Motion and Manipulation

2019/2020
Frank van der Stappen
Frank van der Stappen
http://people.cs.uu.nl/frankst/

- office: Buys Ballotgebouw 422
  phone: 030 2535093
  email: A.F.vanderStappen@uu.nl

- MSc projects on grasping, manipulation, motion planning, simulation, animation
Contents

- Introduction
  - Robotics
  - Geometric Modeling
- Math
  - Linear Algebra
  - Functions and Derivatives
- Motion
  - Kinematics (rotations, orientations, quaternions, rigid transformations, screws, Plücker coordinates)
  - Configuration Spaces
  - Collision Detection
  - Path Synthesis
Contents

• Manipulation
  – Kinematics for Linkages
  – Inverse Kinematics
  – Grasping (form closure, force closure)
  – Non-prehensile Manipulation
• Control and Sensing
Basic Motion Planning

Given a *workspace* $W$, a *robot* $A$ of fixed and known shape moving freely in $W$, a collection of *obstacles* $B$ of fixed and known shape and location,
Basic Motion Planning

and an initial and a final placement for A,

find a path for A connecting these two placements along which it avoids collision with the obstacles from B [80s]

Solution takes place in high-dimensional configuration space C
Motion Planning with Constraints

- Non-holonomic systems: differential constraints [early 90s]
Motion in Complex Environments

- Applications for logistics: assembly, maintenance [late 90s]
Motion Planning with Many DOF

- Applications in virtual environments [early 00s]
Motion in Games

- Natural paths for characters and cameras
Motion in Games

- Simulation of individuals in crowds and small groups
  [Crowd Simulation course by Roland Geraerts]
Motion in Games

- Animation
  - Motion of virtual characters
  - Facial animation

[Computer Animation course by Zerrin Yumak]
Muscle-Based Locomotion for Bipeds

Musculoskeletal model for broad class of morphologies

Optimization of
- muscle routing and physiology
- muscle control

Objective function depends on
- target speed
- stability
- energy expenditure
Muscle-Based Locomotion for Bipeds

Flexible Muscle-Based Locomotion for Bipedal Creatures
Motions

- User in a virtual environment: Collision detection
- Autonomous entity: Motion planning
Manipulation: Arms

- Kinematic constraints
Linkages

- VR Hardware
Holding and Grasping
Robotics and Automation

- Robotics and Automation
  - involve physical world, geometry, algorithms,
  - are multi-disciplinary.

- Robotics emphasizes unpredictable environments like homes, undersea, outer space.

- Automation emphasizes predictable environments like factories, labs.
Assembly Lines: 100 Years ago
Assembly Lines: 50 Years Ago

Welding, spray painting
Conventional Manipulation

Anthropomorphic robot arms (accompanied by advanced sensory systems) performing pick-and-place operations.
Conventional Manipulation

Anthropomorphic robot arms + advanced sensory systems =

- expensive
- not always reliable
- complex control
RI SC

‘Simplicity in the factory’ [Whitney 86] instead of ‘ungodly complex robot hands’ [Tanzer & Simon 90]

Reduced Intricacy in Sensing and Control [Canny & Goldberg 94] =
- simple ‘planable’ physical actions, by
- simple, reliable hardware components
- simple or even no sensors
Grand Challenge

1770: Interchangeable Parts

1910: Assembly Lines

20xx: Computer-Supported Design of Assembly Lines for Interchangeable Parts
Manipulation Tasks

- Fixturing, grasping
- Feeding

push, squeeze, topple, pull, tap, roll, vibrate, wobble, drop, …
Grasping and Fixturing
Fundamental Problems in Immobilization

- **Analysis**: Does a given placement of fingers immobilize a part?

- **Existence**: How many fingers are necessary or sufficient to immobilize a part?

- **Synthesis**: Determine one/some/all placement(s) of the fingers such that a part is immobilized.
Immobilization

- Form Closure: Analysis of Instantaneous Velocities [1870s]
- Force Closure: Analysis of Forces and Moments [1970s]
  - 4 fingers sufficient for most 2D parts
  - 7 fingers sufficient for most 3D parts
- 2nd Order Immobility: Mobility Analysis in Configuration Space [1990s]
  - 3 fingers sufficient for most 2D parts
  - 4 fingers sufficient for most 3D parts
Caging

- Three-finger grasp

  • Immobilizing grasp
  • No immobilization, but caging
Caging

- Rigid motion of the fingers forces part to move along
Part Feeding

• Feeders based on various actions: push, squeeze, topple, pull, tap, roll, vibrate, wobble, drop, …
Fundamental Problems

Given: class of parts, manufacturing task, type of physical actions.

• **Analysis**: What is the result of a (combination of) action(s) performed on a part?

• **Existence**: Does a combination of actions that accomplishes the task on the parts always exist?

• **Synthesis**: Determine one/some/all combination(s) of action(s) that accomplish(es) the task on the parts.
Parallel-Jaw Grippers

- Every 2D part can be oriented by a sequence of push or squeeze actions.

- Shortest sequence is efficiently computable [Goldberg 93].
Feeding with ‘Fences’

- Every 2D part can be oriented by fences over conveyor belt.

- Shortest fence design efficiently computable
  [Berretty, Goldberg, Overmars, vdS].
Sorting on Belts with Fences

Sorting scenario: forking belt sorts parts of types P and Q onto different belts [de Berg, Goaoc, vdS].

Planning Algorithm: computes fence design that separates P and Q with n vertices each in $O(n^4 \log^2 n)$ time.
Feeding by Toppling

- Shortest sequence of pins and their heights efficiently computable [Zhang, Goldberg, Smith, Berretty, Overmars].
Vibratory Bowl Feeders
Vibratory Bowl Feeders

- Shapes of filtering traps efficiently computable [Berretty, Goldberg, Overmars, vdS].
Simulation Sample
Course Material


Classes

• Wednesdays 15:15-17:00 in Buys Ballotgebouw 223

• Fridays 13:15-15:00 in Buys Ballotgebouw 214

• No class on Wednesday October 9!
Exam Form

• Written exam on the theory of motion and manipulation; weight 60%.
  – first chance: November 8, 17:00-19:30
  – second chance: January 8, 17:00-19:30

• Practical research exercise and report (2500 words); weight 20%.
  Deadline: Friday October 25, 13:15.

• Homework exercises; weight 10% each.
  Deadlines: Wednesday September 18, 15:15 and
  Wednesday October 23, 15:15
Exam Requirements

• Additional requirements:
  – Need to score at least 5.0 for the written exam to pass.
  – Need to score at least 5.0 for the practical exercise to pass.
  – Need to score at least 4.0 overall to be admitted to second chance.