Lecture #3: Introduction to Data Acquisition

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Professor

12-770: Autonomous Sustainable Buildings: Theory to Practice

Civil & Environmental
ENGINEERING
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Some updates…

- Assignment #1 will be out tonight
- Piazza is ready (please register)
- There are 18 brave souls this week
- Lecture notes were updated, let's review them
- Readings for next week will be posted tonight

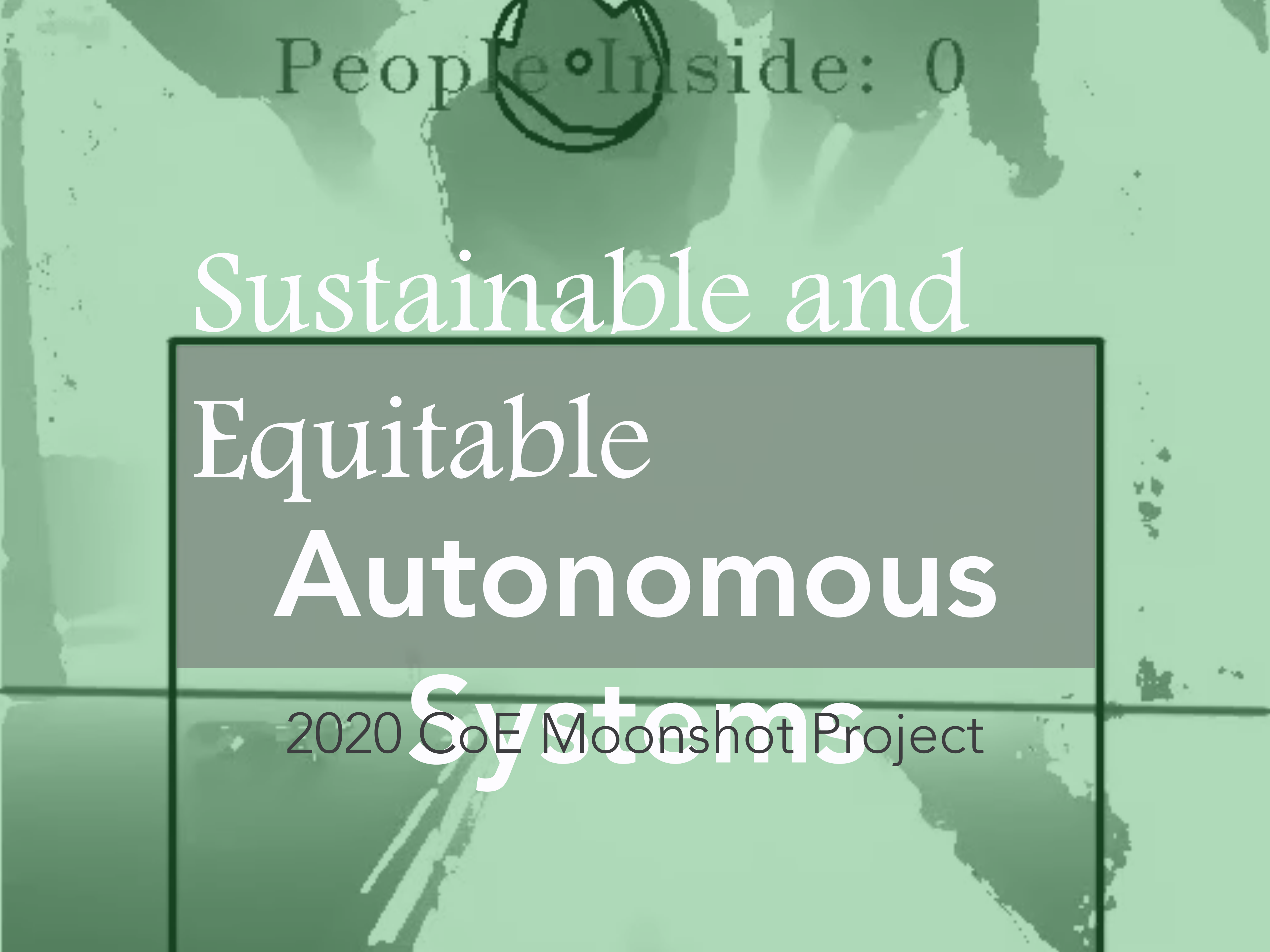
Autonomous Sustainable Buildings

- Autonomous
  - *What do you think this means?*

- Sustainable
  - *What do you think this means?*

- Buildings

SLIGHT DIGRESSION



Sustainable and Equitable Autonomous Systems

2020 CoE Moonshot Project

Per-Capita
GDP
CO2

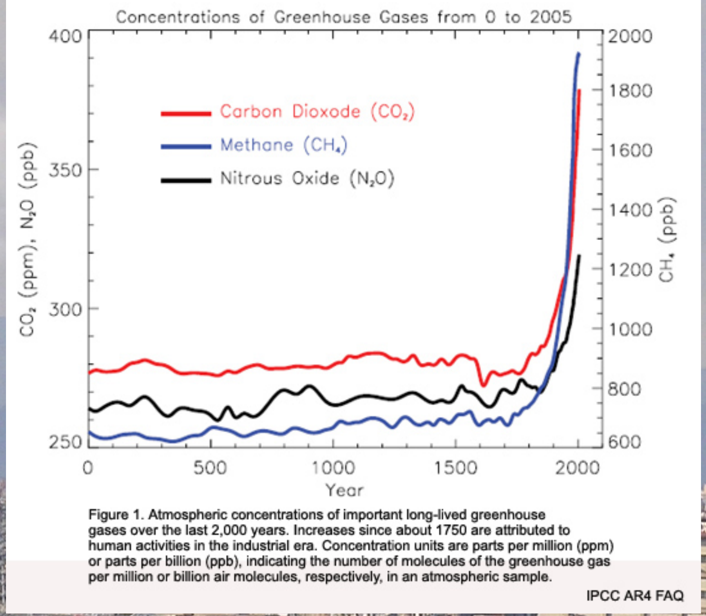
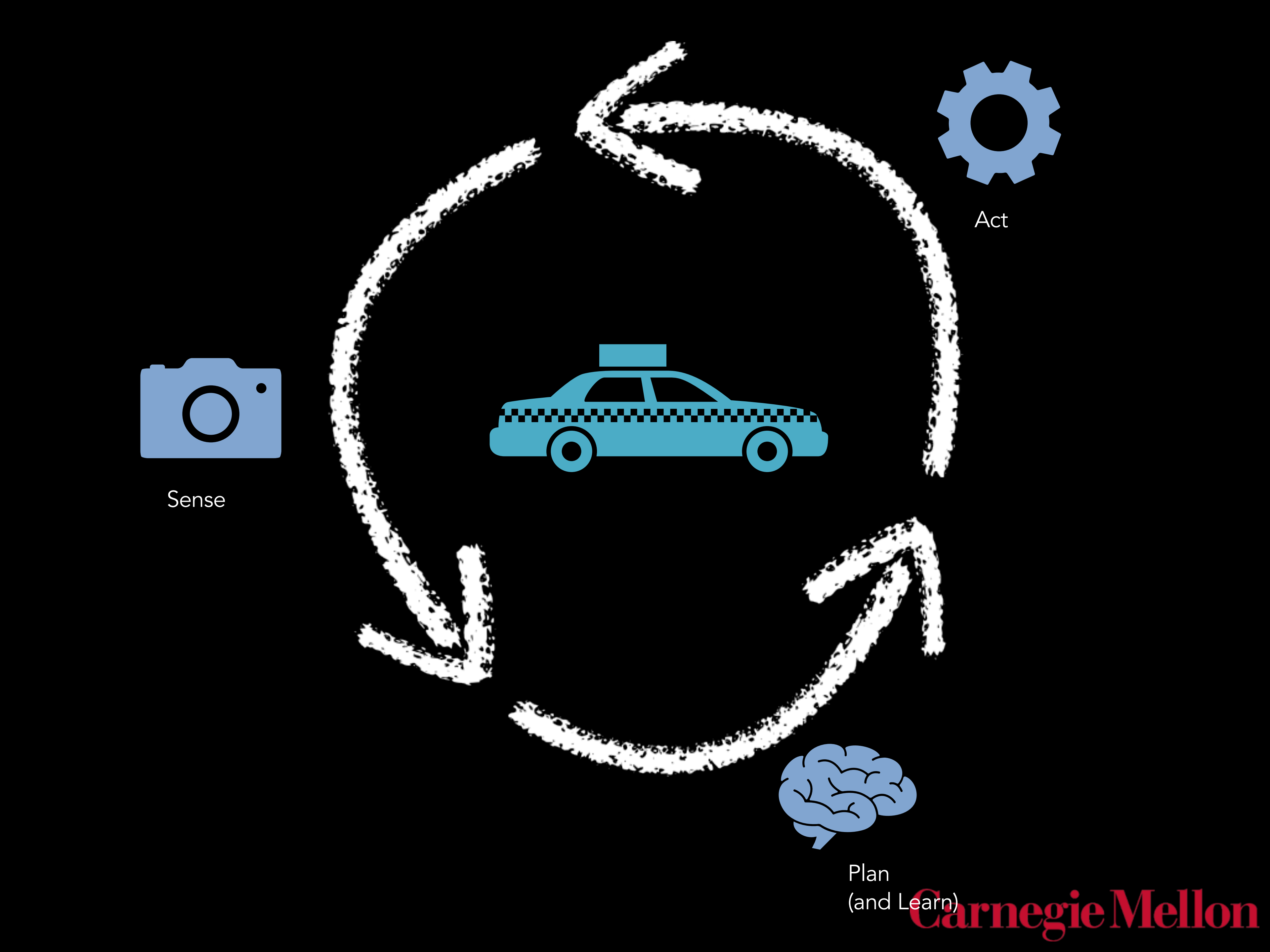


Figure 1. Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample.

IPCC AR4 FAQ


Act
Sense
Plan
(and Learn)
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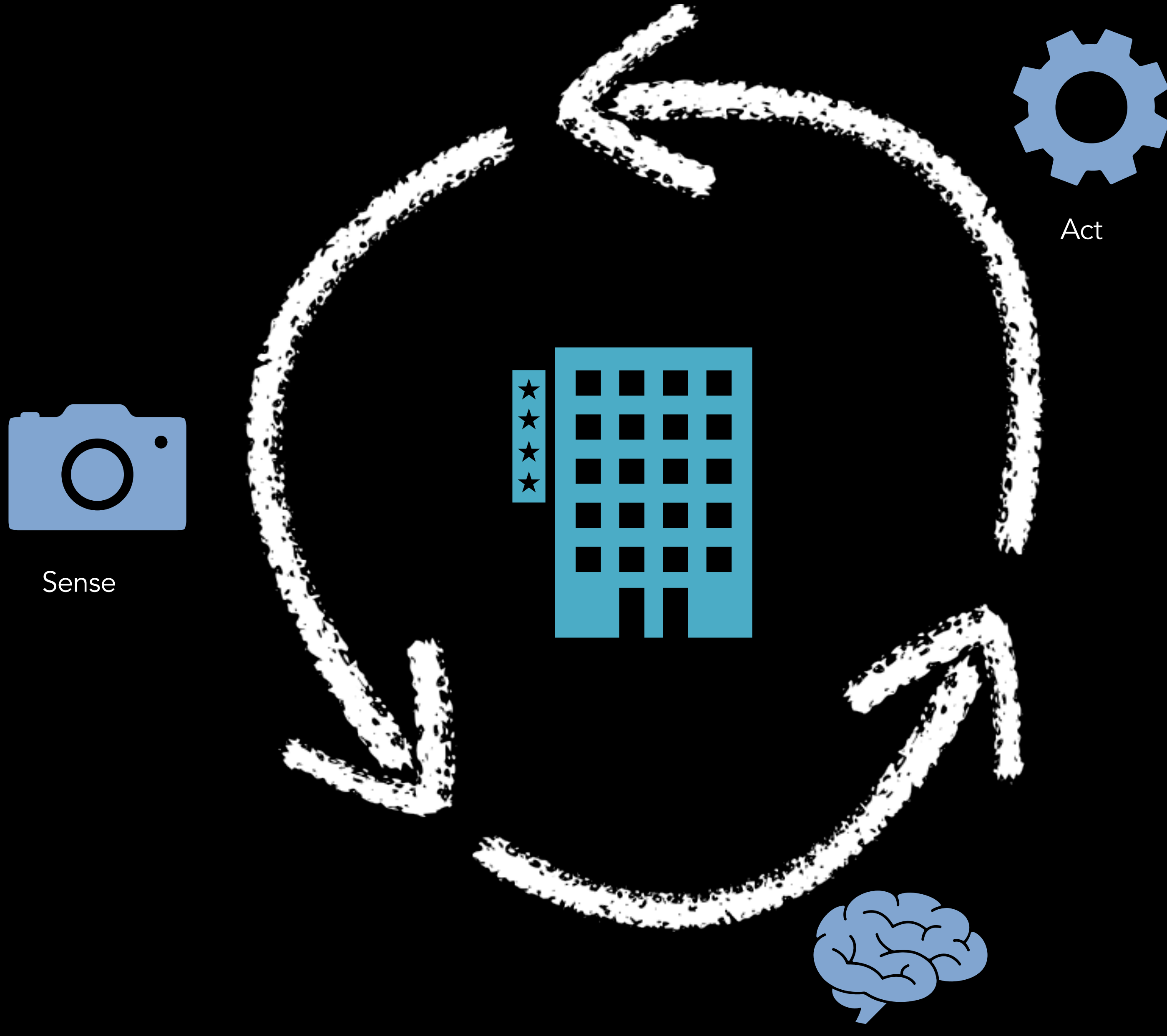

