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Knowledge Centre of Robotics

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Time-optimal motion planning for robots

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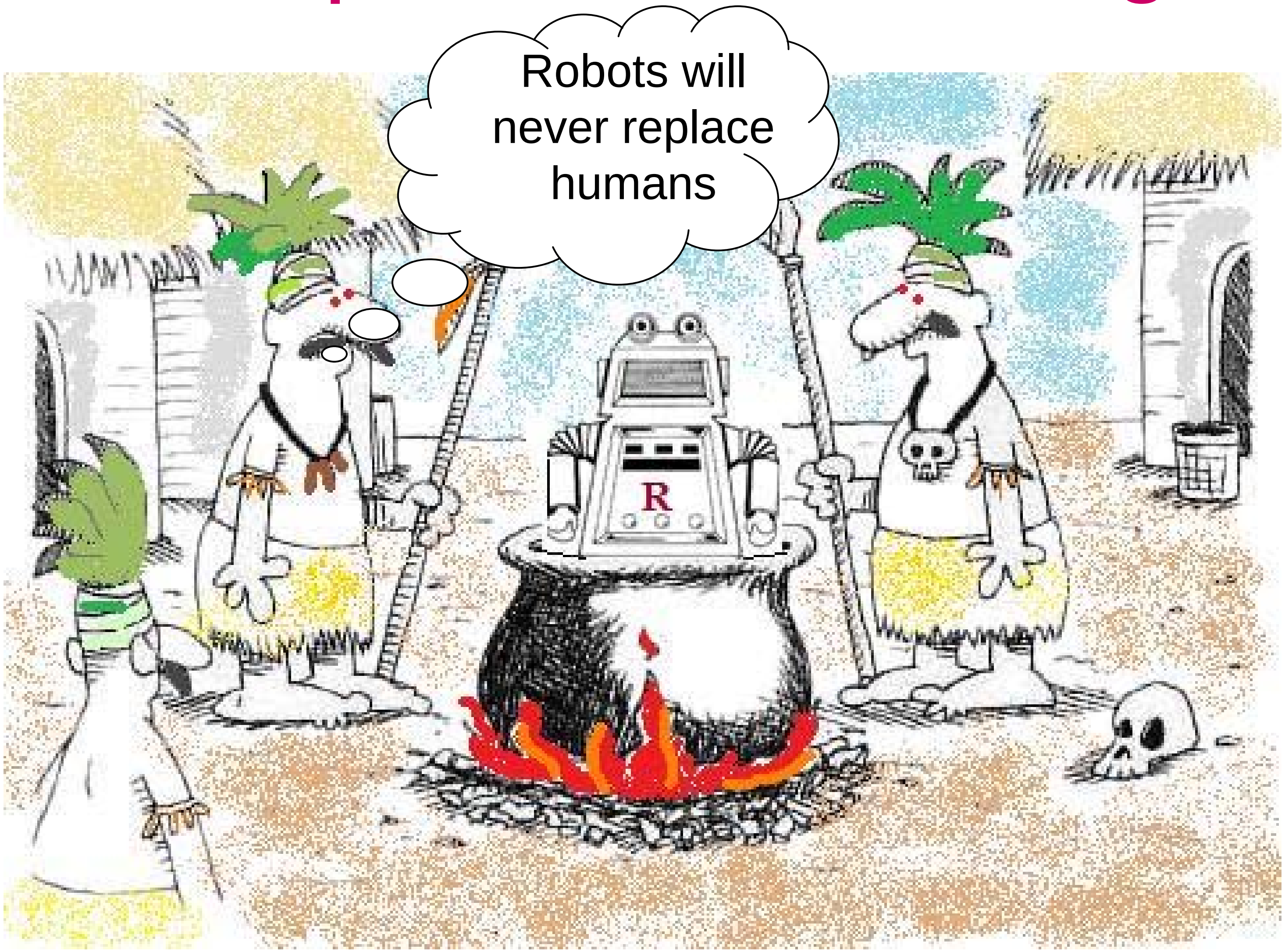
RAAD 2010

A new aspect of robot using



Cannibal:

- „Robots will never replace humans”

•A new research topic: Is a robot with time-optimal motion tastier?

Content

- Introduction
- Robot Motion Planning
- Time-Optimal Cruising Trajectory Planning
- Time-Optimal PTP Motions
- Realization
- Applications
- Conclusions

Introduction

The Lagrange equation of the robot motion

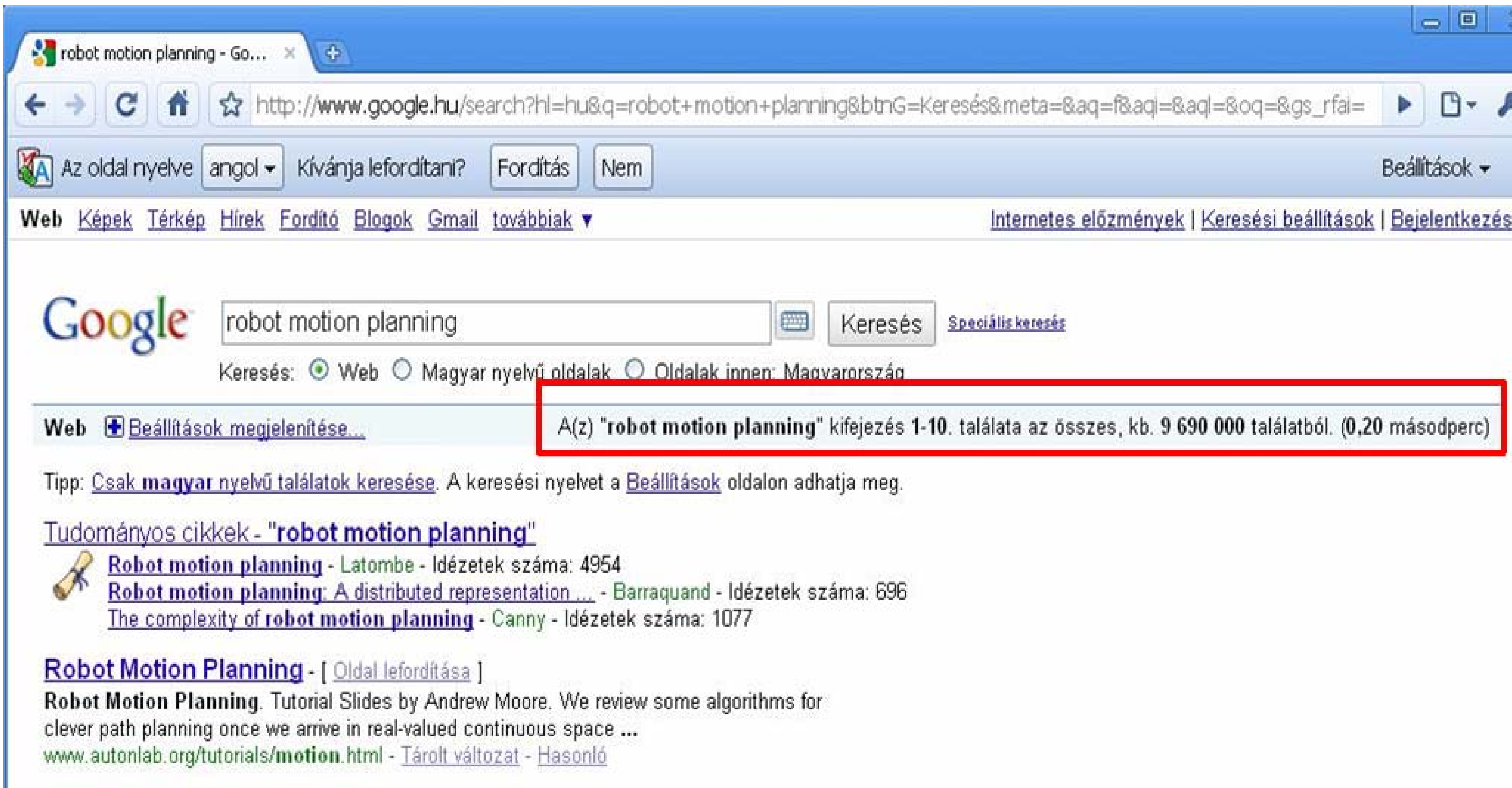
$$\mathbf{H}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{h}(\dot{\mathbf{q}}, \mathbf{q}) = \tau$$

