Lecture 01.03 Robot sensitivity

A necessary part of a robot's intelligence is its ability to sense its environment. The old joke that

> *to a hammer*
> *everything looks like a nail*

is apropos and pairs well with the gibe

> *dummer than a bag of hammers*

to suggest that intelligence requires a sensitivity utterly lacking in a hammer, which, of course, makes a poor robot. But what does it mean to be sensitive? Fundamentally, it involves an interaction between a robot and itself or its environment. This interaction is called *perception* or *measurement*, which is another fascinating field of study. This is not the place to delve into the theory of measurement, but I do highly recommend doing so at some point.

perception
measurement

01.03.1 Measurement and perception

So a robot measures itself (*proprioception*) and its environment (*exteroception*). Clearly, for intelligent behavior in an environment, it must act in accordance with this measurement. In Lecture 01.05 we will consider the details of acting in accordance with a measurement, but for now, we can just acknowledge that it must be so.

proprioception
exteroception

What about itself and its environment does a robot measure? Given the mechanicality discussed in the preceding lecture, it certainly has to measure aspects of space and time: length, position, duration, velocity, acceleration, force, torque, etc. But additional quantities will be important in many applications: voltage, current, pressure, flowrate, temperature, heat, sound, light, etc.

How does a robot measure? Consider Figure 01.3. The device at the point of measurement is called a *sensor*. A sensor output is almost always a electronic *signal*: a low-power, information-bearing voltage through time. A sensor is frequently supported by electronics that provide power to the sensor, amplify the signal, or filter the signal. The output signal of the support electronics is usually connected to more electronics or a computing device that decides what to do with the measurement.

sensor
signal

Measurements are never perfectly accurate; in fact, it is a fundamental quality of measurement that

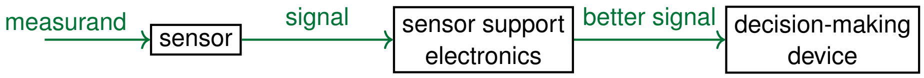

Figure 01.3: diagram of a measurement.

> *every measurement affects the measurand.*

thermal noise

That is, measuring changes the state of the thing measured. And beyond this fundamental limit, virtually all measurements include *thermal noise* a random signal that is introduced through the microscopic motion of matter at nonzero temperature.

01.03.2 Sensors

transducer
nanotechnology
MEMS

A sensor, then, is a type of energy *transducer*, converting one form of energy into another. Since the output energy domain is normally electronic, sensors are electro-mechanical/photo/thermo/etc. transducers. This is one reason there has been such interest in materials and processes that exhibit this type of transduction. For instance, piezo-electric materials convert mechanical stress into a flow of charge (current). Research into transducers like this have been combined with *nanotechnology* to build *micro-electro-mechanical systems* (MEMS) sensors that fit on a microchip.

01.03.2.1 Types of sensors

proprioceptive
exteroceptive

Sensors that measure quantities related to the robot's own state are called *proprioceptive*. Those that measure quantities related to its environment are called *exteroceptive*.

passive
detector
active
emitter

Passive sensors measure by means of a *detector* alone. Conversely, *active sensors* use an *emitter* with a detector.

simple

A *simple sensor* is one that provides a signal that requires relatively little post-processing by the sensor support circuitry or decision-making device. Examples of simple sensors include the following.

Switches are sensors that have only two states, typically instantiated as a circuit with contacts that close or break the circuit.

Pressure or force sensors are touch sensors that are sensitive to pressure on or force through the sensor by piezoelectric transduction or resistance-based strain gauge.

Photocells are electronically resistive sensors, the resistance of which varies with light exposure; these are typically slow.

Polarizing filters polarize light such that the light not parallel to the polarizing plane is filtered.

Reflective optosensors are sensors that detect light from an *emitter* (usually an LED) that is collected by a *photodiode* or *phototransistor*. These are much faster detectors than photocells. There are two types.

