Sensors, Microcontrollers & Packet Tracer

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Agenda

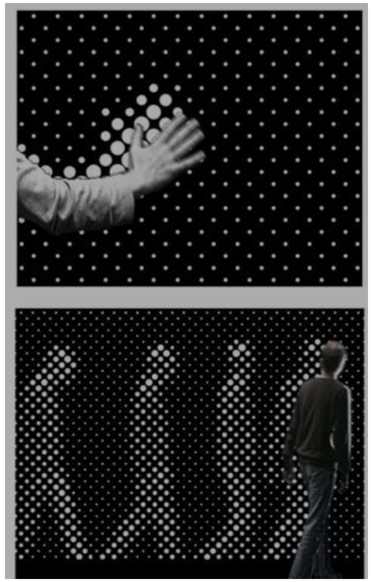
Main aim is to provide enough knowledge so we can build sensor/actuator systems using a Microcontroller

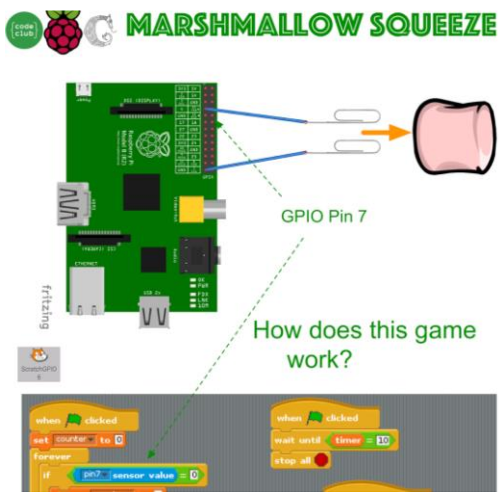
- Can simulate this in PacketTracer for now

- Sensors/Transducers
- Sensor Types
- Connecting to a Microcontroller
- Sensors in Packet Tracer

Context: Physical Computing

- Break away from conventional input/output peripherals:
    - Keyboard, mouse, screen
- Think about how human/environment signals can be captured and changed into electronic signals that can be interpreted by a computing device.
- Physical computing applications tend to depend on people for input (and sometimes output), and transform that input into another form, like an animation, a sound, or motion.
- Sometimes powerfully fuses art and technology.





Electricity 101: Ohms Law

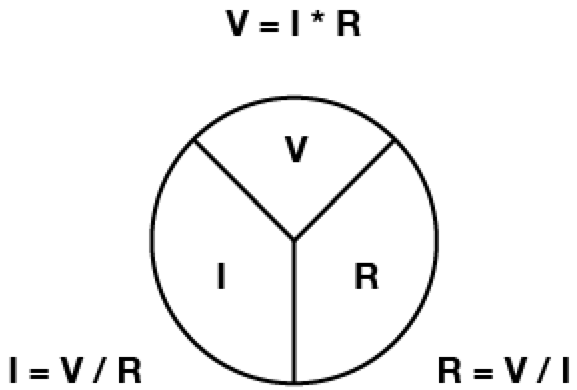
- **Voltage (V)**, **Current (I)**, and **Resistance (R)** are all related, by the following formula:

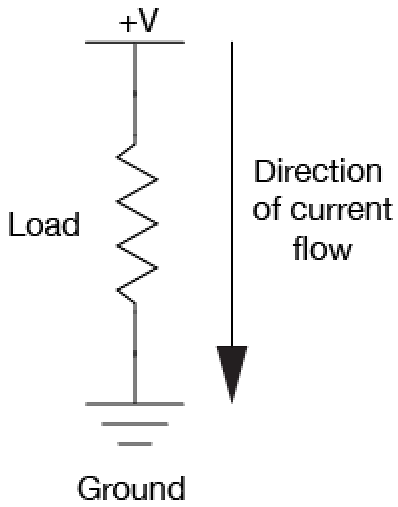
V = I x R

- **electrical power (P)** (measured in watts), as follows:

Watts = Volts * Amps

P = V * I

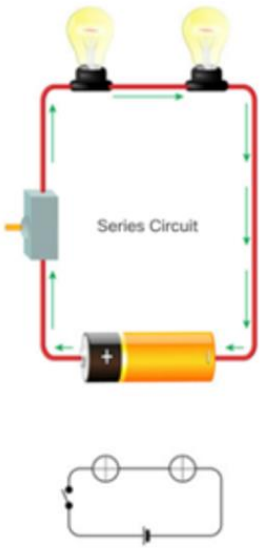


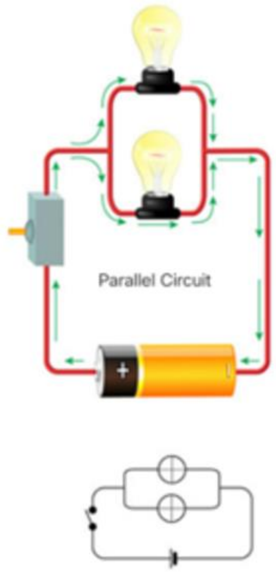


Electricity 101: Circuits

- Series & Parallel Circuits

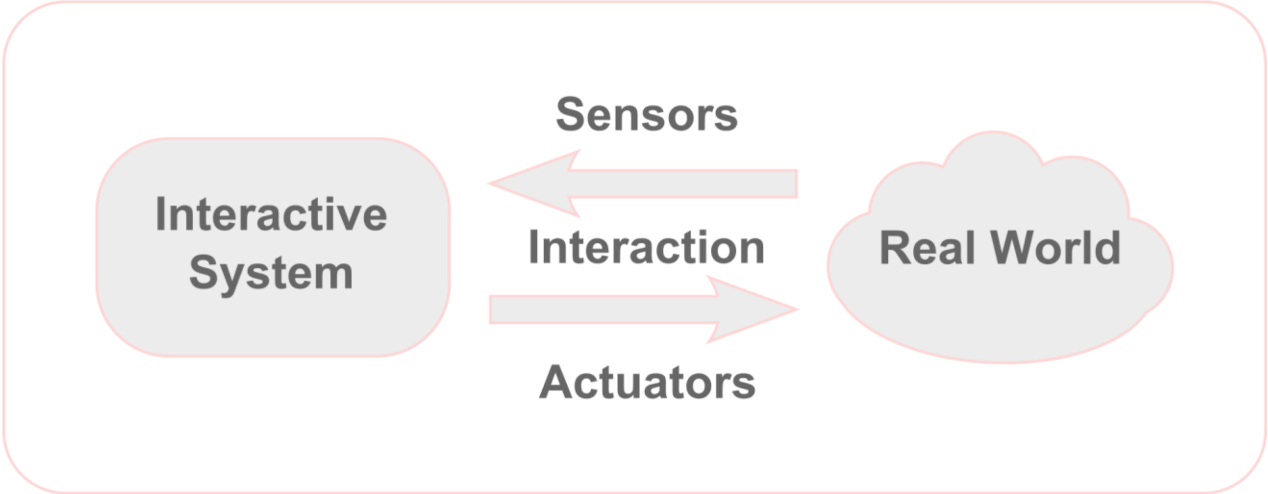
Series Circuit:	**Parallel Circuit:**
• Components are interconnected one after another in a path between the positive and negative terminals of the power source	• Current flows from the battery terminal but splits at a junction which leads to parallel pathways through the circuit. • Components connected along each pathway each get their own share of current