Introduction

- **Path planning**
- **Trajectory planning**
- **Trajectory tracking**

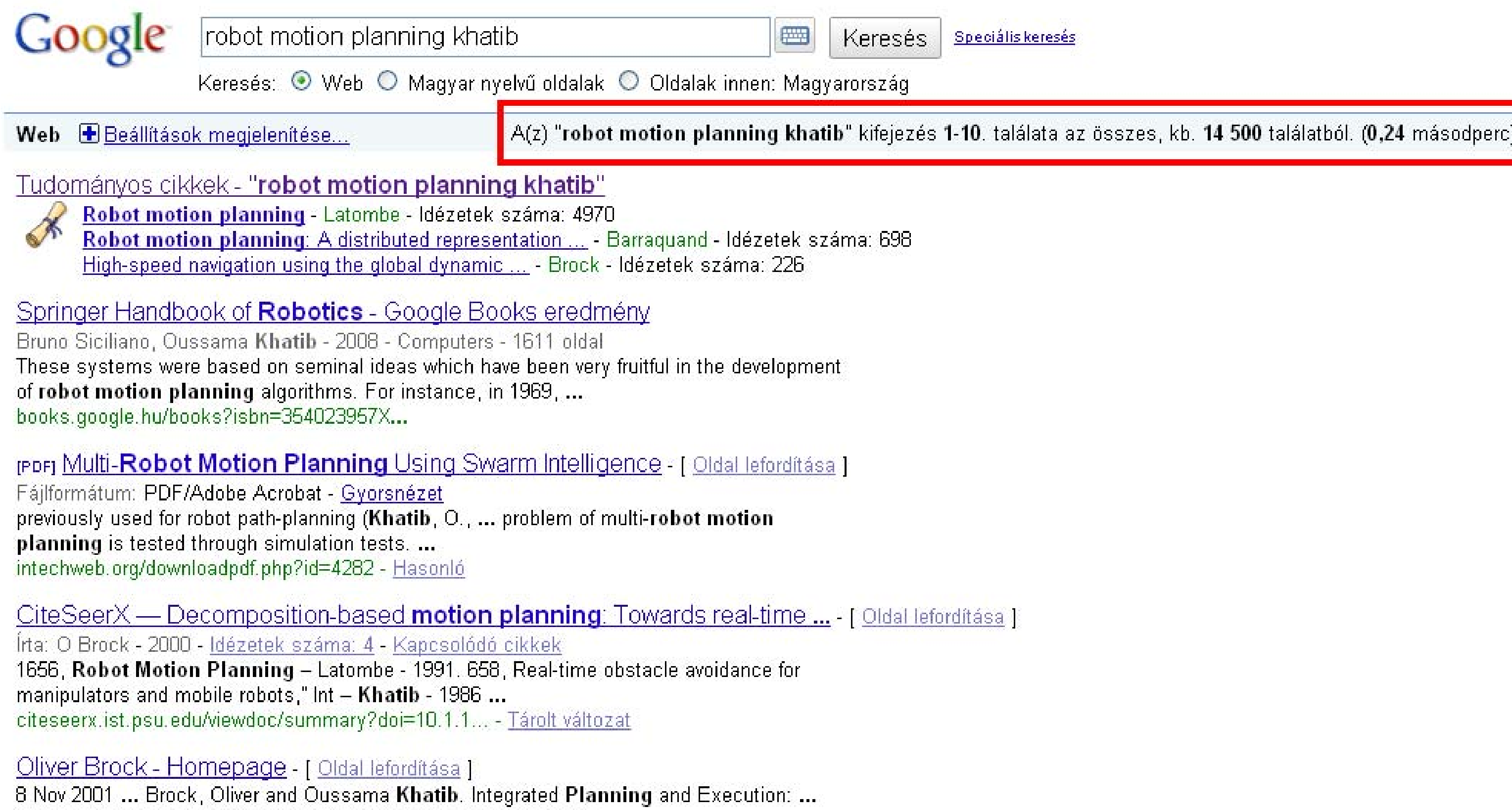
Robot Motion Planning

State-of-the –Art



Robot Motion Planning

State-of-the –Art



Google | robot motion planning khatib | Keresés | Speciális keresés

Keresés: Web / Magyar nyelvű oldalak / Oldalak innen: Magyarország

Web | Beállítások megjelenítése... | A(z) "**robot motion planning khatib**" kifejezés **1**-**10**. találata az összes, kb. **14 500** találatból. (**0,24** másodperc)

Tudományos cikkek - "**robot motion planning khatib**"
Robot motion planning - Latombe - Idézetek száma: 4970
Robot motion planning: A distributed representation ... - Barraquand - Idézetek száma: 698
High-speed navigation using the global dynamic ... - Brock - Idézetek száma: 226

Springer Handbook of **Robotics** - Google Books eredmény
Bruno Siciliano, Oussama **Khatib** - 2008 - Computers - 1611 oldal
These systems were based on seminal ideas which have been very fruitful in the development of **robot motion planning** algorithms. For instance, in 1969, **...**
books.google.hu/books?isbn=354023957X**...**

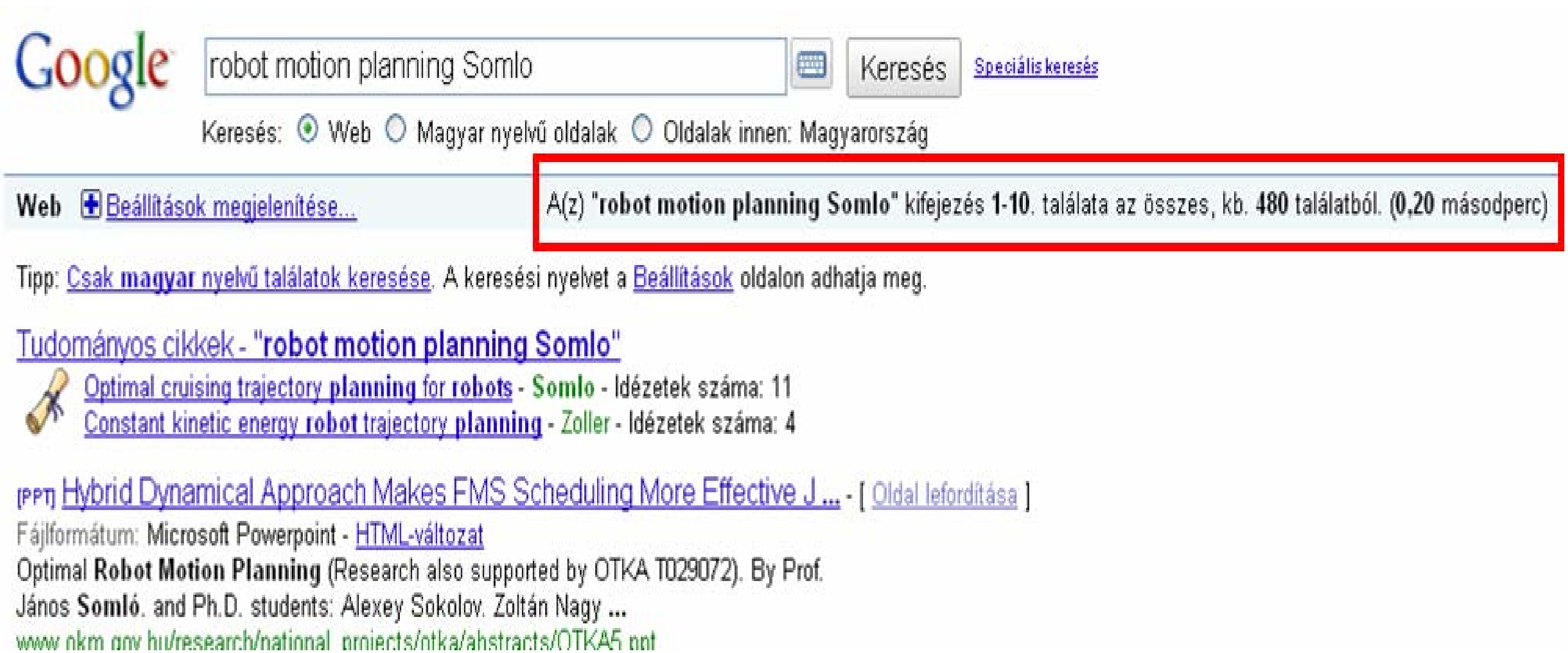
[PDF] Multi-**Robot Motion Planning** Using Swarm Intelligence - [Oldal lefordítása]
Fájlformátum: PDF/Adobe Acrobat - Gyorsnézet
previously used for robot path-planning (**Khatib**, O., **...** problem of multi-**robot motion planning** is tested through simulation tests. **...**
intechweb.org/downloadpdf.php?id=4282 - Hasonló

CiteSeerX — Decomposition-based **motion planning**: Towards real-time **...** - [Oldal lefordítása]
Írta: O Brock - 2000 - Idézetek száma: 4 - Kapcsolódó cikkek
1656, **Robot Motion Planning** – Latombe - 1991. 658, Real-time obstacle avoidance for manipulators and mobile robots," Int – **Khatib** - 1986 **...**
citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1... - Tárolt változat

Oliver Brock - Homepage - [Oldal lefordítása]
8 Nov 2001 **...** Brock, Oliver and Oussama **Khatib**. Integrated **Planning** and Execution: **...**
Generation of **Robot Motion**: Integrating **Planning** and Execution

Robot Motion Planning

State-of-the –Art



Robot Motion Planning

COMPUTER SCIENCE REVIEW 1 (2007) 67–72

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Computer Science Review

Book review

Understanding motion planning better: A comparative review of "Principles of Robot Motion: Theory, Algorithms, and Implementations", by H. Choset et al.

Pablo Jiménez

Institut de Robòtica i Informàtica Industrial (CSIC - UPC), Llorens i Artigas 4-6, E-08028 Barcelona, Spain

ARTICLE INFO

Article history:

ABSTRACT

The textbook on motion planning "Principles of Robot Motion: Theory, Algorithms, and Implementations", by H. Choset et al., MIT Press, which appeared in June 2005, is reviewed and compared with two other textbooks on the same subject, from 1991 and 2006, respectively. The ground-breaking developments over the last decade justify the necessity of the newer textbooks, which appear to be complementary, despite some overlap in the contents.

1. Overview

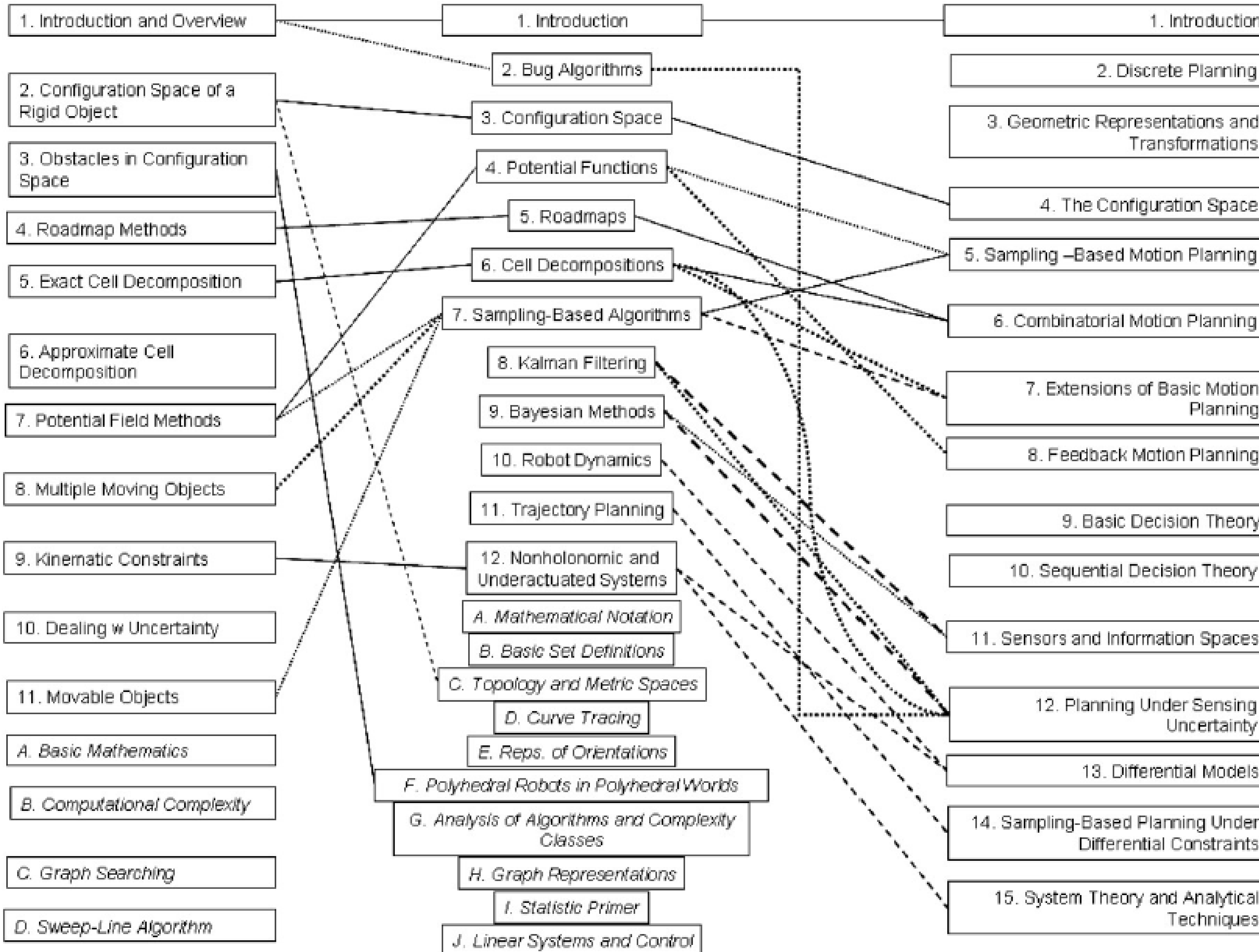
goes beyond geometry and covers all control topics related to