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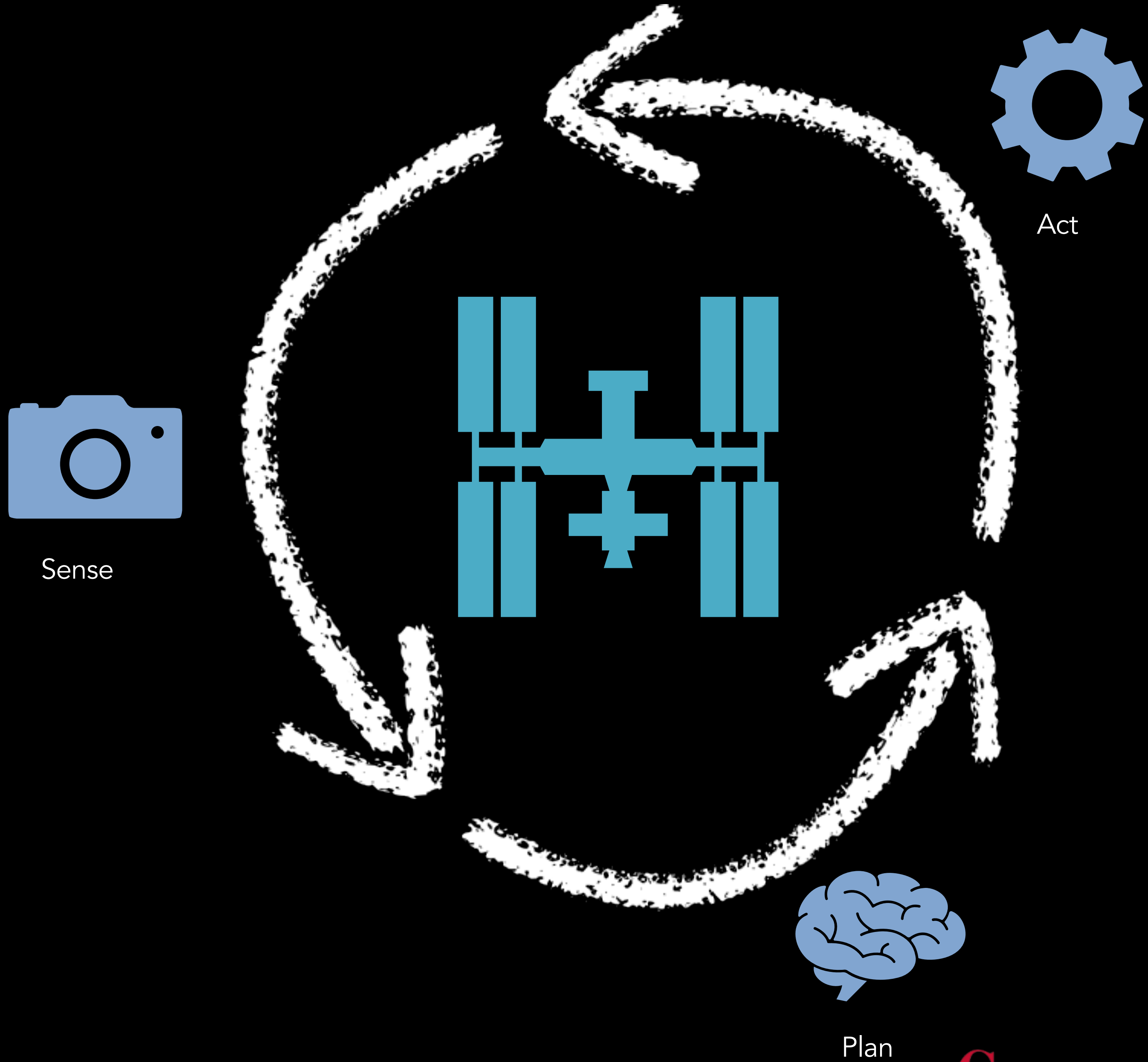
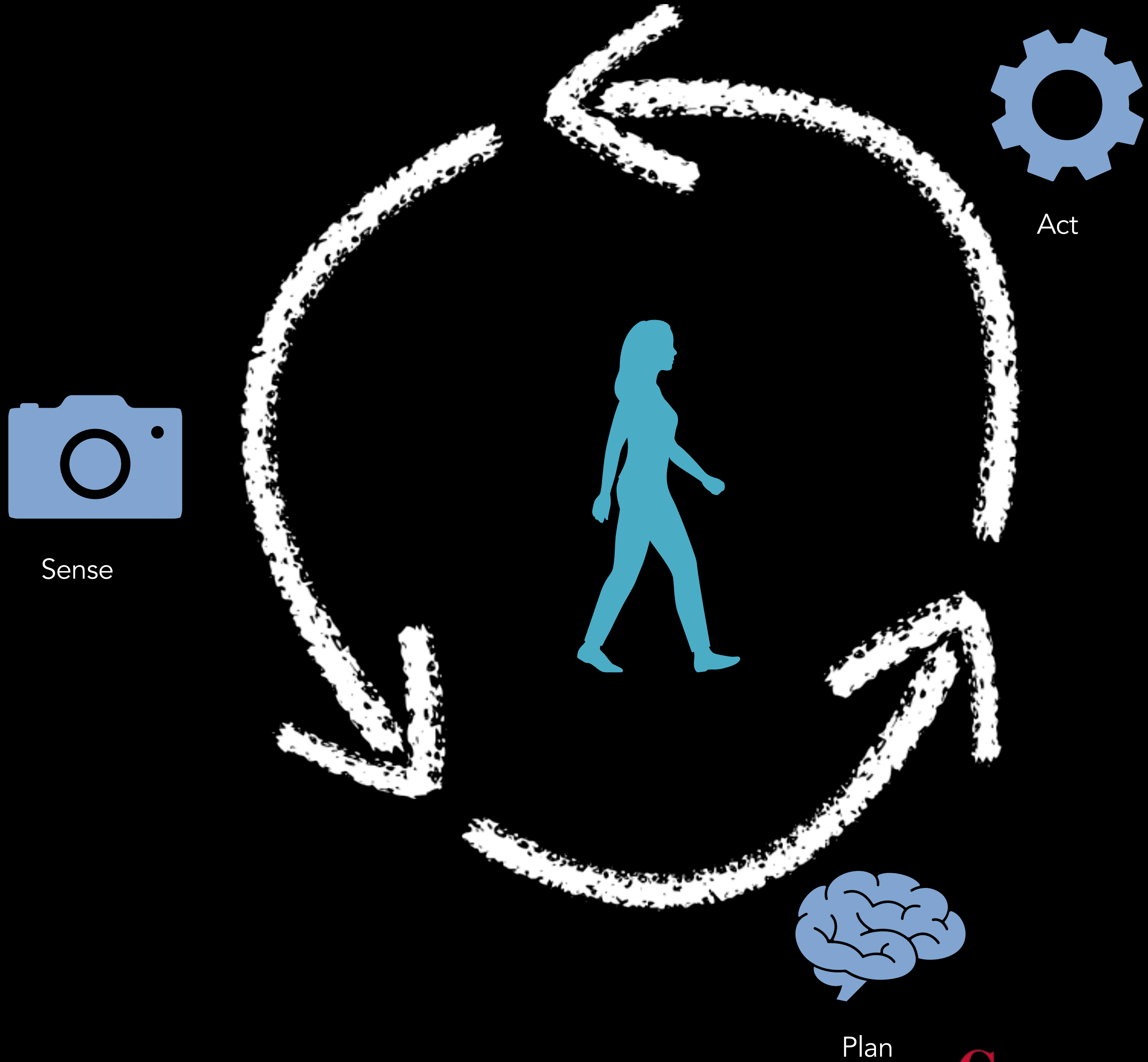
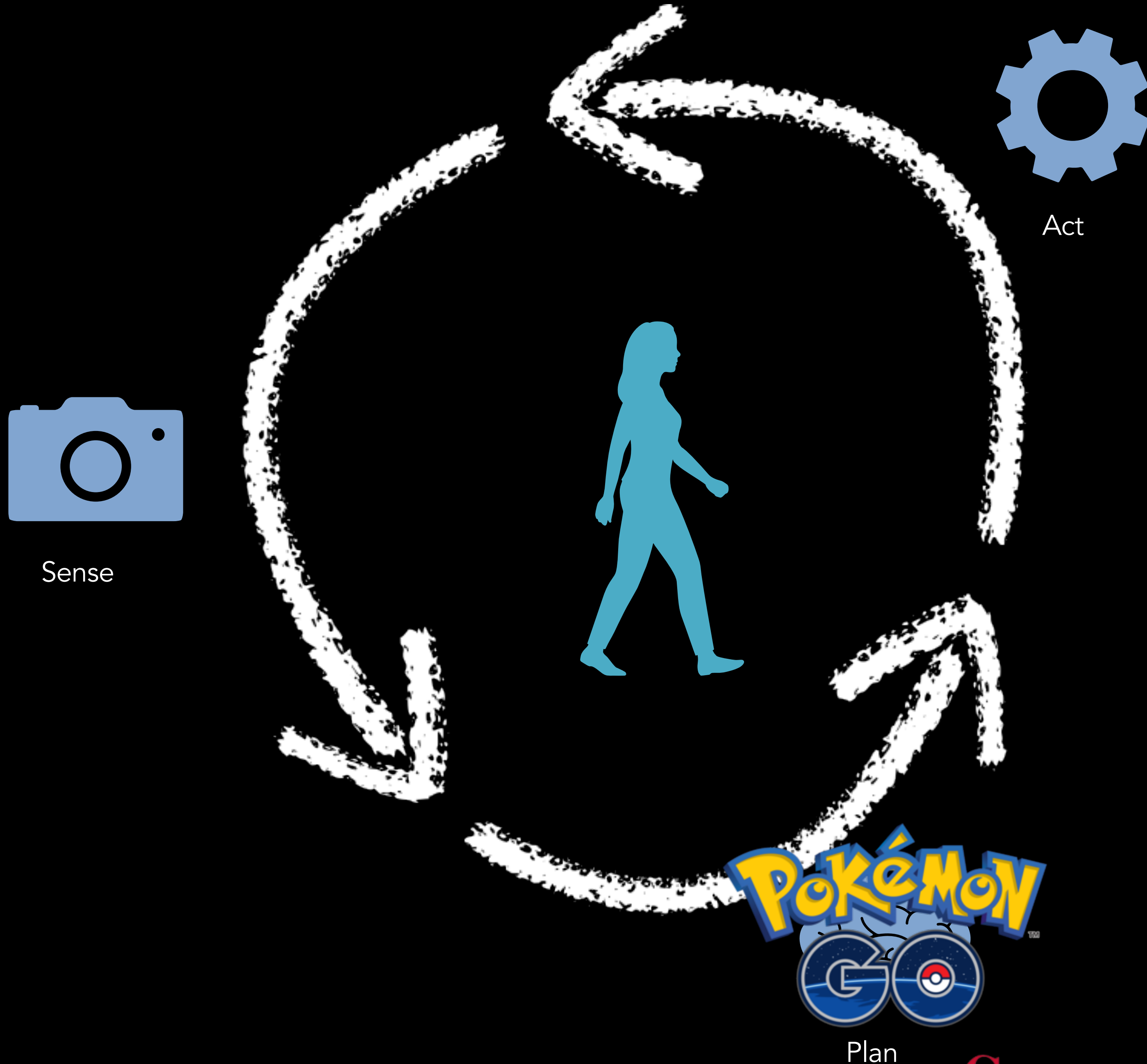

