Introduction to Game Programming and Robotics

Unit # 6

Sensors

- Developing a robot program often takes the form of an iterative search, in which the programmer seeks the proper balance between the needs of the algorithm on one hand and the abilities of available sensors on the other.
- The algorithm you choose to employ will dictate the sensors you select; but often the limitations of existing sensors will force you to modify your preferred algorithm or replace it all together.

Sensor and Transducer

- The *sensor* is a device that measures some attribute of the world.
- The term *transducer* is often used interchangeably with sensor.
- A transducer is the mechanism, or element, of the sensor that transforms the energy associated with what is being measured into another form of energy.
- A sensor receives energy and transmits a signal to a display or a computer.
- Sensors use transducers to change the input signal (sound, light, pressure, temperature, etc.) into an analog or digital form capable of being used by a robot.

Proprioceptive vs. Exteroceptive Sensors

- We classify sensors using two important functional axes: *proprioceptive/exteroceptive and passive/active.*
- *Proprioceptive sensors measure values internal to the system (robot); for example,* motor speed, wheel load, robot arm joint angles, battery voltage.
- *Exteroceptive sensors acquire information from the robot's environment; for example,* distance measurements, light intensity, sound amplitude.
- Hence exteroceptive sensor measurements are interpreted by the robot in order to extract meaningful environmental features.

Active vs. Passive Sensors

- A sensor is often classified as being either *passive sensor or active sensor.*
- Passive sensors rely on the environment to provide the medium for observation. Examples of passive sensors include temperature probes, microphones, and CCD or CMOS cameras.
- Active sensors put out energy in the environment to either change the energy or enhance it.
- A sonar sends out sound, receives the echo, and measures the time of flight.

Proprioceptive Sensor

- Proprioception is dead reckoning, where the robot measures a signal originating within itself.
- In robotics, actuators are generally motors.
- Many motors come with a *shaft encoder* which measures the number of turns the motor has made.
- If the gearing and wheel size is known, then the number of turns of the motor can be used to compute the number of turns of the robot's wheels, and that number can be used to estimate how far the robot has traveled.
- Proprioception is often only an estimate. This is due to the impact of the environment on the actual movement of the robot.
- A wheeled robot may travel different distances for the same encoder count on a sidewalk, grass, and wet grass.

Proximity Sensors

- Proximity sensors measure the relative distance (range) between the sensor and objects in the environment.
- Since the sensor is mounted on the robot, it is a straightforward computation to translate a range relative to the sensor to a range relative to the robot at large.
- Most proximity sensors are active.
- Sonar, also called ultrasonics, is the most popular proximity sensor, with infrared, bump, and feeler sensors not far behind.

Sonar

- Sonar is possibly the most common sensor on commercial robots operating indoors and on research robots.
- Sonar refers to any system for using sound to measure range.
- They are active sensors which emit a sound and measure the time it takes for the sound to bounce back.
- The *time of flight (time from emission to bounce back)* along with the speed of sound in that environment is sufficient to compute the range of the object.

Sonar (Cont'd)

- Sonars for different applications operate at different frequencies; for example, a sonar for underwater vehicles would use a frequency appropriate for traveling through water, while a ground vehicle would use a frequency more suited for air.
- Ground vehicles commonly use sonars with an ultrasonic frequency, just at the edge of human hearing.
- As a result the terms "sonar" and "ultrasonics" are used interchangeably when discussing extracting range from acoustic energy.

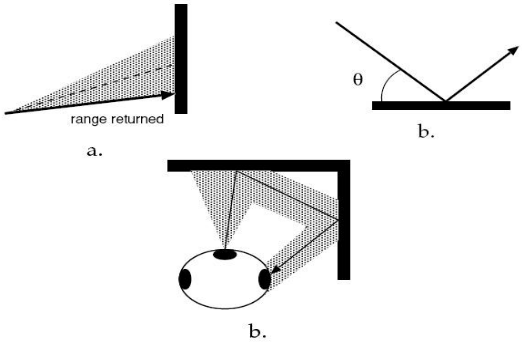
Sonar (Cont'd)

- In ideal indoor venues, a sonar might return ranges of up to 25 feet, while in the outdoors, the same sonar might go no further than 8 feet with any repeatability.
- So while the upper limit of the range reading depends on the sensor and the environment, the lower limit does not.
- Ultrasonic transducers have a "dead time" immediately following emission. The decay time translates into an inability to sense objects within 11 inches because measurements made during this period are unreliable.

Specular Reflection

- Although they are inexpensive, fast, and have a large operating range, ultrasonic sensors have many shortcomings and limitations which a designer should be aware of.
- Ultrasonic sensors rely on reflection, and so are susceptible to *specular reflection.*
- *Specular reflection* is when the wave form hits a surface at an acute angle and the wave bounces away.
- Even with severely acute angles, the surface is usually rough enough to send some amount of sound energy back. An exception to this is glass, which is very common in hospitals and offices where mail robots operate, but induces serious specular reflection.