Robot Motion Planning

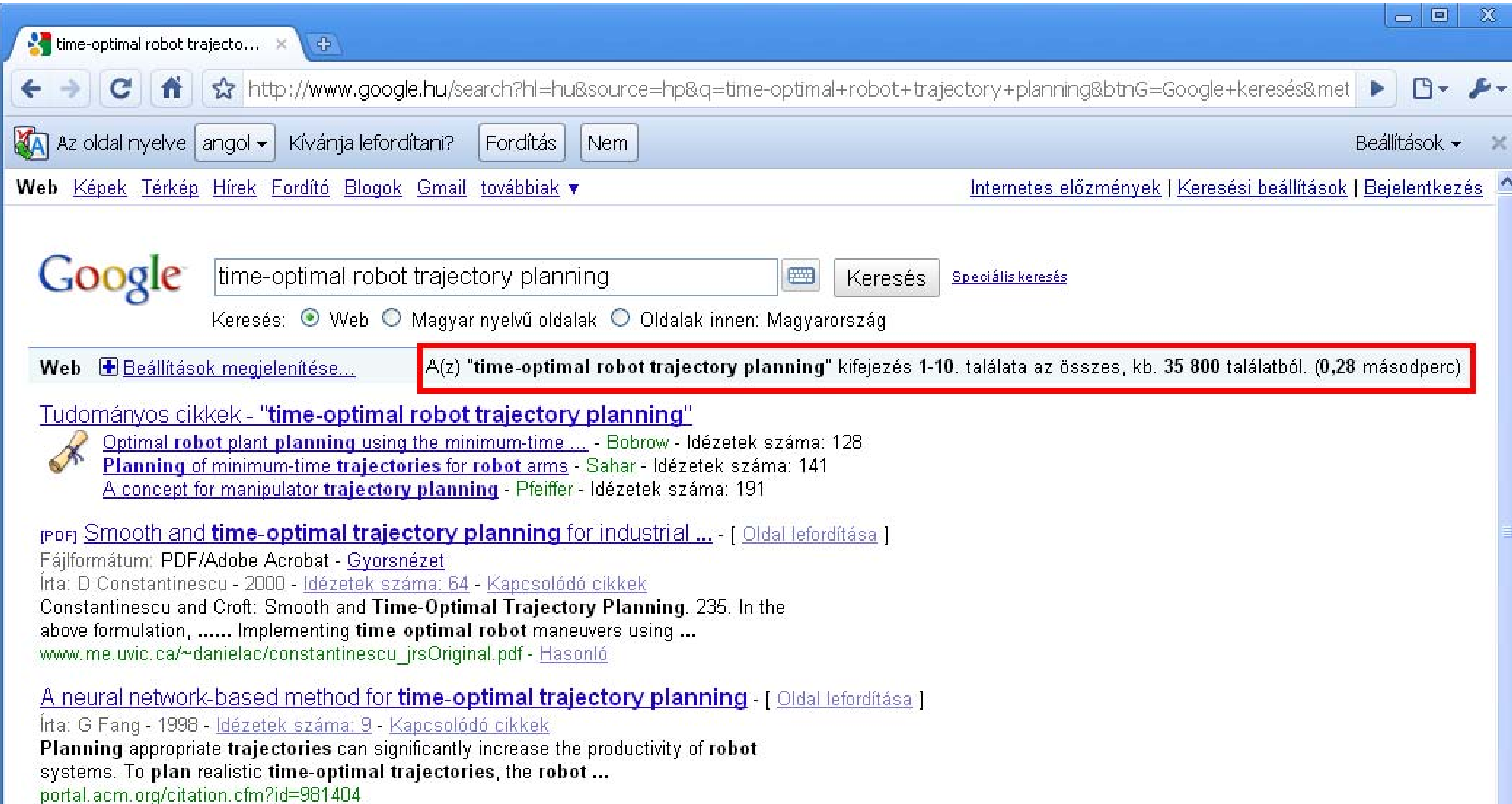
- H. Choset, K.M. Lynch, S. Hutchinson, G.A. Kantor,
- W. Burgard, L.E. Kavraki, S. Thrun, Principles of Robot
- Motion: Theory, Algorithms, and Implementations, MIT
- Press, 2005.

- [2] J.C.Latombe, Robot Motion Planning, Vol. SECS 0124, Kluwer,
- Dordrecht, The Netherlands, 1991.

- S.M. LaValle, Planning Algorithms, Cambridge University
- Press, Cambridge, UK, 2006. Available at:
- http://planning.cs.uiuc.edu/.


1. Introduction and Overview
2. Configuration Space of a Rigid Object
3. Obstacles in Configuration Space
4. Roadmap Methods
5. Exact Cell Decomposition
6. Approximate Cell Decomposition
7. Potential Field Methods
8. Multiple Moving Objects
9. Kinematic Constraints
10. Dealing w Uncertainty
11. Movable Objects
A. Basic Mathematics
B. Computational Complexity
C. Graph Searching
D. Sweep-Line Algorithm
1. Introduction
2. Bug Algorithms
3. Configuration Space
4. Potential Functions
5. Roadmaps
6. Cell Decompositions
7. Sampling-Based Algorithms
8. Kalman Filtering
9. Bayesian Methods
10. Robot Dynamics
11. Trajectory Planning
12. Nonholonomic and Underactuated Systems
A. Mathematical Notation
B. Basic Set Definitions
C. Topology and Metric Spaces
D. Curve Tracing
E. Reps. of Orientations
F. Polyhedral Robots in Polyhedral Worlds
G. Analysis of Algorithms and Complexity Classes
H. Graph Representations
I. Statistic Primer
J. Linear Systems and Control
1. Introduction
2. Discrete Planning
3. Geometric Representations and Transformations
4. The Configuration Space
5. Sampling –Based Motion Planning
6. Combinatorial Motion Planning
7. Extensions of Basic Motion Planning
8. Feedback Motion Planning
9. Basic Decision Theory
10. Sequential Decision Theory
11. Sensors and Information Spaces
12. Planning Under Sensing Uncertainty
13. Differential Models
14. Sampling-Based Planning Under Differential Constraints
15. System Theory and Analytical Techniques

Time-Optimal Cruising Trajectory Planning



Trajectory planning (methods used)

- Fu K. S., Gonzalez R. C., Lee C. S. G. (1987), „Robotics: Control, Sensing, Vision, and Intelligence." McGraw-Hill.

- Sciavicco L. Siciliano B. (2001), "Modelling and Control of Robot Manipulators" Springer. Pp. 378.

Trajectory planning

- Sciavicco L. Siciliano B. (2001), ”Modelling and Control of Robot Manipulators” Springer. Pp. 378.
- At this approach, the coordinates of a series of points in Cartesian coordinate system. are given The corresponding joint coordinates values are determined by inverse transformation. If the joint positions, speeds and possibly accelerations (deceleration) are known in the given points (and, also, the desired time of motion from point to point), the paths for joints satisfying the given conditions can be determined using proper-order splines.

Trajectory planning

- For example, if in two points the joint coordinates and speed values are given,

$$q_i(t_i), \dot{q}_i(t_i), q_i(t_{i+1}), \dot{q}_i(t_{i+1})$$

- a third-order spline

$$q_i(t) = a_{0i} + a_{1i}t + a_{2i}t^2 + a_{3i}t^3$$

- may be used for path determination of the motion. Because
- the parameter values can be determined from the 4 equations obtained at
- t=ti and t=ti+1.

- For Path Motions:
- Interpolating Polinomials with Velocity Constraints at Path Points
- are proposed

Time-Optimal Trajectory Planning

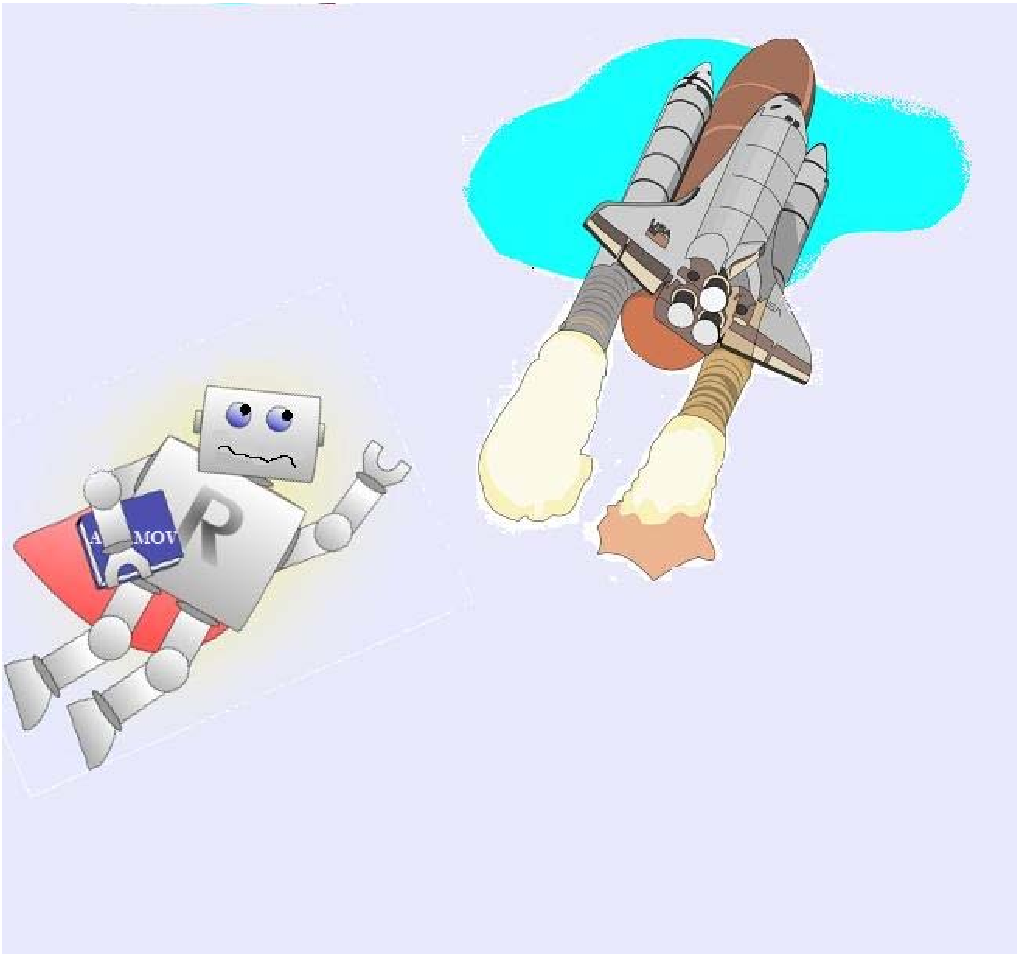
Geering H.P., Guzzella L., Hepner S.A.P., Onder C.H. (1986): "Time-Optimal Motions of Robots in Assembly Tasks" IEEE Transe. on Automatic Control, AC-31. N6.