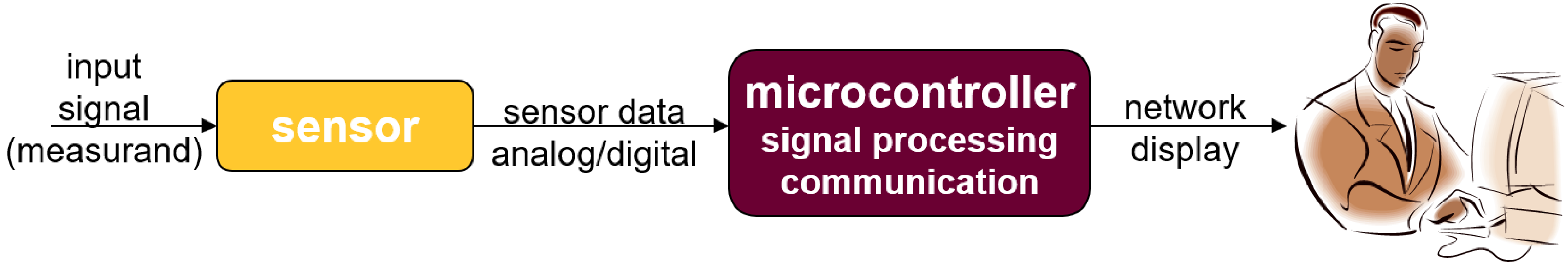
What are Sensors

- Transducer
  - a device that converts a primary form of energy into a corresponding signal with a different energy form
  - Primary Energy Forms: mechanical, thermal, electromagnetic, optical, chemical, etc.
  - Can be a **sensor** or an **actuator**
- A Sensor is a device that detects/measures a signal/stimulus
  - Acquires data from the “real world”
- An Actuator generates a signal or stimulus from electrical signal.
  - Example: Servo Motor.
- Sensors are everywhere
  - In our bodies, automobiles, airplanes, cellular telephones, radios
  - Necessary for automation.



Sensor Systems

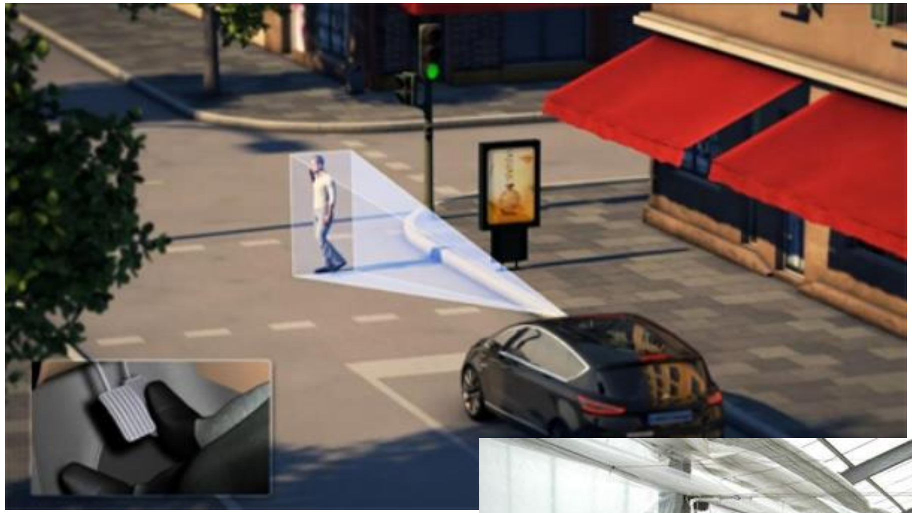
- Typically interested in electronic sensors
  - convert desired parameter into electrically measurable signal
- A Sensor may include:
  - <u>primary transducer</u>: changes “real world” parameter into electrical signal
  - <u>secondary transducer</u>: converts electrical signal into analog or digital values
- Simple Electronic Sensor System:

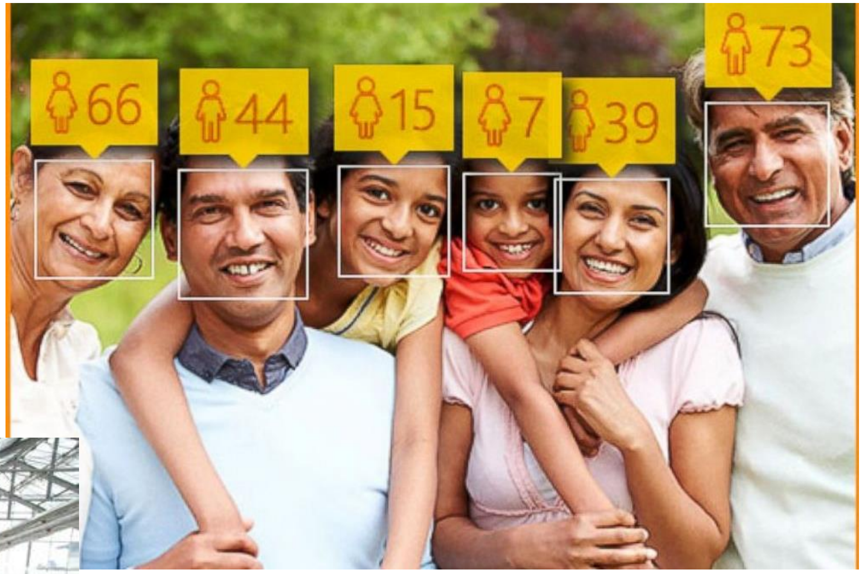


Detectable Phenomena

Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

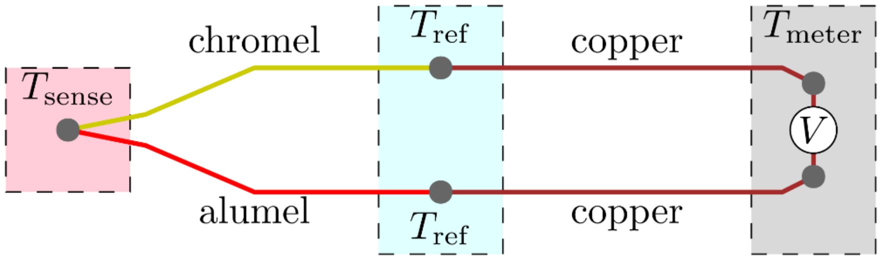
Sensor Use: Project Examples





Temperature Sensors

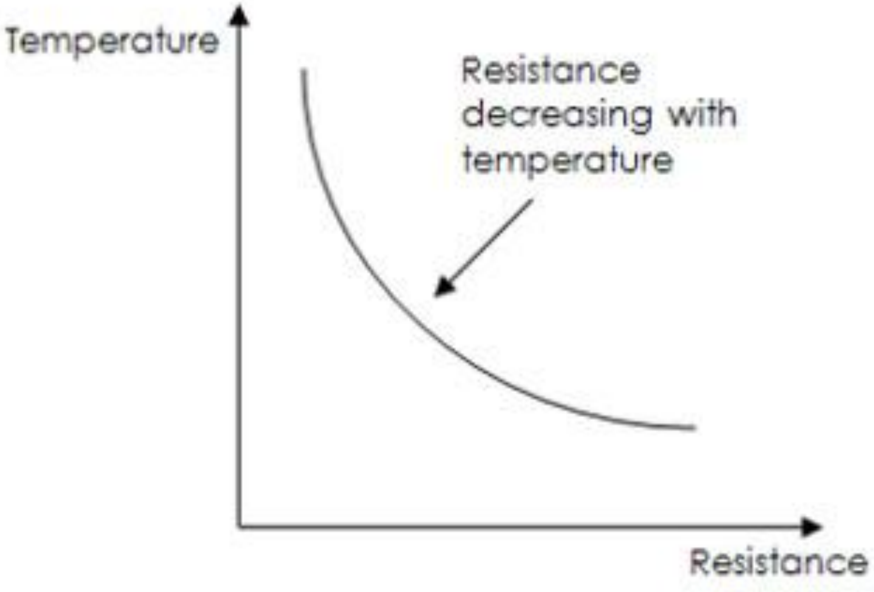
- Temperature sensors appear in building, chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring
- Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, volume, electrical resistance, and strain
- Type of common temperature transducer
  - Resistance Temperature Detector (RTD)
  - Thermistors
  - Thermocouples