Specular Reflection (Cont’d)



- (a) foreshortening
- (b) specular reflection
- (c) cross-talk

Foreshortening

- Recall that a sonar has 30^{o} field of view. This means that sound is being broadcast in a 30^{o} wide cone.
- If the surface is not perpendicular, one side of the cone will reach the object first and return a range first.
- Most software assumes the reading is along the axis of the sound wave.
- If it uses the reading (which is really the reading for 15^{o}), the robot will respond to erroneous data.
- There is no solution to this problem.

Cross-talk

- Specular reflection is not only by itself a significant source of erroneous readings; it can introduce a new type of error in rings of sonars.
- Consider a ring of multiple sonars. Suppose the sonars fire (emit a sound) at about the same time.
- Even though they are each covering a different region around the robot, some specularly reflected sound from a sonar might wind up getting received by a completely different sonar.
- The receiving sonar is unable to tell the difference between sound generated by itself or by its peers.
- This source of wrong reading is called *cross-talk*, because the sound waves are getting crossed.

Resolution Problem

- The 30^{o} cone also creates resolution problems. While sonars often have excellent resolution in depth, they can only achieve that at large distances if the object is big enough to send back a significant portion of the sound wave.
- The further away from the robot, the larger the object has to be.
- Most desk chairs and table tops present almost no surface area to the sensor and so the robot will often not perceive their presence and run right into them.

Power

- In practice, another problem leads to spurious sonar readings: power.
- The generation of a sound wave requires a significant pulse of energy. If the robot is operating at low power levels, the correct waveform will not be generated and the return signal will be worthless.
- This problem is often difficult to debug by looking at the sonar returns, which often suggest specular reflection or crosstalk.

Infrared

- Infrared sensors are another type of active proximity sensor. They emit near infrared energy and measure whether any significant amount of the IR light is returned.
- If so, there is an obstacle present, giving a binary signal.
- IR sensors have a range of inches to several feet, depending on what frequency of light is used and the sensitivity of the receiver.

Bumper/Feeler Sensors

- Another popular class of robotic sensing is *tactile*, or touch, done with bump and feeler sensors.
- Placement of bump sensors is a very important issue.

Collision Sensor

- The robot/environment force is non-zero anytime a collision occurs between the robot and an object in the environment.
- The robot itself generates the force of collision through the torque supplied by the drive wheels.

Collision Sensor (Cont’d)

- (a) If wheel/floor traction is high and the object with which the robot collides is heavy, the wheels will stall during the collision, i.e., the wheels stop turning even though the robot continues to apply power.
- (b) If traction is poor, the collision with a heavy object will stop the robot, but the robot’s wheels may not stall; instead, either or both wheels may continue to spin.

Collision Sensor (Cont'd)

- (c) If the object is light in weight, the robot may impel the object – both object and robot will move, but the robot will perhaps move more slowly or consume more power than before the collision.
- A properly functioning bumper will always detect situation (a). In situations (b) and (c) however, the sensitivity of the bumper determines whether the bump sensors accurately report a collision or generate a false negative.

Modern Day Sensors

- Historically, reactive robots used either inexpensive infrared (IR) or ultrasonic transducers to detect range.
- The earliest behaviors focused on basic navigational skills such as obstacle avoidance and wall following.
- The percept for these behaviors all involve knowing the distance to an occupied area of space.
- Now with the advent of inexpensive miniature cameras and laser range finders for consumer applications, computer vision is becoming increasingly common.
- In agricultural and transportation applications of reactive robots, GPS technology has become popular as well.

GPS

- GPS, or Global Positioning System, is becoming more common on robots, especially those used to automate farm equipment (an effort called *precision agriculture).*
- GPS systems work by receiving signals from satellites orbiting the Earth. The receiver triangulates itself relative to four GPS satellites, computing its position in terms of latitude, longitude, altitude, and change in time.
- GPS isn't a proprioceptive sensor per se since the robot must receive signals from the satellites, external to the robot. However, they are not exteroceptive sensors either, since the robot isn't computing its position relative to its environment.

