What Is a Sensor?

- Anything that detects the state of the environment.

**Classification of sensors**

Attributes which can be used to classify sensors:
- stimulus
- working principle
- properties (attributes of the characteristic)
- application
Measurement

- Measurement Error
- Deterministic Error
- Random Error
- Precision: Small Deviation
- Accuracy: Small Error

**Some types of Sensors:**

- Ladar (laser distance and ranging)
  - Time of Flight
  - Phase shift
- Sonar
- Radar
- Infra-red
- Light sensing
- Heat sensing
- Touch sensing
- Resistive Sensing

**Robot Sensors**

- Manipulators
  - Proprioception, Force
- Mobile Robots
  - Dead reckoning, Tactile and proximity, Ranging, etc.
- Recommended reading:
  - Mobile Robots by Joseph J. Jones and Anita M. Flynn
  - Sensors for Mobile Robots by H.R. Everett

**Robot State**

- Battery level
  - Time until recharging is required
- Stall current
  - Detects when wheels are not turning
  - Needs to respond slowly
- Temperature
  - Of motors, microprocessor

<table>
<thead>
<tr>
<th>Model No Type</th>
<th>TC-10 Temperature Sensor Thermocouple K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input signal</td>
<td>Temperature</td>
</tr>
<tr>
<td>Range of operation</td>
<td>-200°C to 1200°C</td>
</tr>
<tr>
<td>Output signal</td>
<td>4-20 mA or 0-10V</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.2% of span</td>
</tr>
<tr>
<td>Repeatability</td>
<td>±0.1%</td>
</tr>
<tr>
<td>Speed of response</td>
<td>fast</td>
</tr>
<tr>
<td>Size</td>
<td>Probe length: 10 cm</td>
</tr>
<tr>
<td>Mounting</td>
<td>On tank wall</td>
</tr>
<tr>
<td>Environment</td>
<td>-40°C to 100°C</td>
</tr>
<tr>
<td>Power requirements</td>
<td>12-25V DC</td>
</tr>
<tr>
<td>Guarantee</td>
<td>90 days</td>
</tr>
<tr>
<td>Typical application</td>
<td>Chemical</td>
</tr>
</tbody>
</table>
How to Choose a Sensor:

There are four main factors to consider in choosing a sensor.

1) **Cost**: sensors can be expensive, especially in bulk.
2) **Environment**: there are many sensors that work well and predictably inside, but that choke and die outdoors.
3) **Range**: Most sensors work best over a certain range of distances. If something comes too close, they bottom out, and if something is too far, they cannot detect it. Choose a sensor that will detect obstacles in the range you need.
4) **Field of View**: depending upon what you are doing, you may want sensors that have a wider cone of detection. A wider “field of view” will cause more objects to be detected per sensor, but it also will give less information about where exactly an object is when one is detected.

Creative Uses:

- Sharp IR sensors are very accurate and operate well over a large range of distances proportional to the size of a Lego robot. However, they have almost no spread. This can cause a robot to miss an obstacle because of a narrow gap. One solution is to make the sensor pan.
- One could also use a light sensor to detect obstacles indoors. Inside, there tend to be lights at many angles and locations. Thus, around the edges of most obstacles, a slight shadow will be cast. A light sensor could detect this shadow and thus the associated object. Warning: this could be a very fickle design.
- Touch sensors can have their spread increased with large bumpers, and can be used for wall following to implement bug2. They are also dirt cheap.

Example of sharp IR mounted to sweep for a wider field of view.

Shadow cast indicates obstacle: one way to navigate with photo resistors.

Mobile Robot “force” sensors

- Microswitches for bumpers
- Bend Sensors (conductive ink)
  - 3-5x resistance change
- Force-sensing resistors
  - Several orders of magnitude resistance change

Resistive Sensors

- **Bend Sensors**
  - Resistance = 10k to 35k
  - Force to produce 90deg = 5 grams
  - www.jameco.com = 10$

- **Potentiometers**
  - Fixed Rotation Sensors
  - Easy to find, easy to mount

- **Light Sensor**
  - Good for detecting direction/presence of light
  - Non-linear resistance
  - Slow response

- **Cadmium Sulfide Cell**
- **Piezo Ultrasonic Transducers**
- **Pyroelectric Detector**
- **Thyristor**
- **Gas Sensor**
- **Piezo Bend Sensor**
- **Resistive Bend Sensors**
- **Mechanical Tilt Sensors**
- **Pendulum Resistive Tilt Sensors**
- **CDS Cell**
- **Resistive Light Sensor**
- **Hall Effect Magnetic Field Sensors**
- **Compass**
- **IRDA Transceiver**
- **IR Amplifier Sensor**
- **IR Modulator**
- **Remote Receiver**
- **IR Sensor w/lens**
- **GyroAccelerometer**
- **IR Reflection Sensor**
- **IR Pin Diode**
- **UV Detector**
- **Metal Detector**
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Potentiometers
- Produce a voltage proportional to shaft position
- Voltage divider

