Advanced Mobile Robotics

Introduction/Review

John (Jizhong) Xiao
Department of Electrical Engineering
City College of New York
jxiao@ccny.cuny.edu

Outline

• Syllabus
  – Course Description
  – Prerequisite, Expected Outcomes
  – Primary Topics
  – Textbook and references
  – Grading, Office hours and contact
• How to …
  – How to read a research paper
  – How to write a reading report
• G5501 Review
  – What is a Robot?
  – Why use Robots?
  – Mobile Robotics

Syllabus

Course Description
• This course is an in depth study of state-of-the-art technologies and methods of mobile robotics.
• The course consists of two components: lectures on theory, and course projects.
• Lectures will draw from textbooks and current research literature with several reading discussion classes.
• In project component of this class, students will do simulation or implement algorithms on mobile robot platforms at the CCNY Robotics Lab.

Prerequisite:
– G5501 (Introduction to Robotics)
– Good C++ Programming Skill
or
– Get Instructor’s permission

Expected outcomes:
– Knowledge

– Abilities
  • Be able to read technical papers
  • Be able to write technical papers

Primary Topics
• Control algorithms
  – How to reduce odometry errors,
  – Advanced control methods
• Software architectures
  – reactive, hybrid & behavior-based system
• Localization and mapping
  – SLAM (simultaneous localization and mapping)
• Motion planning and Navigation
• Adaptation and learning
• Multi-robot systems.
Syllabus

Textbooks:

Reference Material:
- Papers from research literature
- Player/Stage Simulation Software
- Saphira/Aria User’s Manual
- Activmedia Pioneer Robot User’s Guide

Grading Policy:
- Homework: 30%
- Midterm: 30%
- Final Project: 40%

Office hours: Mon. 3:30pm-4:30pm
Thu. 1:00pm-2:00pm
or by appointment

Office: Steinman Hall, T-534
Phone: 212-650-7268
E-mail: jxiao@ccny.cuny.edu
Website: http://robotics.ccny.cuny.edu

How to …
- How to read a research paper
  - Conference papers (ICRA, IROS)
  - Journal papers
    - IEEE Transactions on Robotics
    - International Journal of Robotics Research

CCNY recourse:
http://www.ccny.cuny.edu/library/Menu.html
IEEE Xplorer
- How to write a reading report

G5501 Review

What are Robots?
- Machines with sensing, intelligence and mobility (NSF)

To qualify as a robot, a machine must be able to:
1) Sensing and perception: get information from its surroundings
2) Carry out different tasks: Locomotion or manipulation, do something physical—such as move or manipulate objects
3) Re-programmable: can do different things
4) Function autonomously and/or interact with human beings

Why use Robots?
- Perform 4A tasks in 4D environments
  4A: Automation, Augmentation, Assistance, Autonomous
  4D: Dangerous, Dirty, Dull, Difficult

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G5501 Review

- Robot Manipulator
  - Kinematics
  - Dynamics
  - Control

- Mobile Robot
  - Kinematics/Control
  - Sensing and Sensors
  - Motion planning
  - Mapping/Localization

Mobile Robot Examples

- ActivMedia Pioneer II
- Sojourner Rover

Mobile Robot Locomotion

Locomotion: the process of causing a robot to move

- Differential Drive
- Tricycle
- Synchronous Drive
- Ackerman Steering
- Omni-directional

Differential Drive

Property: At each time instant, the left and right wheels must follow a trajectory that moves around the ICR at the same angular rate \( \omega \), i.e.,

\[
\omega R = \frac{1}{2} \left( V_r - V_l \right)
\]

- Kinematic equation
- Nonholonomic Constraint

Differential Drive

- Basic Motion Control

\[
\frac{V_r - V_l}{L} = \frac{V_l}{R + \frac{L}{2}}
\]

- Straight motion
  - \( R \to \infty \) \( \Rightarrow \) \( V_r = V_l \)
- Rotational motion
  - \( R \to 0 \) \( \Rightarrow \) \( V_r = -V_l \)

Differential Drive

- Velocity Profile

\[
\rho = \frac{L}{2} \left( \frac{V_r + V_l}{V_r - V_l} \right) \frac{\phi}{\theta}
\]

\( R \): Radius of rotation
\( D \): Length of path
\( \phi \): Angle of rotation
**Tricycle**

