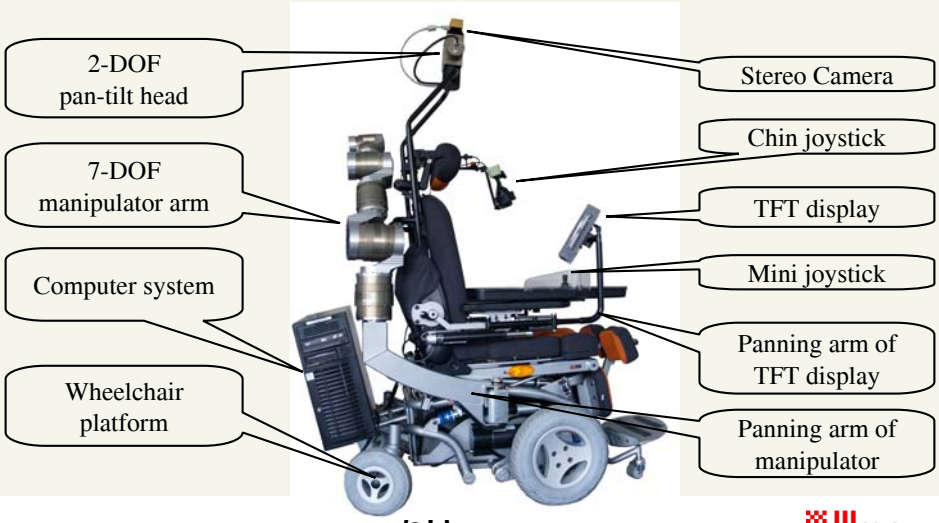
Institute of Automation

michels@iat.uni-bremen.de

FRIEND

Institute of Automation

- FRIEND = Functional Robot Arm with User-FrIEndly INterface for Disabled People
- 1.5 hours independence from care taking personal.
- Functionalities for 3 support scenarios: ADL (All Day Living), Library and Workshop scenarios.



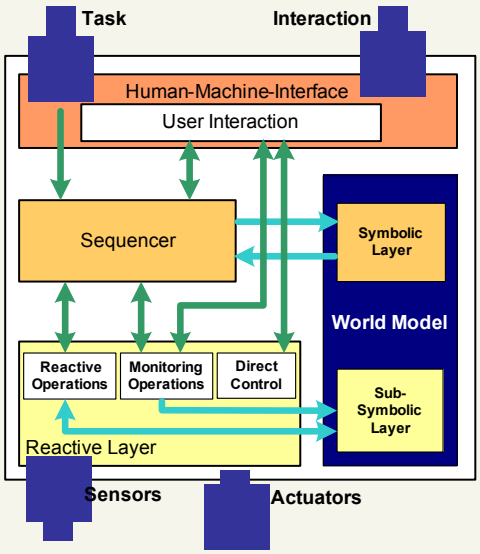
Universität Bremen

FRIEND::MASSiVE

Institute of Automation

Multi-Layer Architecture for Semi-Autonomous Service-Robots with Verified Task Execution

- Hybrid multilayer architecture
- Adaptation to requirements of semi-autonomy
- Verifiable process structures for robust task execution



- Platform independent using C++ and:

Contact persons:
Torsten Heyer (theyer@iat.uni-bremen.de)
Henning Kampe (kampe@iat.uni-bremen.de)

- TAO – CORBA implementation on top of ACE

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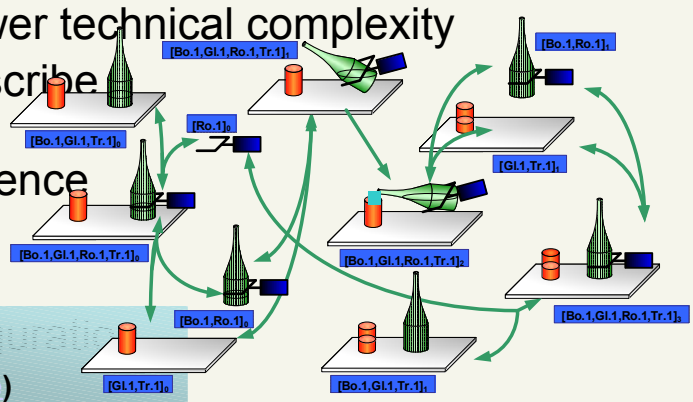
FRIEND::MASSiVE

Institute of Automation

- **High level abstract task input via Human-Machine-Interface (HMI)**
  - Integration of natural speech recognition
  - Use of non-invasive Brain-Computer-Interface (BCI)
- **Autonomous** task panning and execution
- Get **feasible** system – lower technical complexity
  - Process-structures describe task knowledge
  - Integrate user's intelligence
  - Include distributed smart devices