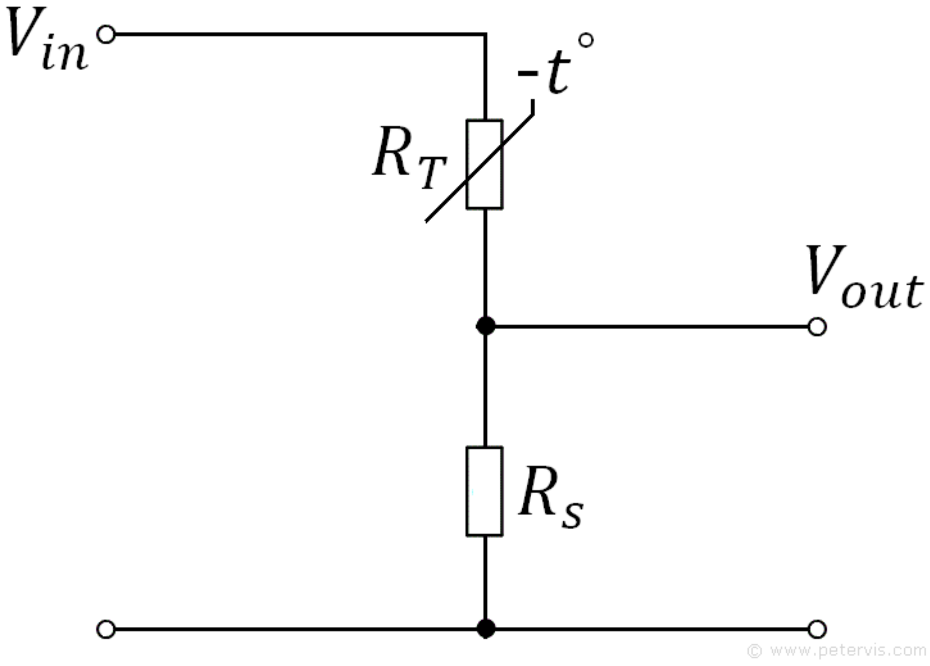


$$L = L_0[1 + \beta(T - T_0)]$$

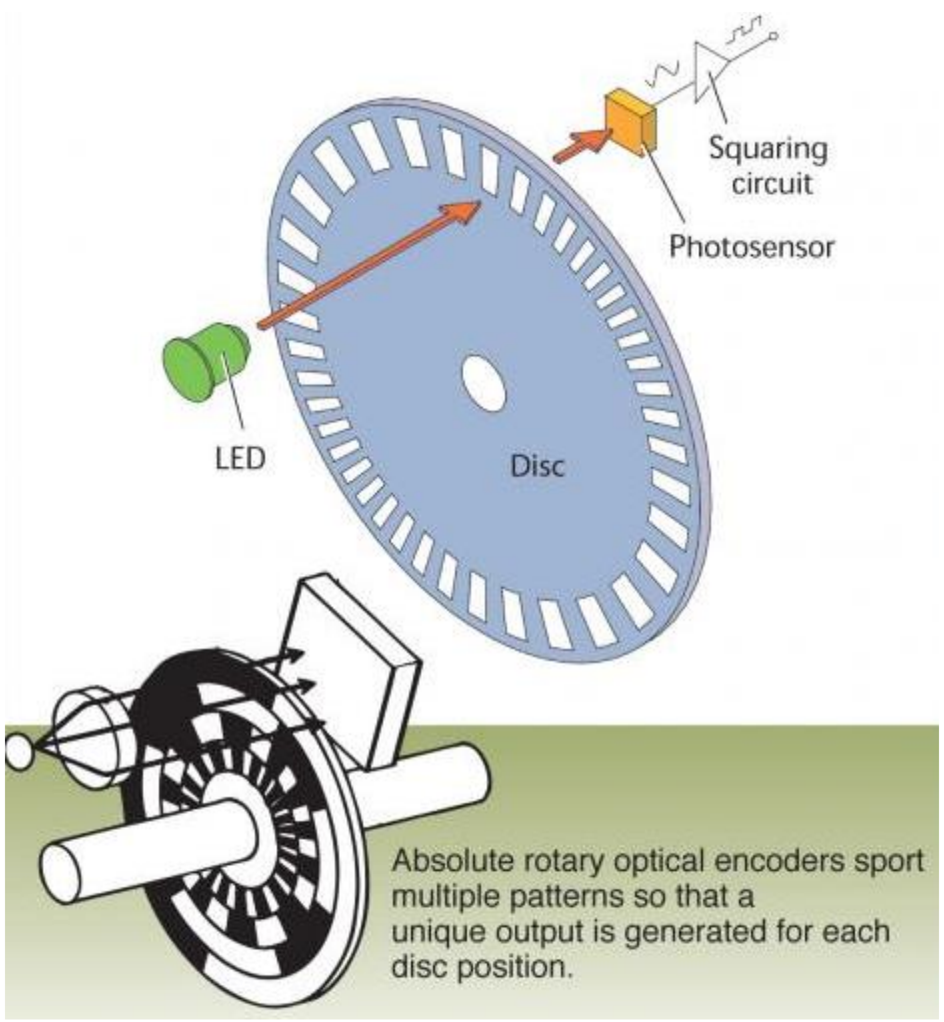
Thermistor

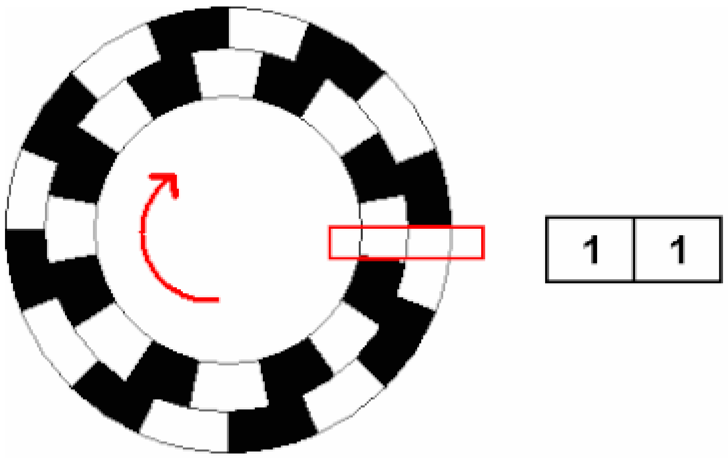
- A thermistor is a type of resistor with resistance varying according to its temperature. The resistance is measured by passing a small, measured direct current through it and measuring the voltage drop produced.



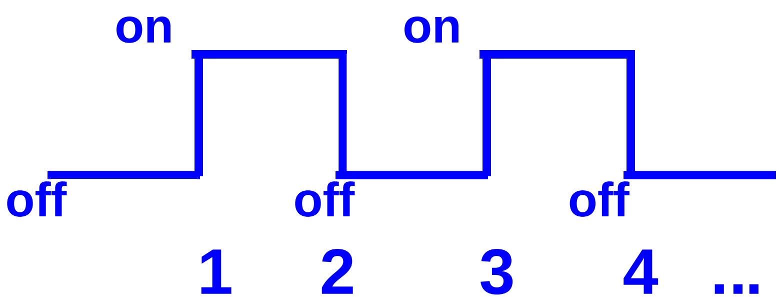


Optical Encoders





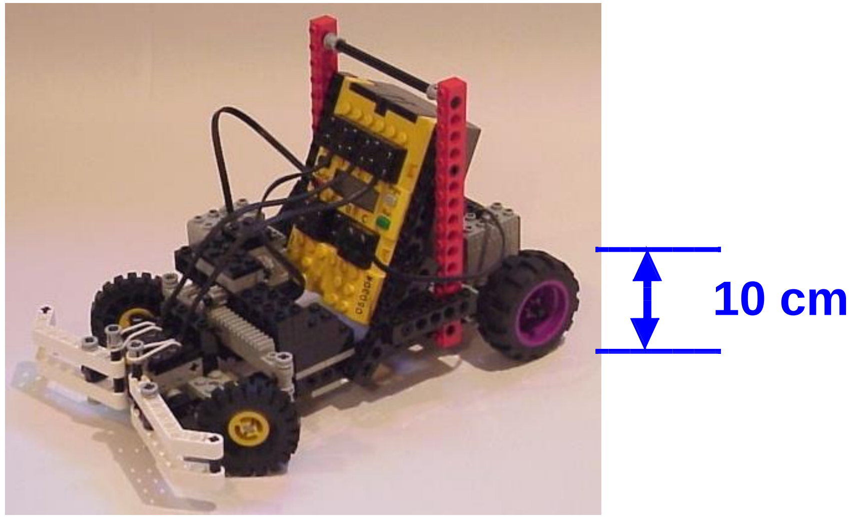
Voltage square wave



Important spec:
Number of counts per revolution

Sample Problem: Sensor Analysis

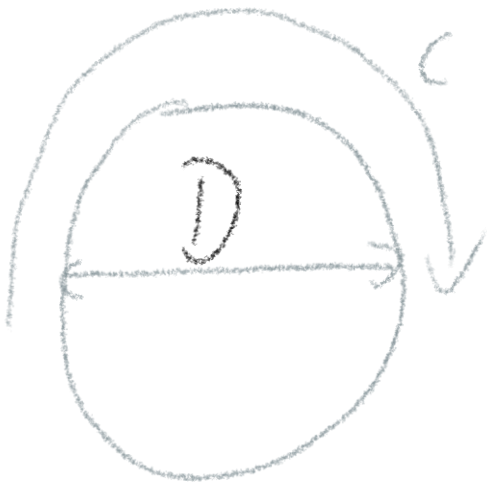
16 counts per rev.



10 cm wheel diameter

- How far does vehicle travel for 1 encoder count?
- How many counts are there per meter of travel?
- What should the wheel diameter be for 1cm / count.

