Lecture 15: Sensors and Input

Seyed-Hosein Attarzadeh-Niaki

Review

- Sensors and actuators
- Models of sensors
  - Calibration
- Range and dynamic range
- Quantization
- Noise
- Sampling
  - Aliasing
- Harmonic distortion
- Signal conditioning
- Analog-to-digital converters

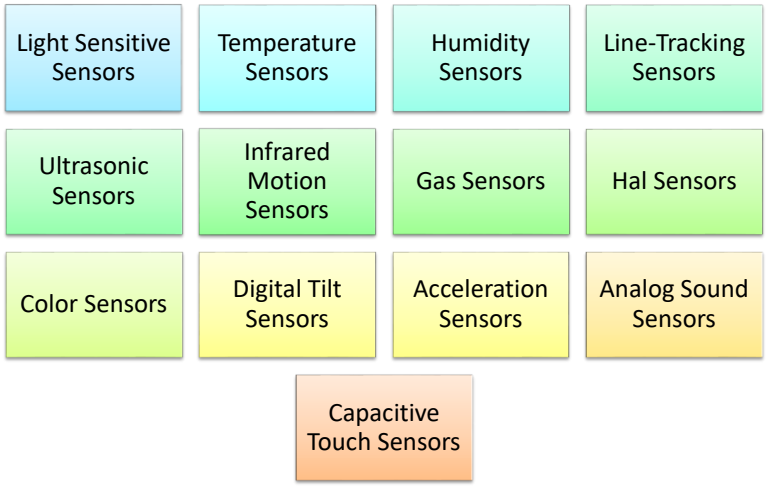
Outline

- Sensor Characteristics
- Sensor Types

Sensor Characteristics

Active vs. Passive	Active sensors: Require an external source of power (excitation voltage)
	Passive sensors: The output power is almost entirely provided by the measured signal
Digital vs. Analog	Digital sensors: The signal produced or reflected by the sensor is binary
	Analog sensors: The signal produced by the sensor is continuous and proportional to the measurand

Sensor Types



Light Sensitive Sensors

- Electric signal of a light sensor can be produced by two kind of response from a sensing material when photons are absorbed
  - Quantum
  - Thermal
- Energy of a single photon: $E = hv$
- When a photon strikes a conductor, it may result in the generation of a free electron.
  - Photoelectric effect: $hv = \Phi + K_m$

Light frequency

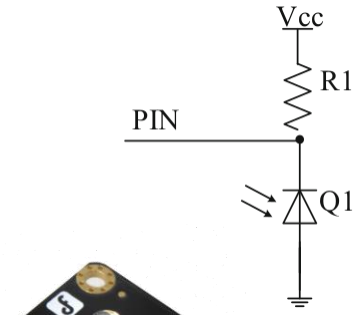
Planck's constant $h = 6.626 \times 10^{-34}$ JS

Work function of photon energy

maximum kinetic energy of the electron upon it exiting the surface

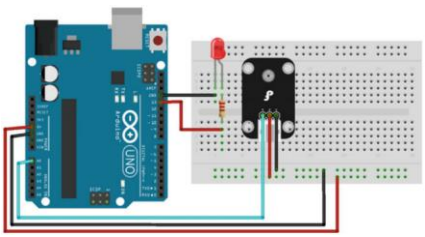
Photodiodes

- Semiconducting optical sensor
- Biased against its easy flow direction
- The current is very low
- An electron is freed when a photon is absorbed
- A photodiode produces detectable currents for photons with wavelength less than the *cutoff*



Demonstration using DFR0026

```
int LED = 13; //define LED digital pin 13
int LIGHT = 0; //define light analog pin 0
int val = 0; //define the voltage value
void setup() {
  pinMode(LED, OUTPUT); //Configure LED as output mode
  Serial.begin(9600); //Configure baud rate 9600
}
void loop() {
  val = analogRead(LIGHT); // Read voltage value (0 - 1023)
  Serial.println(val); // read voltage value from serial monitor
  if (val < 700) { // If lower than 700, turn off LED
    digitalWrite(LED, LOW);
  }
  else { // Otherwise turn on LED
    digitalWrite(LED, HIGH);
  }
  delay(10); // delay for 10ms
}
```