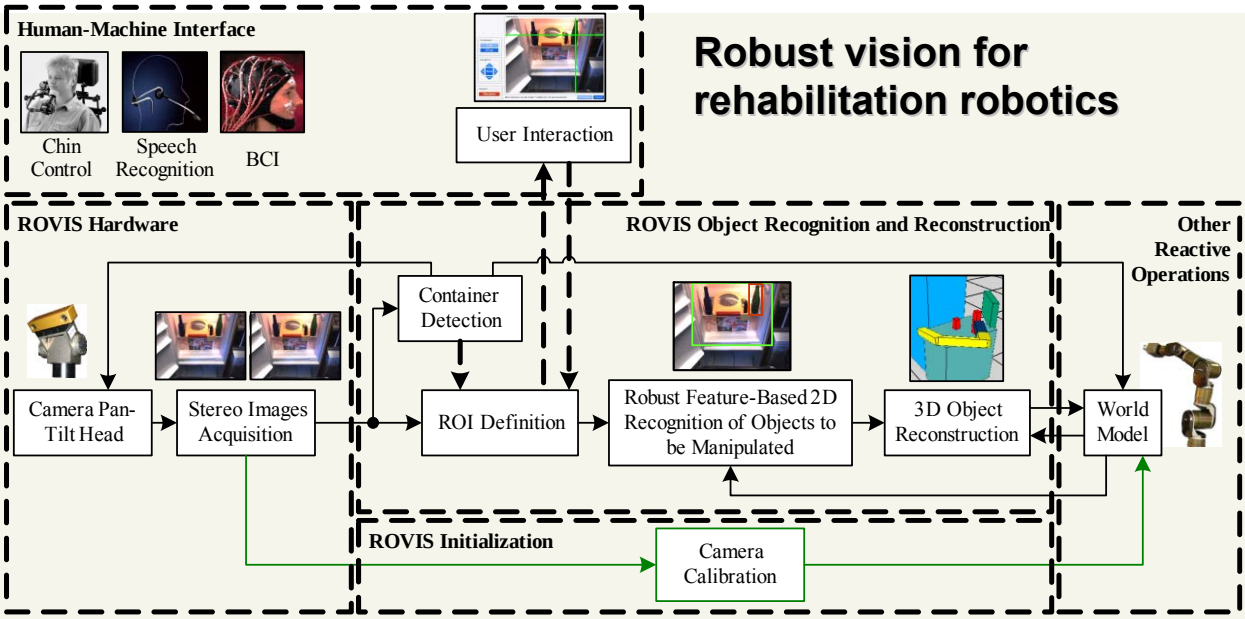
Contact persons:

Torsten Heyer (theyer@iat.uni-bremen.de)
Henning Kampe (kampe@iat.uni-bremen.de)

FRIEND::ROVIS Structure

Institute of Automation

Robust vision for rehabilitation robotics



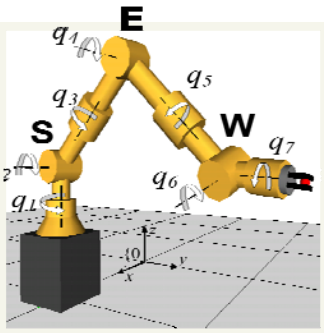
Contact persons:

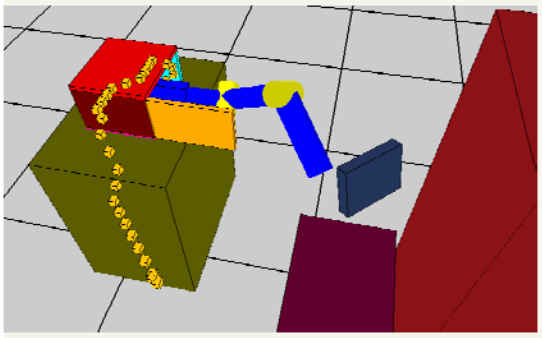
Saravana Natarajan (natarajan@iat.uni-bremen.de)
Danijela Ristić-Durrant (ristic@iat.uni-bremen.de)

FRIEND::Motion Planning

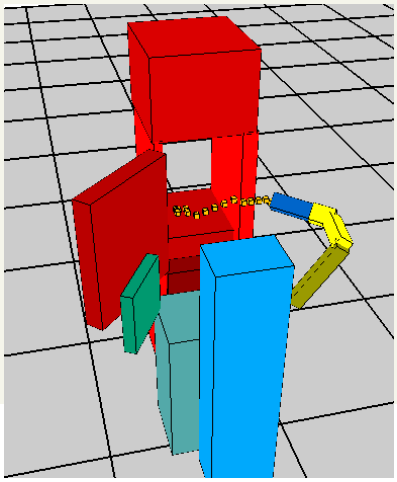
Institute of Automation

- Calculation of analytical solutions of inverse kinematics for a 7 DoF Manipulator
- Avoiding obstacles and collisions
- Trajectory smoothing
- Implementation of fast motion planning algorithms
- Real-time application
- Direct control of 7DoF manipulator by the user





