mc375: intro to robotics

sensors, sensing and perception.

- overview
  - sensor basics
  - perception
  - sensor types
- basic electronics
- types of sensors
  - passive sensors.
    - switch sensors
    - light sensors
    - resistive positive sensors
    - potentiometers
  - active sensors.
    - reflective optosensors
    - shaft encoding
    - modulation and demodulation of light
    - Infra Red (IR)
- advanced topics.
  - ultrasonic distance sensing
  - machine vision

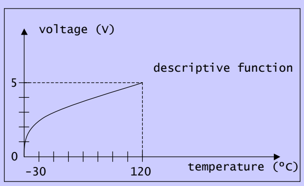
sensor basics:

why is robotics hard?

- sensors are limited, inaccurate, noisy
- effectors are limited, crude
- state (internal and external, but mostly external) of the robot is partially-observable, at best
- environment is often dynamic (changing over time)
- environment is full of potentially-needed information
- environment is noisy

sensor basics.

- the perceptual system of a robot
- physical devices that measure physical quantities and convert them to electrical signals



sensor basics:

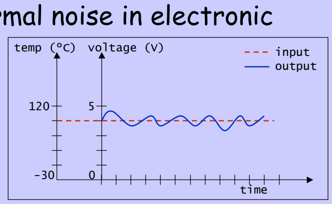
properties.

- *descriptive function* is an electrical signal that is a crude approximation of physical reality
- properties
  - range: fixed interval of output
  - sensitivity: how change in input is mapped to change in output
    - logarithmic, linear
  - speed: time interval between reading input and outputting output
  - stability: how vulnerable it is to noise

sensor basics:

internal noise.

- represents a deviation from the descriptive function
- modeled by Gaussian distribution (the bell curve)
- caused by thermal noise in electronic components



sensor basics:

complexity of sensor types.

- varies greatly!
- simple
  - e.g., switch: on/off
- complex
  - e.g., human retina: 100M photosensitive elements (rods and cones)

sensor basics:

sensor fusion.

- combining multiple sensors to get better information about the world
- multiple sensor channels, one abstract signal
  - not simple -- can't just compute an average
  - different sensors give different types, accuracy, complexity of information
  - requires assimilating, processing these in an intelligent and useful way, *in real time!*
- e.g., human brain

sensor basics:

processing and complexity.

- simple sensor simple processing, simple reaction
  - e.g., simple switch

    on go

    off stop
- complex sensor complex processing, allows more complex reaction (though not necessary)
  - e.g., computer vision with a camera

    >= N grey levels go

    < N grey levels stop

sensor basics:

processing properties.

- *processing* converts signals to state
- sensors provide signals
- sensors do not provide state!
- processing may require lots of computation
- processing touches on several areas:
  - electronics
  - signal processing
  - computation

sensor basics:

processing components.

- electronics
  - measure voltage going through a circuit on a switch
- signal processing
  - recognize a voice, separate it from noise
- computation
  - edge detection of objects in an image, followed by object recognition

sensor basics:

processing requirements.

- analog or digital processing capabilities (i.e., a computer)
- wires to connect everything
- electronics to interface with computer
- batteries to provide power

perception.

- components
  - what the robot senses
  - how it senses it (sensor type)
  - how it processes it (processing)
  - how it uses it
- don't separate -- otherwise: large, bulky, ineffective robot
- historically
  - perception in isolation
  - perception as "king"
  - perception as reconstruction
  - origins in computer vision (most complex data)

perception: one system.

- consider at once:
  - the task robot has to perform
  - the best sensors for the task
  - the best mechanical design that will allow the robot to get the necessary sensory information to perform the task
  - e.g., body shape of robot, placement of sensors

perception: current methods.

- perception in the context of action and task
- action-oriented perception
- expectation-based perception
  - use knowledge about the world as constraints on sensor interpretation
- focus-of-attention perception
  - provide constraints on where to look
- perception classes
  - partition the world into useful categories

perception: in nature.

- provides clever solution to perception
- evolves sensors with special geometric and mechanical properties
  - e.g., facetted eyes of flies
  - polarized light sensors of birds
  - horizon/line sensors of bugs
  - shape of human ear
- maximize sensor's properties
  - range and accuracy

perception: divisions.

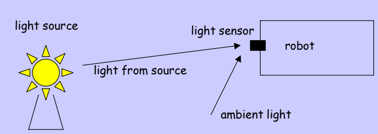
- proprioception
  - sensing internal state
  - e.g., muscle tension, limb position
  - examples: path integration (dead-reckoning); balancing
- exteroception
  - sensing external state
  - e.g., vision, audition, smell

perception: affordances.