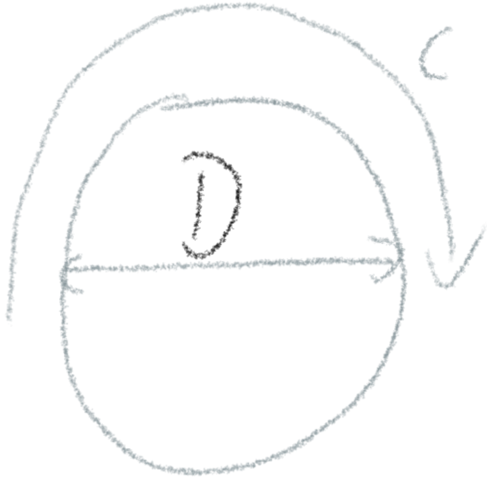
Sample Problem: How far does vehicle travel for 1 encoder count?



$D = 0.1\text{m}$ $\quad C = \pi D = 0.1\pi$, 16 counts/rev

$$\frac{0.1\pi}{16}$$

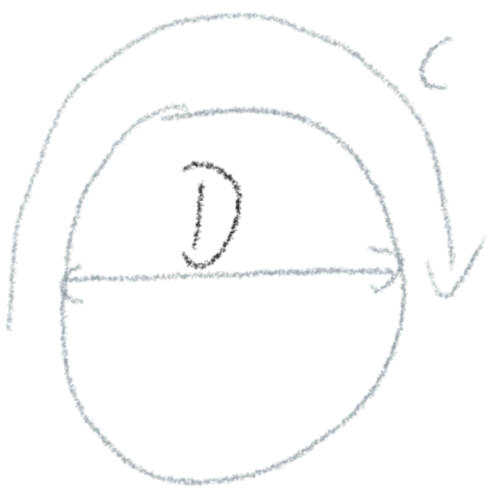
Sample Problem: How many encoder counts will there be for 1 meter of travel?



$D = 0.1m$, $C = \pi D = 0.1\pi$, 16 counts/rev

$$n_e = \frac{1}{0.1\pi} \times 16$$

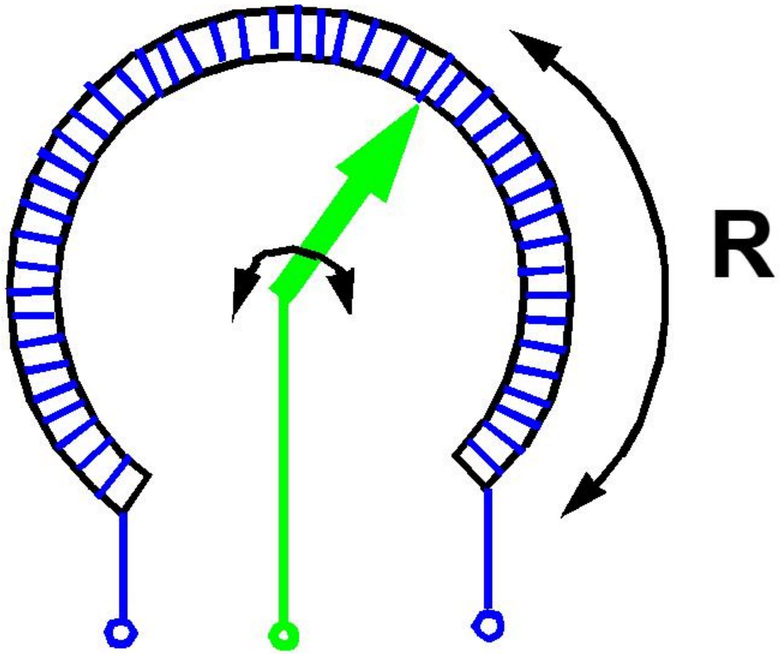
Sample Problem: Suppose I want 1.0 cm / count, what wheel diameter