Using PMP (Pontryagin Maximum Principle)

The results are very nice but not very simple

Time-Optimal Trajectory Planning

I am not an aeroplane or a spacecraft



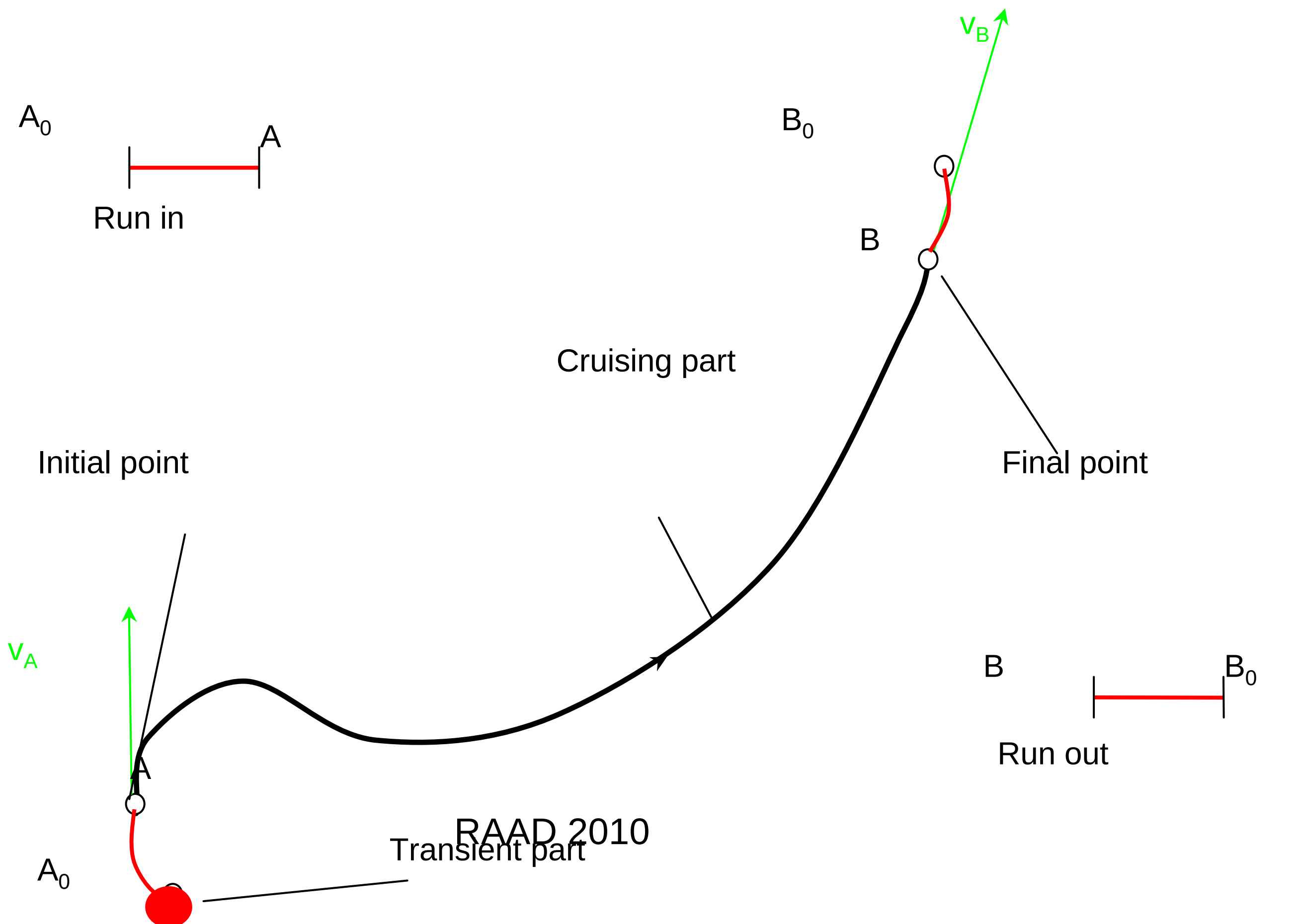
Indeed, who I am!!!!!

O.K.

- You are a good boy !!!!!
- You should behave well !!!!!

Time-Optimal Cruising Trajectory Planning

Motion on a path

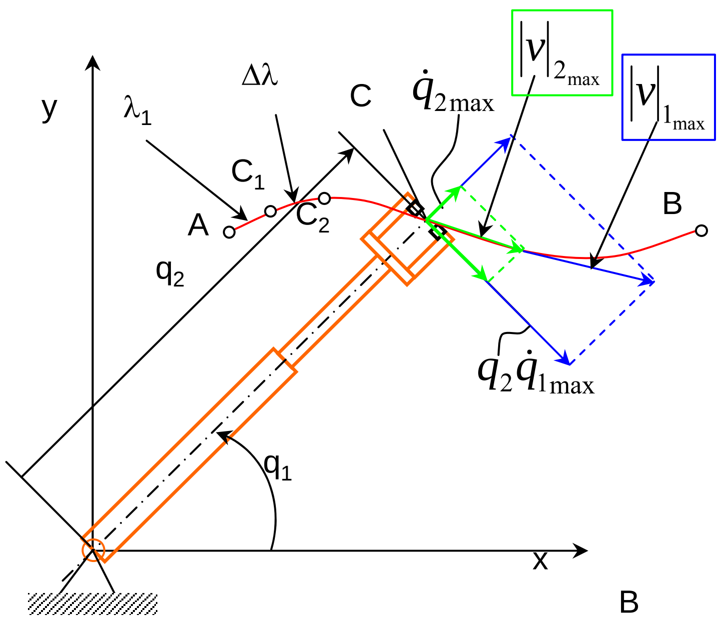


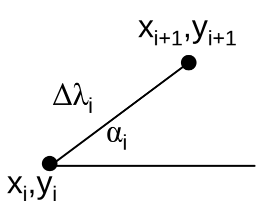
Time-Optimal Cruising Trajectory Planning

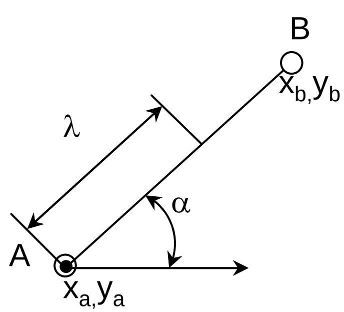
- Somló J. Lantos B. Cat P.T. (1997),”Advanced Robot Control”. Akadémiai Kiadó. Budapest. Pp. 425.
- Features:
- The use of Parametric Method (Shin, McKay 1983-86)
- Use of the limit velocities of the joints

