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

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*Presentation at*
National technical University of Athens

*Greece 2012*

Contents

- Introduction
- Approach
- Experiment Results with Video
- Conclusions
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

• 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

• 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

Requirements for Robot arm Motion Planning

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

RRTs

Random configuration generated. Expansion with step $\epsilon$ directed to Qrand follows.

Possible metric in order to calculate the smallest distance?

• Euclidean – cartesian space $\sqrt{\sum (\Delta x_i)^2}$
• C-Space $\sqrt{\sum (\Delta q_i)^2}$
### 1. RRTs

#### RRT Algorithm

1. \( V \leftarrow \{x_{init}\}, \ E \leftarrow \emptyset \)
2. repeat
3. \( x_{rand} \leftarrow \text{NewSample} \)
4. \((V,E) \leftarrow \text{Extend}((V,E), x_{rand})\)

#### Extend procedure

1. \( x_{\text{nearest}} \leftarrow \text{Nearest}(V, x_{rand}) \)
2. \( x_{\text{new}} \leftarrow \text{Steer}(x_{\text{nearest}}, x_{rand}) \)
3. If \( \text{ObstacleFree}(x_{\text{nearest}}, x_{\text{new}}) \) then
4. \( V \leftarrow V \cup \{x_{\text{new}}\}, \)
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1. Introduction

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
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 behaviour (PRM, RRTs)*, refinement is also necessary

2. CellBiRRT

Forward Tree
2. CellBiRRT

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

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-Space with a specific size. Reduce unnecessary space.

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: $L_i = a \cdot \Delta q_i / \Delta q_{max}$

Exponential: $L_i = 1 - \exp(-a \cdot |\Delta q_i / \Delta q_{max}|)$
2. CellBiRRT

Random configuration (Qrand) is generated inside the cuboid.

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**

Algorithm repeats again for backward tree

Trees connection

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

probability < \( P_g \)

Final Path
2. CellBiRRT

Main Problem:
No extra criterion for constraints in orientation and position
Can solve also problems with constraint orientation, but the execution 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)

- Extra Constraints

\[
C = \begin{pmatrix}
X_{\text{max}} & X_{\text{min}} \\
Y_{\text{max}} & Y_{\text{min}} \\
Z_{\text{max}} & Z_{\text{min}} \\
\text{Rot}X_{\text{max}} & \text{Rot}X_{\text{min}} \\
\text{Rot}Y_{\text{max}} & \text{Rot}Y_{\text{min}} \\
\text{Rot}Z_{\text{max}} & \text{Rot}Z_{\text{min}}
\end{pmatrix}
\]
2.CelBiRRT

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 \( d\text{Cost} = dB \times \text{CostCome} + (1-dB) \times \text{CostGo} \) and maximum obstacle distance. Target is the last expanded node of the opposite tree.

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

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

\[ \dot{x} = J \cdot \dot{\theta} \Rightarrow d\theta = J^{-1} \cdot dx \]

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

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

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

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

Motion Rate Control

H is a performance criterion function.

Weighted Least Norm method

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

2. CellBiRRT - Refinement

Pruning procedure

![Diagram showing obstacle avoidance and path planning](image-url)
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 degradation of velocities \( v = \frac{D_{\text{user}}}{D_{\text{max}}} \cdot v_{\text{max}} \)

3. Experimental Results

Service robotic wheelchair systems (like FRIEND - Functional Robot arm with user-friendly interface for Disabled 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

Application to Rehabilitation System FRIEND

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

- 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

- 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).
Thank you for your attention

Concept of Grasping

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

Diagram showing coordinate systems and transformations.
Concept of Grasping

Extra Experiment results
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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 (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

- 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

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.
The University of Bremen

The science centre of North West Germany

In 1971 the University was founded

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

• ca. 20,000 Students
• ca. 1,600 Scientists from Germany and 126 other countries
The Institute of Automation (IAT)

Geographical Information

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The Institute of Automation (IAT)

Robotics and Process Automation Research Group

Head: Prof. Dr.-Ing. Axel Gräser

ag@iat.uni-bremen.de
The Institute of Automation (IAT)

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

Secretary: 2
Technical staff: 4

Possible Student Projects
Research Projects IAT

- Service / Rehabilitation Robots
  - FRIEND III
  - ReIntegraRob
  - RoboWalker
  - LeRoS-F / KoBSAR
  - PORTASOR
  - ...

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

Research Projects IAT

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

- Rehabilitation
  - CORBYS
  - RehaAtHome
Research Projects IAT

Process control in a steel plant

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

Sampling robot in dangerous environment

michels@iat.uni-bremen.de
FRIEND

- 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.

- 2-DOF pan-tilt head
- 7-DOF manipulator arm
- Computer system
- Wheelchair platform
- Stereo Camera
- Chin joystick
- TFT display
- Mini joystick
- Panning arm of TFT display
- Panning arm of manipulator

FRIEND::MASSiVE

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:
  - ACE – Network and Thread programming library
  - TAO – CORBA implementation on top of ACE

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

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

- 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

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

Further Projects within FRIEND ...

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

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

- Safety 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)
Scenario: “Preparation of a meal“

Working in a library: „Library“

Actual library scenario:  
Library 1  
Library 2  
Library 3

FRIEND in Action

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

FRIEND - User Tests
ReIntegraRob

- 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)

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

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

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

PROJECT GOAL

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

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
Agent Cognitive Systems and Robotics
LeRoS-F / PORTASOR

Lightweight Robots with Flexible fluidic Servo actuators

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

• 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)

Brain Computer Interface (BCI)

- Non-invasive capturing brain signals
- Data evaluation and interpretation
- Translations of the signals into commands for the robotic system
BCI Robotic Applications

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

![Diagram of BCI Robotic Applications](image1)

sBCI
Fast Brain-Computer Interface

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

Contact persons:
Tatsiana Malechka (malechka@iat.uni-bremen.de)
**RoboWalker**

Mobile Gait Rehabilitation System

- 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 prosthesis

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

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**HiSpe3D-Vision**

Advanced Driver Assistance Systems

- 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

Contact persons:
Adrian Leu (leu@iat.uni-bremen.de)
Virtual and Augmented Reality

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)

Student Projects

- 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

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

You are free to attend some of the lectures offered in English language as well as those 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

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ERASMUS Program

- 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

- 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
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

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
The City of Bremen

Bremen’s city centre-
The Market Square

“Stadtmusikanten”

Böttjerstraße

Schnoor

“Schlachte” promenade
along the river Weser

River Weser
The City of Bremen

Universum Science Center

Soccer Team: SV Werder Bremen

Freimarkt

German Emigration Center
The European Museum Of the Year Award 2007

Economy of Bremen

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

Beck’s brewery
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
More Information?

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!

Thank you for your attention!

Questions?