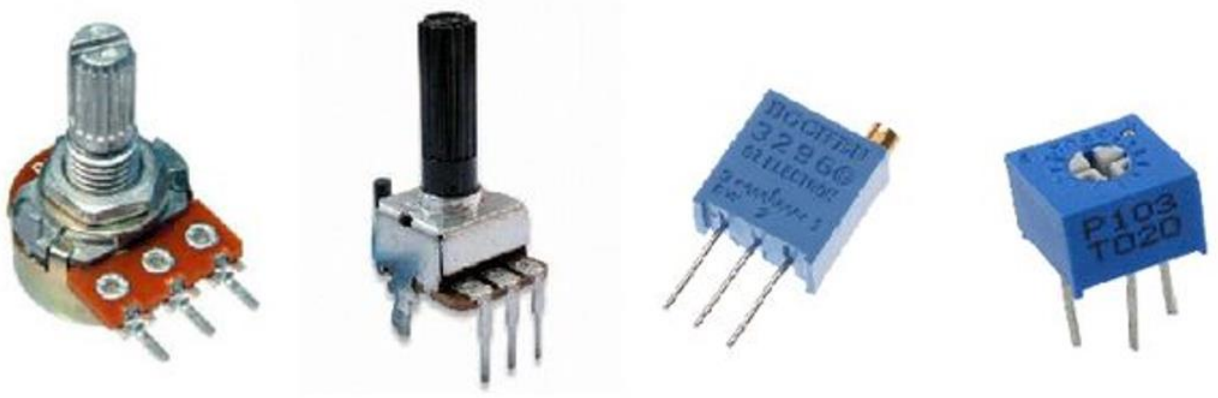


$D = ?$, $C = \pi D$, $C = 0.16$, 16 counts/rev

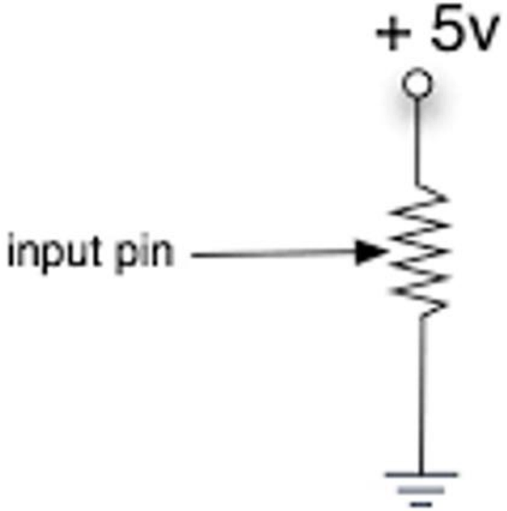
Potentiometer

Another rotational sensor



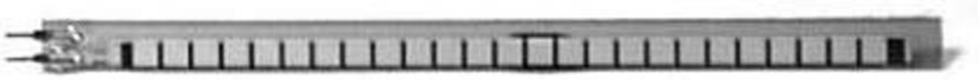


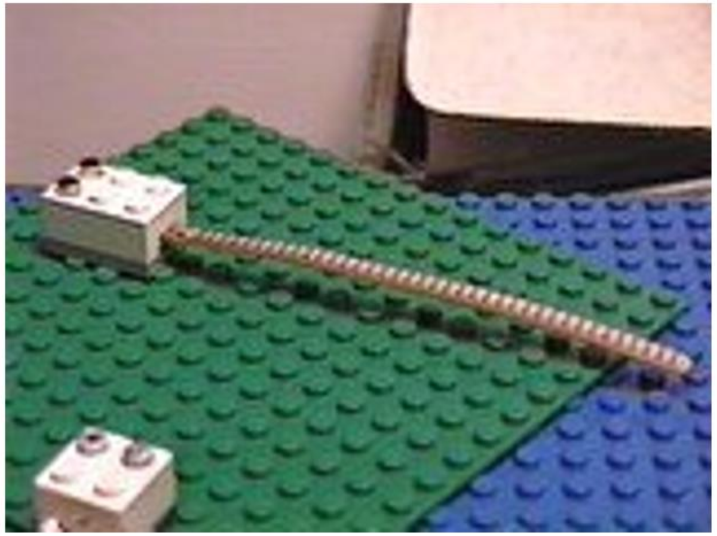
Resistance changes
with position of dial



Band Sensor

A variable resistor

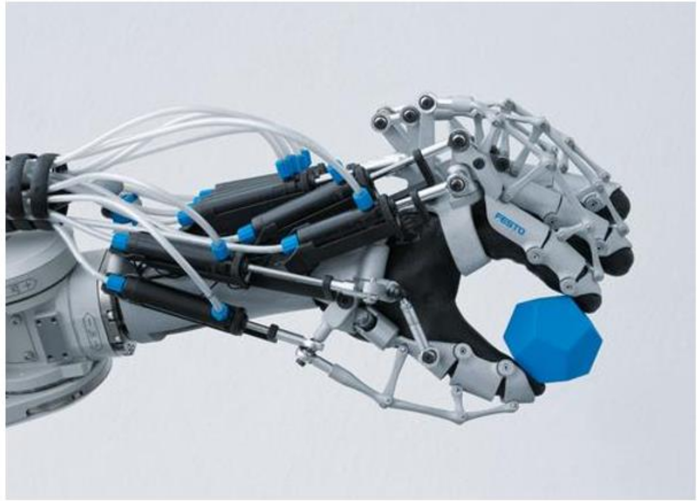




resistance changes as it bends

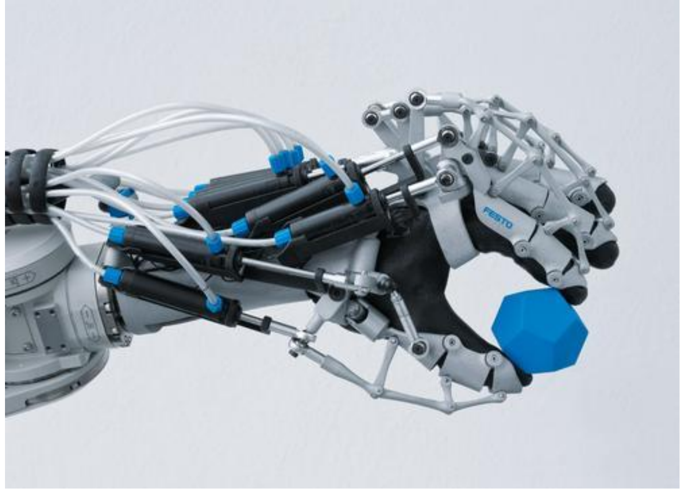
$$V = I \times R$$

assuming constant current, the measured voltage changes with resistance



Force Sensor

- Detect and measure a relative change in force or applied load
- Detect and measure the rate of change in force
- Identify force thresholds and trigger appropriate action
- Detect contact and/or touch
- Applications:
    - Touch Pads (i.e. VR Gloves, Joysticks)
    - Alarm Systems
    - Aerospace
    - Robotic Grip Force



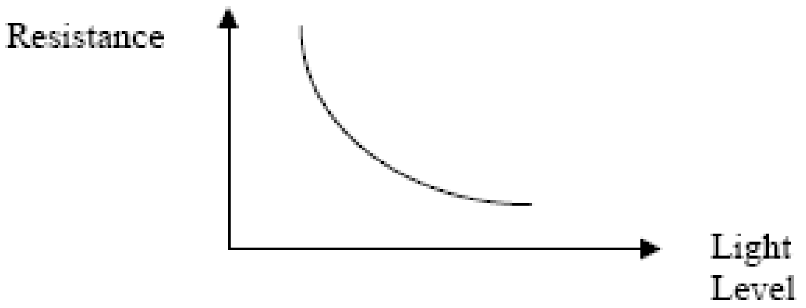
Accelerometers

- Measures Acceleration
- Application:
    - Vibrations, blasts, impacts, shock waves
    - Air bags, washing machines, car alarm
- They can come in 1, 2 or 3 axis configurations
    - With 3 axis it gives a vector of the accelerations direction (after accounting for gravity)
- Used in electronics like the Wii and iPhone for user input

Light Sensor

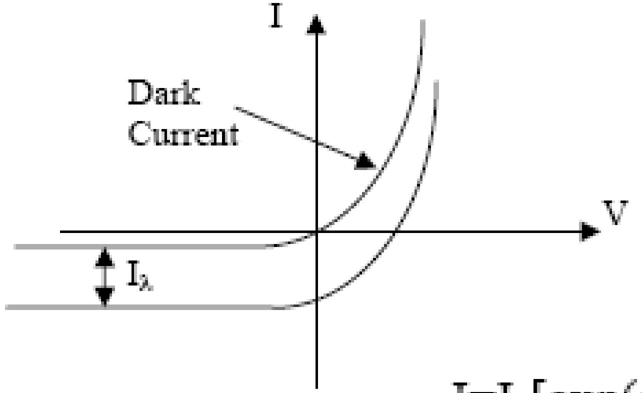
- photoconductor
  - light → ΔR

Photoconductor: (Light sensitive semiconductor resistor)



