COSC 4P78

Sensors

Week 2

Brock University

Intro to Sensors

What's a sensor?

- Sensors are analogous to human senses
  - (and thus, sensory organs)
- They are necessary for any notion of *perception*
- They are tied to an intelligent agent's notion of *state* (world, self, etc)
- They allow an intelligent agent to make informed decisions

Sensors detect information from the environment (or self), and communicate it in a form that the agent can use to infer knowledge of that environment

Interruption

Ostensibly, we should be discussing *exteroception*, *interoception*, and *proprioception*.

However, for the most part, today's lecture will mostly apply to exteroception.

Intro to Sensors

Biological Analogues

How do humans sense? How do we even categorize it?

- The "Five Senses"?
  - Sight
    - The ability to perceive light
    - The ability to distinguish between different energy levels of radiation
    - The ability to receive and process radiation from multiple angles and infer information about size/shape/orientation/distance/etc.
  - Smell
    - The ability to detect minute traces of airborne chemicals
    - These can be things we wish to avoid, or are seeking
  - Touch
    - The ability to detect contact
    - The finegrain ability to feel contours and texture
    - The ability to judge temperature
    - Bonus: differing levels of *resolution* depending on where it's likely to be needed

Intro to Sensors

Biological Analogues (cont)

- (The *Five Senses* continued)
  - Hearing
    - ★ The ability to detect rapid changes in air pressure
    - ★ The ability to distinguish between different rates of change of air pressure
  - Taste
    - ★ Additional ability to detect chemicals
    - ★ The ability to categorize based on acids, bases, simple carbohydrates, and ionic salts
    - ★ The ability to trick high school teachers into thinking that these chemicals can only be perceived in specific localized/dedicated portions of the tasting surface

So then, how many *sensors* does a human have?

- Probably more than five

Intro to Sensors

Biological Analogues (continued some more)

- What about animals other than humans?
  - (At this point, I should be asking you what you think)
- How many biological sensors would have logical electronic counterparts?
- Do we need additional ones to address the design/capabilities/needs of mechanical robots?

But first...

Active or Passive Sensors?

- Passive: Energy primarily comes from the environment
  - Typically requires less power
  - Less likely to interfere with other sensors/devices/humans
- Active: Devices provide their own energy (e.g. illumination)
  - Usually requires more power
  - Allows you to sense things you might otherwise not be able to
    - e.g. Seeing in the dark
    - Recording the response from a burst of energy (more on this later)
    - There's the potential for interference, though!

But first...

Communicating with the 'Brain'

Analog or Digital?

- Analog
  - True analog is hard on a computer (big surprise)
  - Strength of signal can be indicated via voltage
    - e.g. "3.1V $<$5V", "1V $<<$5V"
    - Requires a *reference voltage*
  - Read into device via Analog to Digital Converter (ADC)
    - Converted into a discrete value in some range. e.g. 0–1023
- Digital
  - Suitable when the information is already digital (or the sensor itself does the conversion)
  - Parallel or serial communication
    - e.g. an Inter-Integrated Circuit (I^2C), SPI, etc.
    - Oftentimes, the clockrate is flexible
  - Pulse-Width Modulation
    - This one's neat...

But first...

Pulse-Width Modulation

Imagine you wanted to "dim" an LED

- Could you just reduce the voltage?
  - Fine for incandescent bulbs, but not for LED!
  - LEDs are happier when at a constant voltage
  - (Note: I also could have used motors as an example; torque, etc.)
- What if you just turned it off half of the time?
  - Well, you'd get half of the photons hitting your eye, which is *sort of* the same thing... right?
    - ★ Actually, in essence, yes!
- Suppose we break up time into slices (e.g. $0.008\overline{3}$s, or 120Hz)
  - If voltage were applied for half of each slice, it would be on for 0.5s of every second
  - Human eyes wouldn't perceive it as "blinking"
  - When on, it's always at the full voltage, just like the LED likes!
- How does this help for a sensor?
  - Because one could also measure the portion of each 0.008333s slice with voltage and translate that into a discrete value based on some range

Types of Sensors
An Overview

What types of sensors are there?

- This is *not* going to be exhaustive!
- We're leaving out strictly human-input sensors entirely (joysticks, keypads, etc.)

