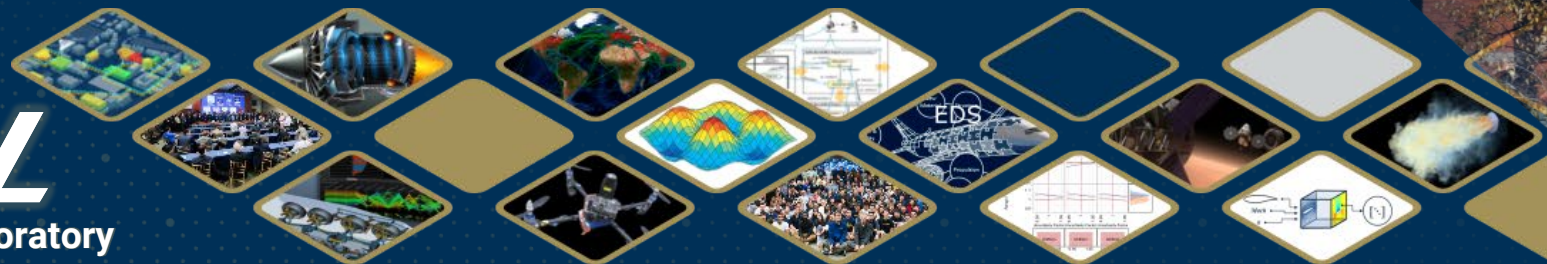
The Development and Evaluation of a Low-Cost Building Occupancy Estimation System

Kendeda Micro Grant Symposium – April 18, 2023

Undergraduate Researchers: Alex Lomis and Devi Patel

Research Advisor: Dr. Jung-Ho Lewe



ASDL

Aerospace Systems Design Laboratory

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Project Statement

This project sought to develop a **low-cost, non-intrusive, and highly-scalable** building occupancy sensor capable of detecting **bi-directional motion** at accessways.


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Project Motivation

This data is useful for the efficient utilization of building resources, and allows building operations to operate proactively rather than reactively.

More data, from **affordable** and **reliable** sensors, is critical for characterizing building efficiency.


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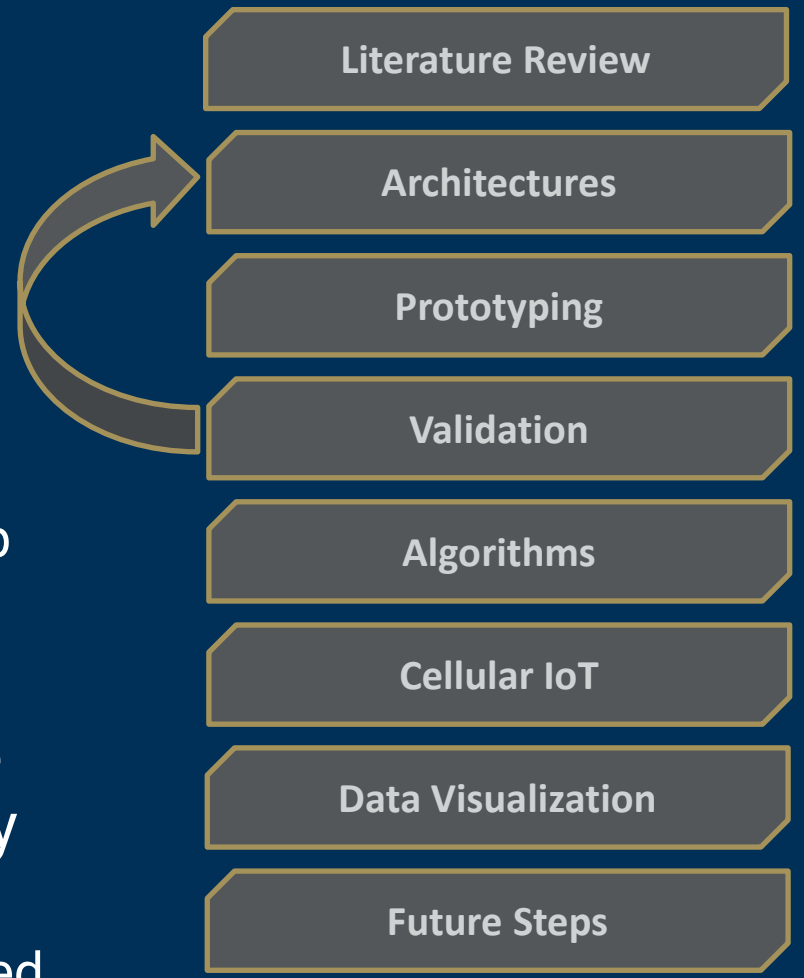
Development Process