GPS (Cont'd)

- Currently the only sets of GPS satellites that a receiver can triangulate itself against are the Navstar "constellation" maintained by the United States Air Force Space Command or the Russian counterpart, GLONOSS, maintained by the Russian Federation Ministry of Defense.
- Until early in the year 2000, the U.S. military actually introduced an error in the satellite message as to where the satellite actually is, which could result in triangulation errors of up to 100meters.
- The error was called *selective availability,* because it made accurate positioning available only to those users selected by the U.S. military.
- This was intended to prevent a hostile country from putting a GPS receiver on a guided missile.
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Heading Sensors

- Heading sensors can be *proprioceptive (gyroscope) or exteroceptive (compass).*
- They are used to determine the robot's orientation and inclination.
- They allow us, together with appropriate velocity information, to integrate the movement to a position estimate.
- This procedure, which has its roots in vessel and ship navigation, is called *dead reckoning.*

Attributes of a Sensor

- **Field of view and range.** Every exteroceptive sensor has a region of space that it is intended to cover. The width of that region are specified by the sensor's *field of view*, often abbreviated as FOV.
- The field of view is usually expressed in degrees; the number of degrees covered vertically may be different from the number of degrees covered horizontally.
- The other aspect is the *range,* or how far the sensor can make reliable measurements.
- Field of view and range are obviously critical in matching a sensor to an application. If the robot needs to be able to detect an obstacle when it's 8 feet away in order to safely avoid it, then a sensor with a range of 5 feet will not be acceptable.

Attributes of a Sensor (Cont’d)

- **Accuracy, repeatability, and resolution.** Accuracy refers to how correct the reading from the sensor is.
- But if a reading for the same conditions is accurate only 20% of the time, then the sensor has little repeatability.
- If the sensor is consistently inaccurate in the same way (always 2 or 3 cm low), then the software can apply a bias (add 2 centimeters) to compensate.
- If the inaccuracy is random, then it will be difficult to model and the applications where such a sensor can be used will be limited.
- If the reading is measured in increments of 1 meter, that reading has less *resolution than a sensor reading* which is measured in increments of 1 cm.

Attributes of a Sensor (Cont’d)

- **Responsiveness in the target domain.** Most sensors have particular environments in which they function poorly.
- Another way of viewing this is that the environment must allow the signal of interest to be extracted from noise and interference.
- For example, sonar is often unusable for navigating in an office foyer with large amounts of glass because the glass reflects the sound energy in ways almost impossible to predict.

Attributes of a Sensor (Cont'd)

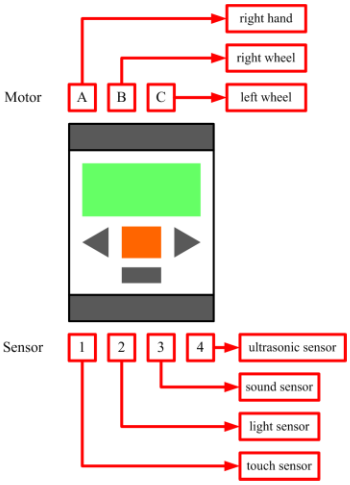
- **Power consumption.** Power consumption is always a concern for robots.
- Since most robots operate off of batteries, the less power they consume, the longer they run.
- Sensors which require a large amount of power are less desirable than those which do not. In general, passive sensors have less power demands than active sensors because they are not emitting energy into the environment.
- The amount of power on a mobile robot required to support a sensor package is sometimes called the *hotel load.* The sensor suite is the "guest" of the platform.
- The power needed to move the robot is called the *locomotion load.*

Attributes of a Sensor (Cont'd)

- **Hardware reliability.** Sensors often have physical limitations on how well they work.
- For example, Polaroid sonars will produce incorrect range reading when the voltage drops below 12V.
- Other sensors have temperature and moisture constraints which must be considered.
- **Size.** The size and weight of a sensor does affect the overall design. A micro-rover on the order of a shoebox will not have the power to transport a large camera or camcorder, but it may be able to use a miniature "Quick-Cam" type of camera.

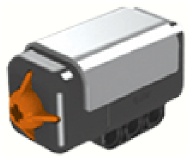
Lego Mindstorms NXT

- 32-bit ARM7 microcontroller
- 256 Kbytes FLASH, 64 Kbytes RAM
- 4 Sensors
  - Ultrasonic
  - Sound
  - Light
  - Touch



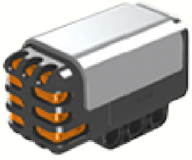
NXT Touch Sensor

- The Touch Sensor gives your robot a sense of touch. The Touch Sensor detects when it is being pressed by something and when it is released again.
- You can use the touch Sensor to make your robot pick up things: a robotic arm equipped with a Touch Sensor lets the robot know whether or not there is something in its arm to grab. Or you can use a Touch Sensor to make your robot act on a command. For example, by pressing the Touch Sensor you can make your robot walk, talk, close a door, or turn on your TV.



