

CS7351 传感系统原理与设计

Principles and Design of Sensing Systems

Other Sensing Modalities

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Definitions

- A sensor is a device that measures a physical quantity
 - IMU
 - Light sensor
 - Temperature sensor
- An actuator is a device that modifies a physical quantity
 - Heater
 - Motor
 - Speaker



Sensor Transform Quantity into an Electric Signal

- Sensors generate analog signal **proportional** to physical quantity
- Then, microcontrollers can interact with analog signals
- How to generate an electrical signal?
 - Ohm's law: $V = I * R$ (voltage = current * resistance)
 - Vary any one of these three, an analog signal is created



Resistive Sensors

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

- L: length of the conductor
 - A: area of the conductor
 - ρ : resistivity of the conductor material
-
- Notice, various materials have resistivity that changes based on
 - Temperature, light, strain, etc.
 - (Can be a double-edged sword!)



Understanding the Sensor Voltage

- Once you get the voltage, what do you do with it?
- Need to understand the transfer function between voltage and the sensed quantity
 - Examples: accelerometer, magnetometer
- Hopefully, the function is linear



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 - Usually, it is NOT 😞



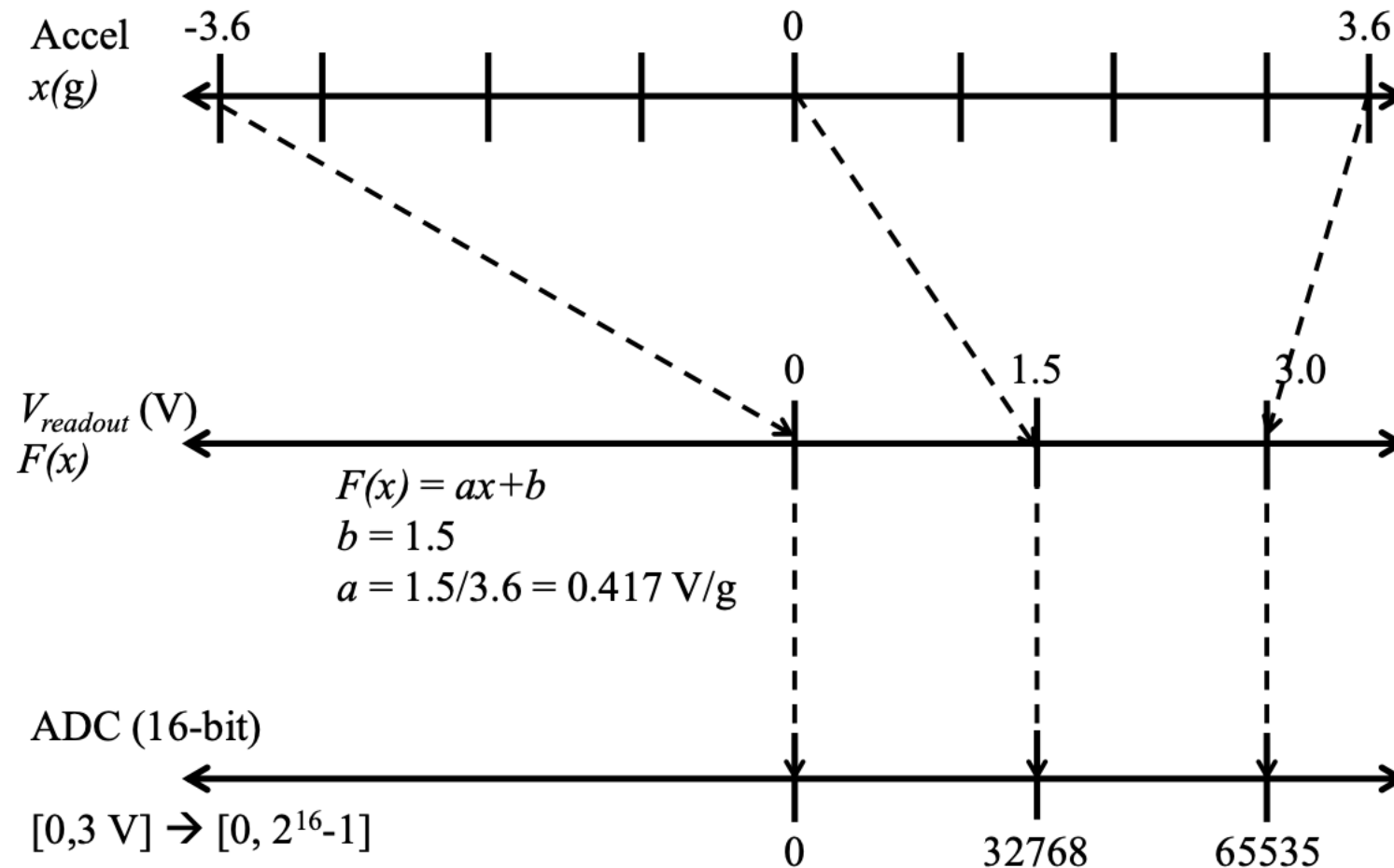
Sensor Model

$$F(x) = ax + b$$

- X is the quantity being sensed
- F(x) is a voltage proportional to that quantity
- Parameters
 - a: sensitivity, units volts/quantity
 - Change in voltage per change in quantity
 - b: bias, units volts
 - Offset in voltage for zero of the quantity



Bias and Sensitivity Example





Read the Datasheet!

- ADXL330 low power, complete 3-axis accelerometer

SPECIFICATIONS

$T_A = 25^\circ\text{C}$, $V_S = 3\text{ V}$, $C_X = C_Y = C_Z = 0.1\text{ }\mu\text{F}$, acceleration = 0 g, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not guaranteed.

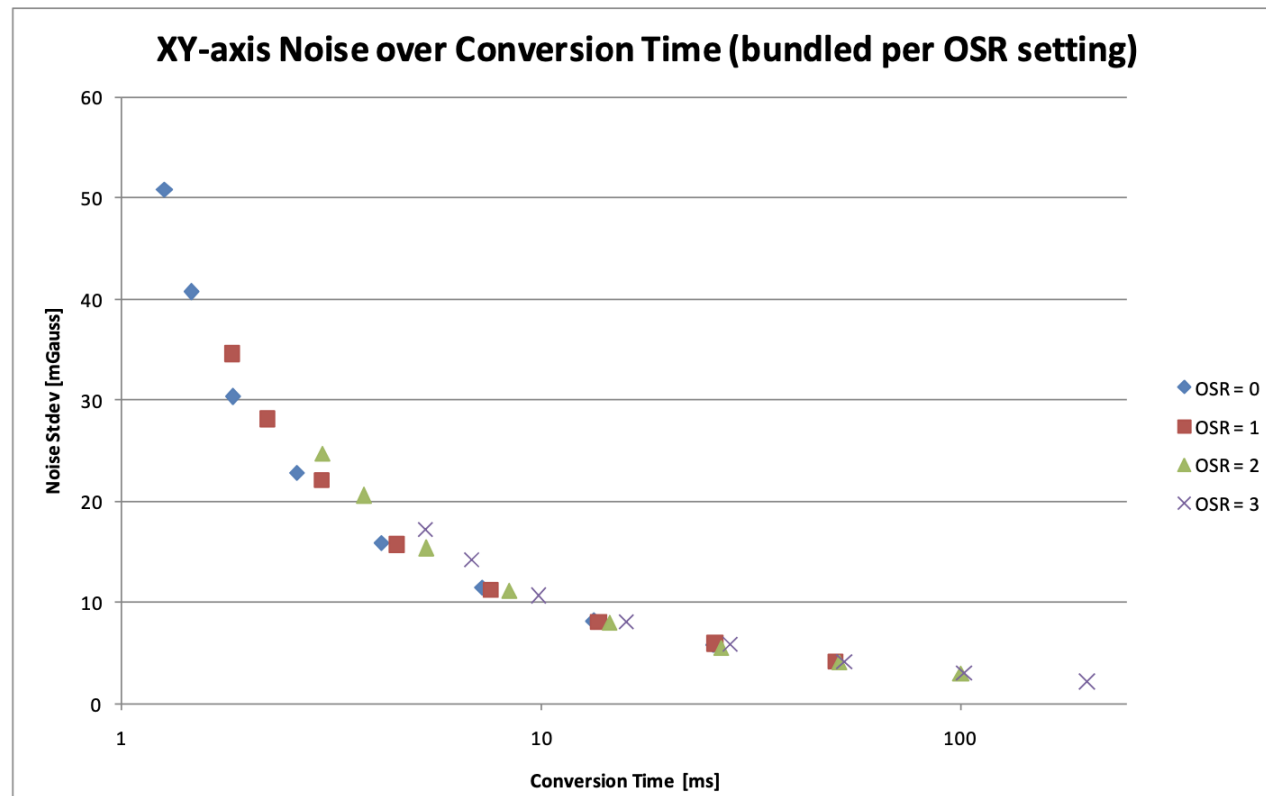
Table 1.