Mapped Virtual Reality (MVR)



Contact person:

Christos Fragkopoulos (fragkopoulos@iat.uni-bremen.de)

Further Projects within FRIEND …

Institute of Automation

- Initial monitoring to determine the current state of the system and the environment
- Development of algorithms to make FRIEND contex-aware

Contact person:

Torsten Heyer (theyer@iat.uni-bremen.de)

- Safty analysis of FRIEND with Time-of-light (ToL) camera in order to guarantee the safety of the user
- Development of a safety concept

Contact person:

Uwe Lange (lange@iat.uni-bremen.de)

FRIEND in Action

Institute of Automation

Scenario: "Preparation of a meal"

Working in a library: „Library"

Actual library scenario: Library 1
Library2
Library3

FRIEND - User Tests

Institute of Automation

- FRIEND was tested with patients in a rehabilitation center in Bremen
  - Feedback from patients and therapists what to improve, change, …

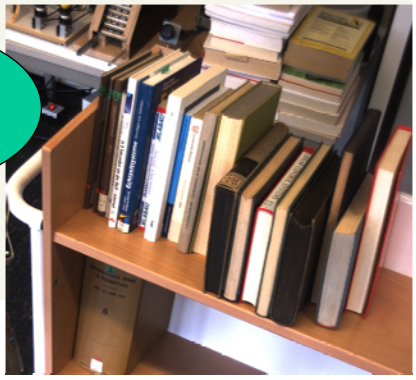
ReIntegraRob

Institute of Automation

- Disabled person should turn back to professional life with support of FRIEND
- Proof that
  - Disabled person can be used completely in a job
  - All necessary abilities in the job can be managed by FRIEND

- Task: Catalogue of books in the university library Bremen (SuUB)

Take book from book shelf → Catalogue book → Lay down book on book shelf



Contact person:

Torsten Heyer (theyer@iat.uni-bremen.de)

Contact person:

Danijela Ristić-Durrant(ristic@iat.uni-bremen.de)

Institute of Automation

To design, develop and validate an integrated cognitive robot control architecture for supporting **robot-human co-working with high level cognitive capabilities:**

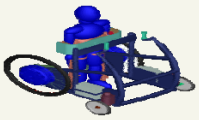
✓situation-awareness
✓attention control
✓goal-setting prioritisation
✓anticipation of behaviour of an external agent

OBJECTIVES

- Sensing systems for assessing dynamic robot environments including humans
- Self-awareness as a basis for adaptation of robot behaviour SAWBB
- Anticipation in the context of a human-robot synergy SOIAA

DEMONSTRATORS

- Cognitive robot control
- Cognitive mobile robot-assisted gait rehabilitation

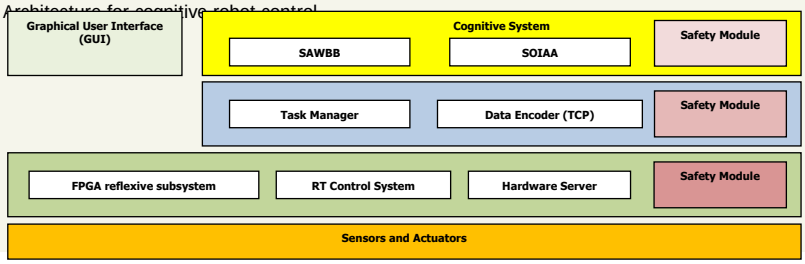


Cognitive Mobile Robotic Gait-Rehabilitation System
to be developed in CORBYS

Reconnaissance Robot
developed within national project RecoRob at the IAT

IAT PROJECT ROLE

Architecture for cognitive robot control



CONSORTIUM

PROJECT COORDINATOR:
Institute of Automation,
University of Bremen,
Germany

Intelligent Systems Research Laboratory
The University of Reading,
United Kingdom

