Intelligent Robotic Systems
CS 685
Jana Kosecka, 4444 Research II
kosecka@gmu.edu, 3-1876

Logistics
• Grading: Homeworks 30% Midterm: 30% Final project: 40%
• Prerequisites: basic statistical concepts, geometry, linear algebra, calculus, CS 580
• Course web page cs.gmu.edu/~kosecka/cs685/
  • Homeworks about every 2 weeks, Midterm, Final Project
  • Start thinking about the project early
  • Implement one of the covered methods on robot/robot simulator, come up with new ideas of robotics tasks
  • Write a report and prepare the final presentation

Recommended Text

Course Logistics
• Required Software MATLAB (with Image Processing toolbox)
• Robot simulators, real robots
  • Availability of robotics platforms
  • Pioneers with range sensors, cameras
  • Humanoid – Small soccer league
  • Flockbots - small platforms
Applications - Robots in manufacturing/material handling

- Manhattan project (1942) – handling and processing of radioactive materials - Telemanipulation
- Manufacturing - storage, transport delivery
- - table top tasks, material sorting, part feeding - conveyor belt
- - microelectronics, packaging
- - harbor transportation
- - construction (automatic cranes)

Suitable for hard repetitive tasks – heavy handling or fine positioning
Successful in restricted environments, limited sensing is sufficient – limited autonomy

Autonomous Robotic Systems
- AGV's - automated guided vehicles
- AUV's - automated unmanned vehicles

Applications - Space Robotics

- 50-ties US space program, exploration of planets, collecting samples
  - Astronauts bulky space suits – difficult
  - NASA, JPL, DARPA - sponsoring agencies
  - Space programs, military application - surveillance, assistance

- Planetary Rovers - initially controlled by humans
  - - large time delays,
  - - poor communication connections

- Need for (semi) - autonomy

Teleoperation - Mars Rover

- Human operator controls the robot
  - Local site - human views the sensory data, sends the commands
  - Remote site - sensors acquire the information

Example 1: Building Virtual Models of Mars

Example of stereo pipeline, from raw data, preprocessing, meshes, texture maps
See http://schwehr.org/photoRealVR/example.html
Applications: Navigation in difficult terrain/harsh conditions

- Antarctica - search for samples of meteorites
- Volcanos - analyze gas samples from volcanos

Applications: Underwater robotics

- Sensor network
- Remotely Operated robot for ocean exploration

Robots in the service of humans

- Robotic surgery - DaVinci robotic surgery robot - human assisted
- Robotics in rehabilitation surgery (Hocome Inc)

- Mobile Robots
  - courier in buildings and hospitals, vacuum cleaners

Variety of domains and tasks
Games and Entertainment

- Furbies
- Aibos Latter & Macaron
- Aibo soccer league - RoboCup

Toy Robot Aibo from Sony

- Size
  - length about 25
- Sensors
  - color camera
  - stereo microphone

Rhino - First Museum Tour giving robot
University of Bonn (96)

Humanoid Robots

by HONDA

MIT Cog Project
APPLICATIONS – Unmanned Aerial Vehicles (UAVs)

Berkeley Aerial Robot (BEAR) Project

Rate: 10Hz
Accuracy: 5cm, 4°

Robotic Navigation

• Stanford Stanley Grand Challenge
• Outdoors unstructured env., single vehicle
• Urban Challenge
• Outdoors structured env., mixed traffic, traffic rules

Intelligent Robotic System

• Mechanical System with some degree of autonomy
• Three Basic Components of the Intelligent Robotic System
• SENSE - process information from the sensors
• PLAN - compute the right commands/directives
• ACT - produces actuator commands

Different organization of these functionalities gives rise to different robot architectures

Robotics and AI

Knowledge representation
- how to represent objects, humans, environments
- symbol grounding problem

Computer Vision
- study of perception
- recognition, vision and motion, segmentation and grouping representation

Natural Language Processing
- provides better interfaces, symbol grounding problem

Planning and Decision Making
How to make optimal decision, actions give the current knowledge of the state, currently available actions
Robot Components (Stanley)

- Sensors
- Actuators-Effectors
- Locomotion System
- Computer system - Architectures - (the brain)

- Lasers, camera, radar, GPS, compass, antenna, IMU,
- Steer by wire system
- Rack of PC's with Ethernet for processing information from sensors

Stanley Software System

- Terrain mapping using lasers
- Determining obstacle course

Robot Components

Sensors:
- State is determined by measuring some physical quantity - voltage, current, distance
- Environment is often dynamic and unknown, robot has only uncertain knowledge of the environment due to the limited and noisy sensing capabilities
- External state - state of environment, temperature, presence of obstacles, people
- Internal state - state of the robot, position, orientation, force, battery charge, happy, sad
**Actuators**