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Measurement Range		± 3	± 3.6		g
Nonlinearity	% of full scale		± 0.3		%
Package Alignment Error			± 1		Degrees
Inter-Axis Alignment Error			± 0.1		Degrees
Cross Axis Sensitivity ¹			± 1		%
SENSITIVITY (RATIOMETRIC) ²	Each axis				
Sensitivity at X_{OUT} , Y_{OUT} , Z_{OUT}	$V_S = 3\text{ V}$	270	300	330	mV/g
Sensitivity Change Due to Temperature ³	$V_S = 3\text{ V}$		± 0.015		%/ $^\circ\text{C}$
ZERO g BIAS LEVEL (RATIOMETRIC)	Each axis				
0 g Voltage at X_{OUT} , Y_{OUT} , Z_{OUT}	$V_S = 3\text{ V}$	1.2	1.5	1.8	V
0 g Offset vs. Temperature			± 1		mg/ $^\circ\text{C}$
NOISE PERFORMANCE					
Noise Density X_{OUT} , Y_{OUT}			280		$\mu\text{g}/\sqrt{\text{Hz}}$ rms
Noise Density Z_{OUT}			350		$\mu\text{g}/\sqrt{\text{Hz}}$ rms
FREQUENCY RESPONSE ⁴					
Bandwidth X_{OUT} , Y_{OUT} ⁵	No external filter		1600		Hz
Bandwidth Z_{OUT} ⁵	No external filter		550		Hz
R_{FILT} Tolerance			$32 \pm 15\%$		k Ω



Read the Datasheet!

- MLX90393 magnetometer
 - How noises change with ADC conversion time?
 - Improve the sensing accuracy by tuning the sampling frequency





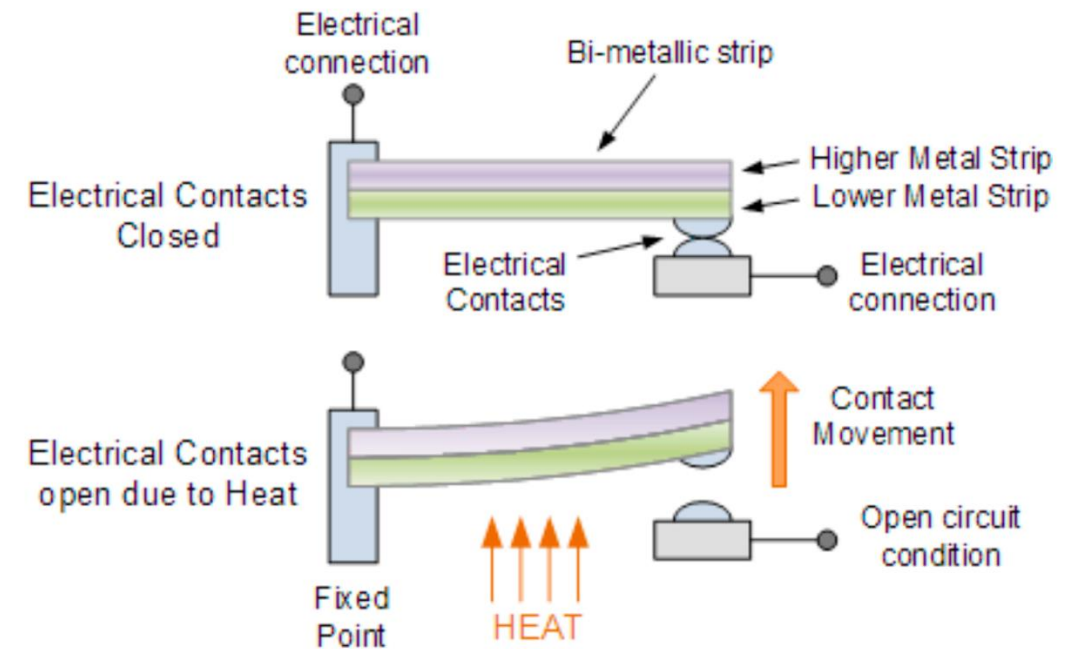
Outline

- Recap on Sensing Principles
- Type of Sensors
 - Temperature
 - Light
 - Pressure
 - Others