- photodiode
  - light → ΔI

Photodiode:

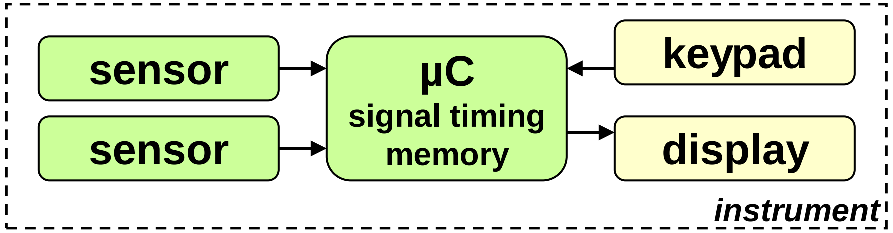


$I = I_o[\exp(eV/kT) - 1] - I_\lambda$

I_λ is proportion to the light level

Connecting Sensors to Microcontroller/Single Board Computer

- Analog Sensors
  - many microcontrollers have a built-in ADC
    - 8-bit to 12-bit resolution common
    - many have multi-channel ADC inputs



- Digital Sensors
  - serial I/O
    - use serial I/O port, store data in memory to analyze later
    - Synchronous (with clock)
      - must match byte format, stop/start bits, parity check, etc.
    - asynchronous (no clock): more common for communication
      - must match baud rate and bit width, transmission protocol, etc.

“Smart” Sensors

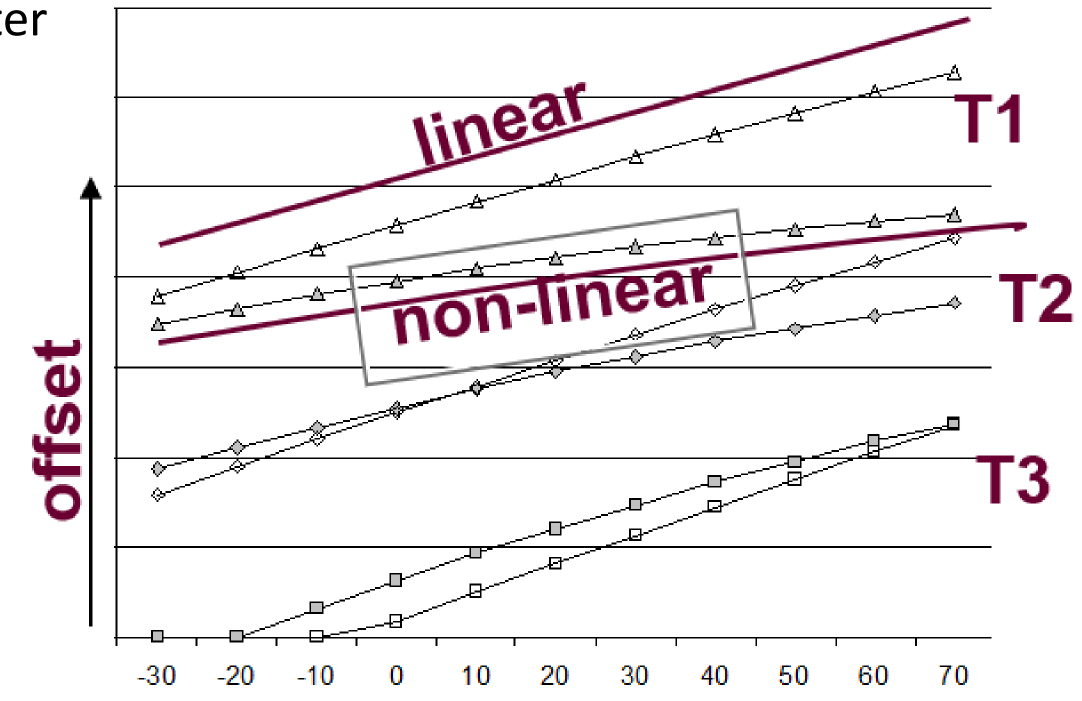
- “Smart sensor” = sensor with built-in signal processing & communication
  - E.g., combining a “dumb sensor” and a microcontroller
- Data Acquisition Cards (DAQ)
  - PC card with analog and digital I/O
  - interface through LabVIEW or user-generated code
- Communication Links Common for Sensors
  - asynchronous serial communication
    - universal asynchronous receive and transmit (UART)
      - 1 receive line + 1 transmit line. nodes must match baud rate & protocol
    - RS232 Serial Port on PCs uses UART format (but at +/- 12V)
    - can buy a chip to convert from UART to RS232
  - synchronous serial comm.
    - serial peripheral interface (SPI)
      - 1 clock + 1 bidirectional data + 1 chip select/enable
    - I2C = Inter Integrated Circuit bus
      - designed by Philips for comm. inside TVs, used in several commercial sensor systems
    - IEEE P1451: Sensor Comm. Standard
      - several different sensor comm. protocols for different applications

Sensor Calibration

- Sensors can exhibit non-ideal effects
  - offset: nominal output ≠ nominal parameter value
  - nonlinearity: output not linear with parameter changes
  - cross parameter sensitivity: secondary output variation with, e.g., temperature

- Calibration - adjusting output to match parameter
  - analog signal conditioning
  - look-up table
  - digital calibration
    - $T = a + bV + cV^2$,
      - T= temperature; V=sensor voltage;
      - a,b,c = calibration coefficients

- Compensation
  - remove secondary sensitivities
  - must have sensitivities characterized
  - can remove with polynomial evaluation
    - $P = a + bV + cT + dVT + e V^2$, where P=pressure, T=temperature