Act
Sense
Plan


Act
Sense
Plan



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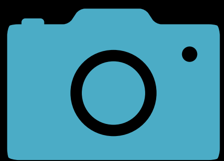
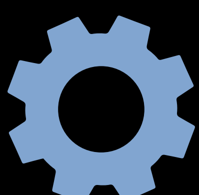
Autonomous systems should sense, plan and act equitably and sustainably

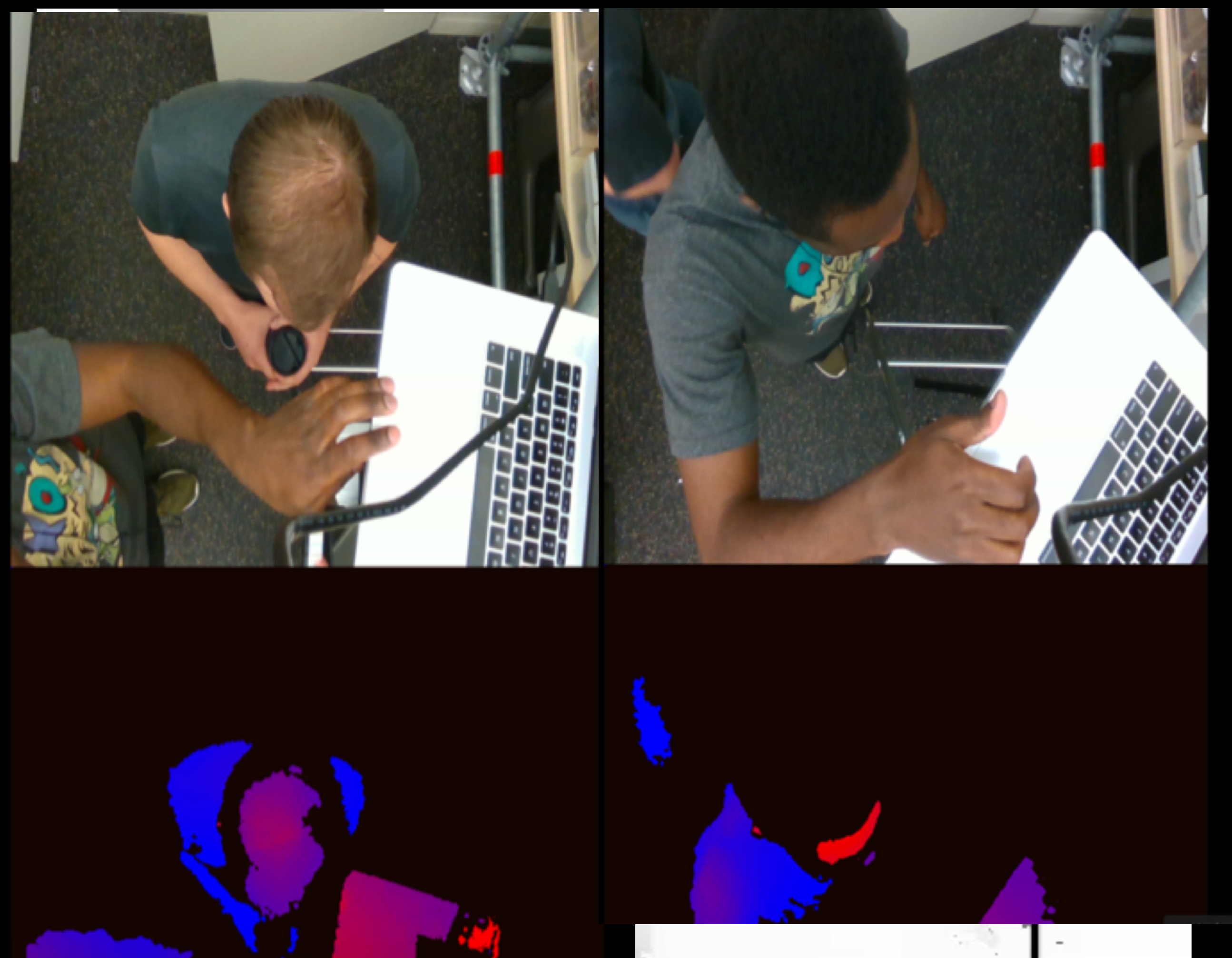


Sense

Plan



Act



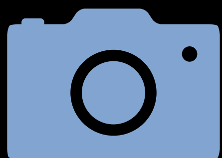
Autonomous systems should sense, plan and act equitably and sustainably

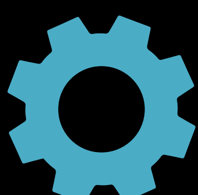
Search Twitter

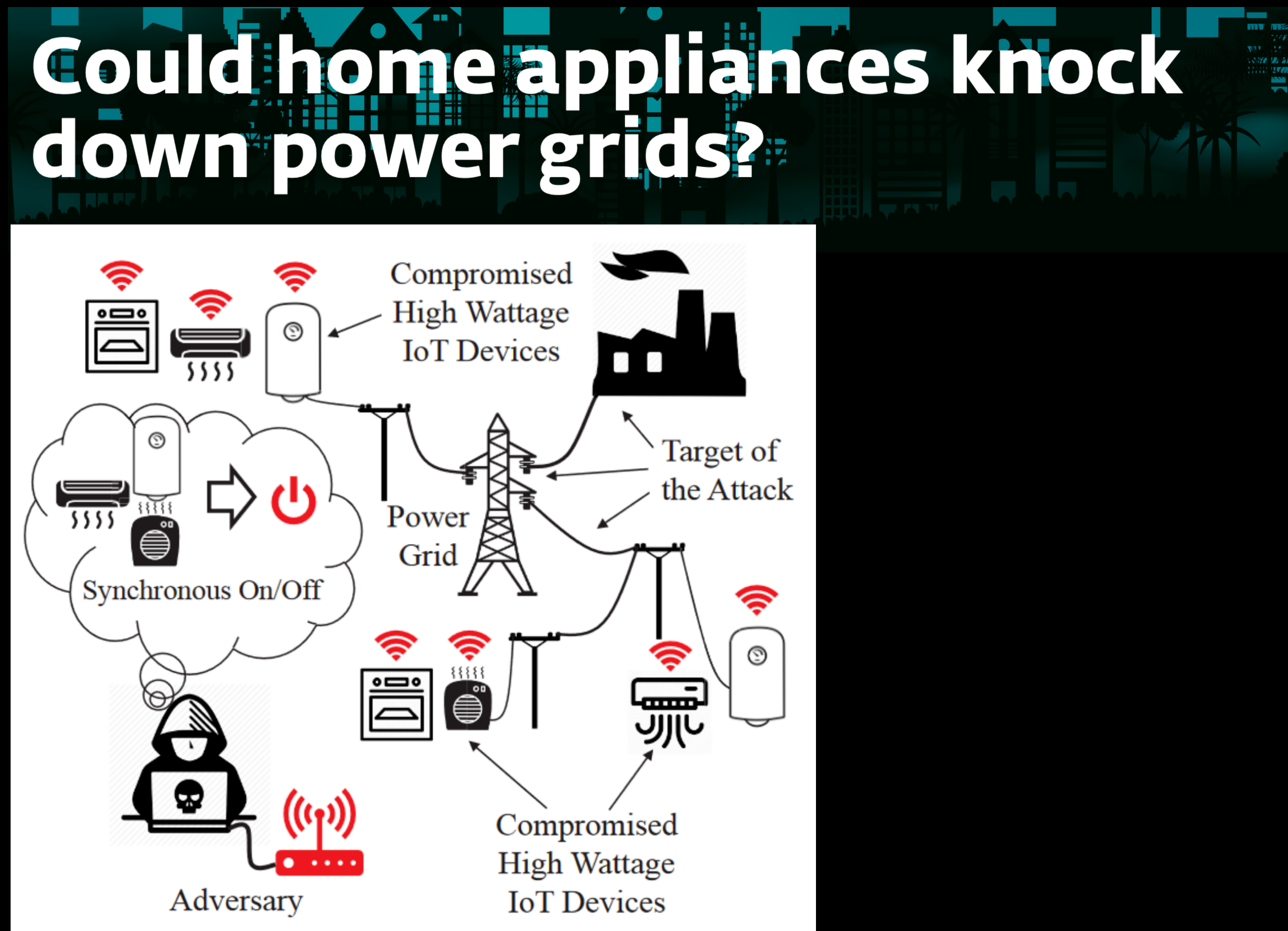
Emily Slackerman Ackerman
@EmilyEAckerman

i (in a wheelchair) was just trapped *on* forbes ave by one of these robots, only days after their independent roll out. i can tell that as long as they continue to operate, they are going to be a major accessibility and safety issue. [thread]

Autonomous systems should sense, plan and act equitably and sustainably








LIVE
LOS ANGELES
ROBO-CARS
TESLA ADMITS BLACK PEOPLE AT HIGHER RISK OF ACCIDENTS
2025
AUTONOMOUS DRIV


LIVE
breakyourownnews.com
BREAKING NEWS
MINORITIES ABANDONED IN CITY
14:58
FAILED AUTONOMOUS RESCUE MISSION AFTER TSUNAMI

Autonomous Sustainable Buildings

- Autonomous
  - Autonomous != Automatic
  - **Sense**, Plan and Act
- Sustainable
  - At each stage of the sense/plan/act
- Buildings

To make a building more autonomous…

WHAT SHOULD WE SENSE?

Examples

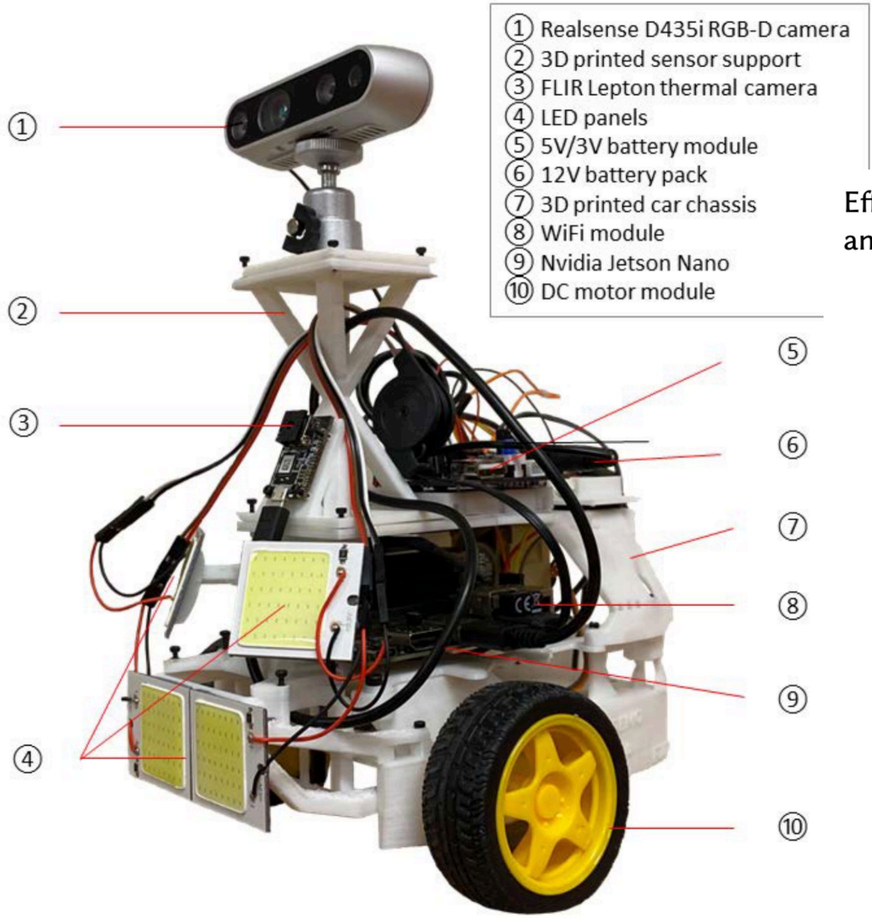


Figure 2: Overview of components of TEA-bot.