Time-Optimal Cruising Trajectory Planning

Polar manipulator kinematics





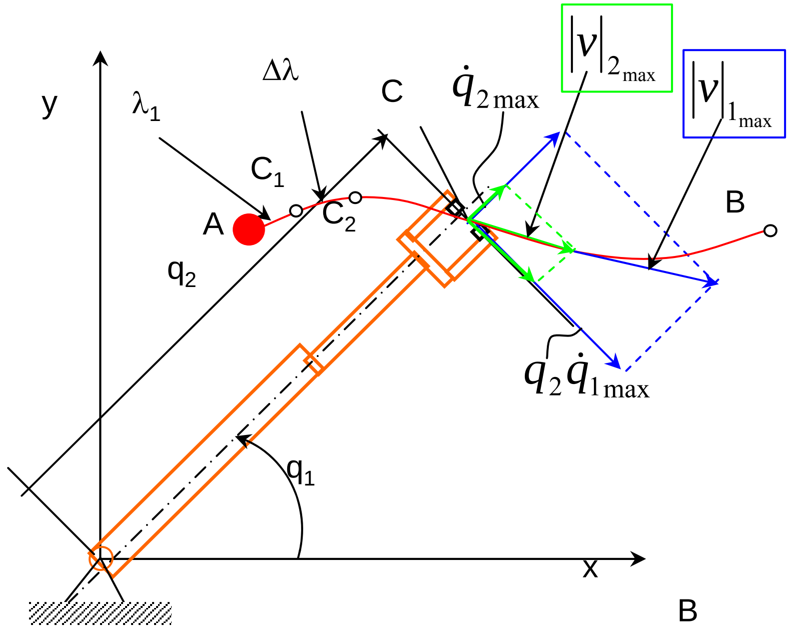


$$\Delta\lambda_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$

$$\alpha_i = \arctan g \frac{y_{i+1} - y_i}{x_{i+1} - x_i}$$

Time-Optimal Cruising Trajectory Planning

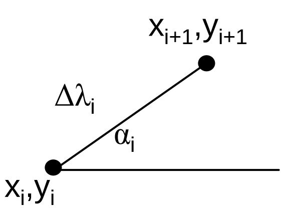
Direct and Inverse Geometry

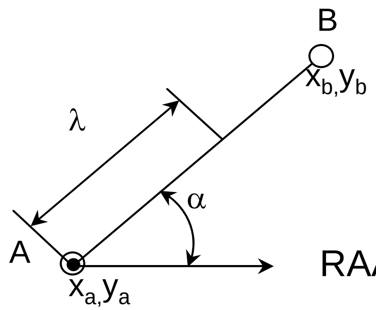


$$x = q_2 \cos q_1$$

$$y = q_2 \sin q_1$$

$$q_1 = arc\,\tan \frac{y}{x}$$

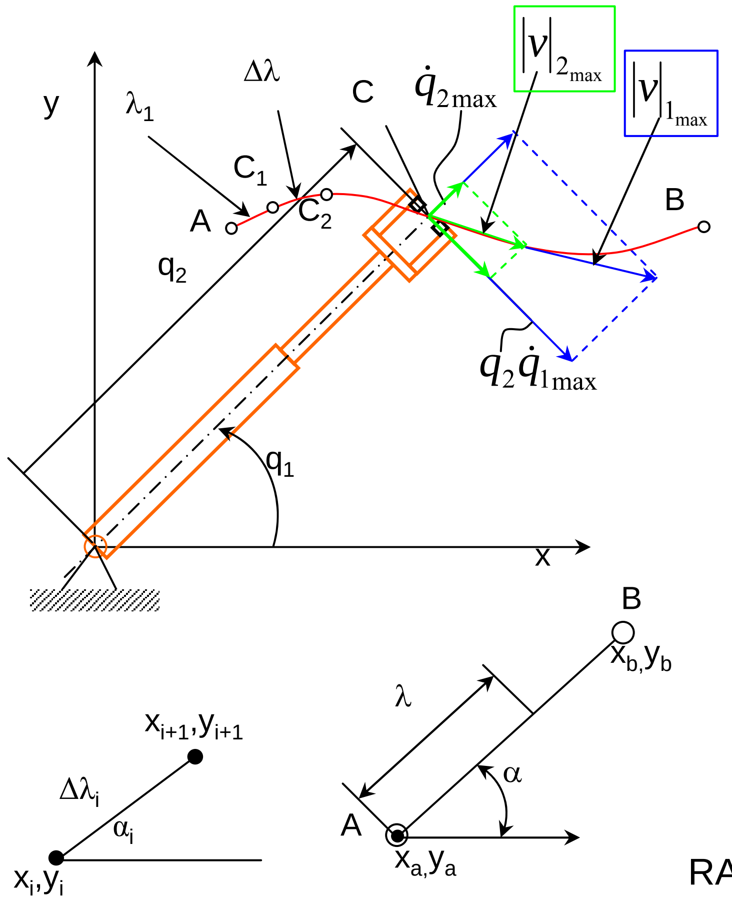




$$q_2 = \sqrt{x^2 + y^2}$$

Time-Optimal Cruising Trajectory Planning

Parametric Method and Projections of lvl



$$\dot{x} = |v| \cos \alpha_i$$

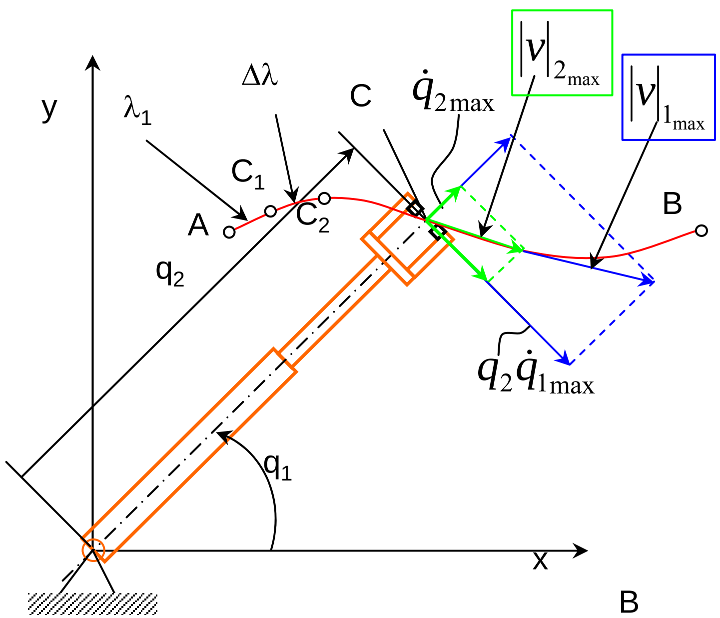
$$\dot{y} = |v| \sin \alpha_i$$

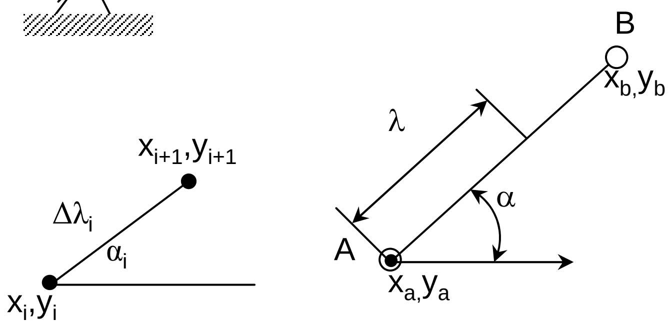
$$x = \lambda \cos \alpha_i$$

$$y = \lambda \sin \alpha_i$$

Time-Optimal Cruising Trajectory Planning

Polar manipulator kinematics





$$\dot{x} = -q_2[\sin(q_1)]\dot{q}_1 + [\cos(q_1)]\dot{q}_2$$

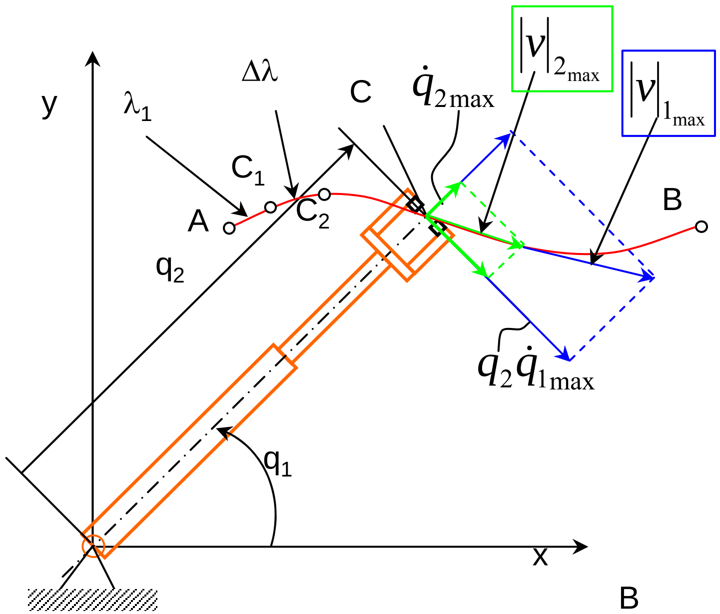
$$\dot{y} = q_2[\cos(q_1)]\dot{q}_1 + [\sin(q_1)]\dot{q}_2$$

$$\dot{q}_1 = \frac{x\dot{x} + y\dot{y}}{\sqrt{x^2 + y^2}}$$

$$\dot{q}_2 = \frac{x\dot{y} - y\dot{x}}{x^2 + y^2}$$

Time-Optimal Cruising Trajectory Planning

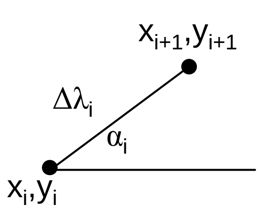
Time-optimal cruising trajectory planning (The dominant joint conception)

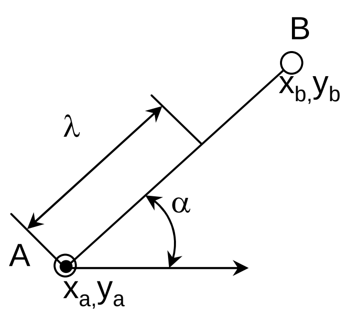


$$\dot{q}_{1\max} = S_1(\ldots)|v|_{1\max}$$

$$\dot{q}_{2\max} = S_2(\ldots)|v|_{2\max}$$

$$|v|_{opt} = Min\left(|v|_{1\max}, |v|_{2\max}\right)$$

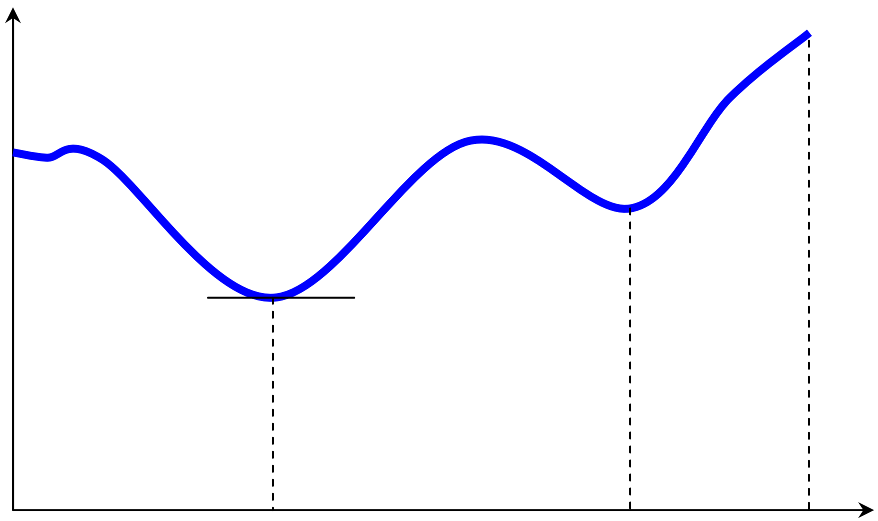




Time-Optimal Cruising Trajectory Planning

The velocity (lenght) diagram

$|v| = \dot{\lambda}$



Time-Optimal Cruising Trajectory Planning

- We get the joint coordinates required values as the function of parameter (path lenght)