> **Reflectance sensors** require the light to reflect off an object and return to the detector.
>
> **Break beam sensors** have their emitter and detector pointed at one another such that an object may interfere with the beam.

Shaft encoders encoders, are used to measure the angular position of a shaft. These are typically *optical* and *quadrature* encoders that also indicate the direction of rotation. Basically, an emitter bounces two lasers off a spinning wheel with stripes offset 90 degrees from each other.

Potentiometers (i.e. "pots" or "rheostats") are variable resistors. They often have a knob on them, the angular positions of which correspond to varying electronic resistance.

Example 01.03-1 a human body's sensors

Thinking about the human body as a very advanced robot can help us better design robots. Identify which of the above types of sensors one could say, by analogy, a human typically has.

For actionable information from a *complex sensor*, more support and potentially computation is required than for simple sensors. The following are important types.

complex

Gyroscopes and accelerometers can be used to detect the motion and especially the orientation of a robot. Gyroscopes used to be built as macroscopic flywheels, the angular momentum of which would maintain its orientation when mounted in gimbals. Today, MEMS mimic this behavior so that gyroscopes can be inexpensively and conveniently placed on a printed circuit board (PCB).

Ultrasound (i.e. "sonar") sensors allow us to use *echolocation* in robotics. Sonars emit a chirp and measure the time-of-flight for the chirp to

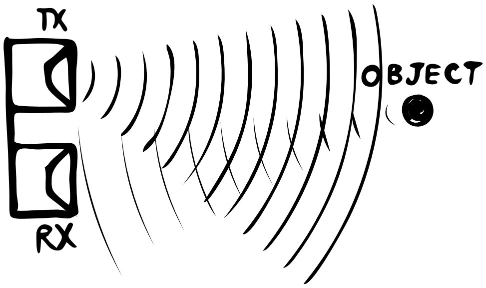

Figure 01.4: a sonar emitter (TX) transmitting a sound wave that reflects of an object and is detected by a receiver (RX). (PR)

specular reflection

return. It's great. *Specular reflection* is the reflection from the surface of an object being detected by sonar. Smooth surfaces are hard to detect because the waves can be completely reflected away from the detector. Rough surfaces are better. More sensors (in configurations called *phased arrays*) improve accuracy of sonar systems. For an illustration of sonar, see Figure 01.4.

Lasers emit coherent beams of light, some visible, others not. Laser sensors can use the same time-of-flight principles as sonar to measure distance, but must use phase-shift information for short distances (because light's pretty fast). Advantages of lasers are that they are faster than sonar, have good resolution, and have fewer specularity issues. Disadvantages include that they are much more expensive than sonar, bulky, and provide limited information (small beams!).

Cameras capture an *image* of a *scene*. Processing these images is a huge challenge.

Edge detection processing attempts to find the edges in an image.

Segmentation is the process of organizing an image into sections that correspond to an object in the image.

Model-based vision uses stored *models* to compare with features in images.

Stereo vision gives two views of one scene, adding depth and three-dimensionality to images.

01.03.3 Sensor fusion

sensor fusion

Sensor fusion is the process of combining information for several sensors. An example of sensor fusion is the fusion of gyroscopic and accelerometer data to yield an accurate estimation of the orientation of an object. Gyroscopes can be used to measure the three-axis angular velocity of an object very quickly (their response is fast), but in order to determine the angle, the angular velocity must be integrated to get position. Unfortunately, this is plagued by an accumulation of error through time. However, the angular position can be measured quite accurately from a three-axis accelerometer by tracking the gravitational acceleration direction. The drawback is the accelerometer is slower to respond. In short, for this application, gyroscopes are fast but lose accuracy over time and accelerometers are slow but accurate.

Enter sensor fusion. A quick response and accurate estimation of the angular orientation can be found by techniques such as the venerable *Kalman filtering*.

Kalman filtering