Digital Temperature Sensor

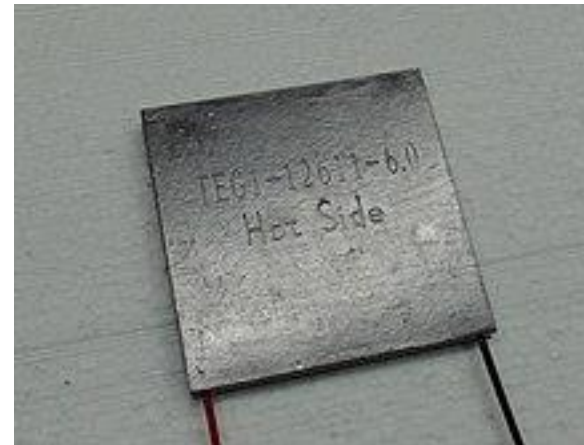
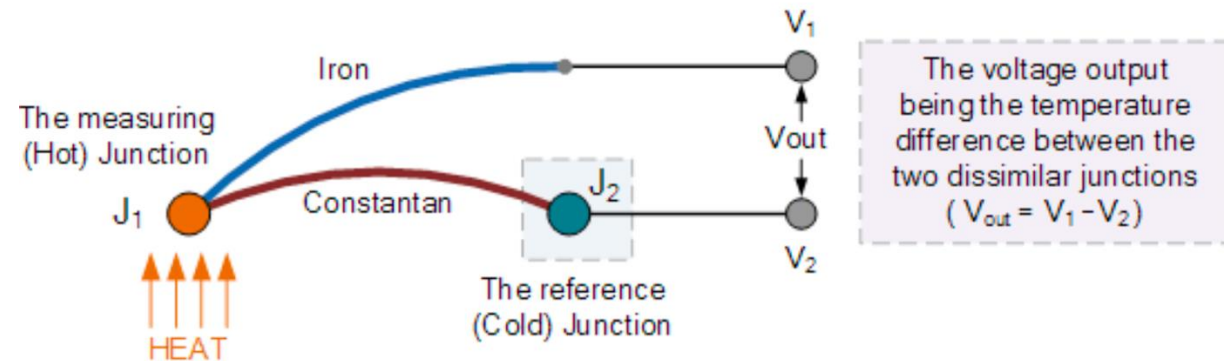
- Thermostat (调温器)
 - Heat bends a strip of two different metals
 - Switches circuit on/off based on the temperature





Digital Temperature Sensor

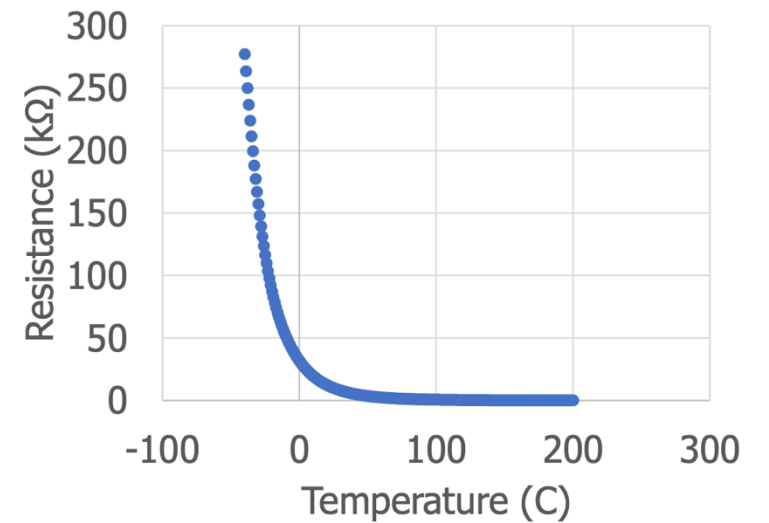
- Thermocouple (热电偶)
 - Generates a voltage based on temperature
 - Can be used to harvest energy to run system
- Science
 - Thermoelectric effect (热电效应)





Resistive Temperature Sensing

- Thermistor (热敏电阻): Thermal + resistor
 - Varies resistance based on temperature
- Advantage
 - Extremely cheap and easy to use
- Disadvantage
 - Non-linear transfer function





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Measuring Light

- Lux: unit of illuminance
 - 1 勒克斯 = 1 流明/平方米 =
1 坎德拉·球面度/平方米 (1 lx
= 1 lm/m² = 1 cd·sr·m⁻²)

