Robotics

Introduction

Marc Toussaint
University of Stuttgart
Winter 2016/17

Lecturer: Peter Englert

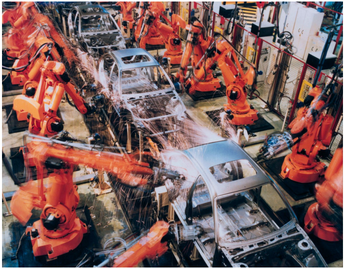
Organization

- Lecture: Tuesdays, 14:00-15:30 (V38.02), Peter Englert
- Tutorials: Wednesdays (No tutorials in the first week.)
  - 11:30-13:00 (0.457), Danny Driess
  - 14:00-15:30 (0.447), Matt Bernstein
  - 17:30-19:00 (0.108), Hung Ngo
- Course Webpage (Slides, Exercises, Software, Mailing list):

  `https://ipvs.informatik.uni-stuttgart.de/mlr/teaching/robotics`
- Admin things (especially exam registration), please ask:

  Carola Stahl, `Carola.Stahl@ipvs.uni-stuttgart.de`, Raum 2.217
- Rules for the tutorials:
  - Doing the exercises is crucial!
  - At the beginning of each tutorial:
    – sign into a list
    – mark which exercises you have (successfully) worked on
  - Students are randomly selected to present their solutions
  - You need 50% of completed exercises to be allowed to the exam
  - Please check 2 weeks before the end of the term, if you can take the exam

Why Robotics?



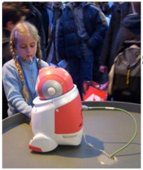

BostonDynamics

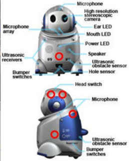
Why Robotics?

- Commercial:
  Industrial, health care, entertainment, agriculture, surgery, etc

Why Robotics?

- Commercial:
  Industrial, health care, entertainment, agriculture, surgery, etc
- Critical view:
  - International Committee for Robot Arms Control
    `http://icrac.net/`
  - Campaign to Stop Killer Robots
    `http://www.stopkillerrobots.org/`
  - Noel Sharkey's articles on robot ethics (Child care robots PePeRo...)





`http://www.nec.co.jp/products/robot/en/`

Robotics as intelligence research

AI in the real world

AI: Machine Learning, probabilistic reasoning, optimization
Real World: Interaction, manipulation, perception, navigation, etc

Why AI needs to go real world

- **Motion** was *the* driving force to develop intelligence
  - motion needs control & decision making $\leftrightarrow$ fast information processing
  - motion needs anticipation & planning
  - motion needs perception
  - motion needs spatial representations
- **Manipulation** requires to acknowledge the structure (geometry, physics, objects) of the real world. Classical AI does not

Robotics as intelligence research

- Machine Learning and AI are **computational** disciplines, which had great success with statistical modelling, analysis of data sets, symbolic reasoning. But they have not solved *autonomous learning, acting & reasoning in real worlds.*
- Neurosciences and psychology are **descriptive** sciences, either on the biological or cognitive level, e.g. with geat sucesses to describe and cure certain deceases. But they are not sufficient to create intelligent systems.
- Robotics is the only **synthetic** discipline to understand intelligent behavior in natural worlds. Robotics tells us what the actual problems are when trying to organize behavior in natural worlds.

History

- little movie...

(http://www.csail.mit.edu/videoarchive/history/aifilms

http://www.ai.sri.com/shakey/)

Four chapters

- **Kinematics & dynamics**

  goal: orchestrate joint movements for desired movement in task spaces

  Kinematic map, Jacobian, optimality principle of inverse kinematics, singularities, configuration/operational/null space, multiple simultaneous tasks, special task variables, trajectory interpolation, motion profiles; 1D point mass, damping & oscillation, PID, general dynamic systems, Newton-Euler, joint space control, reference trajectory following, optimal operational space control

Four chapters

- **Kinematics & dynamics**

  goal: orchestrate joint movements for desired movement in task spaces

  Kinematic map, Jacobian, optimality principle of inverse kinematics, singularities, configuration/operational/null space, multiple simultaneous tasks, special task variables, trajectory interpolation, motion profiles; 1D point mass, damping & oscillation, PID, general dynamic systems, Newton-Euler, joint space control, reference trajectory following, optimal operational space control

- **Planning & optimization**

  goal: planning around obstacles, optimizing trajectories

  Path finding vs. trajectory optimization, local vs. global, Dijkstra, Probabilistic Roadmaps, Rapidly Exploring Random Trees, differential constraints, metrics; trajectory optimization, general cost function, task variables, transition costs, gradient methods, 2nd order methods, Dynamic Programming

