6.141J/16.405: Robotics Science and Systems I

Lecture 6:
Robot Control Architectures
and Sensing

Seth Teller
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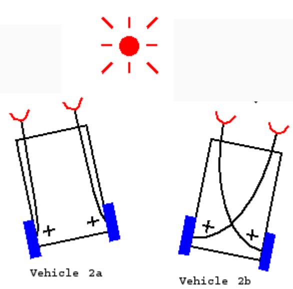
Example Reactive Architecture

- Braitenberg vehicle



http://www.youtube.com/watch?v=NJo5HEdq6y0

science.slc.edu

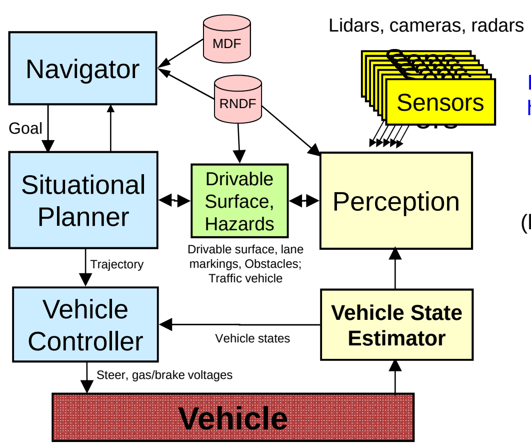
Reactive Architecture

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

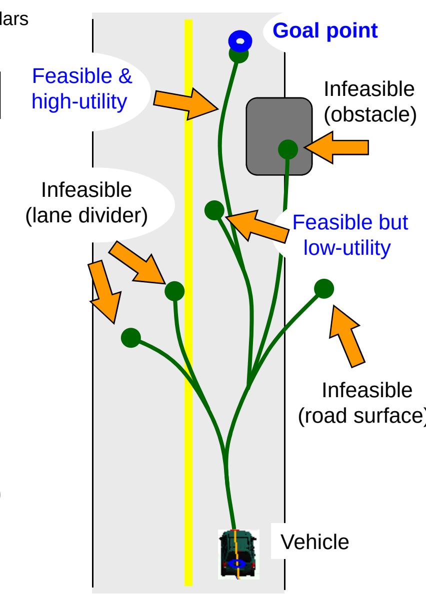
Sense → Primitive response → (Re)Act

- … other examples from biology? … robotics?

Example: MIT Autonomous Vehicle Talos

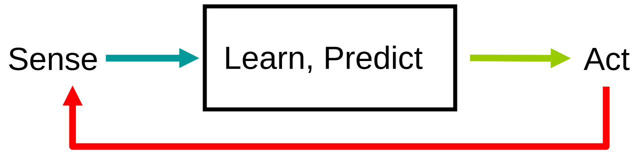


Electrically-controlled drive-by-wire (DBW)
- Continuous elements (steering, gas/brake)
- Discrete actions (turn signals, gear shift)
- Actuation via CAN bus and servomotors



Deliberative Architecture

- Incorporates state (memory), prediction



- … others examples from biology? … robotics?
- Is reactive vs. deliberative a hard distinction?

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

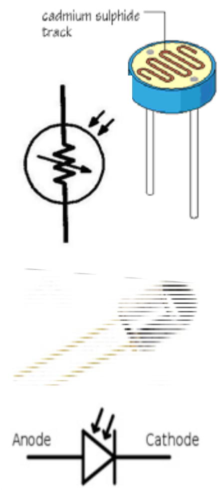
- Simplest sensor: 1-bit digital output
- Minimal circuitry, processing
  - De-bounce hardware or software
- Normally open (NO):
  - Current flows when switch is pressed
- Normally closed (NC):
  - Current flows when switch is released
- Many types:
  - Pushbutton, toggle, rocker, knife, Reed, mercury

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)