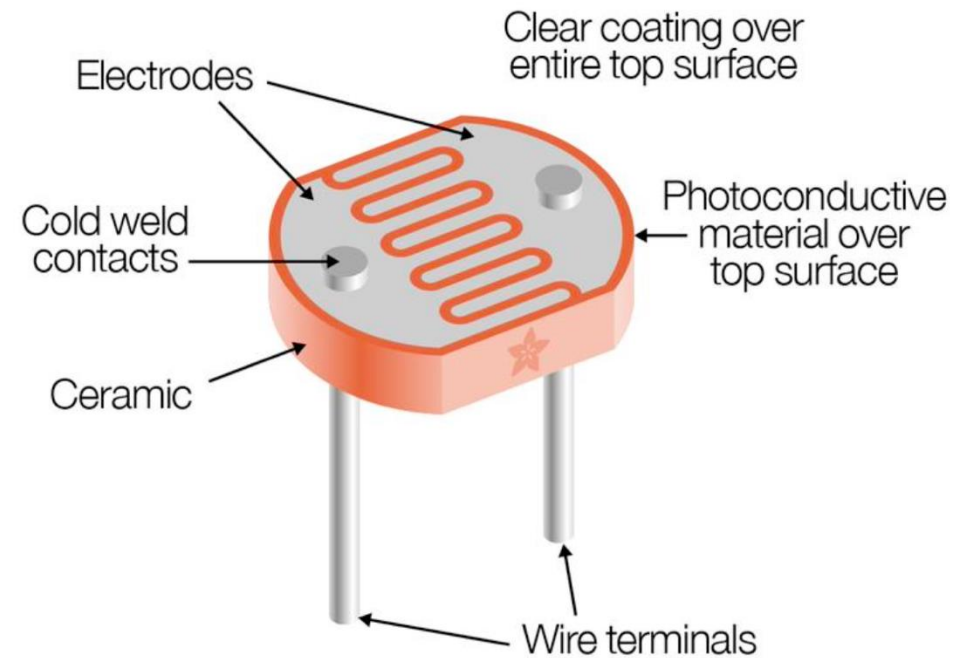
Illuminance	Example
0.002 lux	Moonless clear night sky
0.2 lux	Design minimum for emergency lighting (AS2293).
0.27 - 1 lux	Full moon on a clear night
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Very dark overcast day
300 - 500 lux	Sunrise or sunset on a clear day. Well-lit office area.
1,000 lux	Overcast day; typical TV studio lighting
10,000 - 25,000 lux	Full daylight (not direct sun)
32,000 - 130,000 lux	Direct sunlight



Resistive Light Sensing



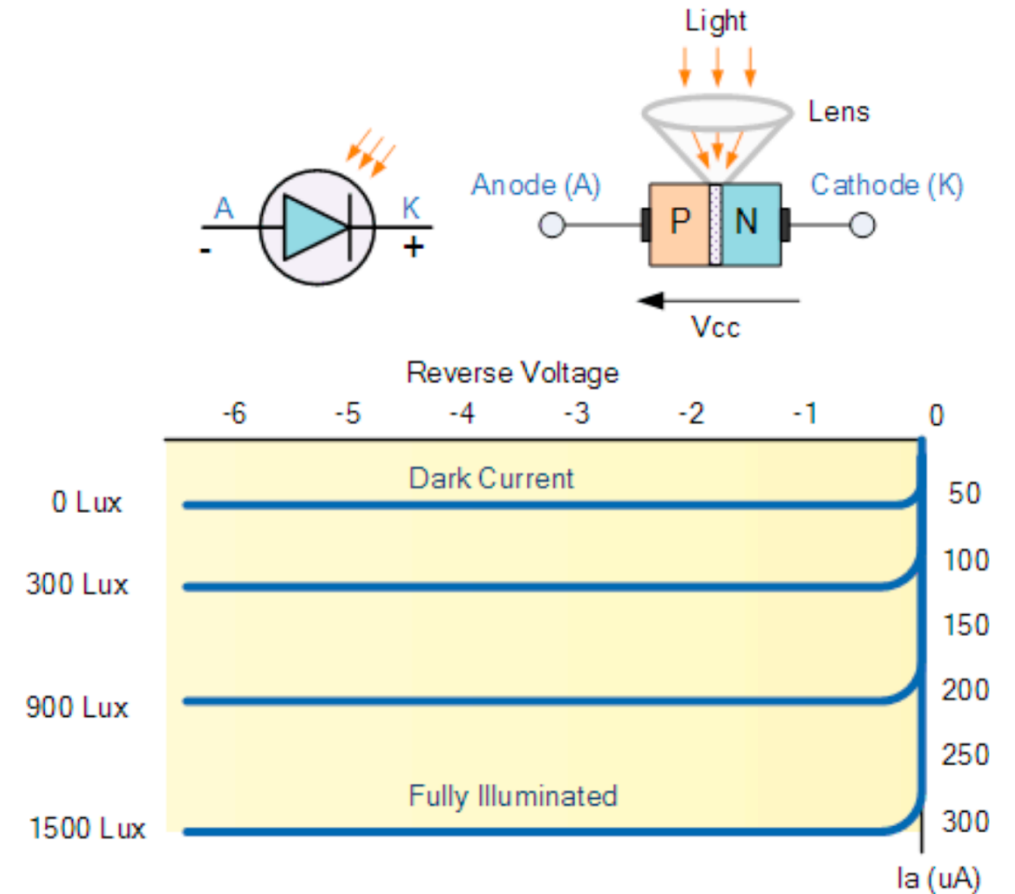
- Photocell (Photoresistor, 光敏电阻)