1. People counting is an open-ended goal
    1. Many valid solutions and methods discovered through literature and market reviews
2. Accuracy is important, but can be sacrificed slightly to achieve low-cost
    1. The goal is not to make the most accurate system, but one that does the job and is cheap
    2. Decide on an architecture, prototype, validate and repeat for the best solution
3. Reliability is important – how do we make sure these systems operate independently of location, Wi-Fi, or conditions?
    1. Utilizing cellular communication and web-based visualization tools



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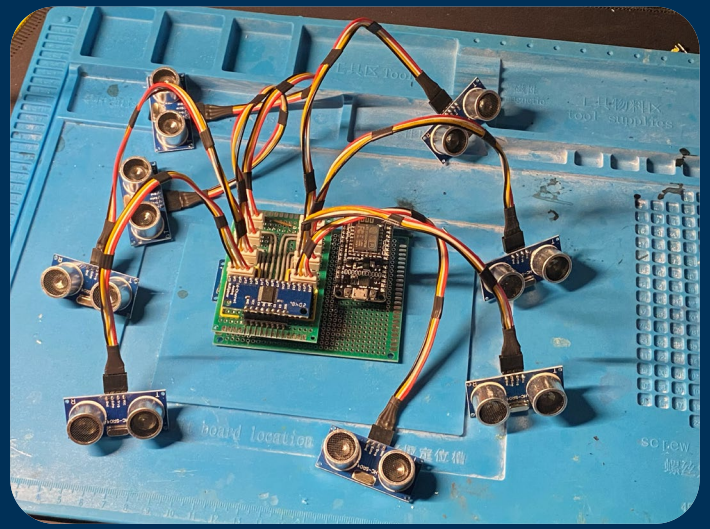
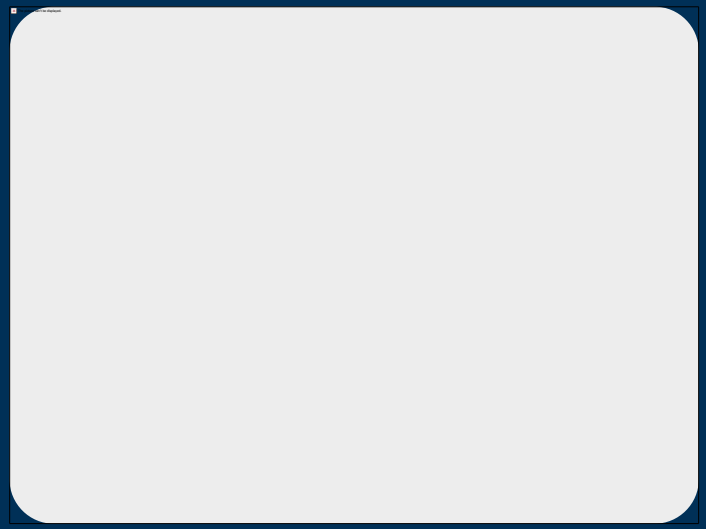
Architecture Choices

Utilizing the understanding of current systems and methods, Ultrasonic and IR TOF sensors were selected as possible distance estimation tools.

- Each system has its own tradeoffs, so prototypes were developed for both



The HC-SR04 Sensor records the short duration time between when a pulse of ultrasonic frequency sound is emitted and when it returns.



The VL53L0X Sensor records the short duration time between when a pulse of infrared light is released and when it returns. Has built-in crosstalk rejection.

