Algorithmic Robotics and Motion Planning

Spring 2018

Introduction

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Dolce & Gabbana 2018 handbag collection
Today’s lesson

• basic terminology
• fundamental problems
• robotics vs. automation
• review of the major course topics
• course mechanics

As time permits:
• the Roomba in the café, combinatorics and algorithms
Robots, take I
An extremely brief history of robotics

The RUR robot which appeared in an adaption of Czech author Karel Capek's Rossum's Universal Robots. Circa 1930’s.

UNIMATE becomes the first industrial robot in use. It was used at the General Motors factory in New Jersey. 1961.

NASA’s Curiosity, 2011

Honda’s ASIMO, 2002
Robotics and robots

RAS field of interest (ICRA, Rome, April 2007):

Robotics focuses on sensor and actuator systems that operate autonomously or semi-autonomously (in cooperation with humans) in unpredictable environments. Robot systems emphasize intelligence and adaptability, may be networked, and are being developed for many applications such as service and personal assistants; surgery and rehabilitation; haptics; space, underwater, and remote exploration and teleoperation; education, entertainment; search and rescue; defense; agriculture; and intelligent vehicles.
Robotics and robots

Here it will be interesting if

- it is autonomous (at least in part), and
- it has non-trivial motion and/or manipulation capabilities

!?
Motion planning: the basic problem

Let B be a system (the robot) with k degrees of freedom moving in a known environment cluttered with obstacles. Given free start and goal placements for B decide whether there is a collision free motion for B from start to goal and if so plan such a motion.
Example I: The Roomba in the café
A disc moving among discs
Example II: Oskar’s cube

- MP with 3 translational dofs
- Hint: Scientific American, Sep 1988 issue
- Jay’s Oskar’s cubes

[oskarvandeventer.nl]
Terminology

• Workspace
• Configuration space
• Degrees of freedom (dofs)
Degrees of freedom

- a polygon robot translating in the plane
- a polygon robot translating and rotating
- a spatial robot translating and rotating
- industrial robot arms
- many robots
Configuration space
of a robot system with k degrees of freedom

▪ C-space, for short
▪ also known as state space
▪ the space of parametric representation of all possible robot configurations
▪ C-obstacles: the expanded obstacles
▪ the robot -> a point
▪ k-dimensional space
▪ point in configuration space: free, forbidden (, semi-free)
▪ path -> curve
C-obstacles

Q - a polygonal object that moves by translation
P - a set of polygonal obstacles
Minkowski sums
and translational C-obstacles

• a central tool in geometric computing applicable to motion planning
  and other domains
More complex systems

new designs, multi-robot systems, and other moving artifacts have many more dofs
Types of solutions

- exact
- probabilistic
- hybrid
- heuristic

major components in practical solutions: nearest-neighbor search, collision detection
Robots, take II
Beyond the basic MP problem

- moving obstacles
- multiple robots
- movable objects
- uncertainty
- nonholonomic constraints
- dynamic constraints
- ...
Multiple robots

[home.ustc.edu.cn/~xiangli]

[cbsnew]

[flow free]

[autonomy.cs.sfu.ca]

[lccRobotics.com]
Path quality

- length
- clearance
- combined measures
- minimum energy
- ...
- hard even in simple settings
Kinematics

- link
- joint
- base
- tcp
- kinematic chain
- direct kinematics
- inverse kinematics
Large kinematic structures

SWIMMING SNAKE ROBOT
Algorithmic robotics and automation

typically structured predictable environment

slightly less structured environment
Cluterred environments
Algorithmic robotics and automation

Packaging: collision detection in tight settings

Dual arm object rearrangement
Algorithmic robotics, sensorless manipulation

Example:

the parallel jaw gripper [Goldberg]

VIDEO
The course at a glance

The main themes

- **Part I: Exact methods**
  - Arrangements, Minkowski sums, visibility graphs, Voronoi diagrams, Collins decomposition

- **Part II: Sampling-based methods**
  - Roadmaps, single vs. multi-query structures, probabilistic completeness, asymptotic optimality, collision detection

- **Part III: Multi-robot motion planning**
  - Hardness, labeled vs. unlabeled, separation assumptions, exact algorithms, SB planners

We will devote about 3-4 lessons to each part
The course at a glance

Additional topics

• Robot kinematics

As time permits

• Large kinematic structures
• SLAM
• ROS
Course mechanics

• requirements (% of the final grade):
  • assignments (>60%)
  • final exam, open book, multiple choice, 2 hours (<40%)

• assignment types:
  • () theory
  • (p) programming, solo
  • (p2) programming, you can work and submit in pairs

• office hours: by appointment
Course team

• Instructor: Dan Halperin
• Teaching assistant: Kiril Solovey
• Grader: Ido Kessler
Course site

http://acg.cs.tau.ac.il/courses

Algorithmic Robotics and Motion Planning, Spring 2018

includes bibliography, lesson summary, assignments and more
Prerequisites

• Computational geometry
• knowledge of C++ or willingness to learn the language
Conferences and journals

• Conferences
  ICRA, RSS, WAFR, IROS, ...

• Journals
  IJRR (International journal of Robotics Research), IEEE TOR (Transactions on Robotics), IEEE TASE (Transactions on Automation Science and Engineering), ...
Before the end, a little more history

- Grey Walter's tortoises ~1948
- Turing’s visit to the Science Museum 1951
THE END