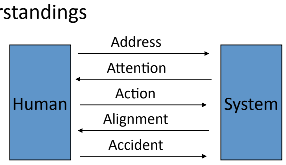
Sensors and Sensor Networks

5 Design Challenges in Communication

- **Address**: Directing communication to a system
- **Attention**: Establishing that the system is attending
- **Action**: Defining what is to be done with the system
- **Alignment**: Monitoring system response
- **Accident**: Avoiding or recovering from errors or misunderstandings



Address: *How do I address one (or more) of many possible devices?*

- GUI Answers
  - Keyboard
  - Mouse
- Exposed Challenges
  - Disambiguate signal-to-noise
  - Disambiguate intended target system
  - How to not address the system
- Possible Problems
  - No response
  - Unwanted response

Examples

- Augmented Objects
  - XeroxPARC's electronic tags project
  - RFID or IR sensors to initiate actions (proximity)

- Listen Reader
  - MIT's interactive children storybook
  - RFID tags to detect which page is open and capacitive field sensors measure human proximity to initiate playback
- Digital Voices
  - UCI's inter-machine communication project
  - communication sounds like music or "nice" sounds like birds, wind, water drops

Attention: *How do I know the system is ready and attending to my actions?*

- GUI Answers
  - Graphical feedback such as blinking cursors
- Exposed Challenges
  - Giving feedback so the user knows it has the system's attention
  - Periphery feedback
- Possible Problems
  - Wasted input if system not responding
  - Unintended action
  - Privacy and security problems

Examples

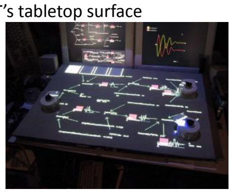
- Conference Assistant
  - GaTech's tool provides conference information (schedules, locations, presenter info, etc.), allows to take notes, indicates when presentation is being recorded, but also records user activities (arrival, location, departure, etc.) and shares this with other attendees
- Media Space
  - EuroPARC's project uses monitors next to cameras in public places to tell people they were on camera

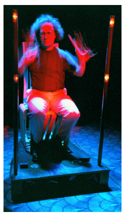
Action: *How do I effect a meaningful action, control its extent and possibly specify a target or targets of my action?*

- GUI Answers
  - Use standard GUI widgets, such as clicking and selecting text, to interact with the system
- Exposed Challenges
  - Identifying and selecting possible actions
  - Binding object to action
  - Avoid unwanted selection
  - Handling complex operations
- Possible Problems
  - Limited operations available
  - Failure to execute action
  - Unintended action

Examples

- Sensor Chair
  - MIT's gesture-based sound control system
  - http://web.media.mit.edu/~joep/MPEGs/penn.mpg
- Sensetable
  - MIT's tabletop surface





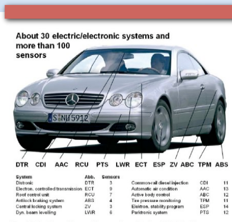
Alignment: *How do I know the system is doing the right thing?*

- GUI Answers
  - Graphical feedback such as text appearing
  - Auditory feedback
  - Detectable new state
- Exposed Challenges
  - Making system state perceivable
  - Timely, appropriate, and distinctive feedback on results and state
- Possible Problems
  - Differentiation problems
  - Inability to detect mistakes
  - Unrecoverable problems

Accident: *How do I avoid mistakes?*

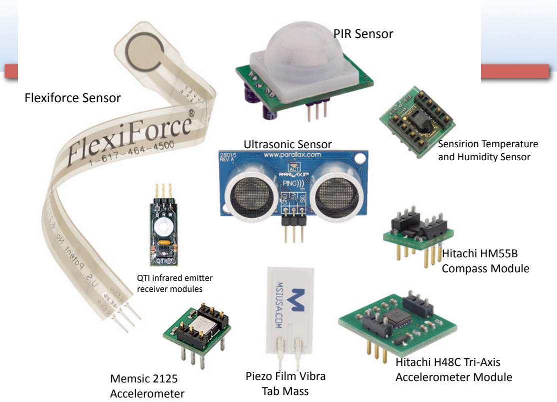
- GUI Answers
  - Control/guide in direct manipulation
  - Stop, cancel, undo or delete
- Exposed Challenges
  - Controlling or canceling system actions in progress
  - Disambiguating what to undo in time
  - Intervening when user makes obvious error
- Possible Problems
  - Unintended action
  - Inability to recover state