Mechanical Switches

- Bump switches, micro switches, contact switches, etc.
- Same principle as a light switch
  - When physical contact is made, a circuit is closed (or opened)
  - Simply *off* or *on*
- Good for:
  - Sensing contact with walls (where the amount of pressure doesn't matter)
  - Knowing if an item is grasped
- Of course, you need to carefully position the switch, and consider likely orientation of potential surfaces with which to be making contact

Potentiometers

- Think "Dimmer Switches" for home lighting
- Depending on the position of a rotary spindle or wheel, the sensor has higher or lower resistance
- N.B. Though less common, linear potentiometers are also a thing
  - Sliders
  - Useful for linear motion
- In addition to sensing, they can also be used to *trim* other sensor inputs

Flexible sensors

i.e. Membrane or elastic-based sensors

- For example:
  - Flex sensors
  - Force Sensing Resistors (FSR)
  - Soft Potentiometers (SoftPots)
    - Returns a different resistance depending on *where* it is pressed
- Most are based on membranes and some conductive or semi-conductive layer (e.g. graphite)
- When a force is applied, the circuit is closed (or further closed), allowing more current through
- Good for:
  - Measuring weight (though often very coarse-grained)
  - Detecting physical pressure (e.g. presence or absence of a weight)
  - Determining how far a joint has bent
  - The Power Glove
    - It's so bad

Vibration sensors

- Detects vibration (duh)
- Typically based on *piezo* elements
  - Piezos can generate AC voltage when stressed/flexed/vibrated
  - They can also oscillate when suitable voltage is applied
    - (Thus, they can be both inputs and outputs, depending on configuration)
  - Also, in addition to vibration, piezos can be used for sensing some degree of "flex", or even generating electricity! Neat, huh?
- In addition to the obvious, they can be good for sensing physical contact across a rigid shell or a membrane (allowing a larger surface the sense of "touch")

Light

- Is there light? Yes/no?
  - Is this actually a reasonable test? Would it be useful?
- Is there *visible* light? Yes/no?
  - Getting better...
- Is there at least X much light?
- Photoresistors
  - Resistance changes based on amount of light absorbed
- Photodiodes
  - Actually generate a small voltage based on intensity of light
- Light sensors often have to be scaled, thresholded, and/or trimmed
- Uses? Your turn to tell me some!

Light Sensing
(continued)

What about cameras?

- Now we're getting into the realm of *machine vision* (dun dun dunnn!)
- This is far outside the scope of the lecture, but just give it some thought for a moment

Maybe we should return to this topic later?

- (Although, mini-question: how should a robot's camera compare to a human's? How *could* it differ?)

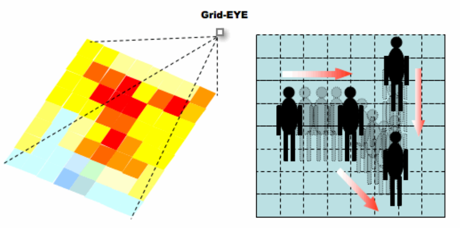
Temperature sensors

There are two basic approaches to detect temperature:

- Contact/ambient
  - e.g. A simple thermistor for a shutoff or other safety mechanism
  - Measuring the temperature in the immediate vicinity
- Non-contact (from a distance)
  - e.g. infrared thermometer
  - Allows "spot readings"

Hey... what'd happen if we were to take multiple spot readings at once?

Thermal array



(panasonic.com)

- Multiple infrared detectors (*thermopile array*)
- Much simpler than machine vision, but applicable to many of the same uses!
  - Shall we discuss?

Break-Beam

- When an object crosses between an emitter and detector of some sort, voltage is either applied or stopped
- Can act as an electronic "gate"
- Often used in more elaborate sensors/detectors
  - e.g. quadrature shaft encoders (next week!)
  - (We *could* infer motion based on the pattern)
  - Ye olde computer mice
- Often a contactless alternative to a mechanical switch
  - Which can, of course, potentially last longer, without constant wear and tear
- Lotsa uses, but typically task-specific outside of the above
- Normally uses IR (except in the movies, where everything is a highly visible red laser)

Reflecting to Photoresistor/Photodiode

- Same basic principle as the last slide, but emitter and detector are positioned together
- Instead of detecting when an object is blocking the light's path, they detect when an object is close enough to reflect light from the emitter back onto the detector
- e.g. Great for line-sensing
  - Typically used in groups for this task
- Again, typically IR
  - So, the detected surface should be reflective to IR!

Tilt Sensor

The simplest tilt sensors are either *on* or *off*, based on how far off they are from "level"

- *Typically* single-axis
- e.g. a tiny drop of mercury
- Good as a safety mechanism (e.g. knowing when flipped or about to flip)

Accelerometers vs Gyros

Both accelerometers and gyroscopes deal with positioning/orientation

- Accelerometers measure *acceleration* (duh)
  - Linear is far more common
    - 3 axes is pretty typical, though you'll sometimes see fewer
  - Rotational is less common (outside avionics/aerospace)
- Force is effectively also acceleration from the sensor's perspective (i.e. gravity counts as acceleration)
  - This means that, based on a constant gravity, it can be used to infer orientation!
    - But, this can also be thrown off by sudden movements, and position is... trickier
- Gyros measure *rotation* (**not** angle!)
  - Using them for angles requires constant measurements to track rotation over time
  - They have the potential for *drift* when used alone

Magnetic Sensors

A magnetic sensor can detect magnets (gasp!)