University Rehabilitation Institute,
Republic of Slovenia

Adaptive Systems Research Group,
The University of Hertfordshire,
United Kingdom

The Robotics and MultiBody Research Group,
Vrije University Brussels, Belgium

SINTEF, Norway

OTTO BOCK Mobility Solutions,
Germany

Neurological Rehabilitation Center Friedehorst,
Germany

BIT&BRAIN Technologies,
Spain

SCHUNK, Germany

OTTO BOCK Healthcare, Germany

EU FP7 ICT Large-Scale Integrating Project

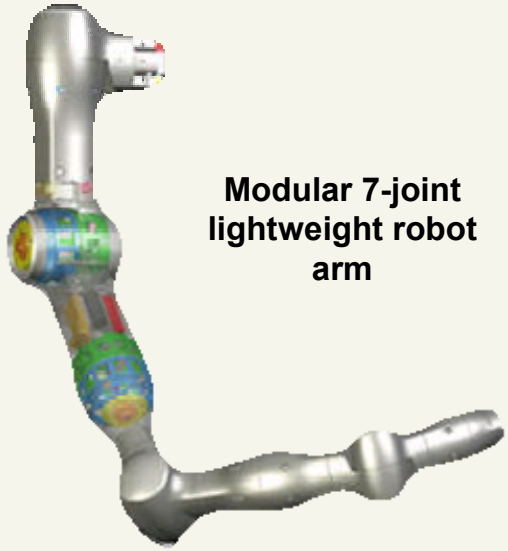
Universität Bremen

Area: Cognitive Systems and Robotics

LeRoS-F / PORTASOR

iat Institute of Automation

Lightweigth Robots with Flexible fluidic Servo actuators



Modular 7-joint lightweight robot arm

Aim

Modular lightweight highly precise robots with natural compliance for safe operations in direct interaction with humans

Research areas

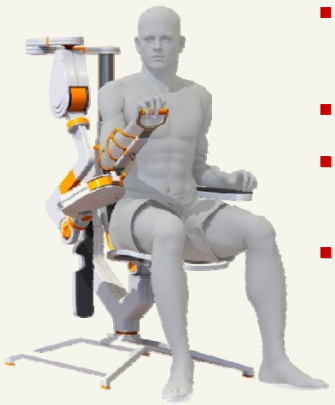
- Application of mechatronics paradigm: integration of ultra-light, small and low cost sensors
- Robust control of a flexible fluidic actuator with position / pressure and torque feedback
- Interaction control of the robot arm with natural compliance

Contact person:

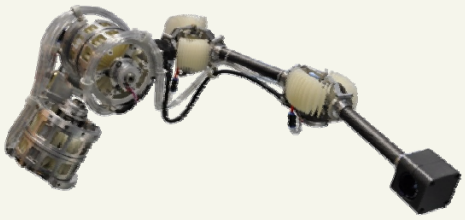
Oleg Ivlev (ivlev@iat.uni-bremen.de)

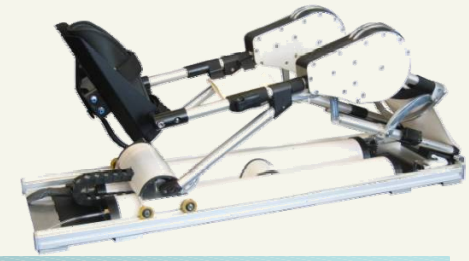
KoBSAR

iat Institute of Automation



- Effective and low-cost patient cooperative motion trainers
- For clinical and domestic use
- Sensory for patient's force detection
- Documentation of the therapy adjustments and corresponding sensor data for evaluation



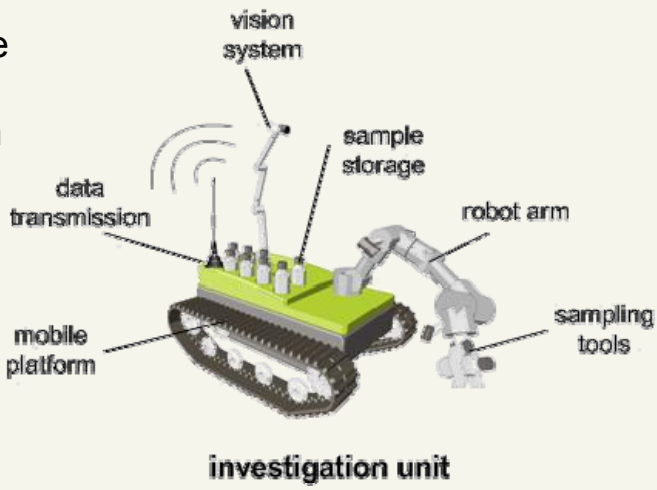


Contact persons:

David Baiden (baiden@iat.uni-bremen.de)
Andre Wilkening (wilkening@iat.uni-bremen.de)

RecoRob

- **Aim:** Development of a mobile robot for automation of sampling
- Intelligent robot control algorithms for automated sampling in contaminated areas
- Intelligent human-machine-interface for easy control
- Sensors for autonomous navigation and environment recognition
- Robot arm with intelligent tools for effective sampling
- Automatic documentation about each sampling



Contact persons:

Olena Kuzmicheva (kuzmicheva@iat.uni-bremen.de)