Sensors

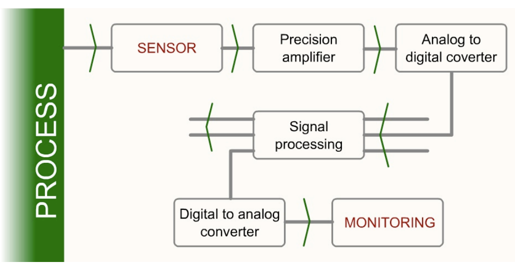


Basic Terms

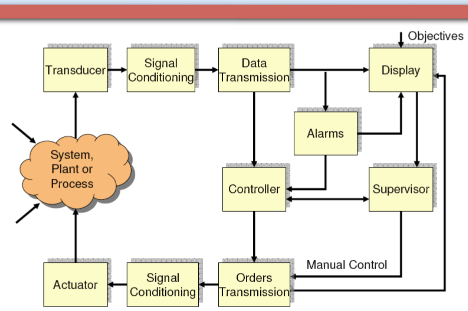
- Transducer: a device which converts one form of energy to another
- Sensor: a transducer that converts a physical phenomenon into an electric signal
  - an interface between the physical world and the computing world.
- Actuator: a transducer that converts electric signal to a physical phenomenon



From Physical Process to Digital Signal



A Measurement and Control System

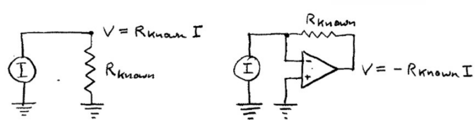


Sensor-to-Signal Interface

- Action of environment on a sensor causes it to generate an electrical signal directly
  - voltage source (V)
  - current (I) or charge (Q) source
- Action of environment on sensor changes an electrical parameter that we can measure
  - resistance changes: V ~ I
  - capacitance changes: $V \sim \int I\,dt$, $I \sim dV/dt$
  - inductance changes: $V \sim dI/dt$, $I \sim \int V\,dt$

Current-to-Voltage Conversion

- Simple: $I = V / R_{known}$
- Better: Use an "op amp"



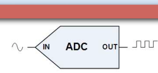
Signal Conditioning

- Filter for expected frequency regime
- Subtract DC offset ("zeroing")
- Amplify or attenuate signal ("scaling")
- Linearize relationship between measured and observed electrical parameter
  - now *usually* done in software after ADC
- ...

4-channel stereo multiplexed analog-to-digital converter for a sound card

Analog-to-Digital Converter (ADC)

- Many different principles



ELECTRICAL SYMBOL FOR ANALOG TO DIGITAL CONVERTER (ADC)

- Often integrated with microcontrollers
  - in some types, e.g., "successive approximation", the CPU participates in the conversion process
    - normally want to avoid this
- All involve trade-offs of speed (conversion time), resolution (number of bits), and cost

$$Q = \frac{E_{FSR}}{2^M} = \frac{E_{FSR}}{N}$$

- "Flash converter" is the fastest, has the lowest resolution and the highest cost
  - required for video digitization

(One) Classification of Sensors

Criterion	Classes	Example
Power supply	Modulating	Thermistor*
	Generating	Thermocouple**
Output signal	Analog	Potentiometer
	Digital	Position encoder
Operating mode	Deflection	Deflection accelerometer
	Null	Servo-accelerometer

*_Thermistor_: a resistor whose resistance changes with temperature.
**_Thermocouple_: a temperature-sensing element which converts thermal energy directly into electrical energy

Power Supply

- Modulating
  - Also known as Active Sensors
  - They need auxiliary power to perform functionality
  - Sensitivity can be controlled
- Self-Generating
  - Also known as Passive Sensors
  - They derive the power from the input

Operating Mode

- Deflection
  - The measured quantity produces a physical effect
  - Generates an apposing effect which can be measured
  - Faster
- Null
  - Applies the counter force
  - To balance the deflection from the null point (balance condition)
  - Can be more accurate but slow

Classification (cont'd)

A better classification would be the Physical Property which we are measuring…

- Temperature
- Pressure
- Humidity
- Light
- Microphone (sound)
- Motion detector
- Chemical detector
- Image Sensor
- Flow and level sensor
- … … …