- May act like a simple switch
  - e.g. Reed switch
- May provide some level of proportional feedback based on magnetic field via transducer
  - i.e. to some extent, can know how far away the magnetic field is
- Often another replacement for mechanical switches
- Also has automotive uses, and can be used for shaft encoders (again, a later topic)

Digital Compass (Magnetometer)

- Provides 3-dimensional feedback on magnetic fields
- At the very least, can be good for use as a compass
- Can also augment knowledge of orientation!
- Unfortunately, can also be thrown off by presence of magnets/metals

Inertial Measurement Units (IMUs)

- A special device that combines accelerometers, gyros, and (ideally) a magnetometer
- By combining information from all three types of sensor, far more reliable data on orientation can be returned
- Especially good for drones/automated flying
- Redundancy of sensors helps to mitigate drift

Global Positioning System (GPS)

- Yes, this counts
- No, I'm not going to explain how GPS works

Rangefinding

Finding your range!

- How do you measure the distance between two points?
  - (particularly when one of those points is you)
- We wish to be able to determine distance without having a physical presence at the end point
  - Although, that could also be a potentially interesting problem to solve!
- How do humans do it?
  - Can we easily adapt that to an electronic equivalent?
    - Spoiler: No. Not easily

Rangefinding

Infrared

Have you noticed how many of our sensors have relied on infrared?

- Similar to the previous IR-based sensors, an IR emitter blasts out IR light
- The IR light (hopefully) hits an object and (hopefully) reflects it back
- A sensor absorbs and recognizes the reflected light and sends a signal
- The angle of reflection is measured
  - Based on triangulation, we can calculate distance!
- Nothing could possibligh go wrong!
  - Possibly go wrong.
    - That's the first thing that's ever gone wrong
- What could go wrong?

Rangefinding
Laser

- Generally used like IR, except lasers have a much farther range
- Lasers can be aimed more narrowly
  - This can actually be both a good thing and a bad thing
- Lasers can also be *very* quickly re-aimed (think laser light show), to take multiple readings in a line
  - This sort of "scanning" rangefinder can give you a set of distances across a wide angle, similar to a primitive height map (except for depth)
- Laser rangefinders can be based on different principles
  - e.g. *time of flight*, or by studying the result of superimposing reflected waves over what's being sent
- Of course, these can require quite a bit of power, and additional processing for fancy features

Rangefinding

Ultrasonic

- Still the same principle, except... neat.
- Could we simply use a microphone? Why or why not?
  - (Seriously, let's discuss it!)
- So, how do we do it?
  - (This is where I'm supposed to get talk-y. Make sure I get talk-y)
- What could go wrong with this one?
- How do we describe the sensor's profile?
  - Angle? Range?
    - Yes.
    - But still more!
  - `http://www.robotshop.com/en/maxbotix-ez2-ultrasonic-ranger.html`

Additional Thoughts

How could we determine the position (angle) of a spindle? Or the angle of a joint?

- Potentiometer?
- Infrared or hall effect quadrature encoder?
- Tune in next week, same bat time, same bat channel!

Additional Examples

- Barometric/pressure
  - Can you think of any uses for this?
- Humidity
- Water (and water *flow*)
- Chemical (i.e. a ‘digital nose’)
  - CO/CO2/Alcohol/Formaldehyde/Benzene/Toluene/Acetone (i.e. gases)
- Flame
  - really just a task-specific, wide-range infrared sensor
- pH
- Capacitance
  - This one’s a neat one!
- UV
- Radiation
- Dust/smoke

Additional Concerns

- Signal processing and filtering
- Increasing gain/amplifying
- Thresholding
- Polarization?
- Modulation? (Did I remember to mention this one?)
- etc.

Just remember that there's a difference between knowing how to do it "in theory" and actually doing it. Be prepared for some fiddling (and revising)

Why are we even discussing this?

Isn't this something you can look up?

Well, yeah, you can. But a familiarity with different types of sensors is still important.

For a given use case (or task, or robot), you'll typically need to decide on a *sensor suite* — a selection of sensors that will collect all useful information (and hopefully *only* useful information) from the environment, so that the agent can make decisions.

Try thinking up a possible use for a robot, and then consider what sensors you might include. This should be included as one of your assignment questions, but should we also try it as a class exercise?

Questions?

Comments?

Helpful tips on avoiding the robot uprising?