$$q_i = f_i(\lambda)$$

$$i = 1,2$$

- We need them as time functions. So we apply

$$t = \int_0^L \dot{\lambda} dt$$

Time-Optimal Cruising Trajectory Planning

We get the inputs for the drives realizing the required motion

$$q_i = g_i(t)$$

$$i = 1,2$$

Example

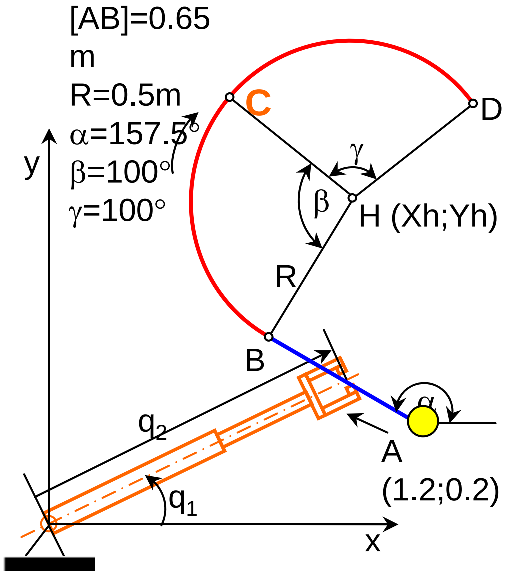
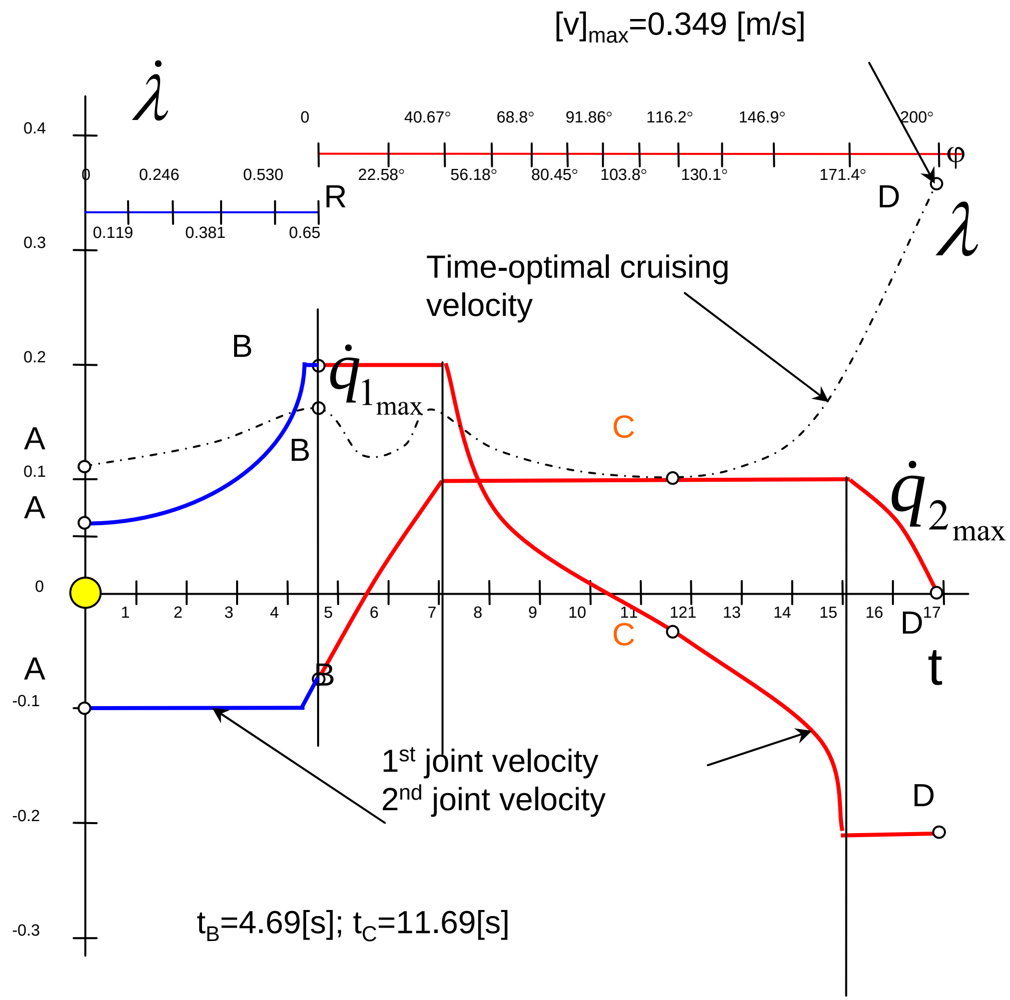


Figure A1
Polar manipulator and given path



Time-Optimal Cruising Trajectory Planning

General Method

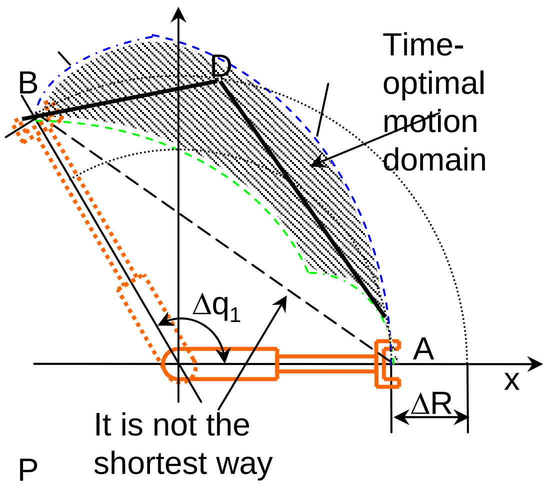
$$q_i = f_i(\lambda)$$

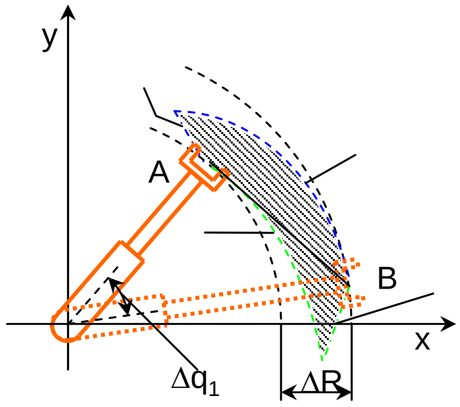
$$\frac{dq_i}{dt} = \frac{\partial f_i}{\partial \lambda}\frac{d\lambda}{dt}$$

$$\left(\frac{d\lambda}{dt}\right)_{i\max} = |v|_{i\max} = \frac{\dot{q}_{i\max}}{\frac{\partial f_i}{\partial \lambda}}$$

$$|v|_{opt} = Min\left\{|v|_{i\max}\right\}$$

Time-Optimal PTP Motions





Time-Optimal PTP Motions

Computing the minimum time (i=1,2)

$$t_{1\min} = \frac{\Delta q_1}{\dot{q}_{1\max}} \quad and \quad t_{2\min} = \frac{\Delta q_2}{\dot{q}_{2\max}}$$

$$t_{\min} = Max(t_{i\min})$$

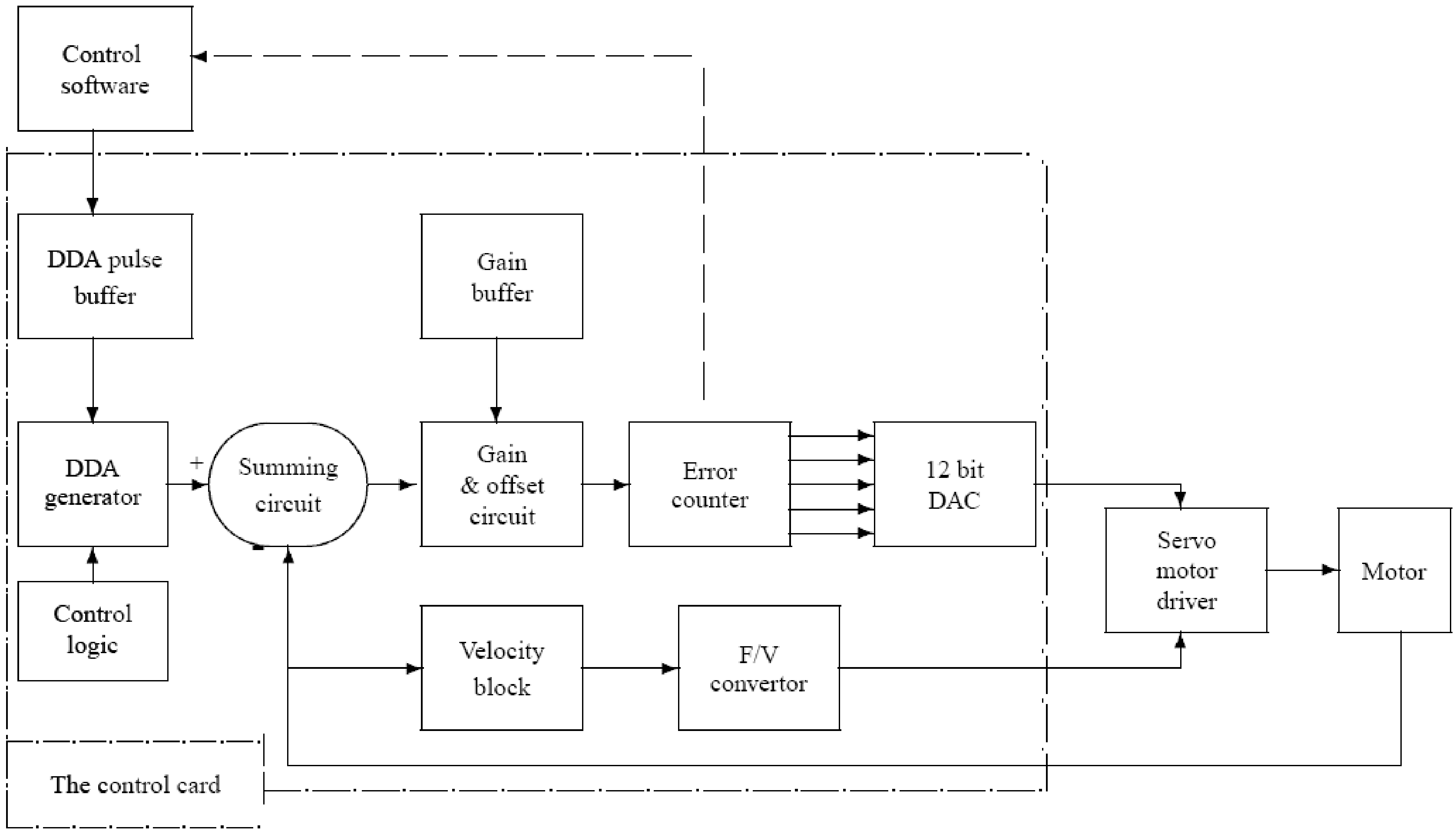
Time-Optimal PTP Motions

- Every realizable trajectory in the „optimal domain” results minimum time motion
- The method is easily applicable to higher D problems

Realization

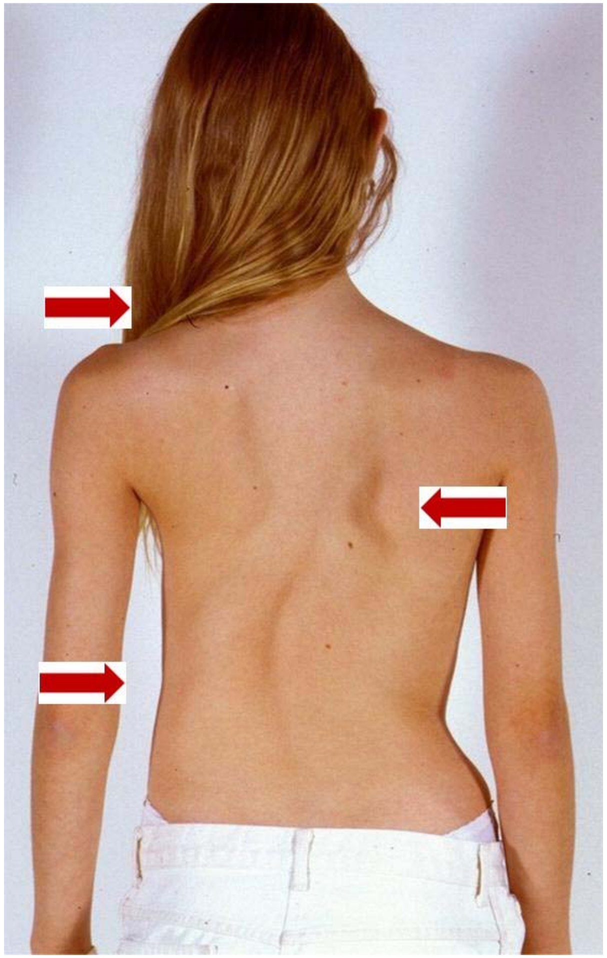
- It is possible to realize the optimal cruising trajectory planning results at many application task. The constraits of robot control constraint the effectiveness. But it still may be very high.