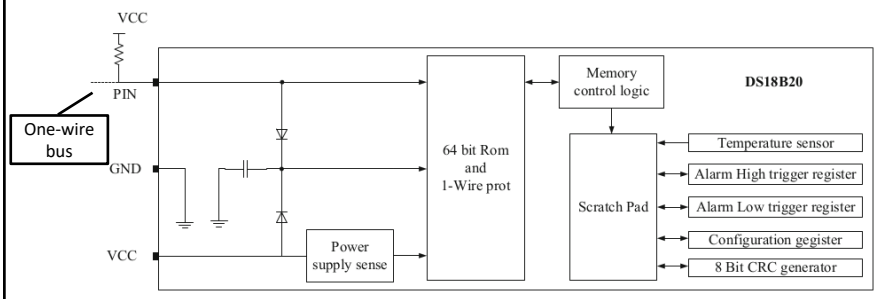


Temperature Sensors

- A number of passive and active temperature sensors
  - Thermocouple – Generates voltage
  - Resistive temperature detector (RTD)
  - Thermistor (thermal resistor) – PTC, NTC
  - Silicon temperature sensor – Analog, Digital
- Many kinds of thermal management products
  - Logic Output
  - Voltage Output
  - Serial Output

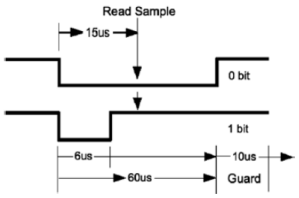
Digital Temperature Sensor

- DS18B20 is a direct-to-digital temperature sensor
- Communicates over a 1-Wire bus
- Can be powered by an external supply on the VCC pin, or it can operate in “parasite power” mode



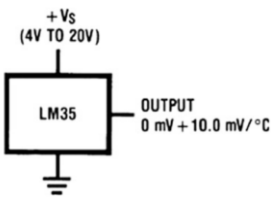
1-Wire Interface

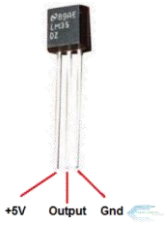
- Low-cost remote sensing by supplying power over the same wire used for data communications
- The data line is driven by open collector transistors in the master and slave devices. The line is held high by a pull-up resistor when the driver transistors are all in the Off state
- The master device is always in control of the 1-Wire bus. Slaves speak only to the master, and only when requested
- Whether writing a 0 or 1 bit, the sending device brings the bus line low.
  - This announces the start of a data bit
  - When a 0 is being transmitted, the line is held low for approximately 60 microsec. Then the bus is released and allowed to return high
  - When a 1 bit is being transmitted, the line is held low for only about 6 microsec before releasing the bus
  - Another data bit is not begun until 70 microsec after the start of the previous bit.

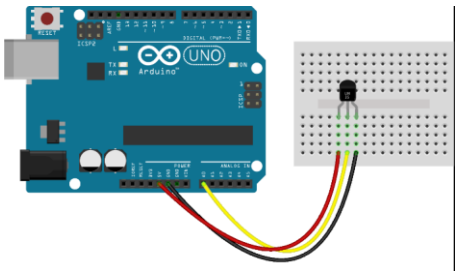


Analog Temperature Sensor

- Acts as a variable resistor
  - As the temperature changes, the voltage output of the sensor changes also
- Platinum resistance: measurement of 800 °C
- Thermal resistance and semiconductor temperature sensor: 100–200 °C
- Well-known semiconductor temperature sensor: LM35

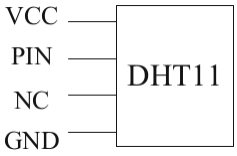


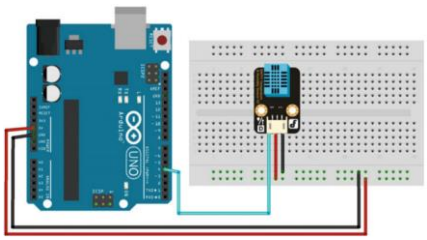




Humidity Sensor

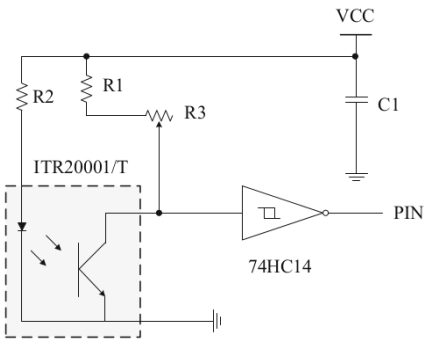
- DHT11 is a four PIN sensor that can measure
  - Temperatures ranging from 0 to 50 °C
  - Relative humidity ranging from 20 to 95%
- Uses its own 1-wire protocol





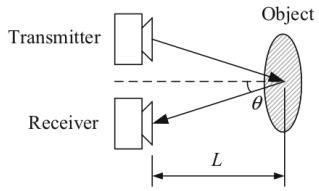
Line-Tracking Sensor: SEN0017

- An infrared emitting diode and an NPN silicon photo-transistor, encased side-by-side on a converging optical axis
- The phototransistor receives radiation from the IR only
- 74HCT14: inverter with Schmitt-trigger inputs