Four chapters

- **Kinematics & dynamics**

  goal: orchestrate joint movements for desired movement in task spaces

  Kinematic map, Jacobian, optimality principle of inverse kinematics, singularities, configuration/operational/null space, multiple simultaneous tasks, special task variables, trajectory interpolation, motion profiles; 1D point mass, damping & oscillation, PID, general dynamic systems, Newton-Euler, joint space control, reference trajectory following, optimal operational space control

- **Planning & optimization**

  goal: planning around obstacles, optimizing trajectories

  Path finding vs. trajectory optimization, local vs. global, Dijkstra, Probabilistic Roadmaps, Rapidly Exploring Random Trees, differential constraints, metrics; trajectory optimization, general cost function, task variables, transition costs, gradient methods, 2nd order methods, Dynamic Programming

- **Control theory**

  goal: designing optimal controllers

  Topics in control theory, optimal control, HJB equation, infinite horizon case, Linear-Quadratic optimal control, Riccati equations (differential, algebraic, discrete-time), controllability, stability, eigenvalue analysis, Lyapunov function

Four chapters

- **Kinematics & dynamics**

  goal: orchestrate joint movements for desired movement in task spaces

  Kinematic map, Jacobian, optimality principle of inverse kinematics, singularities, configuration/operational/null space, multiple simultaneous tasks, special task variables, trajectory interpolation, motion profiles; 1D point mass, damping & oscillation, PID, general dynamic systems, Newton-Euler, joint space control, reference trajectory following, optimal operational space control

- **Planning & optimization**

  goal: planning around obstacles, optimizing trajectories

  Path finding vs. trajectory optimization, local vs. global, Dijkstra, Probabilistic Roadmaps, Rapidly Exploring Random Trees, differential constraints, metrics; trajectory optimization, general cost function, task variables, transition costs, gradient methods, 2nd order methods, Dynamic Programming

- **Control theory**

  goal: designing optimal controllers

  Topics in control theory, optimal control, HJB equation, infinite horizon case, Linear-Quadratic optimal control, Riccati equations (differential, algebraic, discrete-time), controllability, stability, eigenvalue analysis, Lyapunov function

- **Mobile robots**

  goal: localize and map yourself

  State estimation, Bayes filter, odometry, particle filter, Kalman filter, Bayes smoothing, SLAM, joint Bayes filter, EKF SLAM, particle SLAM, graph-based SLAM

Prerequisites

- Is this a practical or theoretical course?

“There is nothing more practical than a good theory.”
(Vapnik, others...)

Prerequisites

- Is this a practical or theoretical course?

  "There is nothing more practical than a good theory."
  (Vapnik, others...)

- Essentially, the whole course is about

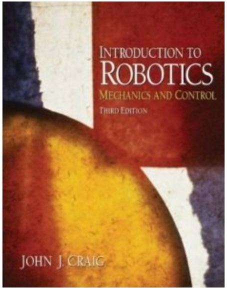
  reducing real-world problems to mathematical problems

  that can be solved efficiently

- Required:
  - Basics in linear algebra, probability theory and optimization.
  - Knowledge in C++ programming

Books

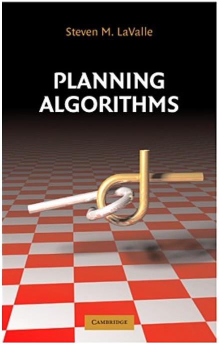
There is no reference book for this lecture. But a basic well-known standard text book is:



Craig, J.J.: *Introduction to robotics: mechanics and control*. Addison-Wesley New York, 1989. (3rd edition 2006)

Books

An advanced text book on planning is this:



Steven M. LaValle: *Planning Algorithms*. Cambridge University Press, 2006.

online: http://planning.cs.uiuc.edu/

Online resources

- VideoLecture by Oussama Khatib: `http://videolectures.net/oussama_khatib/` (focus on kinematics, dynamics, control)
- Oliver Brock's lecture `http://www.robotics.tu-berlin.de/menue/teaching/`
- Stefan Schaal's lecture Introduction to Robotics: `http://www-clmc.usc.edu/Teaching/TeachingIntroductionToRoboticsSyllabus` (focus on control, useful: Basic Linear Control Theory (analytic solution to simple dynamic model $\to$ PID), chapter on dynamics)
- Chris Atkeson's "Kinematics, Dynamic Systems, and Control" `http://www.cs.cmu.edu/~cga/kdc/` (uses Schaal's slides and LaValle's book, useful: slides on 3d kinematics `http://www.cs.cmu.edu/~cga/kdc-10/ewhitman1.pptx`)
- CMU lecture "introduction to robotics" `http://www.cs.cmu.edu/afs/cs.cmu.edu/academic/class/16311/www/current/` (useful: PID control, simple BUGs algorithms for motion planning, non-holonomic constraints)

- *Springer Handbook of Robotics, Bruno Siciliano, Oussama Khatib* `http://link.springer.com/book/10.1007/978-3-319-32552-1`
- LaValle's *Planning Algorithms* `http://planning.cs.uiuc.edu/`