- "potentialities for action inherent in an object or scene" [Gibson 1979]
- focus on interaction between robot and environment
- perception is biased by task
- e.g., a chair can be something to sit on, but can also be something to stand on, to throw, to avoid

perception: external noise.

- originates in the environment
  - not in the sensor (that's internal noise)
- based on an abstract signal or meaning



types of sensors.

- physical properties and the types of sensors that can detect them

contact	→	bump, switch
distance	→	ultrasound, radar, infra red (IR)
light level	→	photo cells, cameras
sound level	→	microphones
strain	→	strain gauges
rotation	→	encoders
magnetism	→	compasses
smell	→	chemical
temperature	→	thermal, infra red
inclination	→	inclinometers, gyroscopes
pressure	→	pressure gauges
altitude	→	altimeters

types of sensors, 2.

- *passive* sensors
  - stimulus (i.e., physical property being measured) comes from the environment
- *active* sensors
  - provide their own stimulus/signal and use its interaction with the environment as the property being measured
  - typically require more energy

some basic electronics.

- voltage, current and power
- resistance
- combining resistance
- dividing voltage

electronics:

voltage, current and power.

- voltage
  - the amount of work needed to move a positive charge Q from a negative/lower potential to a positive/higher potential
  - measured in volts (V)
- current
  - rate of flow of charge Q over time
  - measured in amperes (A)
- power
  - work over time
  - measured in watts (W)

  P = V I

electronics:

resistance.

- electrical current is proportional to the *resistance* property of the material it is flowing through
  - like water flowing through a pipe: diameter of pipe influences speed of flowing water
  - measured in Ohms (Ω)
- Ohm's law:
  - V = I R
  - voltage between two points in a circuit is equal to the amount of current flowing through them times the amount of resistance between them

electronics:

combining resistance.

- it's not hard to figure out how much resistance one resistor gives -- they are labeled!
- but what happens if you connect two resistors in *series*?
- current (I) flowing through any number of resistors has to be equal, since it has only one route to flow on, as it goes from one resistor to the next

electronics:

combining resistance, 2.

- what happens to voltage (V)?

```
V = I R
  = I (R1 + R2)
  = I R1 + I R2
```

- suppose we measure voltage across R1, i.e. the voltage between the input point V and the connection between R1 and R2?
- it would be I R1 volts

electronics:

combining resistance, 3.

- and if we measure voltage across R2, i.e., the voltage between the connection between R1 and R2 and ground?
- it would be I R2 volts
- *the total voltage in an electronic circuit has to add up*
- therefore the input voltage V has to equal the output voltage, after the drop across the two resistors, R1 and R2

electronics:

dividing voltage.

- suppose we take the voltage out at the point between R1 and R2; what will the amount of that voltage V_{out} be?

$V = I R$

$I = V / R$

$\quad = V_{in} / (R1 + R2)$

- then

$V_{out} = I R2 = V_{in} R2 / (R1 + R2)$

passive sensors.

- switch sensors
- light sensors
- resistive positive sensors
- potentiometers

passive sensors:

switch sensors.

- are the simplest sensors
- work without processing, at the electronics (circuit) level
- underlying principle: open vs closed circuit
- open switch no current can flow
- closed switch current can flow and be detected

passive sensors:

contact sensors.

- detect when sensor has contacted another object
- e.g., triggers when robot hits a wall
- examples: bump switch, whiskers

passive sensors:
limit sensors.

- detect when a mechanism has moved to the end of its range
- e.g., triggers when a gripper is opened as wide as it can

passive sensors:
shaft encoder sensors.

- detect how many times a shaft turns by having a switch click (open/close) every time the shaft turns
- e.g., triggers for each turn, allowing for counting rotations

passive switches:
wiring simple switches.

- can be normally open or normally closed, depending on how you wire the switch
- which you want depends on robot's electronics, mechanics and task

passive sensors:
light sensors.

- measure amount of light impacting a *photocell*
- photocell is a resistive sensor:
  - light effects the amount of resistance
  - resistance is low when it is bright
  - resistance is high when it is dark
- applications:
  - light intensity: how light/dark it is
  - differential intensity: difference between photocells
  - break-beam: change/drop in intensity

passive sensors:
positioning of light sensors.

- light sensors can be shielded, positioned, focused in various ways in order to affect its properties
- multiple light sensors can be placed in useful configurations and isolated from each other with shields
- position and directionality can make a great deal of difference!

passive sensors:
polarized light.