NXT Sound Sensor

- The Sound Sensor can detect both decibels [dB] and adjusted decibel [dBA].
- A decibel is a measurement of sound pressure
  - **dBA**: in detecting adjusted decibels, the sensitivity of the sensor is adapted to the sensitivity of the human ear. In other words, these are the sounds that your ears are able to hear.
  - **dB**: in detecting standard [unadjusted] decibels, all sounds are measured with equal sensitivity. Thus, these sounds may include some that are too high or too low for the human ear to hear.

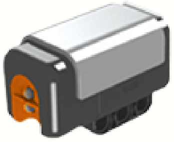


NXT Sound Sensor (Cont’d)

- The Sound Sensor can measure sound pressure levels up to 90 dB – about the level of a lawnmower.
- Sound pressure levels are extremely complicated, so the Sound Sensor readings on the MINDSTORMS NXT are displayed in percent [%]. The lower the percent the quieter the sound. For example:
  - 4-5% is like a silent living room
  - 5-10% would be someone talking some distance away
  - 10-30% is normal conversation close to the sensor or music played at a normal level
  - 30-100% are people shouting or music being played at a high volume

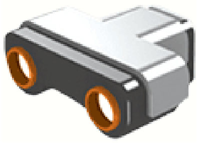
NXT Light Sensor

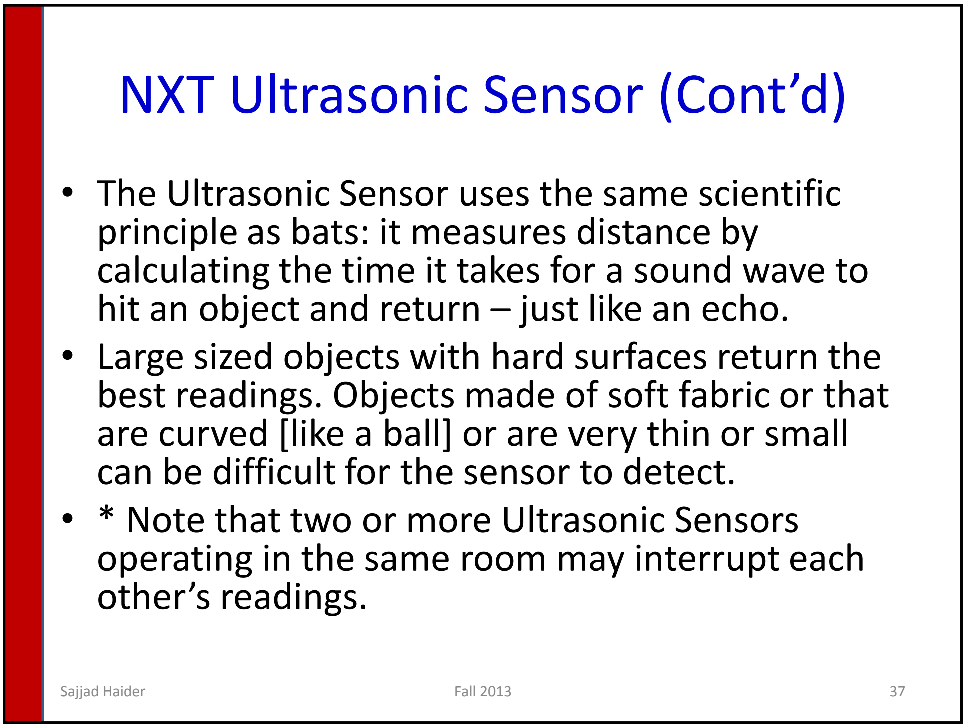
- The Light Sensor is one of the two sensors that give your robot vision [The Ultrasonic Sensor is the other]. The Light Sensor enables your robot to distinguish between light and dark. It can read the light intensity in a room and measure the light intensity of colored surfaces.
- You can use the Light Sensor to make a burglar alarm robot: when an intruder turns on the light in your room the robot can react to defend your property. You can also use the Light Sensor to make a line-following robot or a robot that can sort things by color.



NXT Ultrasonic Sensor

- The Ultrasonic Sensor is one of the two sensors that give your robot vision [The Light Sensor is the other]. The Ultrasonic Sensor enables your robot to see and detect objects. You can also use it to make your robot avoid obstacles, sense and measure distance, and detect movement.
- The Ultrasonic Sensor measures distance in centimeters and in inches. It is able to measure distances from 0 to 255 centimeters with a precision of +/- 3 cm.





NXT Ultrasonic Sensor (Cont’d)

- The Ultrasonic Sensor uses the same scientific principle as bats: it measures distance by calculating the time it takes for a sound wave to hit an object and return – just like an echo.
- Large sized objects with hard surfaces return the best readings. Objects made of soft fabric or that are curved [like a ball] or are very thin or small can be difficult for the sensor to detect.
- * Note that two or more Ultrasonic Sensors operating in the same room may interrupt each other’s readings.