Electrical Phenomena

- Resistive
- Capacitive
- Inductive
- Piezo-electric

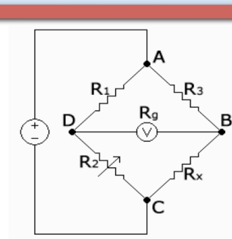
Resistance-based Devices

- Resistance of the material depends on the length, area and resistivity as:

$$R = \frac{L \cdot \rho}{A}$$

- If any one of the terms changes, it affects resistance
- The most common circuit used to measure the change in resistance is a Wheatstone bridge
- The output voltage is related to the source voltage as:

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$



Pressure Sensing: Principle and Types

- Transduces pressure into electrical quantity
- Pressure exerts force which can be converted to electrical voltage using various methods
- Types
  - Strain gauges
  - Capacitive diaphragms
  - Piezo-resistive or silicon cell
  - Bourdon tubes
  - Glass feed through with silicon cell

Pressure Sensor Types (1 of 2)

- Strain Gauges
  - Based on the variation of resistance of a conductor or semiconductor when applied to mechanical stress
  - Made of alloys like constantan, nichrome and also semiconductors
  - Can be bonded or un-bonded

- Capacitive diaphragms
  - Diaphragm acts as one plate of capacitor
  - The stress changes the space between capacitor plates
  - Can be made of strain gauge or other metal

Pressure Sensor Types (2 of 2)

- Piezo-resistive or Silicon Cell
  - Micro-machined silicon diaphragms
  - Piezo-resistive strain gauges diffused into it
  - Very sensitive to pressure

- Tubes and Feed-Through Glass
  - Glass feed through and silicon cell mounted on plastic housing
  - Based on the pressure difference

Humidity Sensing: Principle and Types

- Humidity is defined as the water vapor content in the air or other gases
- Measured as
  - Absolute Humidity
    - Ratio of the mass of water vapor to the volume of air or gas
  - Relative Humidity or RH
    - The ratio of the moisture content of air compared to the saturated moisture level at the same temperature or pressure
  - Dew Point
    - Temperature and pressure at which gas begins to condense into liquids

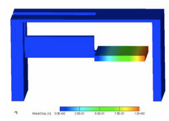
Humidity Sensor Types (1 of 2)

- Capacitive RH sensor
  - Change in dielectric constant is directly proportional to relative humidity in the environment
  - Very low temperature effect
  - 0.2-0.5 pF change in capacitance for 1% RH change

- Resistive Humidity Sensors
  - Measure the impedance change
  - Inverse exponential relationship to humidity
  - Mostly used are conductive polymer, salt etc.
  - Ceramic coated to avoid condensation effect

Humidity Sensor Types (2 of 2)

- Thermal Conductivity Humidity Sensors
  - Measure absolute humidity
  - Calculate the difference between dry air and air containing water vapor
  - One thermistor sealed in dry nitrogen and another exposed to environment
  - Difference in current proportional to humidity
- MEMS-based Humidity sensor
  - Polymide-coated cantilever beam
  - Provided with movable electrode
  - Absorption causes increase in beam mass
  - Deflection causes capacitance change



Temperature Sensing: Principle & Types

- A temperature sensor detects a change in a physical parameter such as resistance or output voltage that corresponds to a temperature change.

Type of Sensing

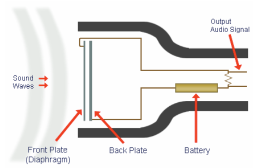
- Contact
  - Sensor is in direct physical contact with the object to be sensed
  - To monitor solids, liquids, gases over wide range
- Non-contact
  - Interprets the radiant energy of a heat source to energy in electromagnetic spectrum
  - Monitor non-reflective solids and liquids

Microphone Sensing: Principle

- A **microphone** is an acoustic to electric transducer that converts sound into an electrical signal.
- Microphones capture sound waves with a thin, flexible diaphragm. The vibrations of this element are then converted by various methods into an electrical signal that is an analog of the original sound.
- Most microphones in use today use electromagnetic generation (dynamic microphones), capacitance change (condenser microphones) or piezo-electric generation to produce the signal from mechanical vibration.