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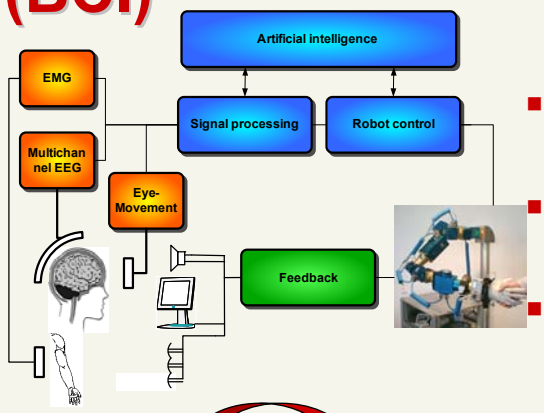
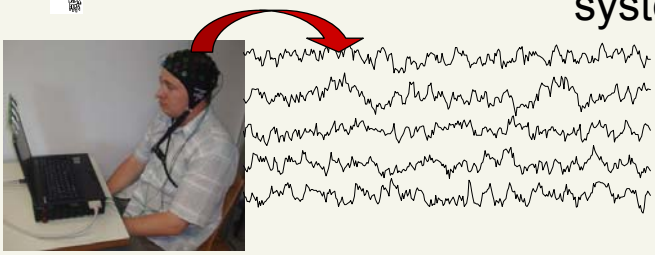
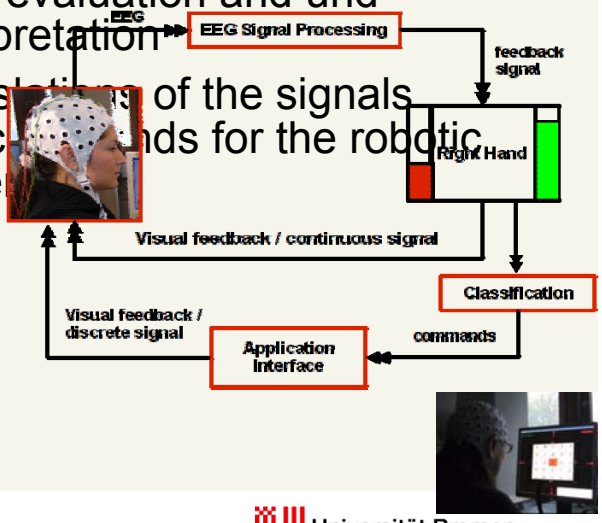
Brain Computer Interface (BCI)



- Non-invasive capturing brain signals
- Data evaluation and und Interpretation
- Translations of the signals into commands for the robotic system





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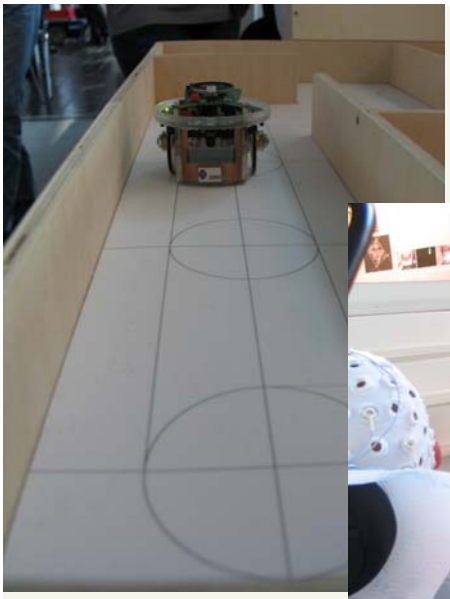
BCI Robotic Applications



- Re-enable handicapped people to control technical systems
- Brain-computer interface with real-time feedback for user training

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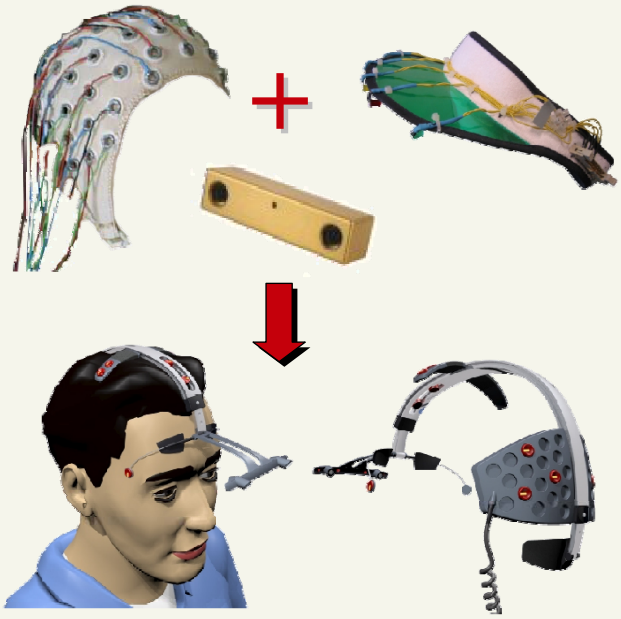
sBCI
Fast Brain-Computer Interface