- The idea can be applied to full extent by using open system architecture robot control devices (see: **Sokolov A.G.,"Optimal Computer Control of Redundant Robots" PhD Dissertation. Budapest University of Technology. 2000.**
- **J. Somló, A. Sokolov, V. Lukanyin, „Automatic Trajectory Planning for Robots" ES2000 Portorozs Slovenija. 2000. September 17-19. pp. 129-134.**)

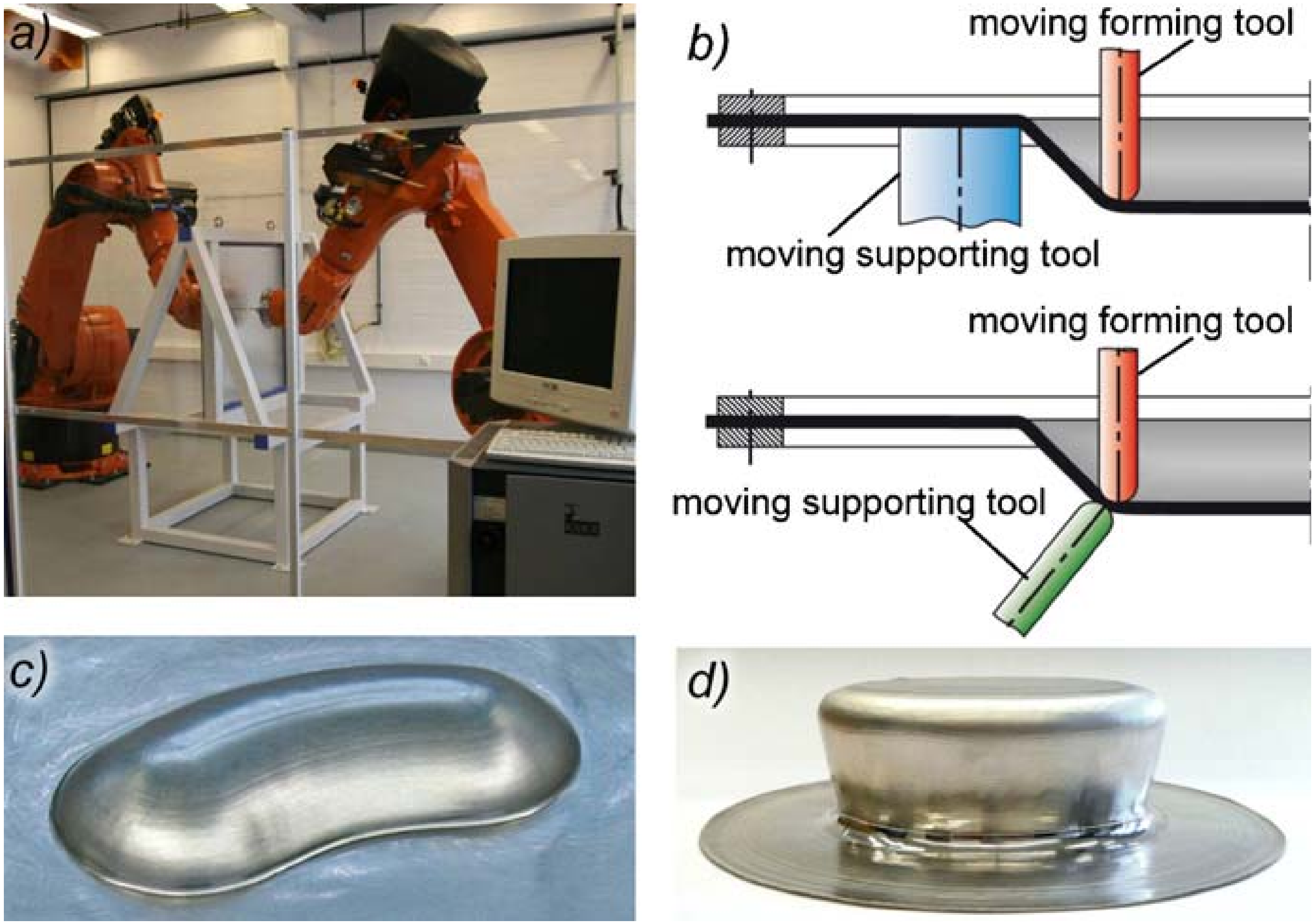


The structure of closed-loop position control.

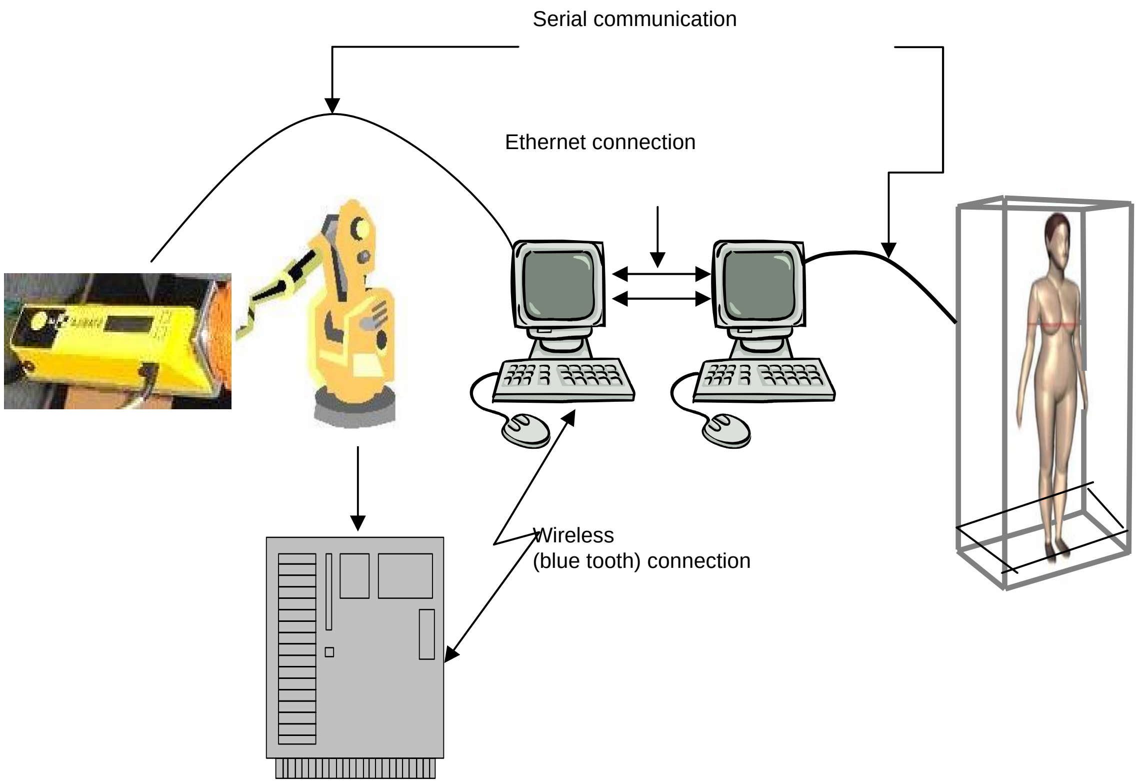
Application example; the Corsettes



DSF (Dieless Sheet Forming)