EffiSenseSee: Towards Classifying Light Bulb Types and Energy Efficiency with Camera-Based Sensing

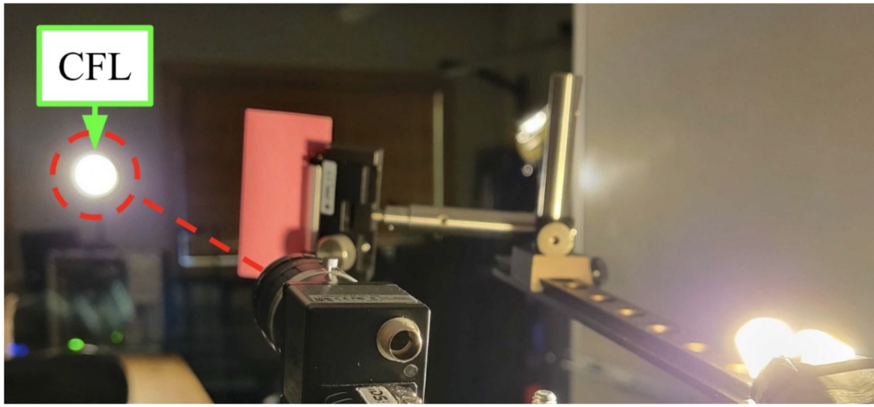


Figure 4: Example indoor setup of imaging a CFL

Examples

Demo Abstract: A toolkit for low-cost thermal comfort sensing

Adam Tyler*
Lancaster University, UK

Oliver Bates*
Lancaster University, UK

Adrian Friday*
Lancaster University, UK

Mike Hazas*
Lancaster University, UK

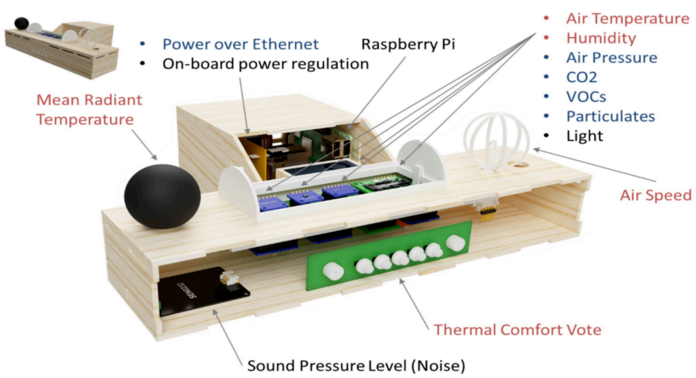


Figure 1: V2 of the thermal comfort sensing device

Presented at BuildSys'19

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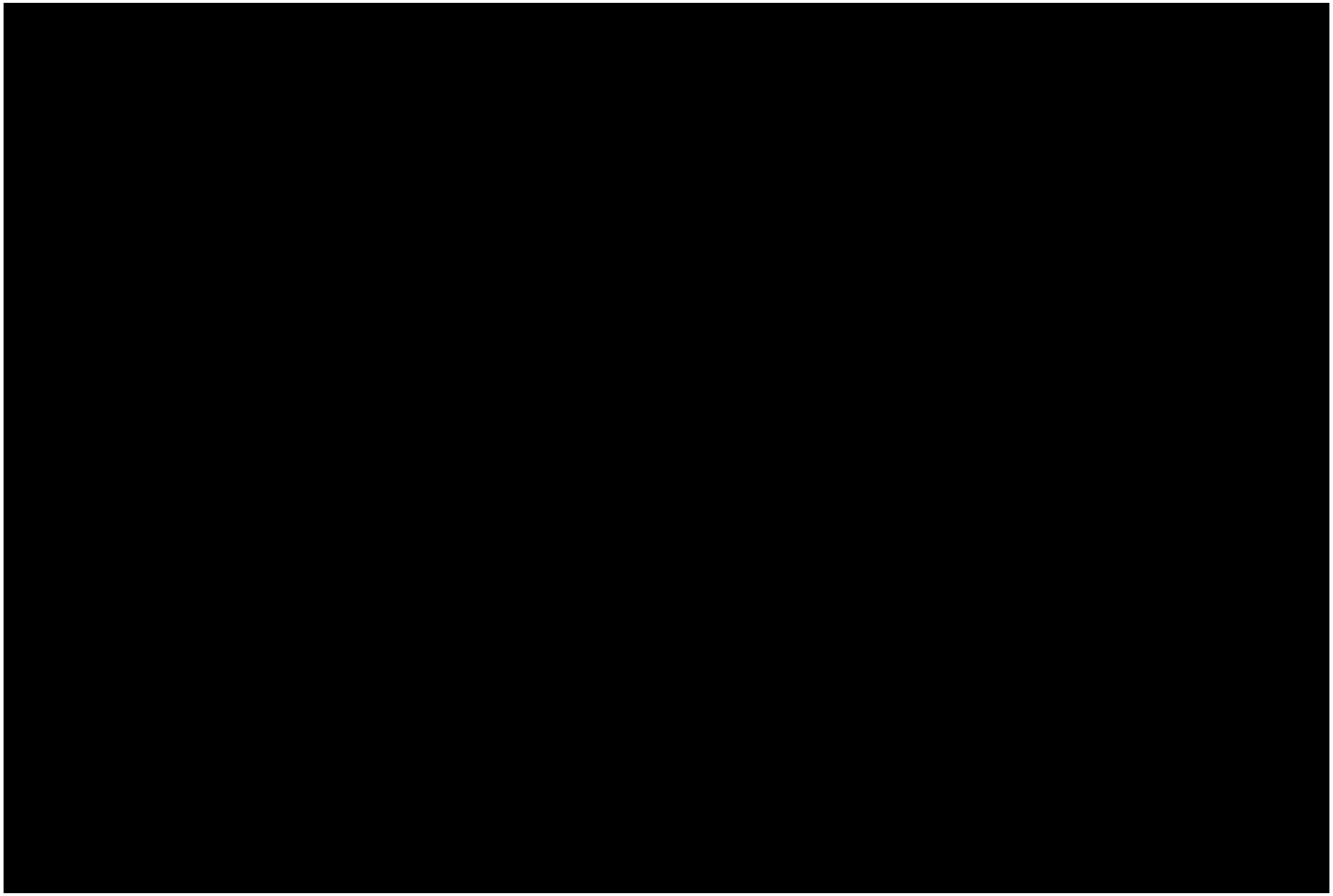
Side-channels: **Visible Light**
Electromagnetic Radiation

Unpublished…



Side-channels: **Visible Light** Electromagnetic Radiation

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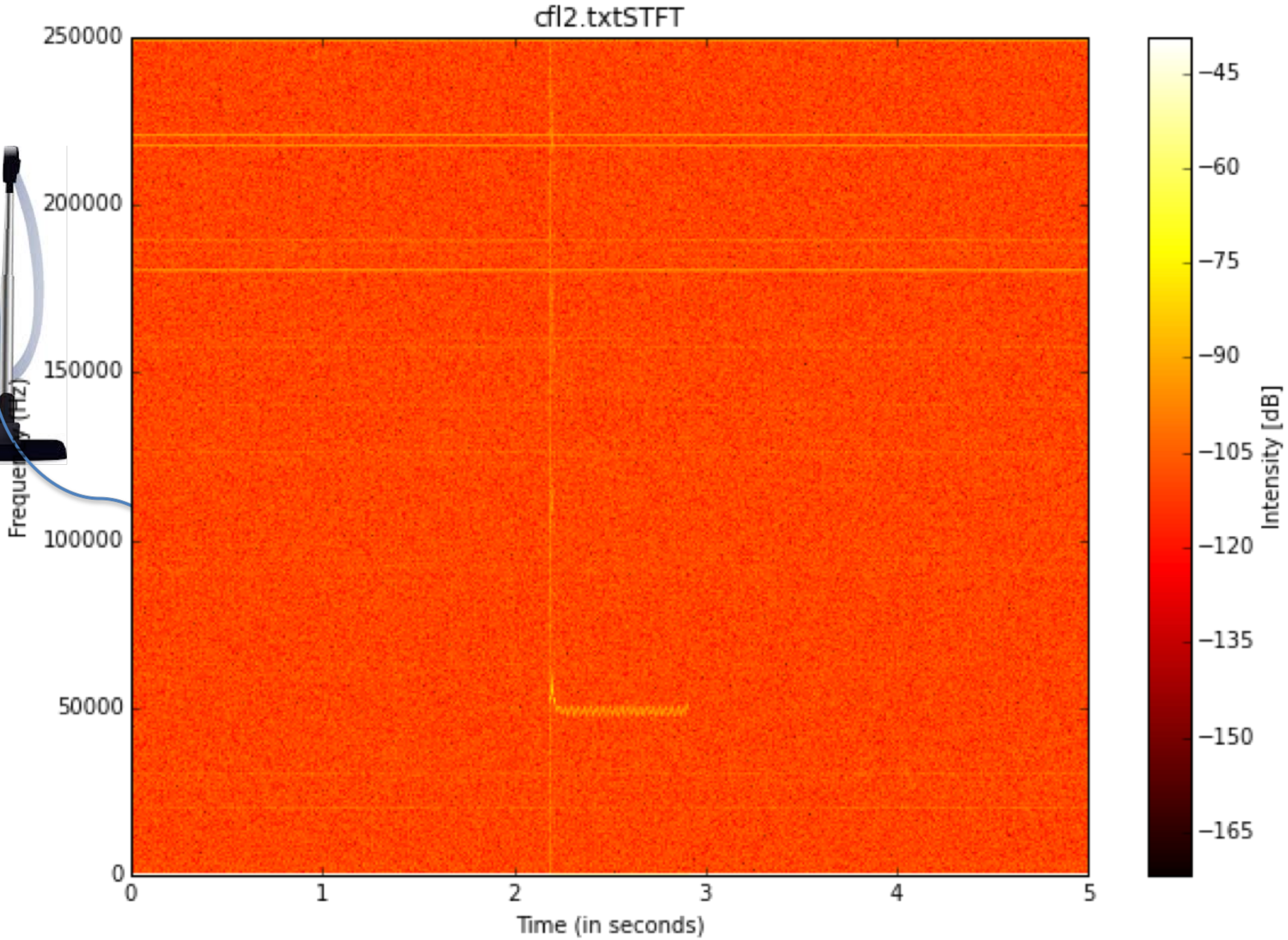

