Introduction to mobile robots

Slides modified from
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Lecture Outline

- Introduction to mobile robots
- Sensors, sensor space
- State, state space
- Action/behavior, effectors, action space
- The spectrum of control
- Reactive systems
Alternative terms

- **UAV**: unmanned aerial vehicle
- **UGV**: unmanned ground vehicle
- **UUV**: unmanned undersea (underwater) vehicle
Anthropomorphomorphic Robots
Animal-like Robots
Unmanned Vehicles
What Makes a Mobile Robot?

- A robot consists of:
  - sensors
  - effectors/actuators
  - locomotion system
  - on-board computer system
    - controllers for all of the above
What Can be Sensed?

- depends on the sensors on the robot
- the robot exists in its *sensor space*: all possible values of sensory readings
- also called *perceptual space*
- robot sensors are very different from biological ones
- a roboticist has to try to imagine the world in the robot’s sensor space
State

- a sufficient description of the system can be:
  - *Observable*: robot always knows its state
  - *Hidden/inaccessible/unobservable*: robot never knows its state
  - *Partially observable*: the robot knows a part of its state
  - *Discrete* (e.g., up, down, blue, red)
  - *Continuous* (e.g., 3.765 mph)
Types of State

- **External state**: state of the world
  - Sensed using the robot’s sensors
  - E.g.: night, day, at-home, sleeping, sunny

- **Internal state**: state of the robot
  - Sensed using internal sensors
  - Stored/remembered
  - E.g.: velocity, mood

The robot’s state is a combination of its external and internal state.
State and Intelligence

- **State space**: all possible states the system can be in

- **A challenge**: sensors do not provide state!

- **How intelligent a robot appears is strongly dependent on how much it can sense about its environment and about itself.**
Internal Models

- Internal state can be used to remember information about the world (e.g., remember paths to the goal, remember maps, remember friends v. enemies, etc.).
- This is called a *representation* or an *internal model*.
- *Representations/models have a lot to do with how complex a controller is!*
A robot acts through its actuators (e.g. motors), which typically drive effectors (e.g., wheels).

Robotic actuators are very different from biological ones, both are used for:
- *locomotion* (moving around, going places)
- *manipulation* (handling objects)

This divides robotics into two areas:
- mobile robotics
- manipulator robotics
Action v. Behavior

- **Behavior** is what an external observer sees a robot doing.

- Robots are programmed to display desired behavior.

- Behavior is a result of a sequence of robot actions.

- Observing behavior may not tell us much about the internal control of a robot. Control can be a black box.
Actuators and DOF

- Mobile robots move around using wheels, tracks, or legs
- Mobile robots typically move in 2D (but note that swimming and flying is 3D)
- Manipulators are various robot arms
- They can move from 1 to many D
- Think of the dimensions as the robot’s degrees of freedom (DOF)
Autonomy

- Autonomy is the ability to make one's own decisions and act on them.
- For robots, autonomy means the ability to sense and act on a given situation appropriately.
- Autonomy can be:
  - complete (e.g., R2D2)
  - partial (e.g., tele-operated robots)
Control

- *Robot control* refers to the way in which the sensing and action of a robot are coordinated.

- The many different ways in which robots can be controlled all fall along a well-defined *spectrum of control*. 


Spectrum of Control

DELIBERATIVE

Purely Symbolic

SPEED OF RESPONSE

PREDICTIVE CAPABILITIES

DEPENDENCE ON ACCURATE, COMPLETE WORLD MODELS

Representation-dependent
Slower response
High-level intelligence (cognitive)
Variable latency

Representation-free
Real-time response
Low-level intelligence
Simple computation

REACTIVE

Reflexive
Control Approaches

- **Reactive Control**
  - Don’t think, (re)act.

- **Behavior-Based Control**
  - Think the way you act.

- **Deliberative Control**
  - Think hard, act later.

- **Hybrid Control**
  - Think and act independently, in parallel.
Control Trade-offs

- Thinking is slow.
- Reaction must be fast.
- Thinking enables looking ahead (planning) to avoid bad solutions.
- Thinking too long can be dangerous (e.g., falling off a cliff, being run over).
- To think, the robot needs (a lot of) accurate information => world models.
Reactive Systems

- *Don’t think, react!*
- Reactive control is a technique for **tightly coupling** perception (sensing) and action, to produce timely robotic response in dynamic and unstructured worlds.
- Think of it as “stimulus-response”.
- A powerful method: many animals are largely reactive.
Reactive Systems’ Limitations

- Minimal (if any) state.
- No memory.
- No learning.
- No internal models / representations of the world.
Reactive Systems

- Collections of *sense-act (stimulus-response) rules*
- Inherently *concurrent (parallel)*
- No/minimal state
- No memory
- Very fast and reactive
- Unable to plan ahead
- Unable to learn
Deliberative Systems

- Based on the *sense-*->*plan-*->*act* (SPA) model
- Inherently sequential
- Planning requires search, which is slow
- Search requires a world model
- World models become outdated
- Search and planning takes too long
Hybrid Systems