- "normal" light emanating from a source is *non-polarized*, which means it (i.e., the light waves) travels at all orientations with respect to the horizon
- a *polarizing filter* in front of a light source will only emit light waves of a given orientation (i.e., the characteristic plane)

passive sensors: polarized light, 2.

- if we pass polarized light waves through a second filter with the same characteristic plane as the first, (almost) all the light will get through
- if we pass polarized light waves through a second filter with a characteristic plane perpendicular to the first, (almost) none of the light will get through

passive sensors: polarized light, 3.

- polarized light can be used to make specialized sensors out of simple photocells
- put a filter in front of a light source (i.e., an emitter) and the same or a different filter in front of a photocell -- you can manipulate what and how much light you detect

passive sensors: resistive position sensors.

whereas a photocell is a resistive device (it senses resistance in response to light)...

- a *bend sensor* can sense resistance in response to physical resistance
  - resistance of the device increases with the amount it is bent
  - developed for video game control
    - e.g., Nintendo Powerglove
  - repeated bending will wear out sensor!
  - so, much less robust than other types of sensors

passive sensors: potentiometers.

- allow user to adjust resistance manually
  - e.g., volume and tone on stereo
- typically called *pots*
- types: carbon, wire wound, conductive plastic
- consist of a movable tap along 2 fixed ends
  - as the tap is moved, the resistance changes
  - resistance between the 2 ends is fixed
  - resistance between movable part in the middle and each end varies

passive sensors: in nature.

- all sensors described so far exist in biological systems
- touch/contact sensors have much more precision and complexity in all species
- polarized light sensors exist in insects and birds
- bend/resistance receptors exist in muscles

active sensors.

- reflective optosensors
- break-beam sensors
- shaft encoding
- quadrature shaft encoding
- modulation and demodulation of light
- Infra Red (IR) sensors
- IR communication

active sensors:

reflective optosensors.

- we can use a light bulb in combination with a photocell to make a break-beam sensor (to detect change/drop in intensity)
- reflective optosensors use same principle
- consist of an emitter and a detector
- two types:
  - reflectance
  - break-beam

active sensors:

reflectance sensors.

- emitter and detector are next to each other
- separated by a barrier
- objects are detected when light is reflected off them (by the emitter) and back into the detector

active sensors:

break-beam sensors.

- emitter and detector face each other
- objects are detected if they interrupt the beam of light between the emitter and the detector

active sensors:

components of reflective optosensors.

- emitter:
  - usually a light-emitting diode (LED)
- detector:
  - usually a photodiode/phototransistor
  - not the same as resistive photocells, which are simple but slow
  - photodiodes and photo-transistors are faster and thus preferred

active sensors:

capabilities of reflective optosensors.

- detect presence of objects
- detect distance to objects
- detect surface features
  - finding/following markers/tape
- track walls/boundaries
- encode rotational shafts
  - using encoder wheels w/ridges or black/white
- decode bar codes

active sensors:

properties of reflective optosensors.

- light reflectivity depends on color and other properties of a surface
- a light surface will reflect better than a dark one
- a black surface may not reflect at all
- i.e., harder to detect dark objects than lighter ones
- so far away light objects will appear closer than near dark objects

active sensors: calibration.

- ambient light: noise
- subtract ambient light level out of sensor reading in order to detect actual change in reflected light
- take 2 readings of detector with emitter on and then off and subtract two values from each other (do this a few times for accuracy and compute average)
- subtract this result from future readings

active sensors: break-beam sensors.

- can be any pair of compatible emitter-detector devices
- e.g.,
  - incandescent flashlight bulb and a photocell
  - red LEDs and visible-light-sensitive photo-transistors
  - infra-red IR emitters and detectors

active sensors: shaft encoding.

- measure angular rotation of an axle providing position and/or velocity information
- e.g.,
  - speedometer measures how fast wheels of a vehicle are turning
  - odometer measures number of rotations of the wheels

active sensors: shaft encoding operation.

- in order to detect a complete or partial rotation, we have to mark the turning element
- usually done by attaching a round disk to the shaft and cutting notches in it
- light emitter and detector are placed on each side of the disk
- as notch passes between, light beam is broken

active sensors: shaft encoder notches.

- number of notches varies
- if only one, then unit of measurement is one complete rotation
  - inaccurate because an entire rotation can be missed due to noise
- usually multiple notches, then many hits are counted
  - sensor (detector) must be fast!

active sensors: alternative to notches.