NOT MEANT FOR PUBLIC RELEASE

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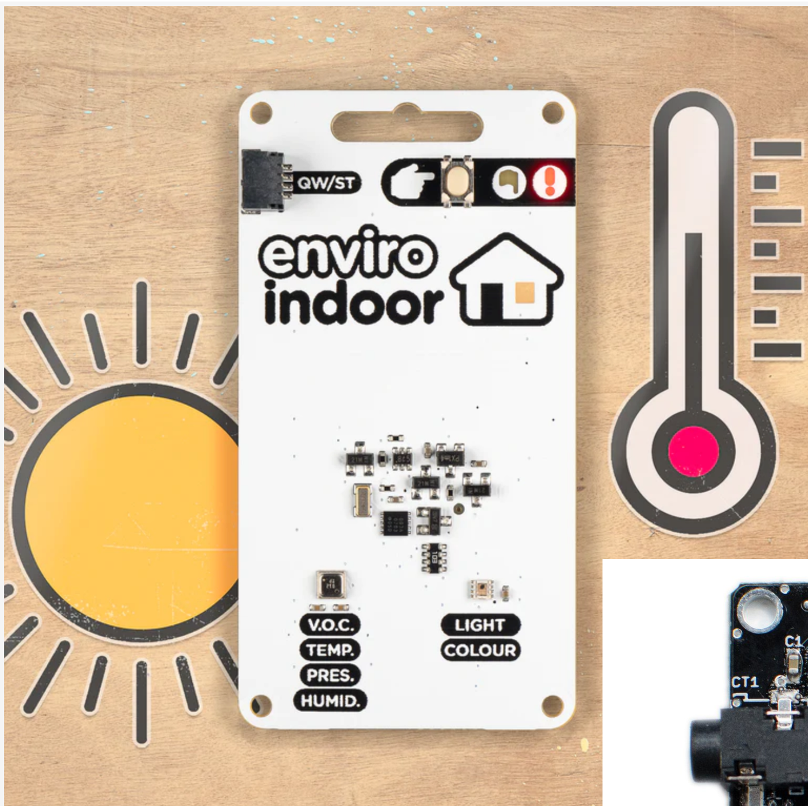
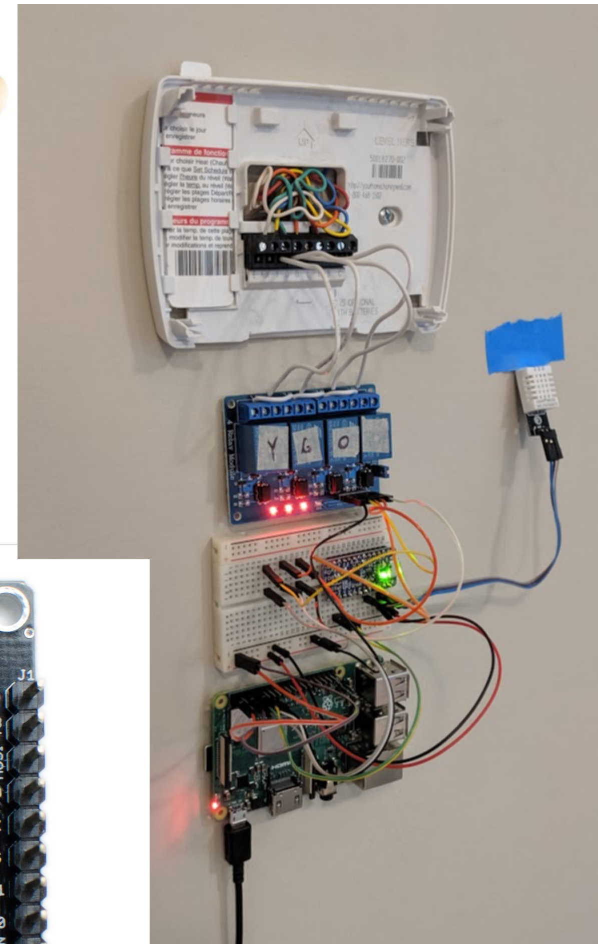
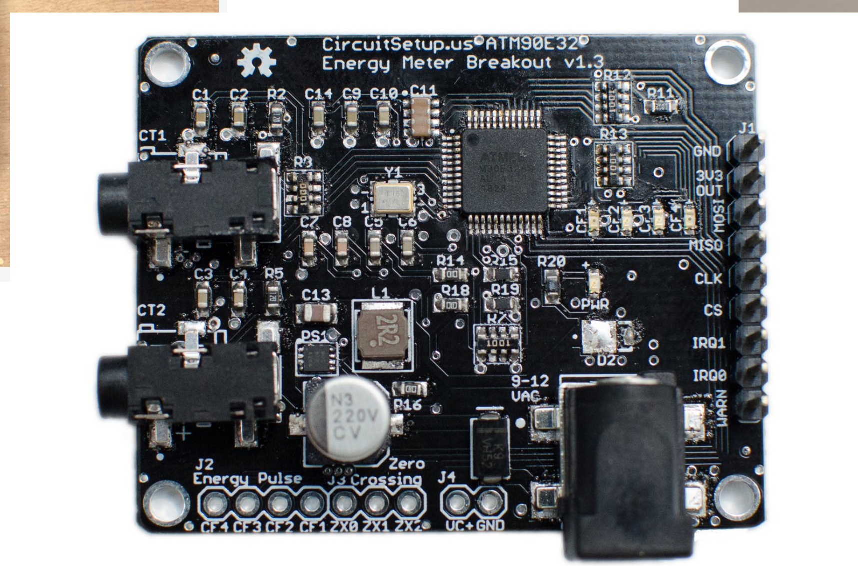
Sensors are a commodity







Sensors are a commodity

- Here are some resources to find yours:
  - Raspberry Pi Hardware by Adafruit:
    - https://www.adafruit.com/category/105
  - Best Raspberry Pi HATs in 2023 by Tom's Hardware:
    - https://www.tomshardware.com/best-picks/best-raspberry-pi-hats
  - Raspberry Pi HATs, pHATS & GPIO by Pihut:
    - https://thepihut.com/collections/raspberry-pi-hats/
  - Rasbperry Pi Pico Hardware by Pimoroni:
    - https://shop.pimoroni.com/collections/pico

Sensors

- Broad definition: “devices that receive and respond to a signal or stimulus”
  - Human eye
  - A trigger in a pistol
- For our scope: “devices that receive a signal or stimulus and responds with an electrical signal”
  - Where electrical signal means: can be amplified, modified and channeled by electronic devices.
  - Examples:
    - Video camera
    - Microphone
    - Accelerometer on your iPhone

Actuators

- For our purpose:
  - They are the inverse of sensors
  - They convert an electrical signal into a physical stimulus
- Example:
  - Sound speakers
  - Electric Motors
  - Relay

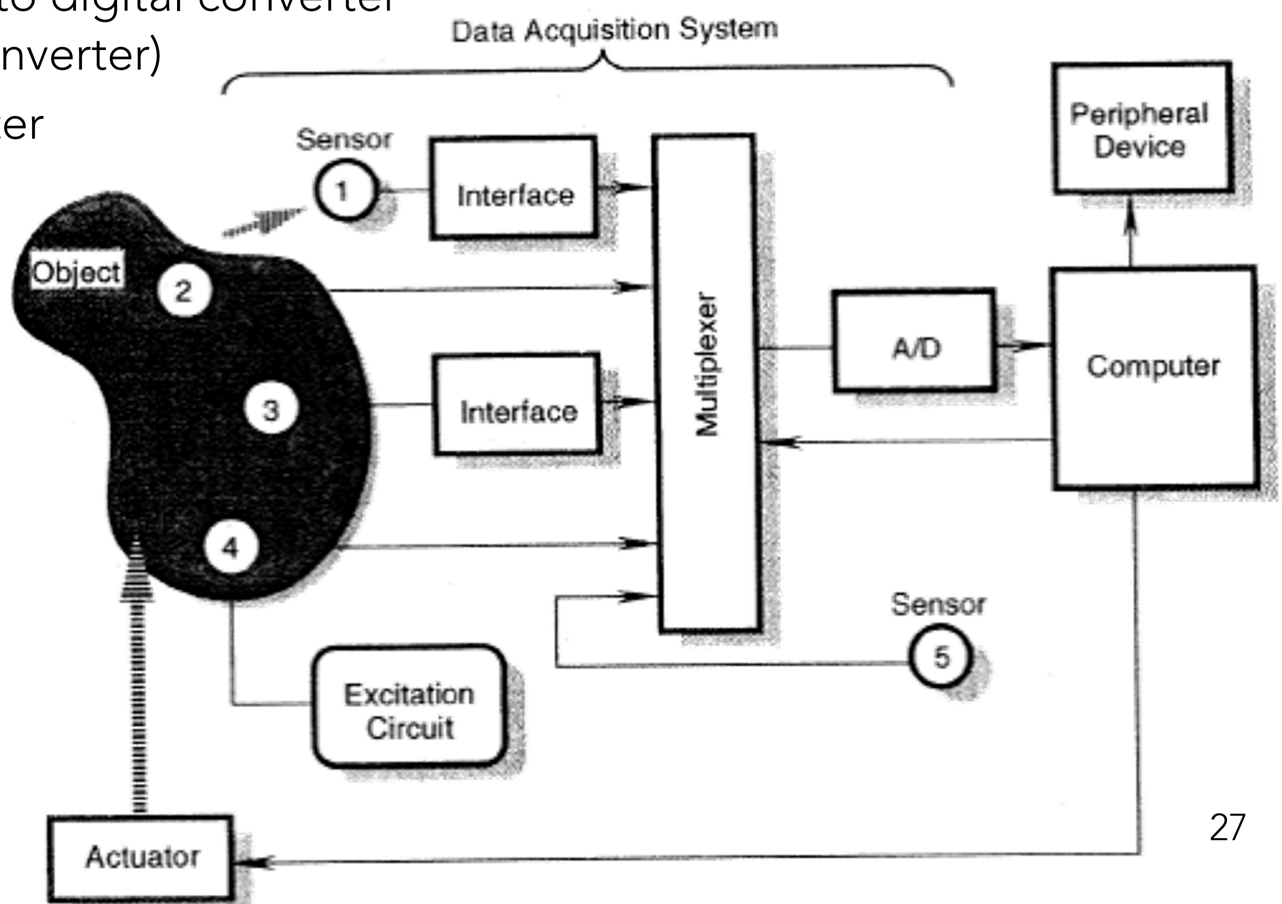
Transducers

- In broad terms:
  - A converter of one type of energy into another.
- For our purposes:
  - A term that encompasses both sensors and actuators.

- Examples:
  - The sound speaker is a transducer and can be used both as an actuator (a speaker) or a sensor (a microphone).

Data Acquisition Systems

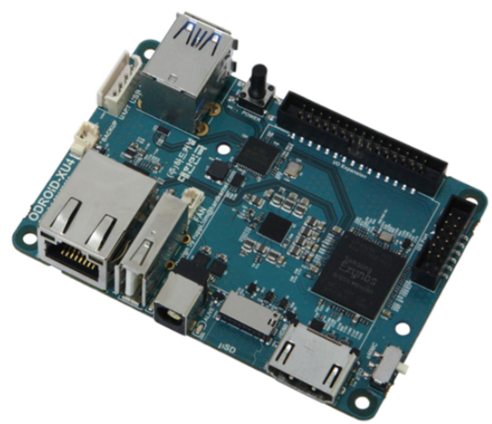
- Components:
  - Sensors
  - Actuators
  - Multiplexer (MUX)
  - Analog to digital converter (A/D Converter)
  - Computer



Example Sensing System

(a)

(b)