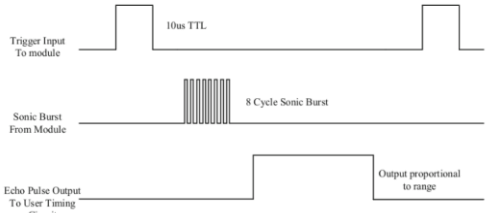
Ultrasonic Sensors

- Uses sonar for distance measurement
  - Similar to bats and dolphins
- The distance *L* to the object can be calculated as $L = \frac{vt\ \cos\theta}{2}$
- Example: L = 10, *v* (the speed of ultrasonic waves) = 340 m/s, t = 294 µs



HC-SR04

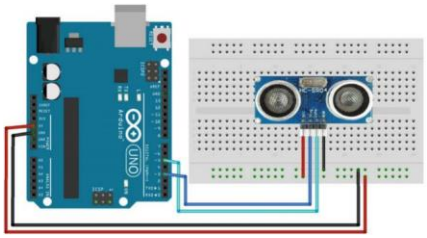
- Measures distances in the range of 2cm–400cm with an accuracy of 3mm
- The sensor module consists of
  - Ultrasonic transmitter,
  - Receiver
  - Control circuit



- Working principle:
  1. High level signal is sent (10 µs) using the Trigger
  2. Sends eight 40 kHz signals and detects reflection
  3. If yes, the time of the high duration is the time gap between sending and receiving
  4. Distance is calculated

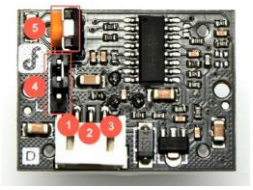
HC-SR04

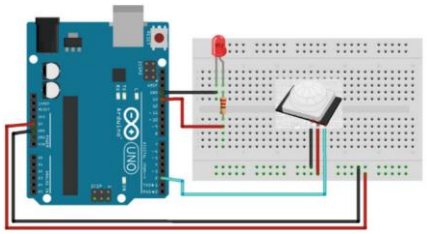
```
const int trigPin = 5; // PWM trigger
const int echoPin = 3; // PWM Output 0-25000US,Every 50US represent
1cm
long duration;      // defines variables
int distance;
void setup() {
  pinMode(trigPin, OUTPUT); //Sets the trigPin as an Output
  pinMode(echoPin, INPUT); // Sets the echoPin as an Input
  Serial.begin(9600); //configure baud rate to 9600 bps
}
void loop() {
  digitalWrite(trigPin, LOW); //Clears the trigPin
  delayMicroseconds(2);
  // Sets the trigPin on HIGH state for 10 micro seconds
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH); // Reads the echoPin, returns
the sound wave travel time in microseconds
  distance = duration * 0.034 / 2; // Calculating the distance

  Serial.print("Distance Measured="); // Prints the distance on
the Serial Monitor
  Serial.print(distance);
  Serial.println("cm");
}
```



Digital Infrared Motion Sensor

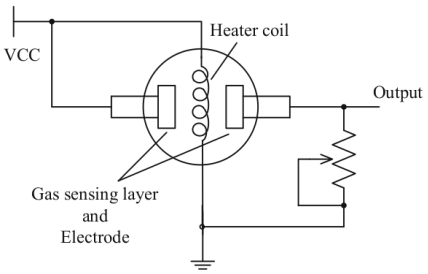
- An electronic device that is used for motion detection
- Vital component of comprehensive security systems for businesses and homes
- Example: SEN0018
  - Power up and wait 12s for the sensor to obtain a snapshot of the still room.
  - If anything moves after that period, the Pinout will go low





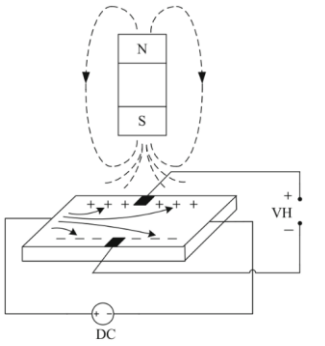
Gas Sensor

- Detect gas leakages of LPG, i-Butane, Propane, Methane, Alcohol, Hydrogen, and smoke in houses and factories
- The conductivity of the gas sensing layer changes when a gas leakage occurs, which changes the voltage value in the output.



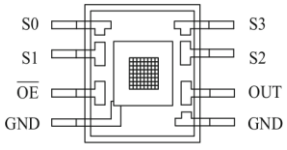
Hall Sensor

- An omnipolar magnet sensor used to detect magnetic objects
- Applications
  - Proximity switching
  - Positioning
  - Speed detection
  - Current sensing
- When a beam of charged particles passes through a magnetic field, forces act on the particles and the beam is deflected from the original path.
  - Particles are deflected
  - Causes Pos/Neg charges
  - voltage between the planes (VH) can be detected
- Example: SEN0185