- Robot can change its state and the state of the world by means of actuators
- Actuators for locomotion
- Actuators for manipulation
- Convert software commands into physical actions (hydraulic, electric, pneumatic)
- Domain of mechanical engineering - new actuator designs (weight, flexibility)
- Actuators - have inaccuracies and are often not true to their model - difficult calibration issues, wear and tear, need to adaptive

---

**Trends in biological and machine evolution**

*Hans Moravec: Robot*

- 1 neuron = 1000 instructions/sec
- 1 synapse = 1 byte of information
- Human brain then processes 10^14 IPS and has 10^14 bytes of storage
- In 2000, we have 10^9 IPS and 10^9 bytes on a desktop machine
- In 25 years, assuming Moore’s law we obtain human level computing power

---

**The Brain (analogy)**

- 100 Billion neurons
- On average, connected to 1 K others
- Neurons are slow. Firing rates < 100 Hz.
- Can be classified into
  - Sensory - vision, somatic, audition, chemical
  - Motor - locomotion, manipulation, speech
  - Central - reasoning and problem solving
Overview of the topics

- Kinematics, Kinematic Chains, Mobile Robot kinematics
- Notion of state, sensing state, elementary control
- Potential Field Based Methods, Robot Behaviors
- Configuration Space, Motion Planning
- Randomized Motion Planning
- Robot Perception - Visual Perception
- Foundations of Probabilistic Robotics
- State estimation and Tracking
- Localization using Particle Filters
- Simultaneous Localization and Mapping
- Dynamic Programming and Markov Decision Processes
- Learning how to act - Reinforcement Learning

Overview - PART I

- Modeling aspects of the robotic system
- Notion of state, state evolution, kinematics
- Systems view suppose vector $X$ denotes the state of the system, vector $U$ types of controls/actions the system can carry out we will discuss ways of characterizing the motion of the system

\[
x_{t+1} = f(x_t, u_t)
\]

\[
\dot{x}(t) = f(x(t), u(t))
\]
Mobile Robot Kinematics – e.g. different arrangements of wheels

- Two wheels
- Three wheels

Omnidirectional Drive, Synchro Drive

Motion Control: Open Loop Control

- trajectory (path) divided in motion segments of clearly defined shape:
  - straight lines and segments of a circle.
- control problem:
  - pre-compute a smooth trajectory based on line and circle segments

Motion Control: Feedback Control, Problem Statement

- Find a control matrix $K$, if exists
  
  \[
  K = \begin{bmatrix}
  k_{i1} & k_{i2} & k_{i3} \\
  k_{j1} & k_{j2} & k_{j3}
  \end{bmatrix}
  \]

- with $k_j=k(t,e)$
- such that the control of $v(t)$ and $\omega(t)$
  \[
  \begin{bmatrix}
  v(t) \\
  \omega(t)
  \end{bmatrix} = K e = K \begin{bmatrix}
  e_1 \\
  e_2
  \end{bmatrix}
  \]

- drives the error $e$ to zero.
  \[
  \lim_{t \to \infty} e(t) = 0
  \]

Environment Representation and Modeling

- Recognizable Locations
- Topological Maps
  - Metric Topological Maps
  - Fully Metric Maps (continous or discrete)
Motion Planning
- Algorithms for determining movements of the robot in cluttered environments
- General techniques - 1st assumption - the environment is known
- Continuous representations of environments
- Discrete representations of the environments
- Deterministic methods - optimality, feasibility guarantees
- Motion planning for mobile robots, arbitrary shaped parts, articulated structures
- Randomized algorithms for motion planning

Methods for Localization: The Quantitative Metric Approach
1. A priori Map: Graph, metric
2. Feature Extraction (e.g. line
3. Matching: Find correspondence of features
4. Position Estimation: e.g. Kalman filter, Markov

Map Representation: Decomposition (2)
- Fixed cell decomposition
- Narrow passages disappear

Dealing with Uncertainty
Probabilistic Robotics
-Taking into account uncertainty of sensors and actions
-Localization in the presence of uncertainty,
-Map building

Robot Perception
-How to process information from sensors
-Visual Sensing
-Range Sensing
Grid-Based Metric Approach


Gaining Information through motion: (Multi-hypothesis tracking)

Markov Localization (4):

- Applying probability theory to robot localization

- Bayes rule:
  \[ p(A|B) = \frac{p(B|A)p(A)}{p(B)} \]

- Map from a belief state and a action to new belief state (ACT):
  \[ p(l_t|o_t) = \int p(l_t|l_{t-1}, o_t)p(l_{t-1})dl_{t-1} \]

- Summing over all possible ways in which the robot may have reached \( l_t \).

- Markov assumption: Update only depends on previous state and its most recent actions and perception.

Reinforcement Learning

- How to improve performance over time from our own/systems experience
- Goal directed learning from interaction
- How to map situations to action to maximize reward

Agent

Environment

state(t)

reward(t+1)

action(t)

state(t+1)