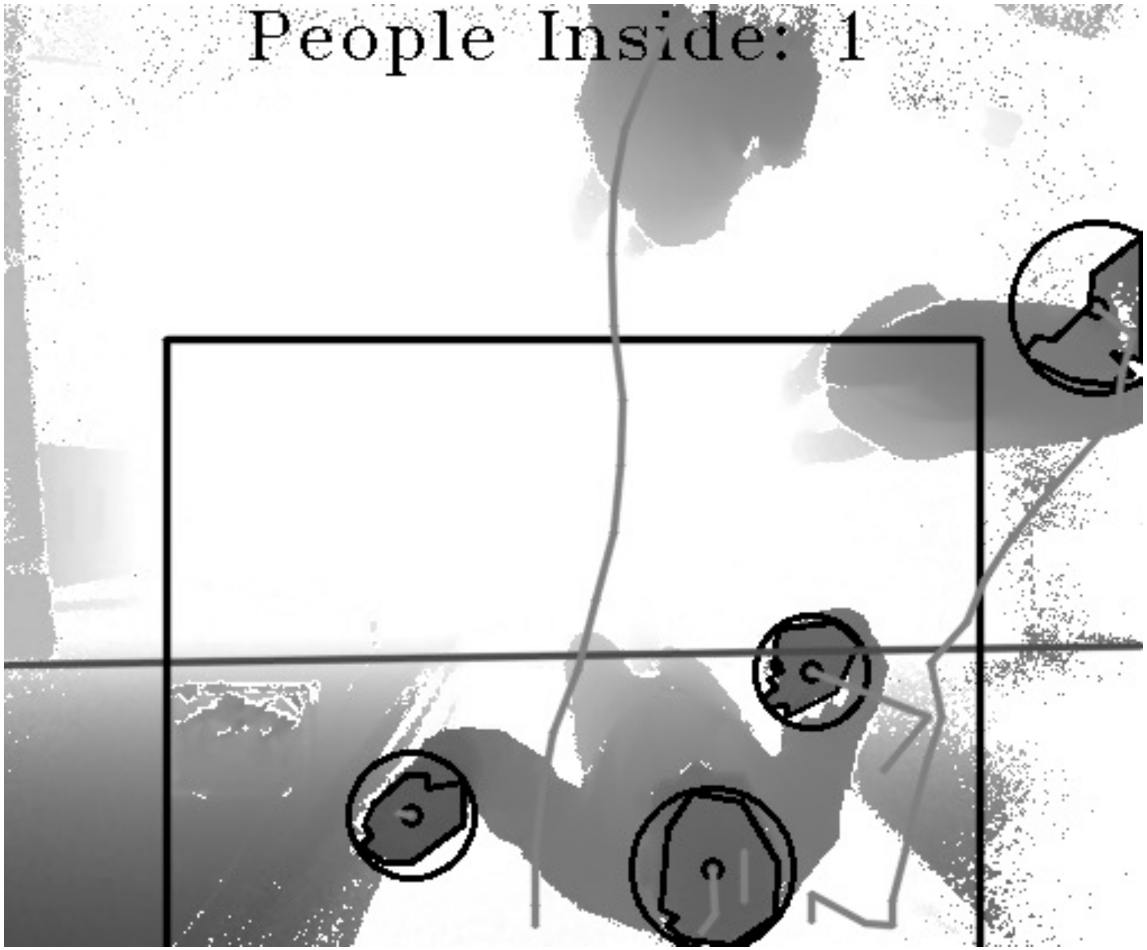
(c)

(a) Placement of a Kinect sensor on ceiling tile.

(b) Kinect sensor

(c) Embedded computer: Odroid-XU4

Data Acquisition + Processing



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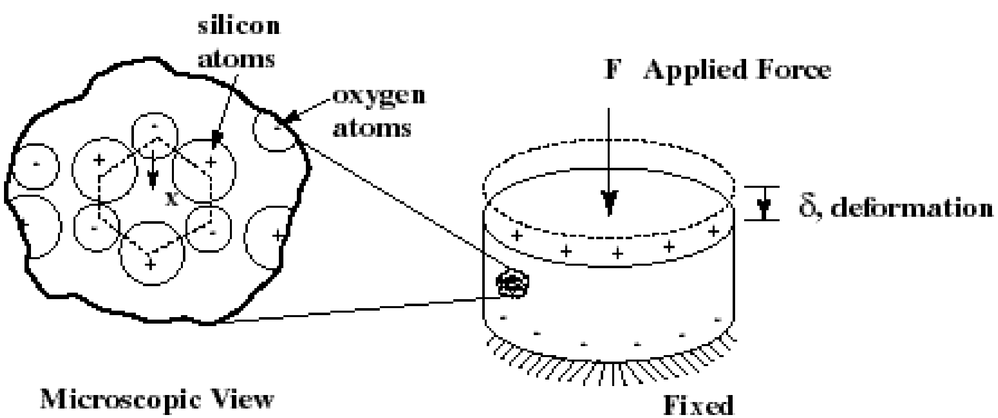
Physics dictate the input/output response

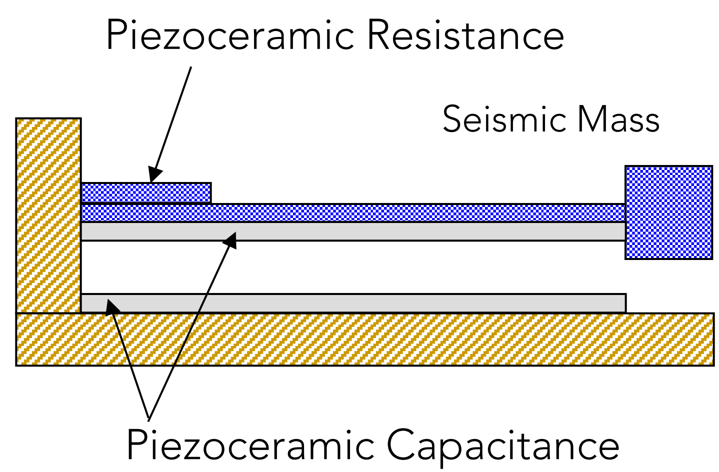
- Piezoelectric Transducer: Charge is proportional to applied force and deformation. Good for a high frequency range. Most commonly used for experimental modal analysis.

- Piezoresistance Transducer: A change in resistance is proportional to imposed deformation. This type of accelerometer has excellent low frequency response down to DC level.

- Capacitance Transducer: The motion of the mass changes the capacitance of the capacitor.



Piezoelectric Transducer



Piezoresistance or Capacitance Transducer

Example: Current Transformer

CR MAGNETICS

Split-Core Current Transformer

CR3110-3000, .40" WINDOW

The 3110 Split-core current transformer is designed to provide a low cost method to monitoring electrical current. A unique hinge and locking snap allows attachment without interrupting the current-carrying wire. High secondary turn will develop signals up to 10.0 Vac across a burden resistor.

SHOWN APPROX. FULL SIZE

Features

- Small Size
- Low cost
- High secondary turns
- Secure locking hinge

Applications

- Portable instruments
- Sub-metering
- Monitor motor loads

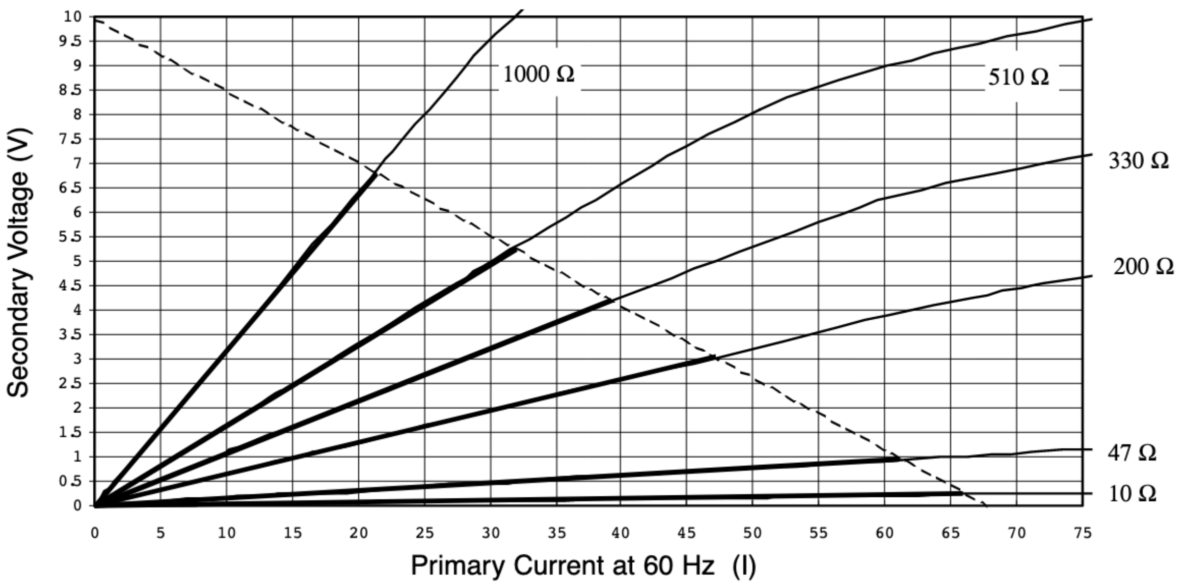
Part Number

Specifications

- Maximum Continuous Primary Current: 75 AAC
- Secondary Turns: 3000
- Wire Lead: AWG #18
- DC Resistance: 460 Ohms @ 20°C
- Frequency: 50/60 Hz

Example: Current Transformer

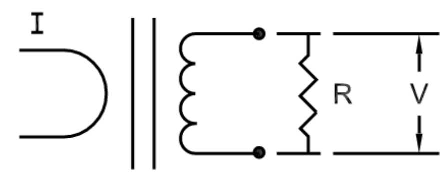
Electrical Output



Bold lines indicate linear region according to formula:

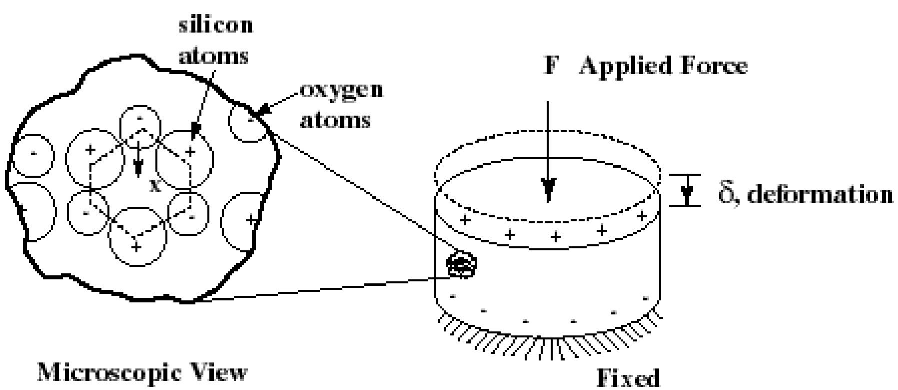
$$V = \frac{I \times R}{3100}$$

V in Volts AC RMS
I in Amps AC RMS
R in Ohms

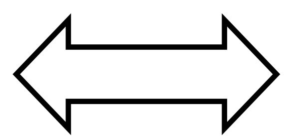


Sensors also have dynamic characteristics

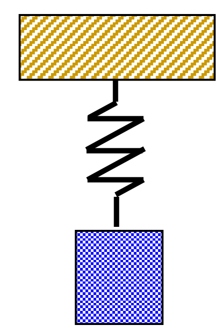
- Dynamic Characteristics: When an input stimulus varies, a sensor response generally does not follow exactly. This is because both the sensor and the interface circuit have a dynamic characteristic.
- Many sensors can be often modeled as a single degree-of-freedom system.
- To understand the dynamic characteristics of a sensor, let's review structural dynamics briefly.



