6.141J/16.405: Robotics Science and Systems I

Lecture 4:
Robot Control Architectures
and Sensing

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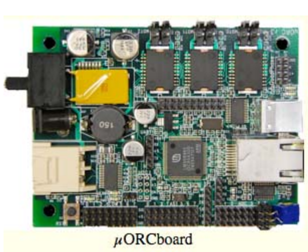
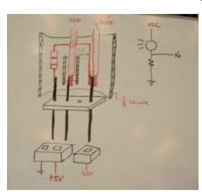
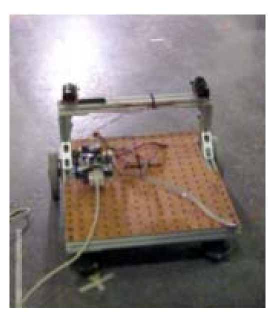
Mon 19 Feb 2013

Today

- Robot architectures: Reactive and Deliberative
- Sensor characteristics and uses
- Outcome: ready for Lab 3 (Braitenberg, tomorrow)
  - A robot that exhibits reactive responses to light







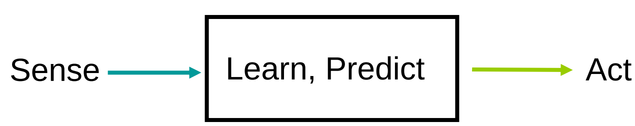
Reactive Architecture

- Couples sensing directly to action
  (i.e., does not incorporate persistent state)

- … examples from biology? … from robotics?

Deliberative Architecture

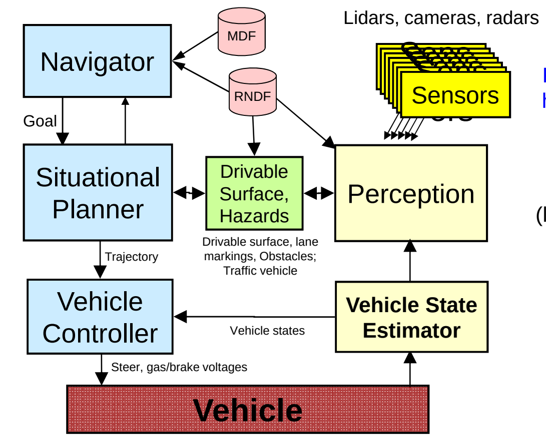
- Incorporates state (memory), prediction

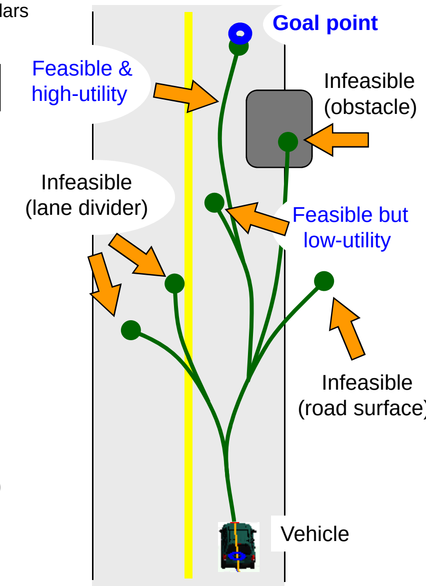


- … examples from biology? … from robotics?

- Is reactive vs. deliberative a hard distinction?

Example: MIT Autonomous Vehicle Talos





Electrically-controlled drive-by-wire (DBW)

- Continuous elements (steering, gas/brake)
- Discrete actions (turn signals, gear shift)
- Actuation via CAN bus and servomotors

Single-Cell Learning

"Single *Paramecium caudatum* were conditioned by pairing generated electric shock (US) with a vibratory stimulus (CS) produced by an auditory speaker. Naive paramecia subjected to shock reliably exhibited a backwards jerk and axial spinning similar to the avoiding reaction described by Jennings in 1904. Such responses did not occur initially to CS alone, but increasingly appeared during the CS period preceding shock pairing (delayed conditioning paradigm). Control subjects given the CS and US at the same intervals, but explicitly unpaired, did not show a sustained increase of responses to the CS alone."

Hennessey et al., Classical conditioning in paramecia, *Animal Learning & Behavior* 1979, 7(4), pp. 417-423

Designing for Behavior

- There is a *spectrum* of design solutions for achieving various desired behaviors
  - All of them couple sensing to action through a physical device (the robot!)
- As robot behavioral competence increases:
  - Design of this control architecture becomes more complicated, requiring additional (and more complex) abstractions
- Specialization for different kinds of robots
  - Health service robots, humanoid robots, autonomous vehicles, mobile manipulators
  - Mission dictates priorities, perspective
- Choice depends on sensors, task domain, and the environment the robot will inhabit

Kim Jackson, RSS '08

Focus on common aspect: Sensing

- What might a mobile robot need to know?
  - What is the state of my body? Joint angles, forces, torques
  - Where am I? Integrate past motion in some coordinate frame
  - What's out there? Freespace, obstacles, static or in motion
- Other quantities of interest depend on mission
  - In utility robotics, we assume a mission perspective
  - Not the "survive, eat, reproduce" creature perspective
- Sensor functions
  - Report internal state (e.g., w.r.t. threshold values) — proprieception
    - Tilted, overheating, low battery etc.
  - Report structure in the world (external state) — exteroception
    - Range sensing, object detectors etc.