- Combine the two extremes
  - reactive system on the bottom
  - deliberative system on the top
  - connected by some intermediate layer
- Often called 3-layer systems
- Layers must operate concurrently
- Different representations and time-scales between the layers
- The best or worst of both worlds?
Behavior-Based Systems

- An alternative to hybrid systems
- Have the same capabilities
  - the ability to act \textit{reactively}
  - the ability to act \textit{deliberatively}
- There is \textit{no intermediate layer}
- A \textit{unified, consistent representation} is used in the whole system $\Rightarrow$ \textit{concurrent behaviors}
- That resolves issues of time-scale
A Brief History

- Feedback control
- Cybernetics
- Artificial Intelligence
- Early Robotics
Feedback Control

- **Feedback**: continuous monitoring of the sensors and reacting to their changes.
- Feedback control = self-regulation
- Two kinds of feedback:
  - Positive
  - Negative
- The basis of control theory
- and + Feedback

- **Negative feedback**
  - acts to *regulate* the state/output of the system
  - e.g., if too high, turn down, if too low, turn up
  - thermostats, toilets, bodies, robots...

- **Positive feedback**
  - acts to *amplify* the state/output of the system
  - e.g., the more there is, the more is added
  - lynch mobs, stock market, ant trails...
Uses of Feedback

- Invention of feedback as the first simple robotics (does it work with our definition)?
- The first example came from ancient Greek water systems (toilets)
- Forgotten and re-invented in the Renaissance for ovens/furnaces
- Really made a splash in Watt's steam engine
Cybernetics

- Pioneered by Norbert Wiener (1940s)
  - (From Greek “steersman” of steam engine)
- Marriage of control theory, information science and biology
- Seeks principles common to animals and machines, especially for control and communication
- Coupling an organism and its environment (situatedness)
W. Grey Walter’s Tortoise

- *Machina Speculatrix*
- 1 photocell & 1 bump sensor, 1 motor

- Behaviors:
  - seek light
  - head to weak light
  - back from bright light
  - turn and push
  - recharge battery

- Reactive control
Turtle Principles

- **Parsimony**: simple is better (e.g., clever recharging strategy)
- **Exploration/speculation**: keeps moving (except when charging)
- **Attraction** (positive tropism): motivation to approach light
- **Aversion** (negative tropism): motivation to avoid obstacles, slopes
- **Discernment**: ability to distinguish and make choices, i.e., to adapt
The Walter Turtle in Action

http://www.youtube.com/watch?v=ILULRlmXkKo
Braitenberg Vehicles

- Valentino Braitenberg (early 1980s)
- Extended Walter’s model in a series of thought experiments
- Also based on analog circuits
- Direct connections (excitatory or inhibitory) between light sensors and motors
- Complex behaviors from simple very mechanisms
Braitenberg Vehicles

- Examples of Vehicles:
Braitenberg Vehicles

- By varying the connections and their strengths, numerous behaviors result, e.g.:
  - “fear/cowardice” - flees light
  - “aggression” - charges into light
  - “love” - following/hugging
  - many others, up to memory and learning!

- Reactive control

- Later implemented on real robots
Early Artificial Intelligence

- “Born” in 1955 at Dartmouth
- “Intelligent machine” would use internal models to search for solutions and then try them out (M. Minsky) => deliberative model!
- Planning became the tradition
- Explicit symbolic representations
- Hierarchical system organization
- Sequential execution
Artificial Intelligence (AI)

- Early AI had a strong impact on early robotics
- Focused on knowledge, internal models, and reasoning/planning
- Eventually (1980s) robotics developed more appropriate approaches => behavior-based and hybrid control
- AI itself has also evolved...
- But before that, early robots used deliberative control
Early Robots: SHAKEY

- At Stanford Research Institute (late 1960s)
- Vision and contact sensors
- STRIPS planner
- Visual navigation in a special world
- Deliberative
Early Robots: HILARE

- LAAS in Toulouse, France (late 1970s)
- Video, ultrasound, laser range-finder
- Still in use!
- Multi-level spatial representations
- Deliberative -> Hybrid Control
Early Robots: CART/Rover

- Hans Moravec
- Stanford Cart (1977) followed by CMU rover (1983)
- Sonar and vision
- Deliberative control
Robotics Today

- Assembly and manufacturing (most numbers of robots, least autonomous)
- Materials handling
- Gophers (hospitals, security guards)
- Hazardous environments (Chernobyl)
- Remote environments (Pathfinder)
- Surgery (brain, hips)
- Tele-presence and virtual reality
- Entertainment
Why is Robotics hard?

- **Sensors** are limited and crude
- **Effectors** are limited and crude
- **State** (internal and external, but mostly external) is partially-observable
- **Environment** is dynamic (changing over time)
- **Environment** is full of potentially-useful information
Key Issues

- **Grounding in reality**: not just planning in an abstract world
- **Situatedness** (ecological dynamics): tight connection with the environment
- **Embodiment**: having a body
- **Emergent behavior**: interaction with the environment
- **Scalability**: increasing task and environment complexity