3D human scanning



KUKA KR6 Robot

Experimental system

- Fixture

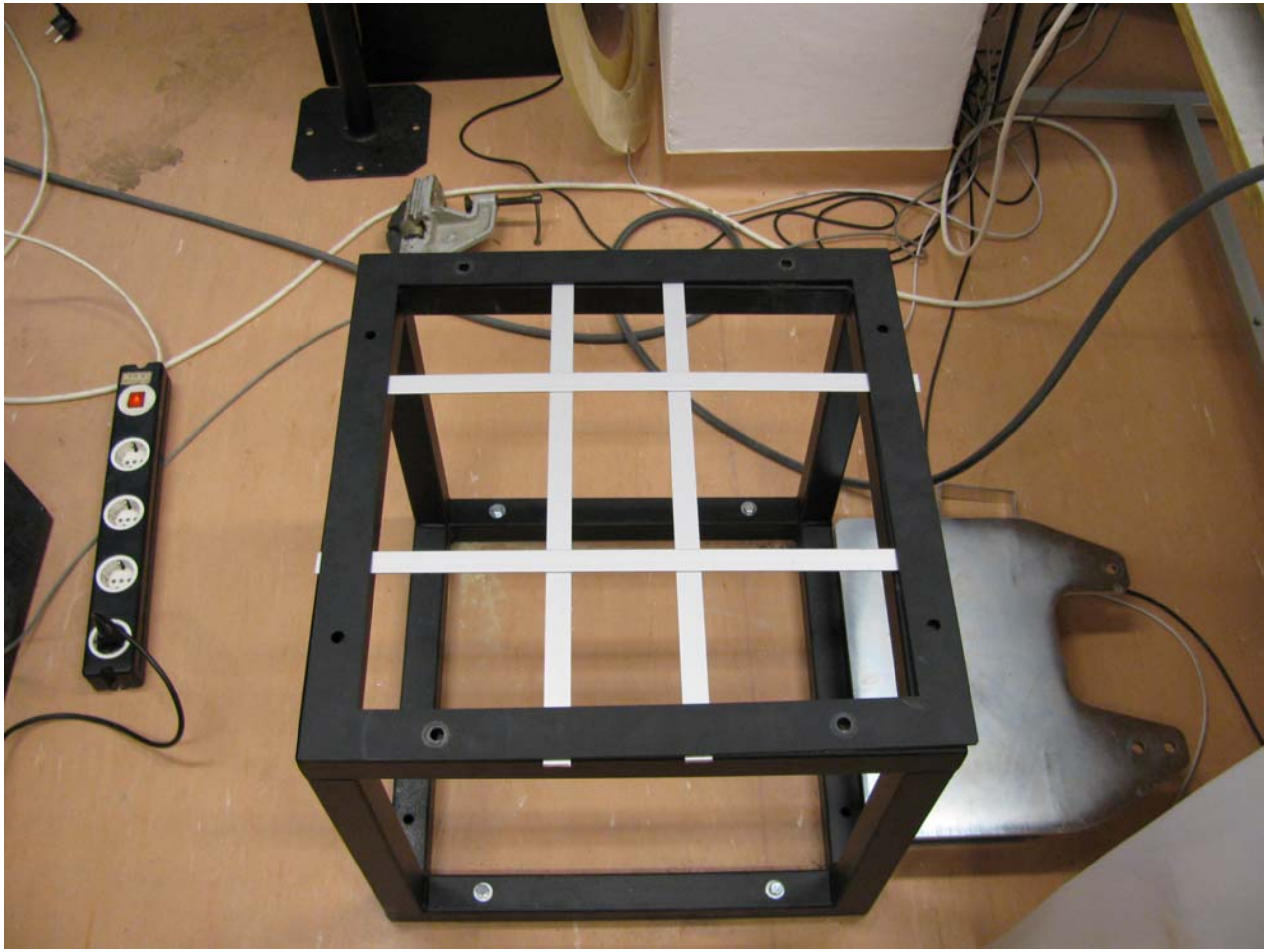
- Tool

- Process

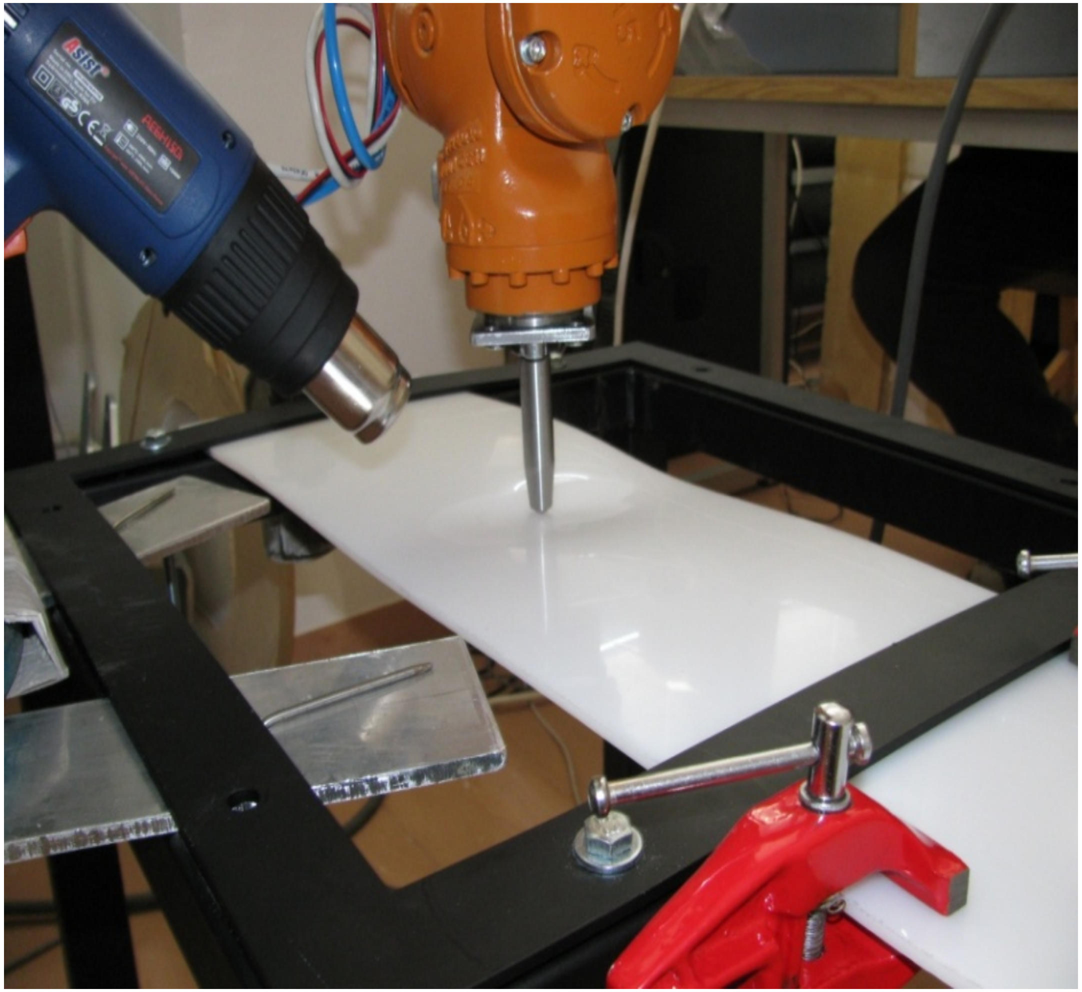
Tool

3 D head-motion pressing tool

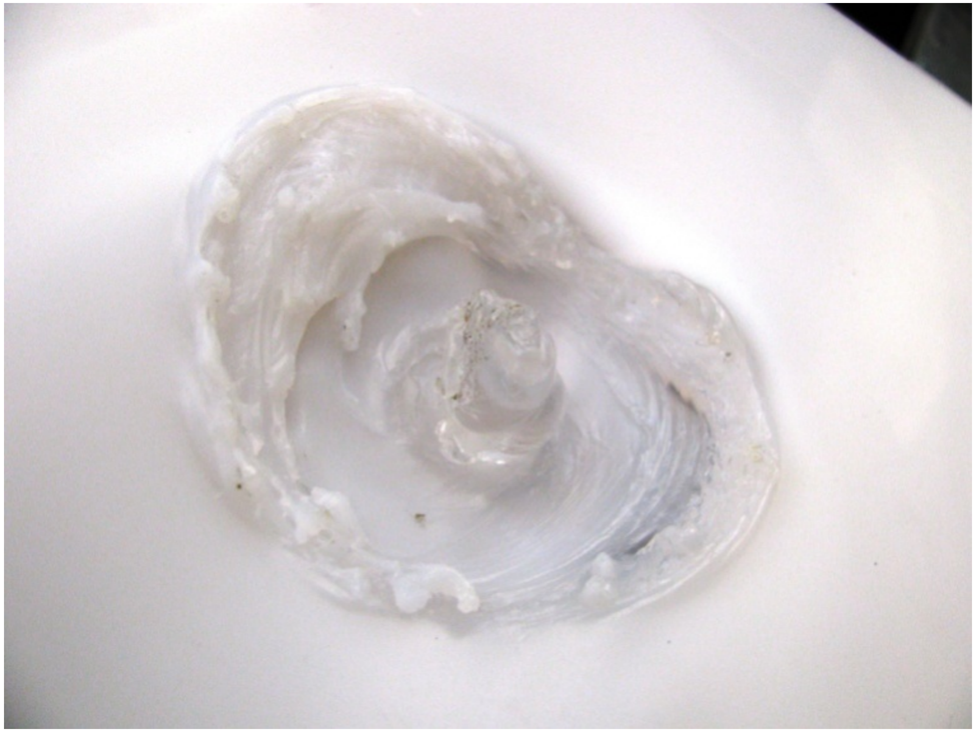
Fixture



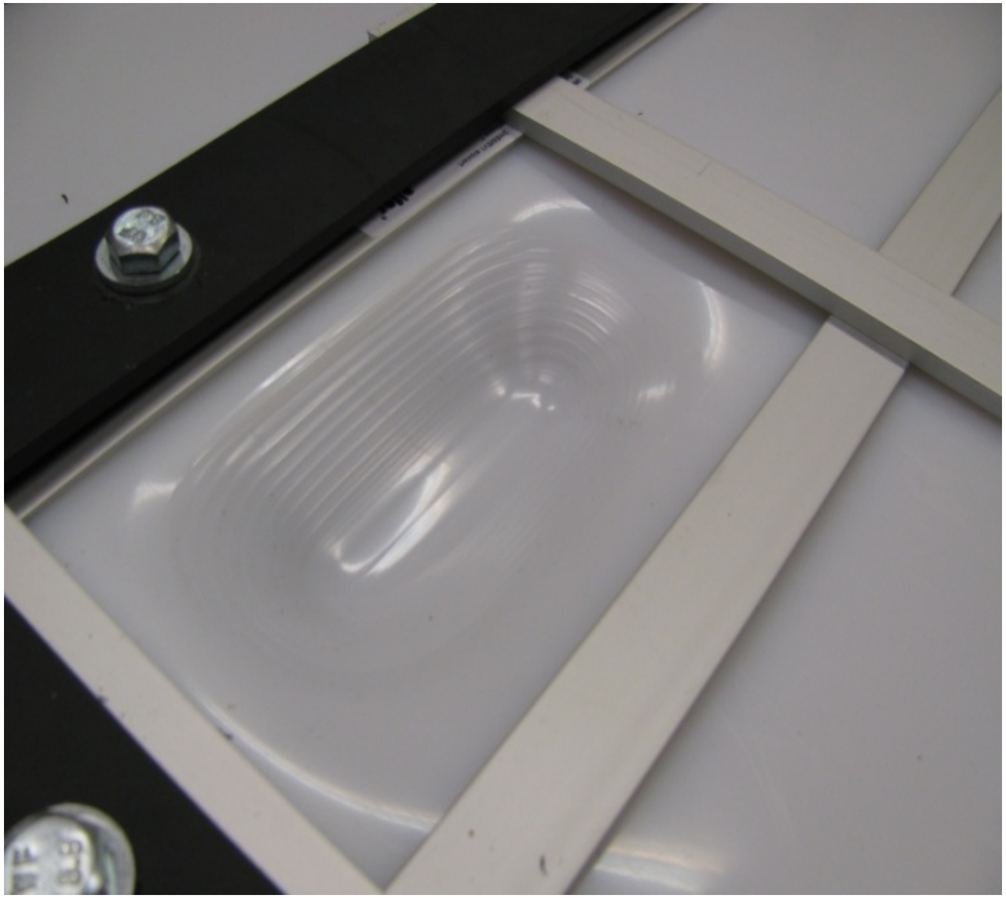
Process



Results of the experiments 1



Results of the experiments 2 (Trough making)



DSF

- The key problem to be solved is: to use small depths, very high speeds

Conclusions 1.

- Proposals in the paper give a general and simple to- realize method for time-optimal cruising trajectory planning for industrial robots. The proposed approach is based on the parametric method. All the parameters which are needed for the application (for example, joint velocities limit values) are easily available. The basic relations reflecting the essence of the approach are given by Equations (3.29) (3.32) of the paper.

Conclusions 2.

- Then determining the $\dot{\lambda}(\lambda)$ function and from that the $t = t(\lambda)$ relations, the joint drives inputs may readily be determined and consequently the time-optimal motion may be realized. A slightly different but in the spirit close method can be used for free paths.
- The time-optimal trajectory planning method provides plenty of information for application planning. Existing applications' time needs may be shortened, and new applications may be developed with outstanding characteristics.

Conclusions 3

- Topics for Future Research

1. New applications and details
2. Velocity-length diagrams tayloring
3. Comparison with time-optimal sequential motions
4. Etc.