- System for Daily Life Applications
- New, leight-weight adaptive and fast brain-computer-interface
- Modular extention for capturing of myo-electrical signals, eye motion and view direction

Contact persons:

Tatsiana Malechka (malechka@iat.uni-bremen.de)

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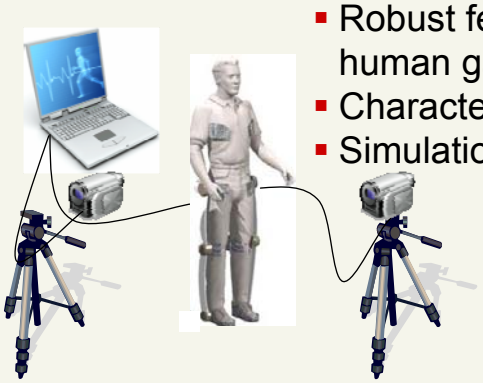
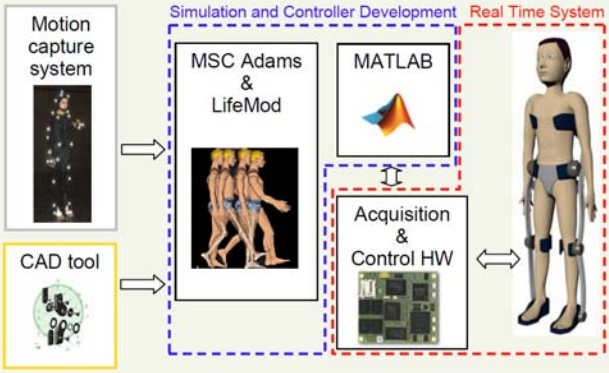
RoboWalker

Mobile Gait Rehabilitation System

Institute of Automation

- Electro mechanical system for rehabilitation
- Improved training effects due to observed rehabilitation
- Robust feature extraction for marker-less vision-based human gait analysis
- Characterization of human motion
- Simulation of human motion for medical prothesis





Contact persons:

Danijela Ristic-Durrant (ristic@iat.uni-bremen.de)

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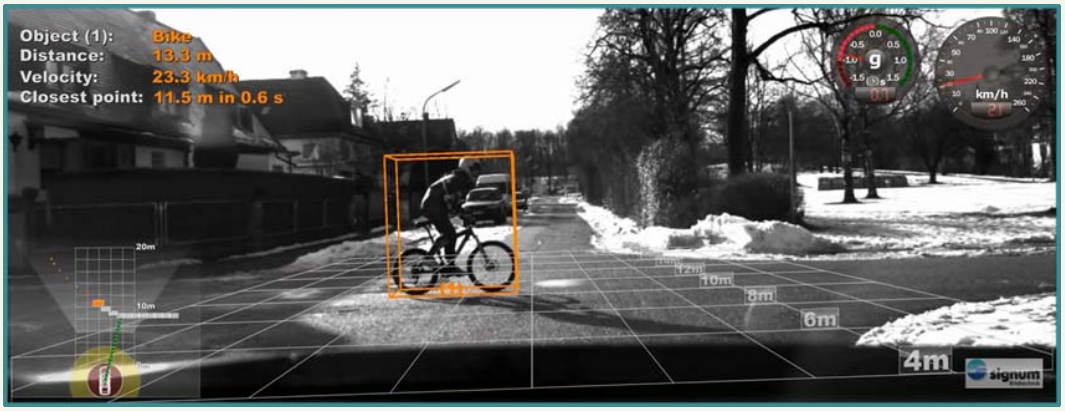
HiSpe3D-Vision

Advanced Driver Assistance Systems

Institute of Automation

- Software based method for autonomous and robust obstacle detection
- Pedestrian detection for advanced driver assistant systems
- High-speed image processing (100Hz) in real-time
- Integration of vehicle movements in the model



Input image with additional information

Contact persons:

Adrian Leu (leu@iat.uni-bremen.de)

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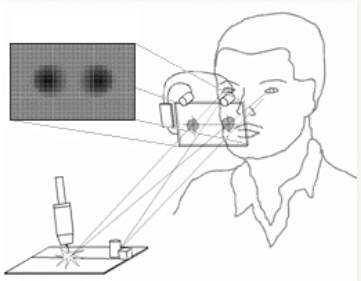
Virtual and Augmented Reality