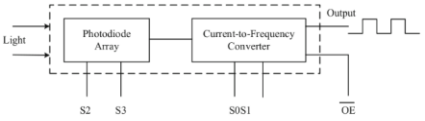


Color Sensor

- Applications
  - Test strip reading
  - Sorting by color
  - Ambient light sensing and calibration
  - Color matching
- Example: TCS3200
  - Reads an 8×8 array of photodiodes
    - 16 blue, 16 green, and 16 red filters; 16 no filter
  - One color is selected (S2&S3) and read
  - Generates a square wave whose frequency relates to the light intensity
    - can change the output signal frequency bandwidth (S0&S1)



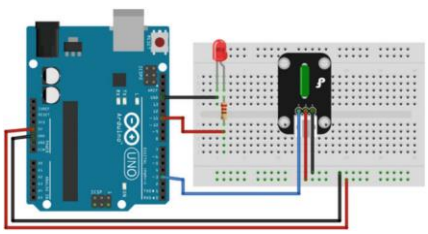
S2	S3	Photodiode type
L	L	Red
L	H	Blue
H	L	Clear (no filter)
H	H	Green

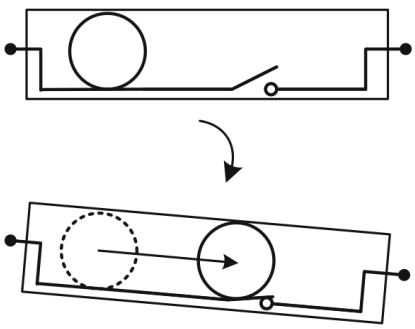


S0	S1	Output frequency scaling (f0)
L	L	Power down
L	H	2%
H	L	20%
H	H	100%

Digital Tilt Sensor

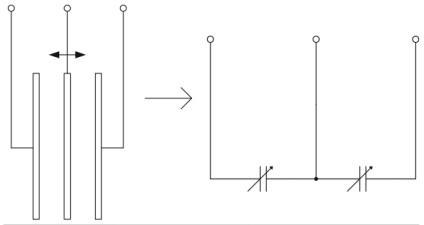
- A digital tilt switch
- Two modules
  - Mercury-based (toxic)
  - Ball-based



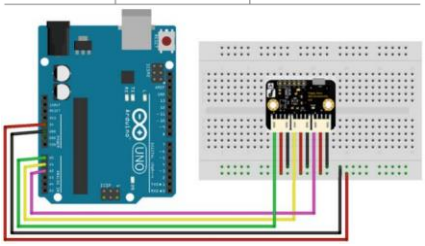


Triple Axis Acceleration Sensor

- An analog voltage output sensor that detects the acceleration of a moving object
- Device consists of
  - Surface micromachined capacitive sensing cell (g-cell)
  - Signal conditioning ASIC
- As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value changes
- Example: DFR0143 (MMA7361 triple axis accelerometer)

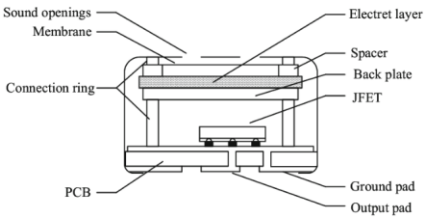


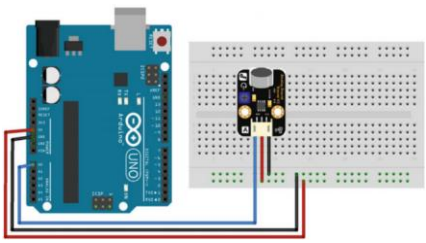
g-select	g-range (g)	Sensitivity (mV/g)
0	1.5	800
1	6	206



Analog Sound Sensor

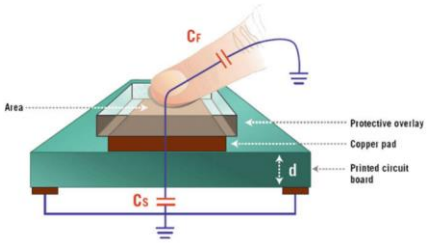
- Used in detecting loud sounds in an ambient environment
- The electret condenser microphone is a parallel plate capacitor and works on the principle of a variable capacitance

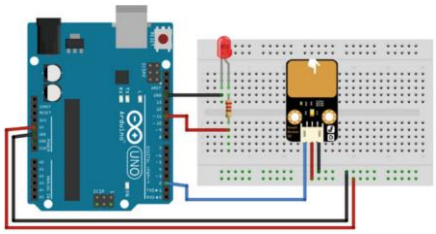




Capacitive Touch Sensor

- New way of touch sensor
- Durability, robustness, attractive product design, and cost
- The iron content in human blood creates strings of capacitors that are aligned to the surface of the body.
- When any object with capacitive characteristics (a finger) comes close to a capacitive touch sensor, it acts as another capacitor
  - Varies the effective capacitance
- Example: DFR0030





Next Lecture

- Actuators and output
- Read chapter 4 of Pan & Zhu