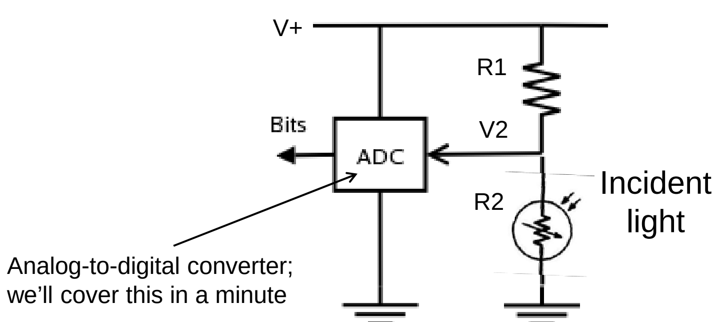
Analog Photocells

- 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



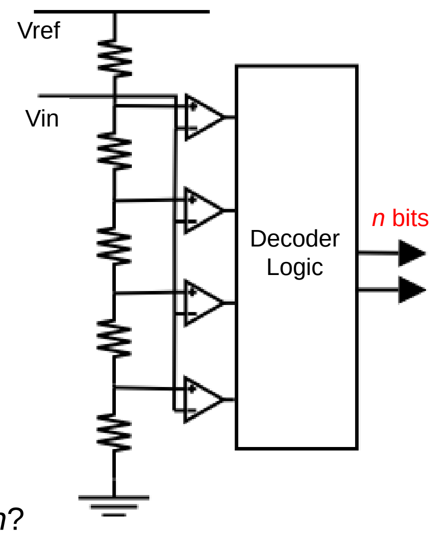
Photoresistor Operation

- 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?



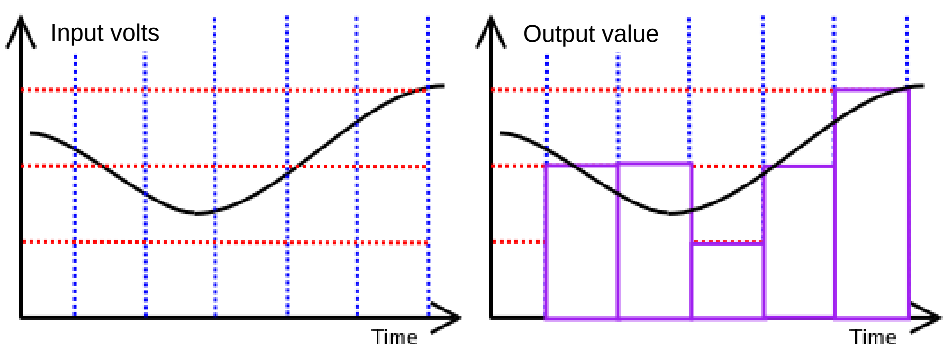
Analog to Digital Conversion

- 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*?



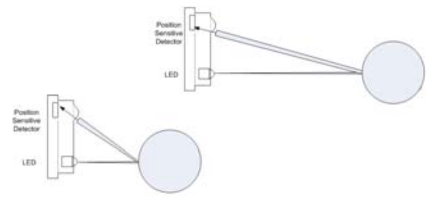
Sampling Rate, Output Resolution

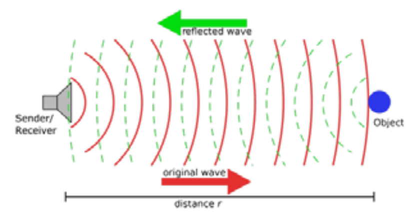
- Analog waveforms are time-varying signals
- ADC samples *input* at some frequency (x axis)
- ADC generates *output* at some resolution (y axis)
- What sample *rate*, output *resolution* should you use?



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?)





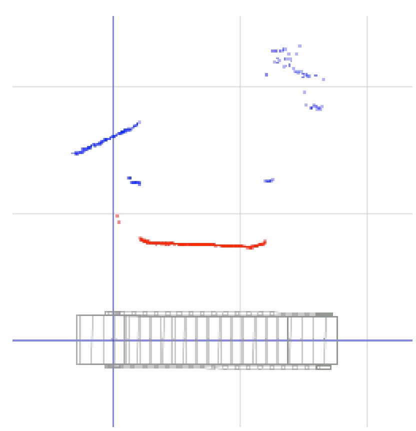
Sensor Characteristics

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 range, rate, 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

- CDE’s returned today

- Wednesday
  - Lecture: System Engineering and Test
  - Lab 3 briefings
  - Lab 4 out