Is there a hard distinction between proprioception and exteroception?

What is a Sensor?

- Physical device measuring a physical quantity
  - *Transduces* quantity of interest into reported *value*
- Provides only an *observation* of relevant state
  - Continuous changes in environment are generally not mapped to smooth changes in the measurement range
  - Sensor data are *noisy*; may not reflect actual value of quantity
- Generally designers face an *inverse* problem:
  - Must estimate robot/world state from sensor data
  - This problem is ill-posed
    - More than one solution (or no consistent solution!)
      - Bring context and prior information to bear
    - Pragmatic deduction of state
- Sensor may be unreliable
  - E.g. if used outside its specified operating envelope

Example Sensors

Measurement:	Sensor:
• Contact	Switch (bump sensor)
• Distance	Ultrasound, infrared, lidar, radar
• Enclosure	Break-beam sensor
• Light level	Photocell, camera
• Sound level	Microphone
• Strain	Strain gauge
• Shaft rotation	Encoder, limit switch
• Temperature	Thermometer
• Tilt w.r.t. *g*	Inclinometer, accelerometer
• Translational acceleration	Accelerometer
• Rotational velocity	Rate gyroscope

Analog and Digital Signals

- Sensors produce output signals as:
  - Analog *levels* (variable resistances or voltages)
  - Digital *values* (with some # of bits of resolution)
  - Robot control software requires *digital* inputs

Simple Digital Sensors: Contact Switches

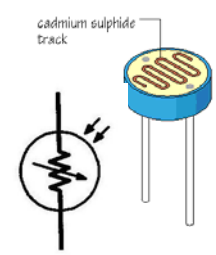
- Simplest sensor: 1-bit digital output
- Minimal circuitry, processing
  - De-bounce hardware or software
- Normally open (NO):
  - Current flows when switch is pressed
- Normally closed (NC):
  - Current flows when switch is released
- Many types:
  - Pushbutton, toggle, rocker, knife, Reed, mercury

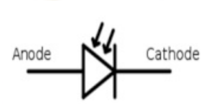
Various Uses of Switches

- Contact sense
  - Trigger on contact with object (bump sensor)
- Limit sense
  - Trigger when a joint is at one end of its range
- Encoders
  - Count shaft revolutions (Reed sensor)
- Orientation
  - Detect if robot has tilted or tipped over (mercury)

Analog Photocells

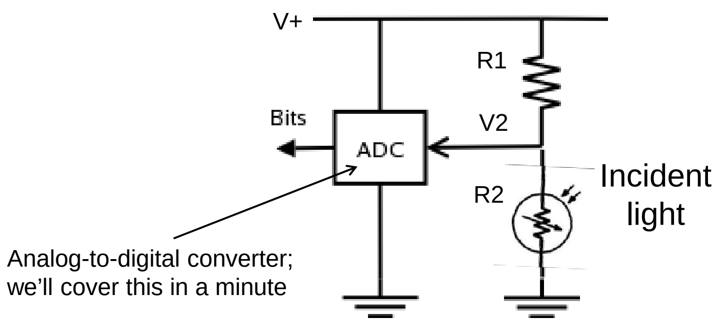
- Passive sensors for measuring light intensity
- Two technologies:
  - Photoresistor: light-dependent resistor
  - Photodiode: light-dependent diode
- Photoresistor:
  - Based on cadmium sulfide semiconductor
  - Resistance drops with increasing incident light
- Photodiode (forward bias):
  - Built from p- and n-type semiconductor
  - Incident light liberates electrons, causing increased current flow





Photoresistor Operation

- Resistance across R2 drops with increasing light
- What is the value of V2 when there's no light?
- What is the value of V2 when there's strong light?
- Why do we need R1? How do you choose its value?

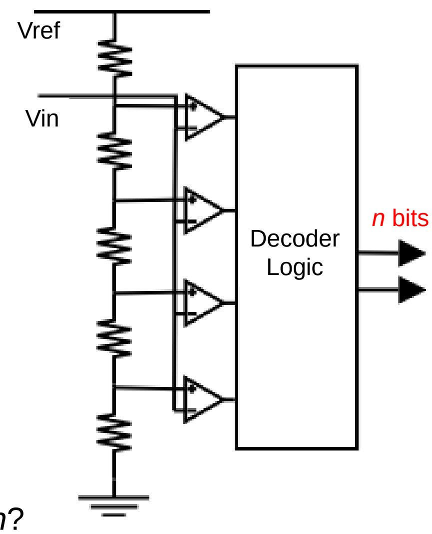


Practical Considerations

- Light sensors can measure:
  - Ambient light intensity
  - Differential intensity (two detectors)
- Light sensors should be:
  - Oriented
  - Shielded
  - Focused
  - Why?