- paint alternating black (absorbing, non-reflecting) and white (highly reflecting) wedges on disk
- detector and emitter are on same side of disk

active sensors:

shaft encoder output.

- a wave function of the light intensity
- processed to produce speed
- i.e., count peaks of the waves

active sensors:

shaft encoding measures...

- position (of shaft)
- rotational velocity, by subtracting difference in position readings after each time interval
- positional velocity tells us how fast the robot is moving (not necessarily the same as rotational velocity)

active sensors:

shaft encoding applications.

- used to
  - measure the speed of a driven (active) wheel
  - measure forward progress using a passive wheel that is dragged by the robot
- position and velocity information can be combined to
  - move in a straight line
  - rotate by an exact amount

active sensors:

shaft encoding noise.

- wheels
  - slip
  - effector noise/error
- gears
  - backlash
- feedback can correct some error
  - but not all

active sensors:

light modulation/demodulation.

- approach to problem of ambient light
- emit *modulated light*, i.e., rapidly turn the emitter on and off
- detect with a *demodulator*, tuned to frequency of modulated light
- detector needs several light flashes in sequence to detect a signal, i.e., obtain its frequency

active sensors:

light modulation/demodulation,2.

- modulated IR light used commonly
  - e.g., household remote controls
- more reliable than basic light sensors
- used for
  - detecting presence of an object
  - measuring distance to a nearby object

active sensors:

Infra Red (IR) sensors.

- type of light sensor that functions in the infra red portion of the frequency spectrum
- active sensors: consist of emitter and receiver
- used in same way as visible light sensors
  - break-beam sensors
  - reflectance sensors

active sensors:

IR sensors, 2.

- generally preferable to visible light in robotics (and other applications)
  - less sensitive to ambient interference (though ambient light is still a factor)
  - easily modulated
  - not visible

active sensors:

IR communication.

- modulated IR can be used as a serial line for transmitting messages
  - e.g., IR modems
- two methods:
  - *bit frames:* sampled in the middle of each bit; assumes all bits take the same amount of time to transmit
  - *bit intervals:* sampled at the falling edge; duration of interval between sampling determines whether it's a 0 or a 1; more common in commercial use

advanced topics: complex sensors.

- ultrasonic distance sensing (sonar)
- machine vision

ultrasonic distance sensing.

- based on time-of-flight principle
- emitter produces a sonar "chirp"
- travels away from source
- if it encounters barriers, it reflects from them and returns to the receiver
- time for beam to return is tracked
- first sonar developed by Polaroid

ultrasonic distance sensing:

specular reflection.

- reflection from outer surface of object
- major disadvantage of ultrasound sensing
- sound wave will not necessarily bounce off surface and "come right back"
- direction of reflection depends on incident angle of sound beam and surface it hits
- if small angle, then sound may *graze* object and give a false far-away reading

machine vision.

- using cameras as sensors
- much more complex than other sensors we've looked at
- model biological eyes, which are of course more sophisticated than any artificial counterpart known today
- so complex, it is a separate branch of AI all by itself!

machine vision:
camera principles.

- general principle of a camera:
  light is scattered from objects in the environment (called the *scene*), goes through an opening (*iris*, in the simplest case a *pin hole*, in the more sophisticated case a *lens*) and impinging on the *image plane*

machine vision:
cameras.

- silver halides are used on photographic film or silicon circuits in charge-coupled devices (CCD) cameras
- in both cases, information about the light (e.g., intensity, color) is detected by the photosensitive elements on the image plane

machine vision:
image plane.

- image plane subdivided into equal picture elements, or *pixels*
  - typically arranged on a rectangular grid
  - typically 512 x 512 pixels on image plane
  - human eye has 120×10^6 rods and 6×10^6 cones, arranged hexagonally
- *image* = projection on the image plane
- brightness of each pixel in the image is proportional to the amount of light directed toward the camera by the surface patch of the object that projects to that pixel

machine vision:
vision processing.

- *edge detection*
  - *edges* are defined to be curves in the image plane across which there is significant change in the brightness
- *segmentation*
  - organize edges into parts that correspond to continuous objects
  - methodologies: model-based vision, motion vision, stereo, texture, shading and contours
- *in real-time*
  - simplify and get help to gain speed:
    - use color
    - use small image plane
    - combine simpler, faster sensors with vision
    - use information about the environment

machine vision:
in nature.

- all of the above strategies for segmentation are used in biological vision
- even for humans, it is hard to recognize unexpected or novel objects
- movement helps catch our attention
- all carnivores have and use stereo vision
- brain is good at quickly extracting and processing information from a scene