- Steering and power are provided through the front wheel
- Control variables:
  - Angular velocity of steering wheel \( \omega_s(t) \)
  - Steering direction \( \alpha(t) \)

\[
R(t) = d \tan \alpha(t)
\]

\[
v(t) = \frac{R(t)}{d} \sin(\alpha(t))
\]

\[
w(t) = \frac{R(t)}{d} \cos(\alpha(t))
\]

\( d \): distance from the front wheel to the rear axle

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**Kinematics model in the world frame**

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**Posture kinematics model**

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**Synchronous Drive**

- All the wheels turn in unison
  - All wheels point in the same direction and turn at the same rate
  - Two independent motors, one rolls all wheels forward, one rotate them for turning
- Control variables (independent)
  - \( v(t) \), \( \omega(t) \)

**Ackerman Steering (Car Drive)**

- The Ackerman Steering equation:

\[
\cot \theta - \cot \theta_o = \frac{d}{l}
\]

\[
\cot \theta = \frac{\cos \phi}{\sin \phi}
\]

\[
cot \theta - \cot \theta_o = \frac{d}{l}
\]

\[
\cot \theta - \cot \theta_o = \frac{R + d/2}{l} - \frac{R - d/2}{l}
\]

\[
\frac{d}{l}
\]

**Car-like Robot**

Driving type: Rear wheel drive, front wheel steering

\[
\dot{\theta} = \frac{R}{u_f} \quad \dot{\theta} = \frac{l}{u_f}
\]

Rear wheel drive car model:

\[
x = u_f \cos \theta
\]

\[
y = u_f \sin \theta
\]

\[
\dot{\theta} = \frac{u_f}{l} \tan \phi
\]

\[
\dot{\phi} = u_i
\]

Non-holonomic constraint:

\[
x \sin \theta - y \cos \theta = 0
\]

- \( u_f \): Forward velocity of the rear wheels
- \( u_i \): Angular velocity of the steering wheels
- \( l \): Length between the front and rear wheels

---

**Robot Sensing**

- Collect information about the world
- Sensor - an electrical/mechanical/chemical device that maps an environmental attribute to a quantitative measurement
- Each sensor is based on a transduction principle - conversion of energy from one form to another
- Extend ranges and modalities of Human Sensing
Sensors Used in Robot

- Resistive sensors:
  - bend sensors, potentiometer, resistive photocells, ...
- Tactile sensors: contact switch, bumpers...
- Infrared sensors
  - Reflective, proximity, distance sensors…
- Ultrasonic Distance Sensor
- Motor Encoder
- Inertial Sensors (measure the second derivatives of position)
  - Accelerometer, Gyroscopes,
- Orientation Sensors: Compass, Inclinometer
- Laser range sensors
- Vision, GPS, …

Mobot System Overview

Abstraction level

- Motion Planning: Given a known world and a cooperative mechanism, how do I get there from here?
- Localization: Given sensors and a map, where am I?
- Vision: If my sensors are eyes, what do I do?
- Mapping: Given sensors, how do I create a useful map?
- Bug Algorithms: Given an unknowable world but a known goal and local sensing, how can I get there from here?
- Kinematics: If I move this motor somehow, what happens in other coordinate systems?
- Control (PID): what voltage should I set over time?

low-level

- Motor Modeling: what voltage should I set now?

Motion Planning

Motion Planning: Find a path connecting an initial configuration to goal configuration without collision with obstacles

Assuming the environment is known!

- Configuration Space
- Motion Planning Methods
  - Roadmap Approaches
  - Cell Decomposition
  - Potential Fields
  - Bug Algorithms

Motion Planning Methodologies

- Roadmap
  - From Cfree a graph is defined (Roadmap)
  - Ways to obtain the Roadmap
    - Visibility graph
    - Voronoi diagram
- Cell Decomposition
  - The robot free space (Cfree) is decomposed into simple regions (cells)
  - The path in between two poses of a cell can be easily generated
- Potential Field
  - The robot is treated as a particle acting under the influence of a potential field U, where:
    - the attraction to the goal is modeled by an additive field
    - obstacles are avoided by acting with a repulsive force that yields a negative field

Full-knowledge motion planning

Roadmaps

Visibility graph

Cell decompositions

exact free space represented via convex polygons

approximate free space represented via a quadtree
**Potential field Method**

- Usually assumes some knowledge at the global level

The goal is known; the obstacles sensed

Each contributes forces, and the robot follows the resulting gradient.