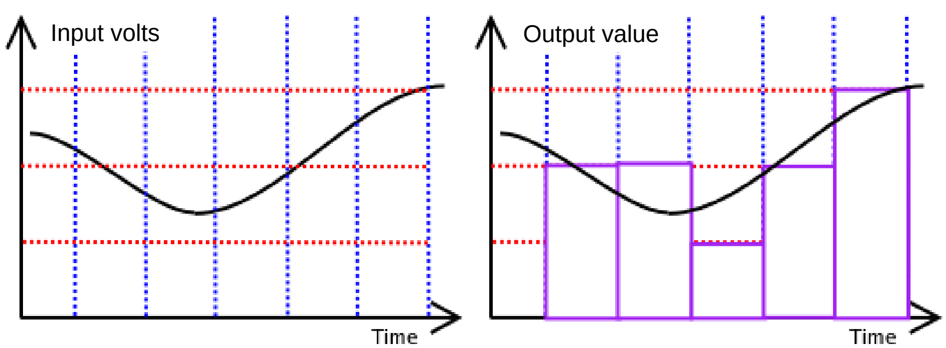
Analog to Digital Conversion

- Analog levels converted to digital values using an analog-to-digital converter (ADC)
- Most ADCs based on analog *comparators*, used in parallel or sequentially
- At right is a “flash” ADC
  - How does it work?
  - How should Vref be chosen?
  - Does device scale well with *n*?



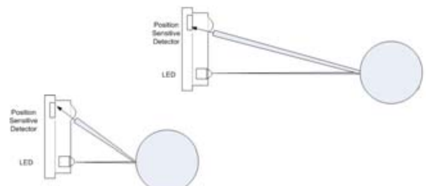
Sampling Rate, Output Resolution

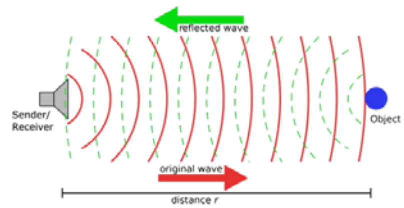
- Analog waveforms are time-varying signals
- ADC samples *input* at some frequency (x axis)
- ADC generates *output* at some resolution (y axis)
- What sample rate, output resolution should you use?



Measuring Distance (Range)

- Infrared (IR) range sensor: illuminate and triangulate (this is how a Kinect works)
- Stereo camera pair can measure distance/depth (how?)
- Ultrasound (sonar) sensor gives distance directly from *time of flight* (how?)
- LIDAR uses time of flight, but of IR light rather than sound (much more costly – why?)





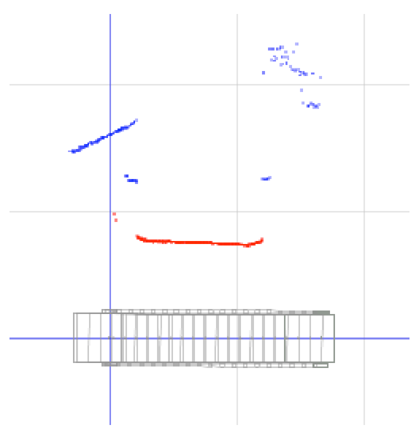
Sensor Characteristics

Sensor Characterization

- Dynamic range
  - Ratio of largest to smallest measurable value
- Sensitivity
  - Smallest change the sensor can detect in the quantity that it is measuring
- Resolution
  - How many distinct, meaningful output values are produced by sensor
- Noise characteristic
  - Distribution of errors in reported sensor values
- Systematic error (e.g. bias)

In practice:

- All real sensors exhibit noise
- No sensor can give a complete picture of robot's surroundings



Sensor Selection

- Task-dependent issues to consider:
  - Sensor sensitivity, resolution, cost
  - Noise and error characteristics
  - Physical properties – size/weight/power, mounting
  - Robustness (tolerance of environment conditions)
  - Speed of operation, data reporting/transfer
  - Computational expense of handling sensor data

Summary, What's next

- Reactive and deliberative architectures
- Introduced sensors, critical to robotics
  - Saw several examples of analog, digital sensors
  - Discussed sensor types, selection criteria
- Tomorrow: the digital camera as a sensor
- Also, tomorrow in lab:
  - Lab 2 briefings by each team
  - Lab 3 (Braitenberg) begins

6.141 CDE Submission Instructions

1) Export your document as a PDF named

    Firstname_Lastname_CDE.PDF

Note capitalization. Feel free to use your nickname rather than your first name if you wish. Make sure to create a .PDF (rather than .doc or other format) file.

2) Make a new page called CDE on your team's wiki, if one of your teammates has not made it already.

3) Upload your PDF to the CDE page.

4) Email rss-staff with the URL of the PDF that you uploaded.

5) Do all of the above by 1pm on Friday, February 22nd, i.e. before the start of the Forum that day.