Photodiodes

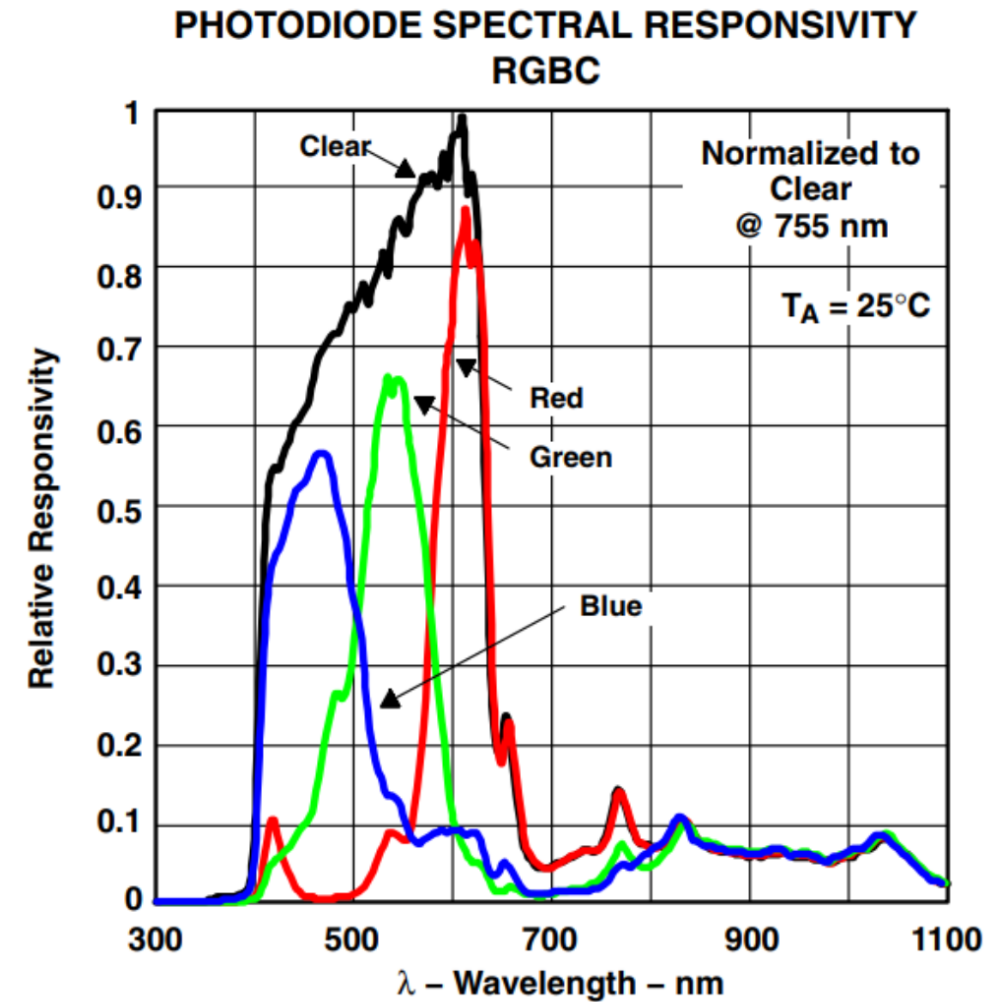
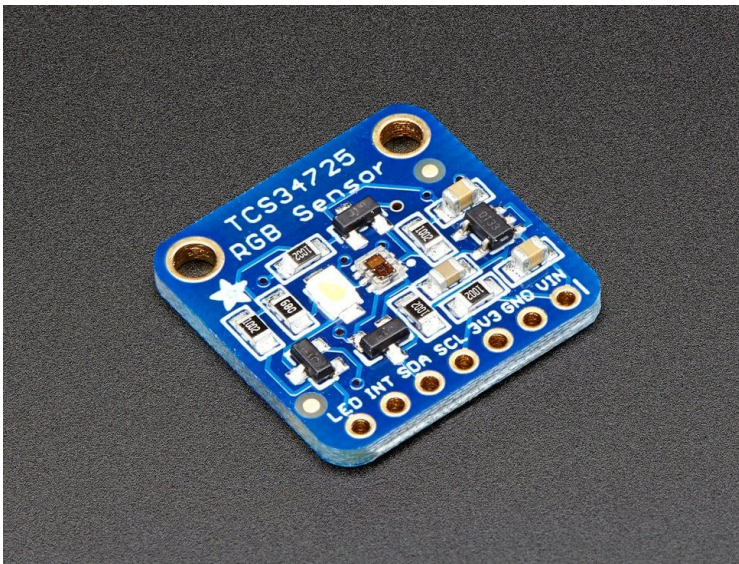
- Photodiodes (光电二极管) leak current based on light levels
- How it works
 - When voltage applied in reverse to an ideal diode, no current flows
 - But, some small amount of current leaks for real-world diodes, it is proportional to light levels