Institute of Automation

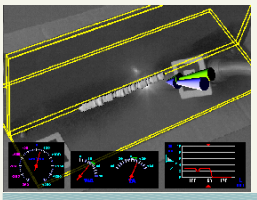
Augmented reality (AR) for the observation of welding processes

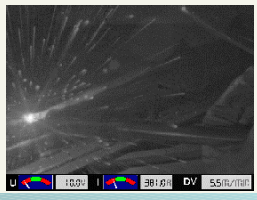


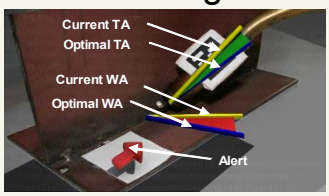
Enhanced view on the welding scene, display of process data using AR elements

An integrated welding trainer for manually welding

Selective dimming of the welding scene







Contact person:

Bernd Hillers (hillers@iat.uni-bremen.de)

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Student Projects

Institute of Automation

- Bachelor / master project, diploma thesis, as Erasmus exchange student, student job
- Tasks is chosen based on
  - student interest
  - student knowledge / background
  - current research work at IAT
- Tasks could be
  - pure theoretical
  - pure practical
  - mixture of both

ERASMUS Program

Bildung und Kultur

Erasmus

International Student Exchange Programmes

- **Several years of experience of the IAT in the international exchange programmes**
  - KAIST (Korean Advanced Institute of Science and Technology), Daejon, South Korea
  - Summer school with the University Brasov, Romania
  - Several guest lectures in "C++ in technical systems" (basics and advanced courses) in Brasov, Romania
- **A number of exchange students under the SOCRATES / ERASMUS Student Exchange Program**
  - Spain, Portugal, Romania, Hungary, France, ...

Lectures in English are offered

iat Institute of Automation

You are free to attend some of the lectures offered in english language as well as whose offered in german

- **Dynamic Systems**
- **System Theory**
- **Control Theory**
- **Electrodynamics**
- **Process Automation**
- **Robotics**
- **Power Converter Technology**
- **Advanced Control Systems Lab**
- **Process Automation Lab**
- **Real-Time Software Design**
- **Communications Networks**
- **Microwave Techniques Lab**
- **C++ Basics and Applications**
- **C++ for advanced Programmers**
- **Semiconductor Devices**
- **Communications Technology**
- **Integrated Systems**
- **Integrated Circuits**
- **Design of Microsystems and Microelectronics**
- **Optoelectronic Components for Information Transmission and Sensors**
- **Micro Actuators**
- **Stochastic Simulations**

and other courses...

Homepage:

http://www.mci.uni-bremen.de

ERASMUS Program

iat Institute of Automation

- Sub-program of the **EU Lifelong Learning Program (LLP)**
  - Promotion of student mobility and co-operation
  - Possibility for a stay abroad at a european co-operation university

Education and Culture DG

Lifelong Learning Programme

- Advantages of the ERASMUS program
  - Complete remission of tuition fee at the host university
  - Intensive supervision at home and host university
  - Acknowledgement of abroad reached work
  - Mobility subsidy

ERASMUS Program

Necessary steps to become an ERASMUS at the IAT

Institute of Automation

- Contact the ERASMUS Office at your university to get information about:
  - deadlines for applications
  - the person to contact at your university
  - the selection criterion your university uses
  - the amount of money available to support your stay in Bremen
- Before an application at the University of Bremen a nomination by means of your home university is necessary
- After receipt of your application you are invited to an on-line application and you will get further information

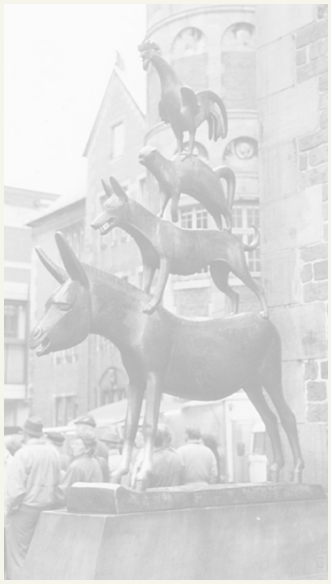
ERASMUS Program

Necessary steps to become an ERASMUS at the IAT

Institute of Automation

- Send an e-mail to Prof. Dr. A. Gräser ag@iat.uni-bremen.de describing your goals:
  - CV
  - the beginning and the duration of your stay
  - special interests
  - the name of the person to contact in your Erasmus office
- Please take into consideration that for a host study at the University of Bremen sufficient linguistic proficiency is a pre-requisite

Make your plan at least half a year ahead!!!