Problems:
- Friction (for backdriveable systems like haptic devices)
- Noise
- Resolution
- Linearity

Applications
- Measure bend of a joint
- Wall Following/Collision Detection
- Weight Sensor

Inputs for Resistive Sensors

Intensity Based Infrared
- Easy to implement (few components)
- Works very well in controlled environments
- Sensitive to ambient light

Modulated Infrared
- Insensitive to ambient light
- Built in modulation decoder (typically 38-40kHz)
- Used in most IR remote control units (good for communications)
- Mounted in a metal Faraday cage
- Cannot detect long on-pulses
- Requires modulated IR signal

Voltage divider:
You have two resistors, one is fixed and the other varies, as well as a constant voltage:
\[ V_1 - V_2 \frac{R_2}{R_1 + R_2} = V \]

Comparator: if voltage at + is greater than at -, high value out
Digital Infrared Ranging

- 5V output
- Insensitive to ambient light and surface type
- Minimum range ~ 10cm
- Beam width ~ 5deg
- Designed to run on 3V -> need to protect input
- Uses Shift register to exchange data (clk in = data out)
- Moderately reliable for ranging

Optics to convert horizontal distance to vertical distance

Polaroid Ultrasonic Sensor

- Mobile Robot
- Electric Measuring Tape
- Focus for Camera

http://www.robotprojects.com/sonar/sonar.htm

Theory of Operation

- Digital Init
- Chirp
  - 16 high to low
  - -200 to 200 V
- Internal Blanking
- Chirp reaches object
  - 343.2 m/s
  - Temp, pressure
- Echoes
  - Shape
  - Material
- Returns to Xducer
- Measure the time

Problems

- Azimuth Uncertainty
- Specular Reflections
- Multipass
- Highly sensitive to temperature and pressure changes
- Minimum Range

Not Gaussian!!
Problem with Naïve Model

Reducing Azimuth Uncertainty

- Pixel-Based Methods (Most Popular)
- Region of Constant Depth
- Arc Transversal Method
- Focusing Multiple Sensor

Pixel-Based Methods
- Region of Constant Depth
- Arc Transversal Method
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Combine info with Bayes Rule (Morevac and Elfes)

Arc Transversal Method
- Uniform Distribution on Arc
- Consider Transversal Intersections
- Take the Median

Mapping Example

Metal Detector

DIODE 1C: Simulator

Diode converts AC signal to DC ripple and supplies bias to T3

When T2 is turned off, T3 is turned on

LED will drop about 2 volts
A comparator can be used to convert a two-state signal to digital logic.
When the + voltage is above the voltage on the - pin, the output is high.
When the + voltage is below the - voltage, the output is low.
The LM311 has an open collector (you need to provide pullup resistor).
This allows conversion from 9 volt logic to 5 volt logic.

Accelerometers

- ADXL202 2-axis accelerometer

- Mem technology provides precision mechanical-electrical devices
- ADXL202 outputs convenient PWM output whose duty cycle is proportional to acceleration
- Cost about 30$ - easy to interface to PIC

Accelerometer Uses

- Measure tilt of arm
- Measure Weight

Optical Encoders

- How do they work?
  - A focused beam of light aimed at a matched photodetector is interrupted periodically by a coded pattern on a disk
  - Produces a number of pulses per revolution (Lots of pulses = high cost)
- Quantization problems at low speeds
- Absolute vs. referential

Optical Encoders

- Phase-quadrature encoder
  - 2 channels, 90° out of phase
  - allows sensing of direction of rotation
  - 4-fold increase in resolution

Light Sensors

- Photoresistors (photocell)
  - Variable resistance, like a potentiometer
- Phototransistors
  - Greater sensitivity
- Photodiodes
  - Highest sensitivity, but low output requires amplifier
**Proximity Detectors**

- Near-infrared detectors (IRs)
  - Signifies whether something is present within a cone of detection
  - Emitter-detector pair
- Pyroelectric detector
  - Output changes with small changes in temperature over time
  - Detects radiation in the range of (6-10 μm)
  - Useful for sensing of humans

**Cameras**

- Video camera technology is rapidly changing
- CCD cameras can pick up near-infrared light
- On-board processing
- Cell phone revolution

**Sound sensors**

- Microphones
- Piezoelectric Film
  - Really senses vibrations
- Sonar
  - Measure time-of-flight with emitter-detector pair (ping, then echo)
  - Very commonly used in advanced robotics research

**Position and Orientation**

- Encoders on Wheels
  - Dead reckoning
  - Does not account for slip
- Rate gyroscope
  - Determines speed of rotation
- Tilt sensors (e.g., mercury switch)
- Compass
  - ~45 degrees error due to metal components/indoors
- GPS