Piezoelectric Transducer



Equivalent



Seismic Mass

Data Acquisition Systems

- Components:
  - Sensors
  - Actuators
  - Multiplexer (MUX)
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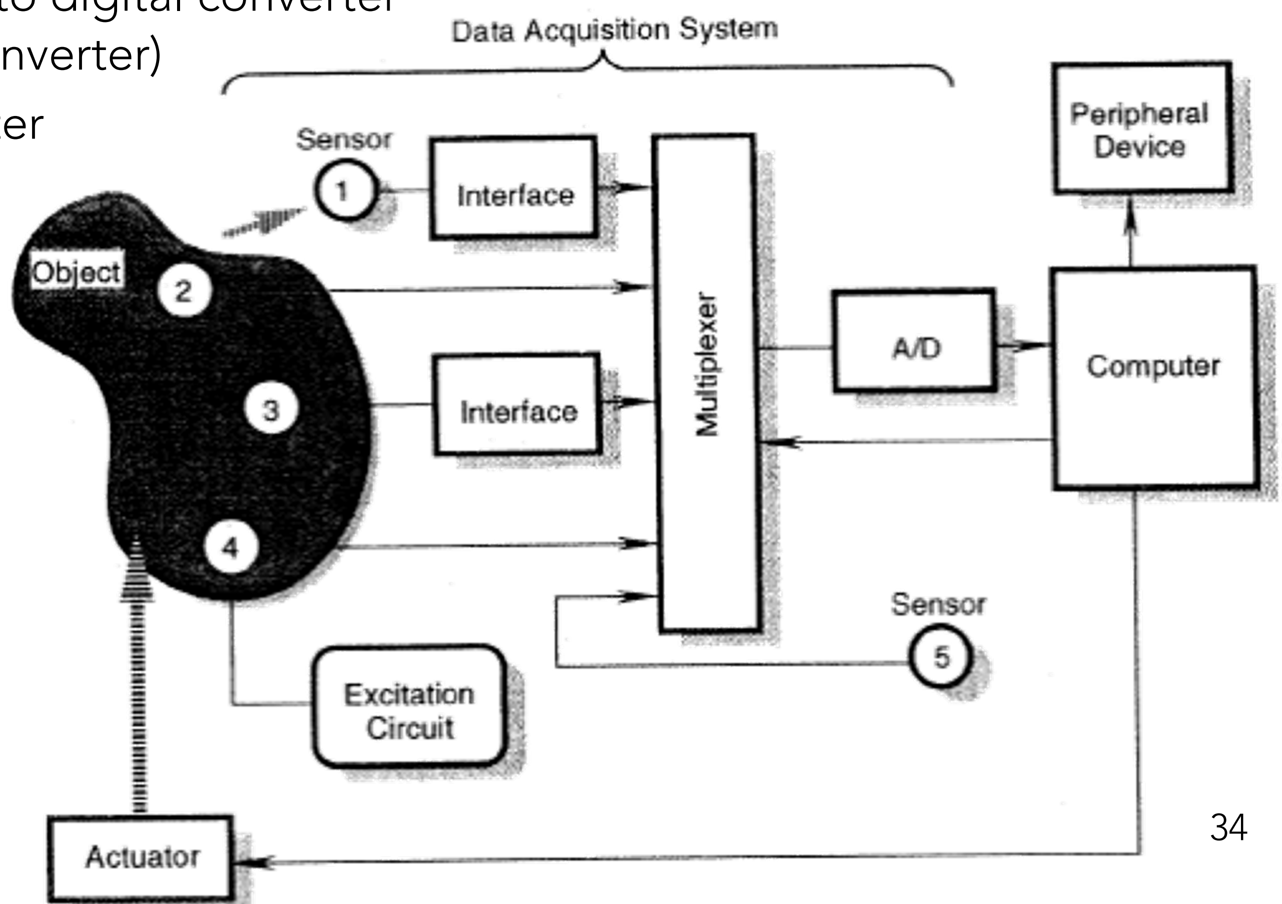
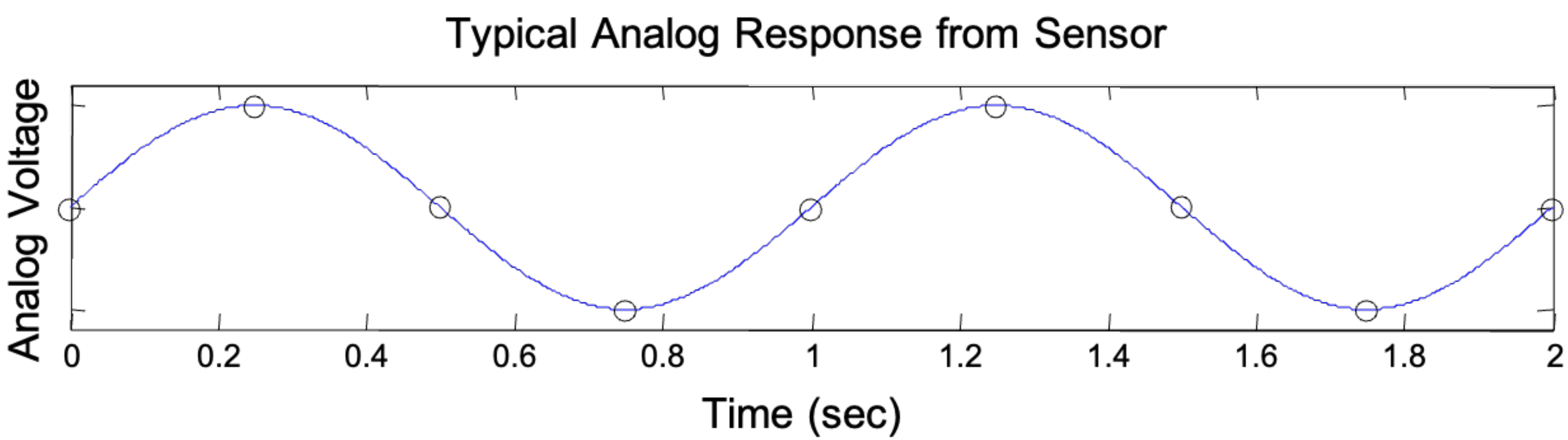


Digitization of Analog Signals

- Sampling: We need to specify how often the data is sampled in time axis.
- Quantization: The amplitude of the analog sensor reading is digitized by A/D converter.



Determination of Sampling Frequency

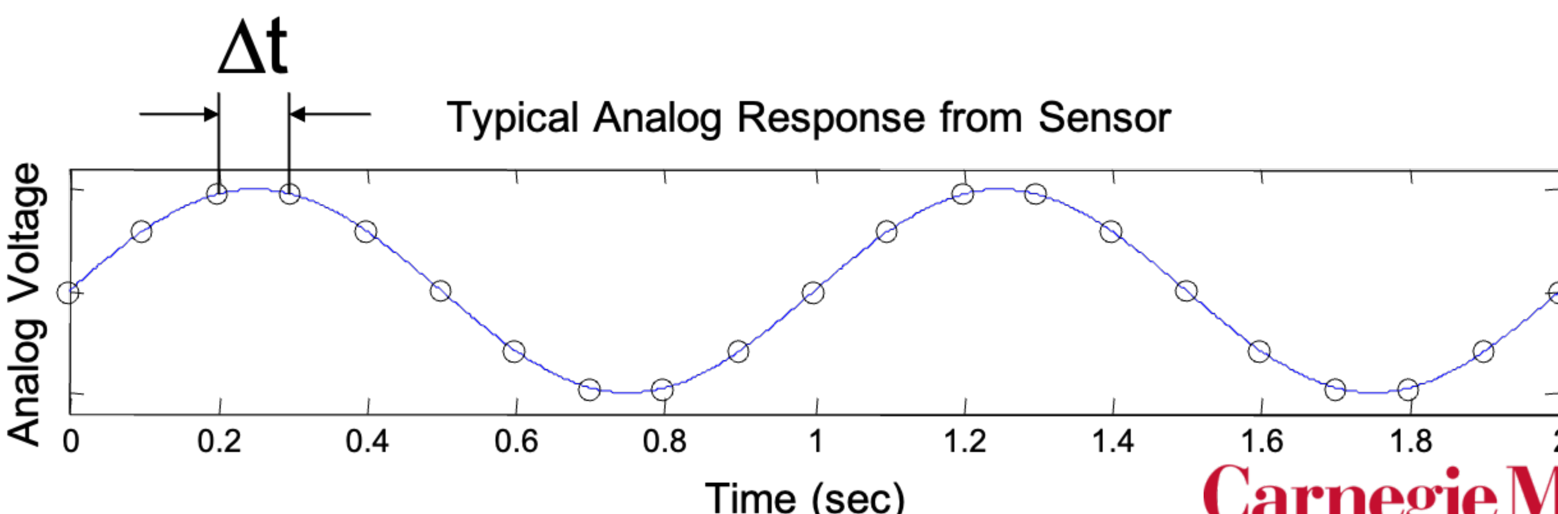
- Sampling frequency (Hz) is the inverse of the sampling interval.

$$f_s = 1/\Delta t \text{ (Hz)} \quad \text{or} \quad \omega_s = 2\pi/\Delta t \text{ (rad/sec)}$$

- Make sure the sampling frequency is at more than twice the desired frequency to be measured.

$$f_h < f_s/2 = 1/(2\Delta t)$$

- Sample 10 or more digital points during the signal period of interest.



Sampling Parameters

- Define the maximum frequency value to measure, then determine the sampling rate.

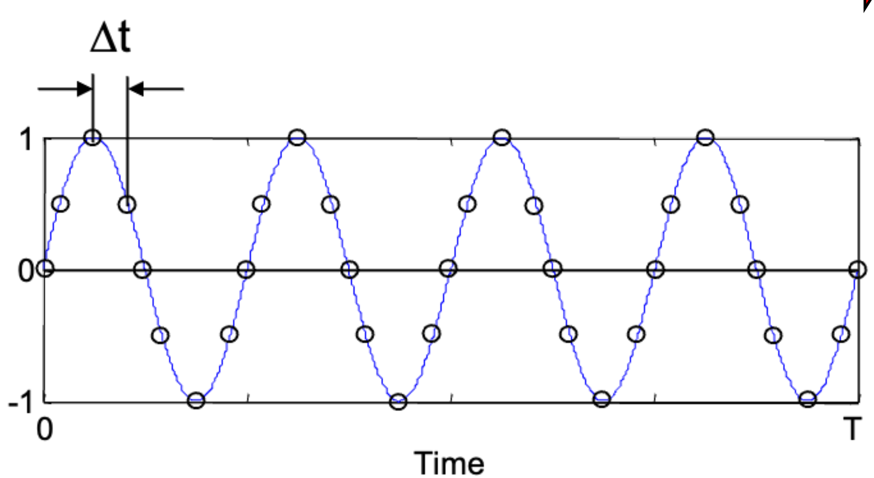
$$f_h < f_s/2 = 1/(2\Delta t)$$

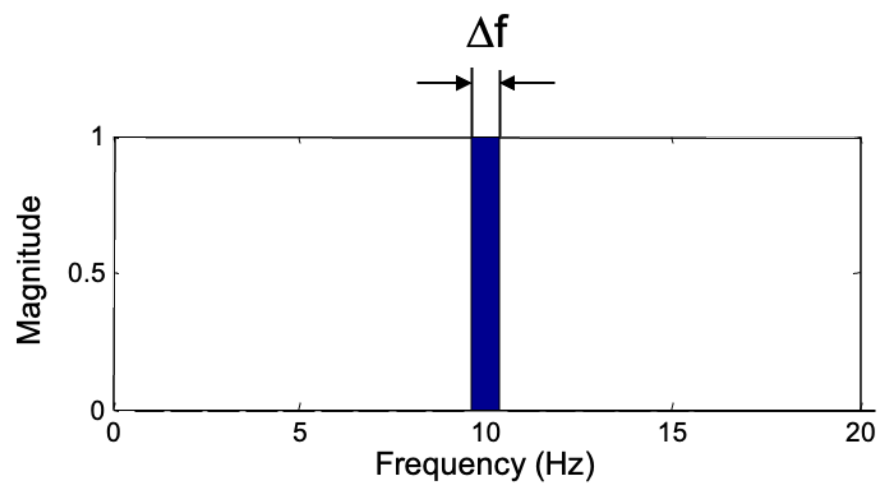
$$\Delta t < 1/(2f_h)$$

- Define the desired frequency resolution, then select required number of data points.