Light Color Sensing

- Color sensor (色彩传感器)
- Respond to specific light colors separately
- 构型举例：
 - TCS34725





Passive Infrared (PIR) Sensor

- 被动红外传感器
- Detect movement in the environment
 - By detecting change in IR levels
- It often come with plastic lens cover to improve field of view and range





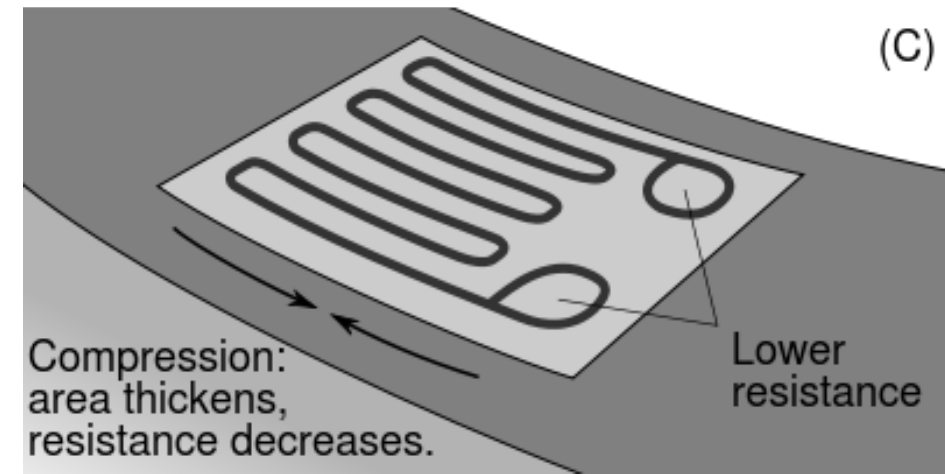
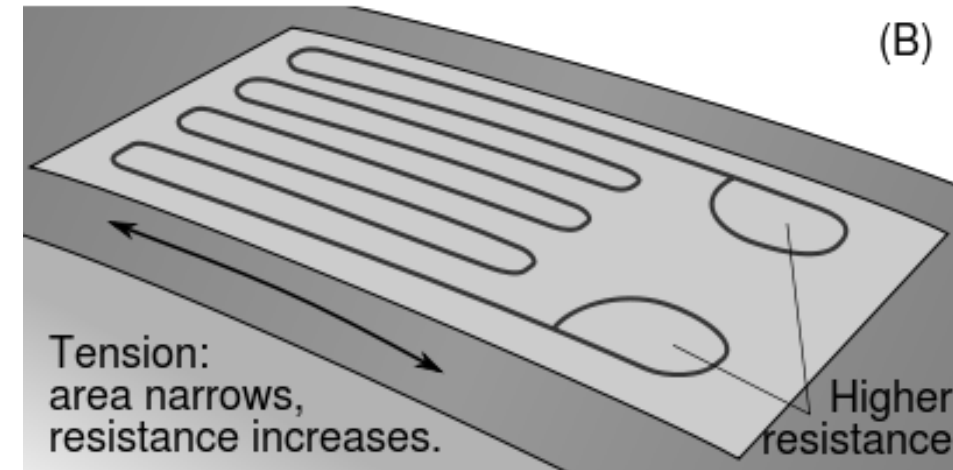
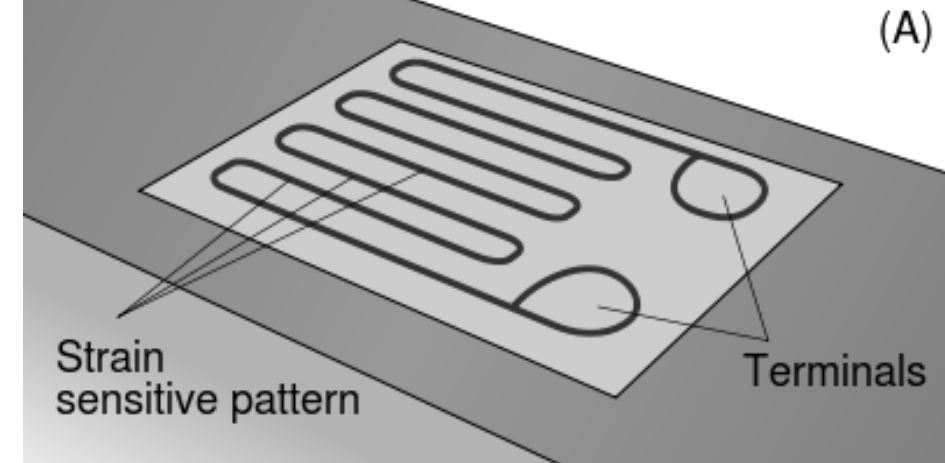
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Strain Sensing