Infos about Bremen

The City of Bremen

Free Hanseatic City of Bremen

- 1,200 years old
- Independent state of Germany
- Consists of Bremen and Bremerhaven
- 700,000 inhabitants

- International seaport
- Trading center right near the North Sea

FREIE HANSESTADT BREMEN

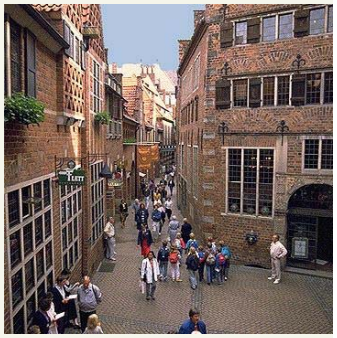
The City of Bremen

iat Institute of Automation

Bremen's city centre-
The Market Square

"Stadtmusikanten"

Böttjerstraße



Schnoor

Universität Bremen

The City of Bremen

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River Weser

"Schlachte" promenade
along the river Weser

The City of Bremen

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Universum Science Center

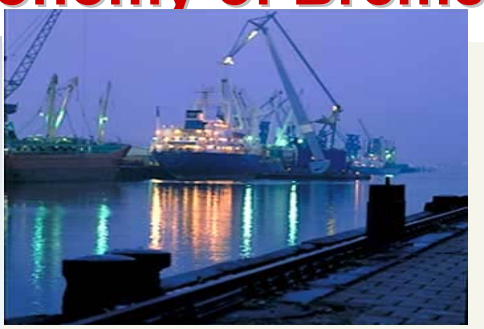
Soccer Team: SV Werder Bremen

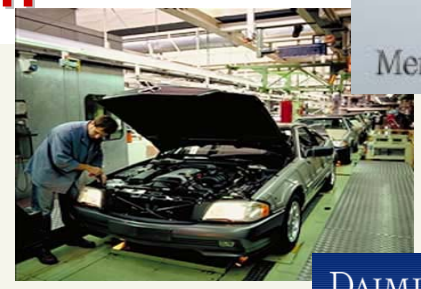
Freimarkt

German Emigration Center

The European Museum
Of the Year Award 2007

Economy of Bremen





Mercedes-Benz

DAIMLERCHRYSLER

World-ranking seaport, important location for automobile manufacture, electronics, steel, shipbuilding and aerospace industry

EADS

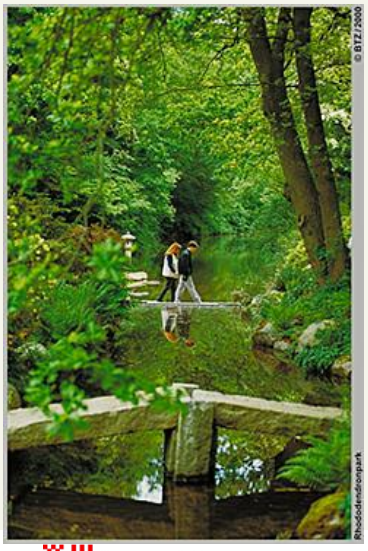
Beck's brewery

Green Bremen

Rhododendronpark

Windmill on the Wall

Bürgerpark



Universität Bremen

Experiences of Spanish ERASMUS students in Bremen

- ✓ Friendly people
- ✓ Beautiful and lively city
- ✓ Good public transport
- ✓ Relatively low cost of living
- ✓ Possibility to learn German
- ✓ "S-Bahn" parties and a lot of fun

http://www.erasmus-initiative.uni-bremen.de

Universität Bremen

More Information?

Institute of Automation

Contact the international office of the University of Bremen:

io@uni-bremen.de

Contact us:

www.iat.uni-bremen.de

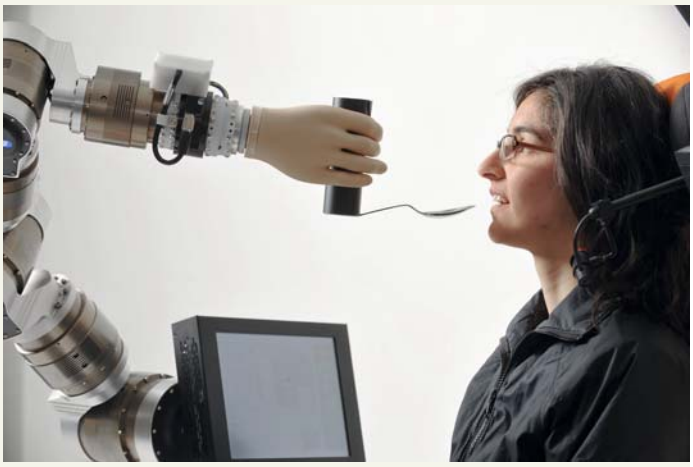
Contact me:

cfragkopoulos@iat.uni-bremen.de

You are very welcome to Bremen.
We hope to see you!

Institute of Automation

Thank you for your attention!



Questions?