**Mapping/Localization**

- Answering robotics’ big questions
  - How to get a map of an environment with imperfect sensors (Mapping)
  - How a robot can tell where it is on a map (localization)
  - SLAM (Simultaneous Localization and Mapping)
    - It is an on-going research
    - It is the most difficult task for robot
      - Even human will get lost in a building!

**Using sonar to create maps**

What should we conclude if this sonar reads 10 feet?

- There isn’t something here
- There is something somewhere around here

Local Map

- Unoccupied
- Occupied
- No information

**What is it a map of?**

Several answers to this question have been tried:

1. It’s a map of occupied cells.
   \[
   P(o(x,y) | S_1, S_2, \ldots, S_i) \]

2. It’s a map of probabilities:
   \[
   p(\neg o | S_1, S_2, \ldots, S_i) \]
   \[
   p(o | S_1, S_2, \ldots, S_i) \]

3. It’s a map of odds:
   \[
   \text{odds}(o | S_1, S_2, \ldots, S_i) = \frac{P(o | S_1, S_2, \ldots, S_i)}{P(\neg o | S_1, S_2, \ldots, S_i)}
   \]

**An example map**

Evidence grid of a tree-lined outdoor path

- Lighter areas: lower odds of obstacles being present
- Darker areas: higher odds of obstacles being present
Combining probabilities

How to combine two sets of probabilities into a single map?

Combining evidence

\[
\text{odds}(o | S_2 \land S_1) = \frac{p(o | S_2 \land S_1)}{p(o)} = \frac{p(S_2 \land S_1 | o)}{p(S_2 \land S_1)} = \frac{p(S_2 | o) p(S_1 | o) p(o)}{p(S_2 | o) p(S_1 | o) p(o)}
\]

Bayes' rule (+)

Def'n of odds

Bayes' rule (+)

Previous odds

precomputed values

the sensor model

Update step = multiplying the previous odds by a precomputed weight.

Mapping Using Evidence Grids

Evidence Grids...

represent space as a collection of cells, each with the odds (or probability) that it contains an obstacle.

evidence = log(odds)

Lighter areas: lower evidence of obstacles being present

Darker areas: higher evidence of obstacles being present

Lab environment

likely free space

likely obstacle

not sure

Evidence Grids...

Mapping Using Evidence Grids

Evidence Grids...

Evidence Grids...

Evidence Grids...

Localization Methods

- Markov Localization:
  - Represent the robot's belief by a probability distribution over possible positions and uses Bayes' rule and convolution to update the belief whenever the robot senses or moves

- Monte-Carlo methods

- Kalman Filtering

- SLAM (simultaneous localization and mapping)

- ...

Class Schedule

Homework 1 posted on the web.

Due date: Feb. 15, 2007

SONY Qrio
Thank you!

Example

- For a differential drive robot as shown in fig, the diameters of the Left and Right wheels are 10cm, the robot width is 30cm (L=30cm). After the Left wheel has made 8 full rotations and Right wheel has made 6 full rotations in one second, where is the robot? That is, what are the coordinates of robot center O, if O initially coincide with the origin of world coordinate frame X-O-Y?

\[
\begin{align*}
V_L &= r_{0L} \omega_L = 0.05 \times 8 \times 2 \pi = 0.8 \pi \\
V_R &= r_{0R} \omega_R = 0.05 \times 6 \times 2 \pi = 0.6 \pi \\
V &= \frac{V_L + V_R}{2} = 0.7 \pi \\
\omega &= \frac{V_L}{L} = \frac{2}{3} \pi \\
\pi &\omega = \frac{2 \pi}{3} \\
\end{align*}
\]

Robot make right turn

\[
\begin{align*}
\dot{x} &= V \cos \theta \Rightarrow x = \int V \cos \theta(t) \, dt = \int V \cos(\omega t + \frac{\pi}{2}) \, dt = \frac{2}{\omega} \sin(\omega t + \frac{\pi}{2}) \\
\dot{y} &= V \sin \theta \Rightarrow y = \int V \sin \theta(t) \, dt = \int V \sin(\omega t + \frac{\pi}{2}) \, dt = -\frac{2}{\omega} \cos(\omega t + \frac{\pi}{2}) \\
\dot{\theta} &= \omega \Rightarrow \theta = \int \omega(t) \, dt = \omega t + \frac{\pi}{2} \quad \text{ICR right side}
\end{align*}
\]