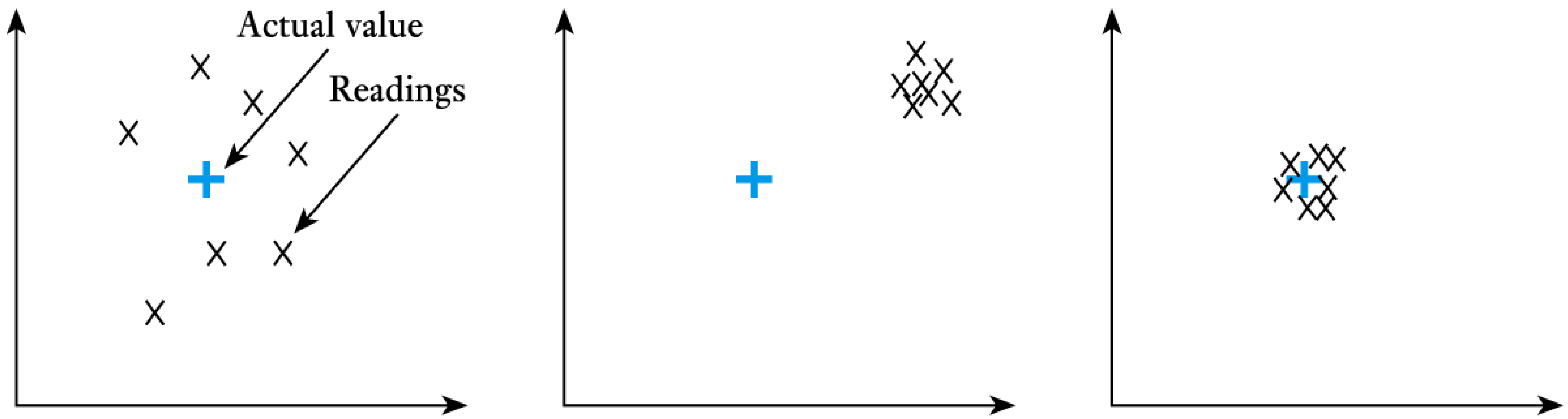
Sensor Performance

- **Range**
  - maximum and minimum values that can be measured
- **Resolution or discrimination**
  - smallest discernible change in the measured value
- **Error**
  - difference between the measured and actual values
    - random errors
    - systematic errors
- **Accuracy, inaccuracy, uncertainty**
  - accuracy is a measure of the maximum expected error
- **Linearity**
  - maximum deviation from a ‘straight-line’ response
- **Sensitivity**
  - a measure of the change produced at the output for a given change in the quantity being measured

Sensor Performance

Precision/Accuracy

- a measure of the lack of random errors (scatter)



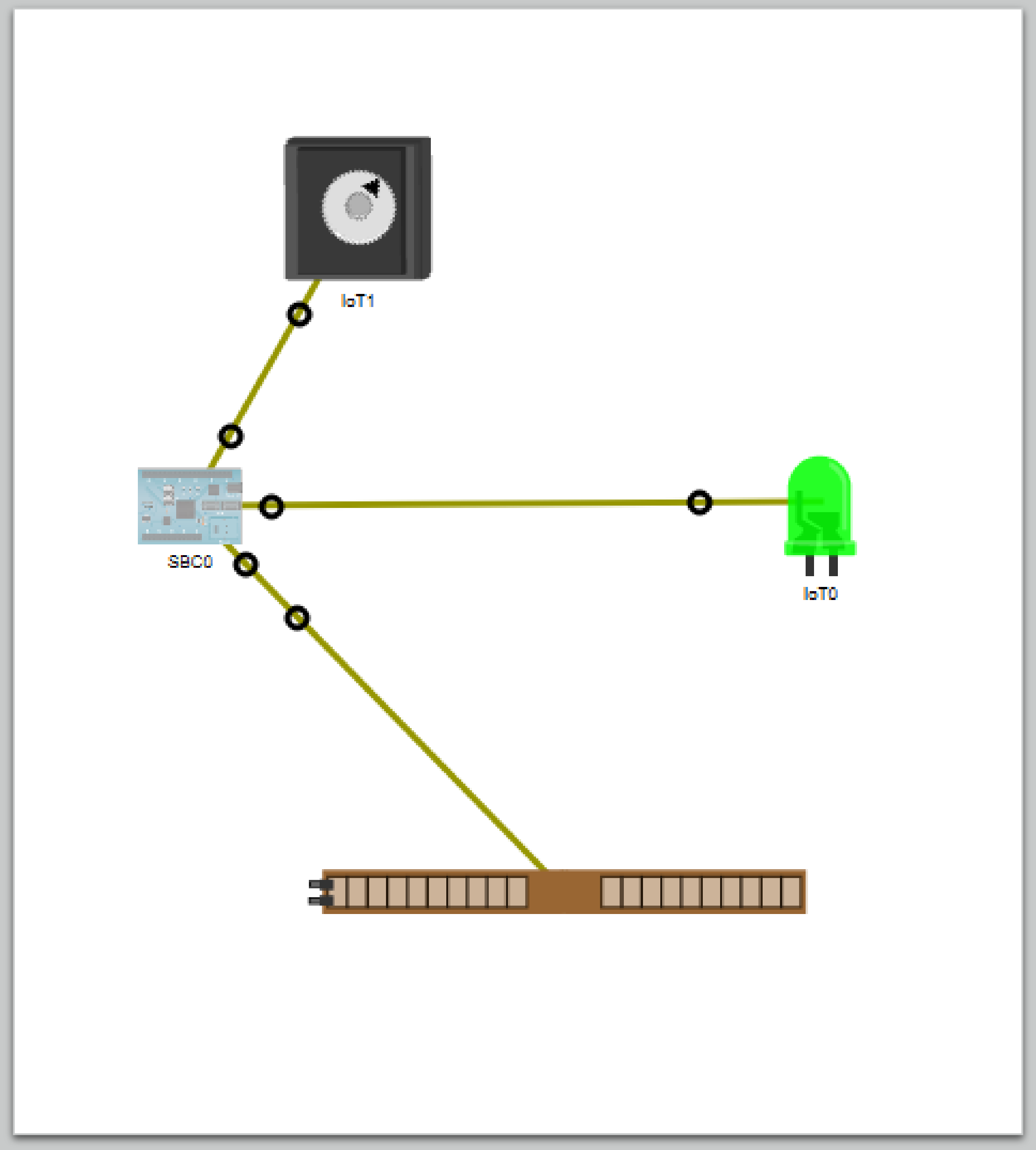
(a) Low precision, low accuracy

(b) High precision, low accuracy

(c) High precision, high accuracy

Packet Tracer 8.x and IoT

- Packet Tracer 8.x can be used as a prototyping tool.
- There is a new group icon contained in Packet Tracer that is labeled Components.
- The PT IoT boards contains an MCU and a SBC.
- The MCU and SBC are similar to an Arduino and a Raspberry Pi, respectively.
- There are also actuators and sensors that can be used in prototypes.
- The IoE Custom Cable found in the Connections group can be used to connect IoT things to an MCU board.



Packet Tracer Demo….