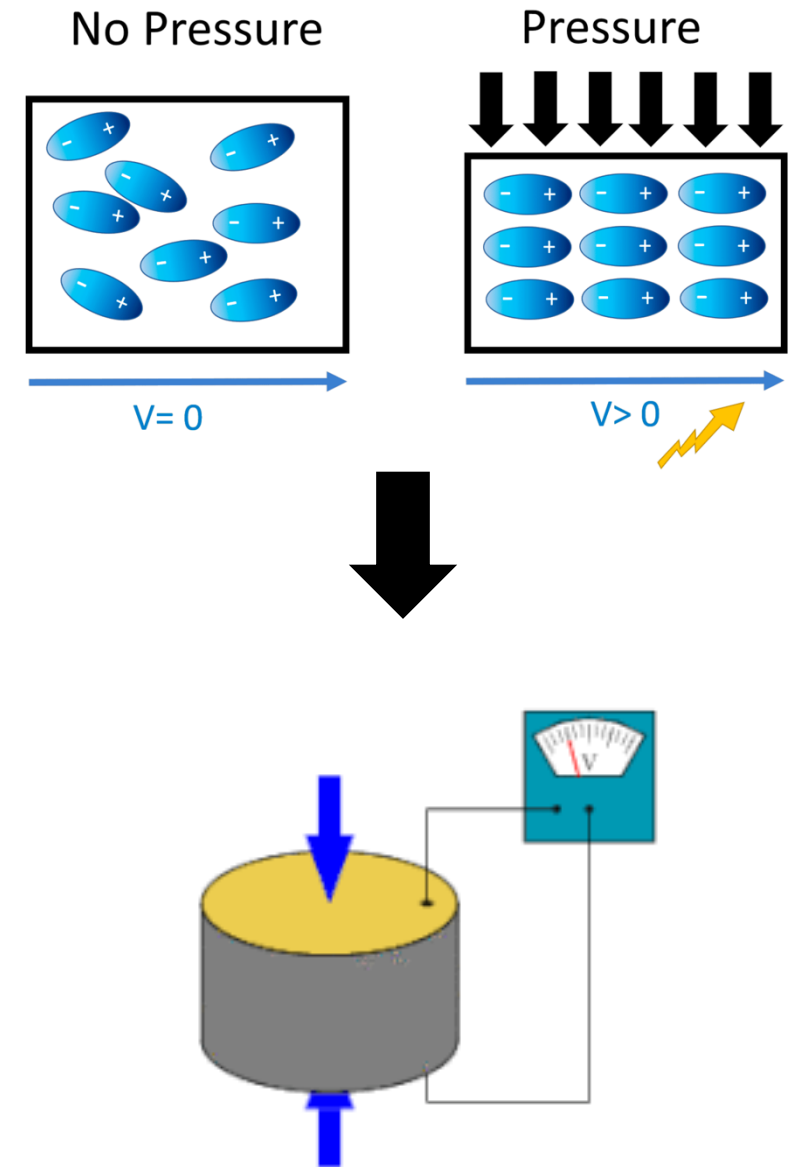
- Strain gauge (应变片): a device used to measure strain on an object
- The resistance change is usually measured by a Wheatstone bridge (惠斯通电桥)





Piezo

- Compression of the material generates a voltage
- How it works
 - Piezoelectric effect (压电效应)





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Other Sensors

- Environment: pressure, humidity, air velocity, air quality
- Distance: ultrasonic, lidar, or radar
- Biometric: pulse oximeter, heart rate
- Agricultural: soil moisture