$$\Delta f = 1/T = 1/(N\Delta t)$$

$$N = T/\Delta t = 1/(\Delta f\,\Delta t)$$





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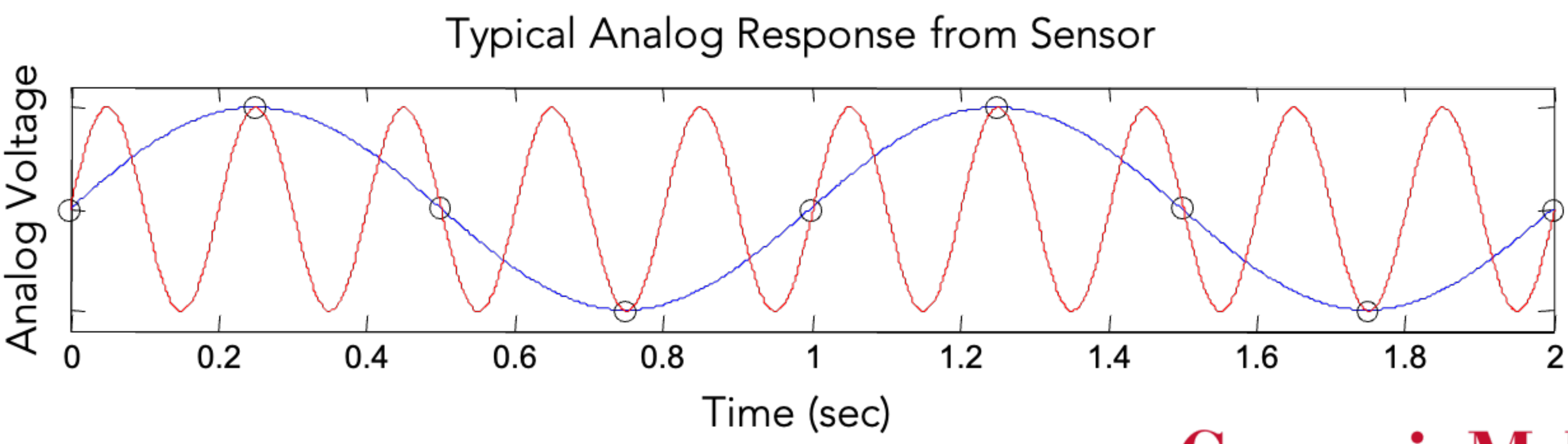
Aliasing

$$y_1(t) = \sin(2\pi f_1 t) \qquad f_1 = 1\,\text{Hz}$$

$$f_s = 4\ \text{Hz} \quad \text{or} \quad \Delta t = 0.25\ \text{sec}$$

$$y_2(t) = \sin(2\pi f_2 t) \qquad f_2 = 5\,\text{Hz}$$



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Data Acquisition Systems

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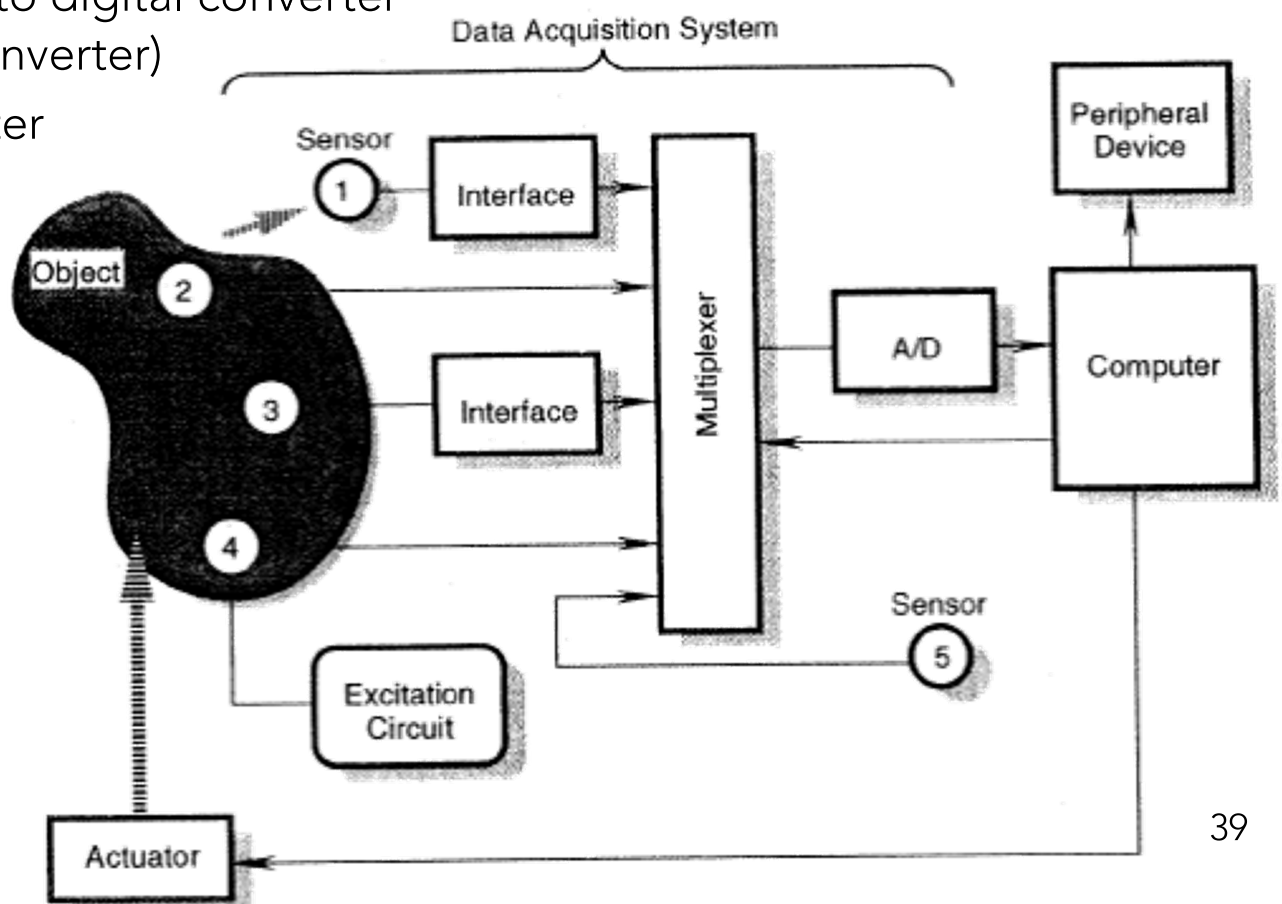
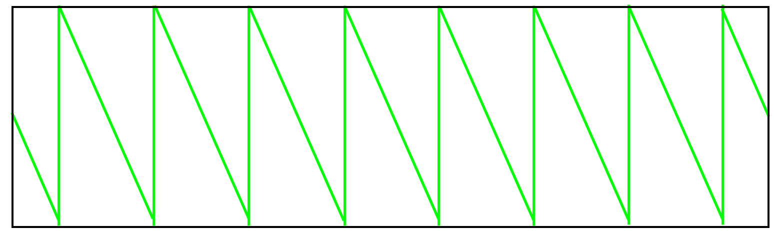
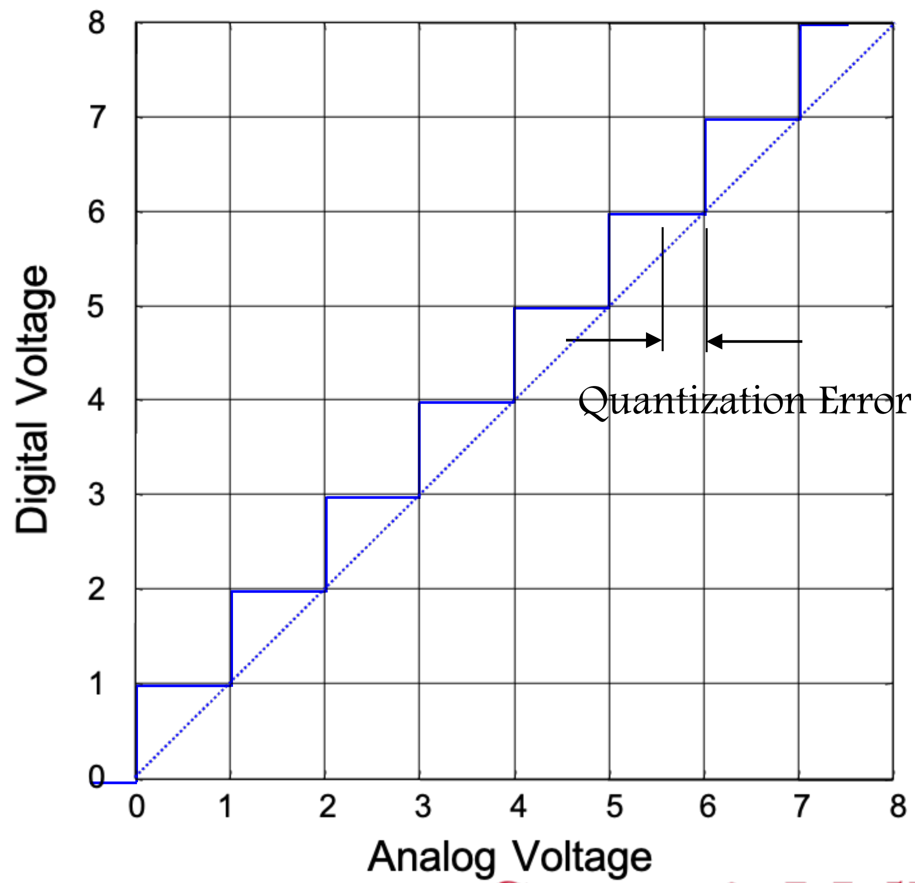


Quantization using 3-Bits Analog-to-Digital Converter

Quantization Error
(0.5 x Resolution)



$$\text{Resolution} = FSV / 2^3$$



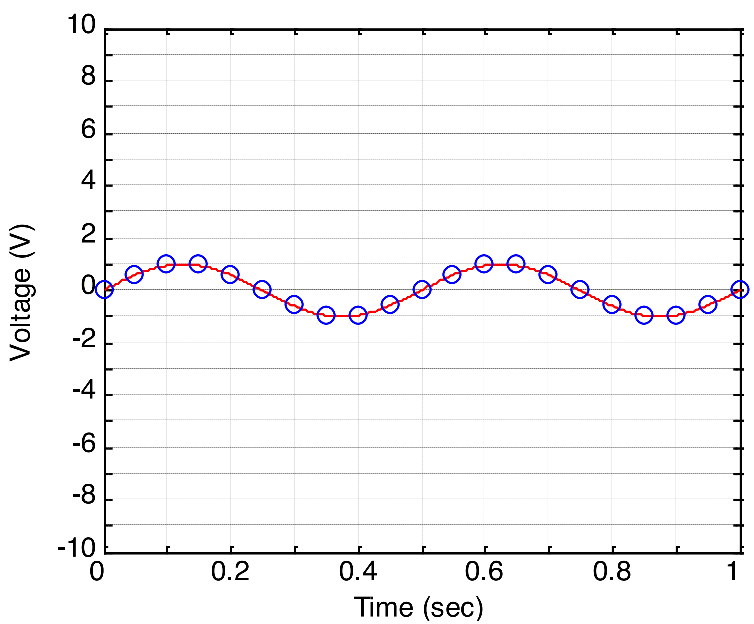
3 bit A/D converter produces

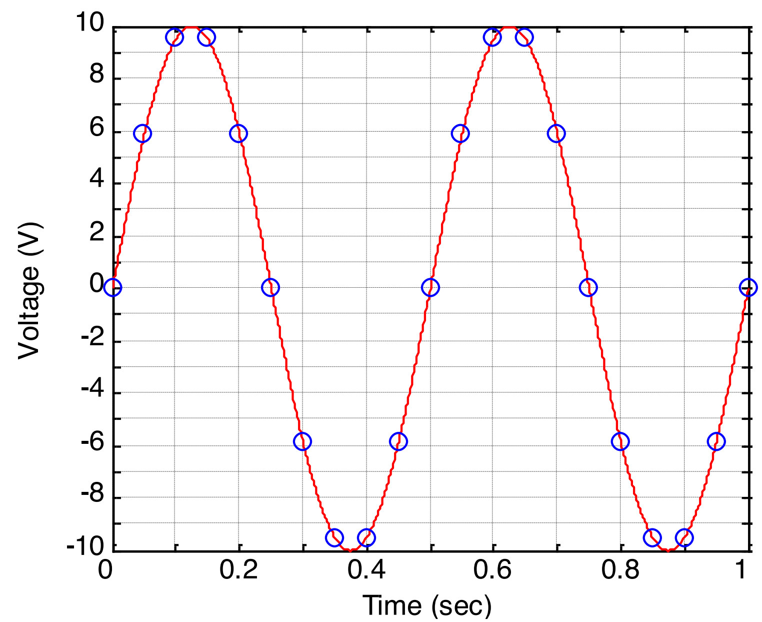
$2^3 = 8$ bins

for full scale voltage (FSV)

Other Considerations for Resolution

- Output Voltage Range: Keep the output voltage range small enough to prevent sensor signals from clipping (overload).
- Effective Resolution: When all of the available dynamic range of the ADC is not fully used, the effective resolution becomes worse. This also causes amplitude and phase distortion of the measured signals in both time and frequency domains.





Keep the maximum signal amplitude close to the dynamic voltage range.

The End

QUESTIONS?

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INFERLab

Intelligent Infrastructure Research Laboratory

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