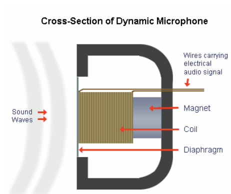
Condenser (or Capacitor) Microphones

- In a condenser microphone, the diaphragm acts as one plate of a capacitor, and the vibrations produce changes in the distance between the plates.
- Since the plates are biased with a fixed charge (Q), the voltage maintained across the capacitor plates changes with the vibrations in the air.



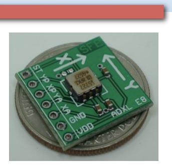
Dynamic Microphones

- In a dynamic microphone, a small movable induction coil, positioned in the magnetic field of a permanent magnet, is attached to the diaphragm.
- When sound enters through the windscreen of the microphone, the sound wave vibrations move the diaphragm.
- When the diaphragm vibrates, the coil moves in the magnetic field, producing a varying current in the coil through electromagnetic induction.

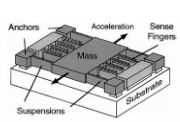


Accelerometer Sensor: MEMS

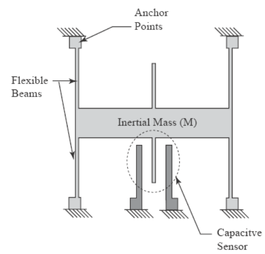
Types
- Piezo-resistive
  - Proof mass suspended with piezo-resistive beams
    - Simple structure, fabrication, and readout (low imp. output)
    - Large temp. sensitivity, smaller overall sensitivity than capacitance devices
- Capacitive
  - Acceleration is measured by the capacitance between a fixed plate and plate on the proof mass.
    - Stable (temperature, drift)
    - Can be susceptible to EMI.
  - Cost: approx $10.



2-axis Analog Devices Breakout Board

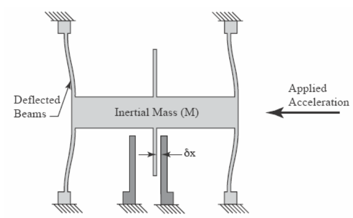


Accelerometer: Inner Working (1 of 2)



It consists of beams and capacitive sensor with some anchor points

Accelerometer: Inner Working (1 of 2)

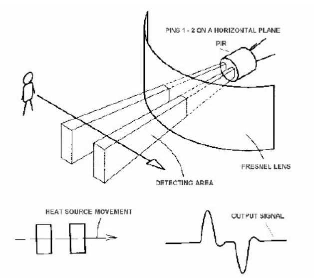


On applying the acceleration, the beams deflect and cause the change in capacitance.

Motion Detector: Types

- Photo Sensor
  - Beam of light crossing the room near the door, and a photo sensor on the other side of the room. When the beam breaks, the photo sensor detects the change in the amount of light and rings a bell (garage doors).
- Microwave- Or Ultrasonic-based
  - Burst of microwave radio energy and waits for the reflected energy to bounce back.
  - When a person moves into the field of microwave energy, it changes the amount of reflected energy or the time it takes for the reflection to arrive.
  - The same thing can be done with ultrasonic sound waves, bouncing them off a target and waiting for the echo.

Pyro-electric Infrared Motion Detector



Pyro-electric Infrared Motion Detector

- Humans, having a skin temperature of about 93 degrees F, radiate infrared energy with a wavelength between 9 and 10 micrometers. Therefore, the sensors are typically sensitive in the range of 8 to 12 micrometers
- The infrared light bumps electrons off a substrate, and these electrons can be detected and amplified into a signal.
- When a person walks by, the amount of infrared energy in the field of view changes rapidly and is easily detected. Electronics package attached to the sensor is looking for a fairly ***rapid change*** in the amount of infrared energy it is seeing.
- There is a single (or sometimes two) sensors inside looking for changes in infrared energy.

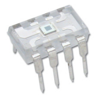
Light Sensing: Principles

- Photo-chemistry
  - Light renders silver halide grains in film “emulsion” “developable”

- Thermal physics
  - Heating effect of incident light heats a sensor that basically measures temperature
- Photo-physics
  - Interaction of light with matter frees electrons or promotes them from valence to conduction band

Photoelectric Effect

- Light absorbed by metal surfaces causes current to be ejected from them
  - for visible light, it is necessary to use alkali metals
  - typically cesium – in a vacuum



- Light absorbed by semiconductors causes their conductivity to increase (i.e., causes their resistivity to decrease)
  - depending on device structure and measuring approach, signal may be seen as photocurrent, photovoltage, or photoconductance