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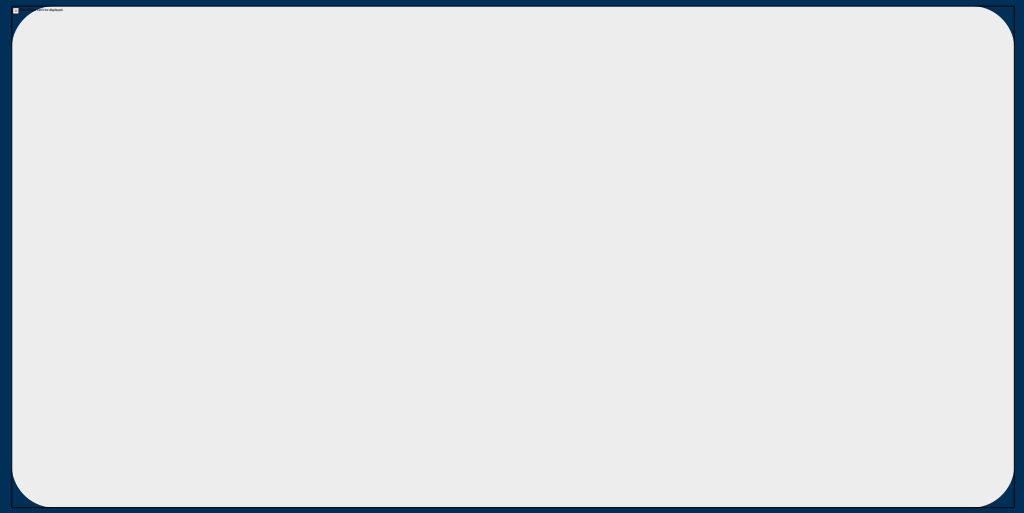
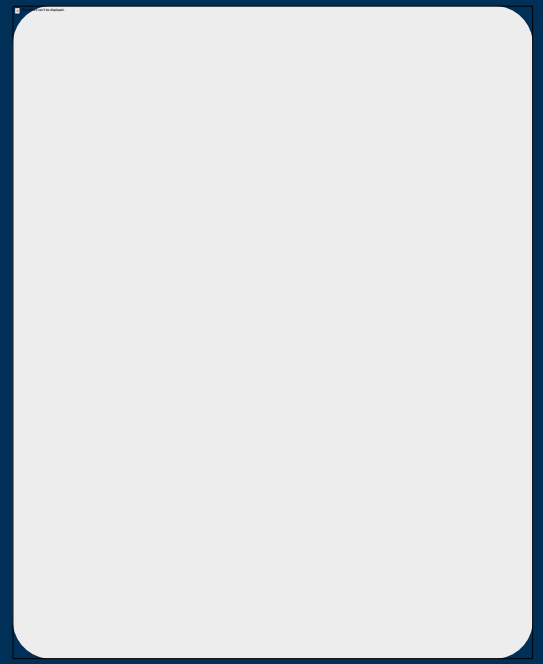
Prototyping – IR Time of Flight

- An IR TOF system was developed to allow algorithm development
  - This test-bed system read sensor values and plotted them in real-time for qualitative visualization
  - Mounts above a doorway, facing downwards, with 0, 15, and 30 degree outward angled sensors





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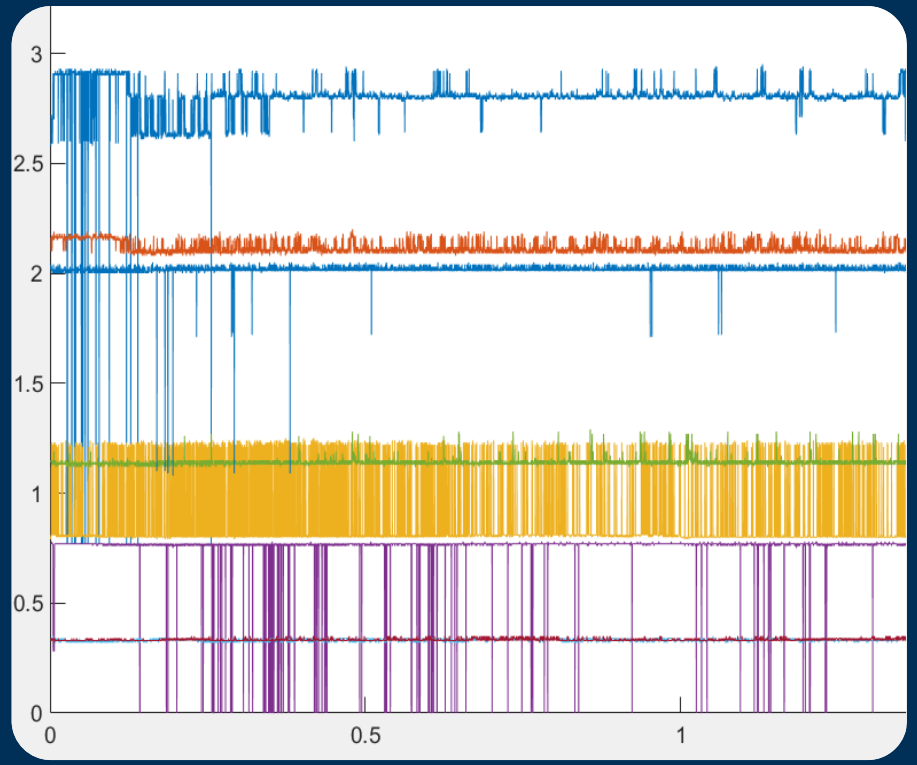
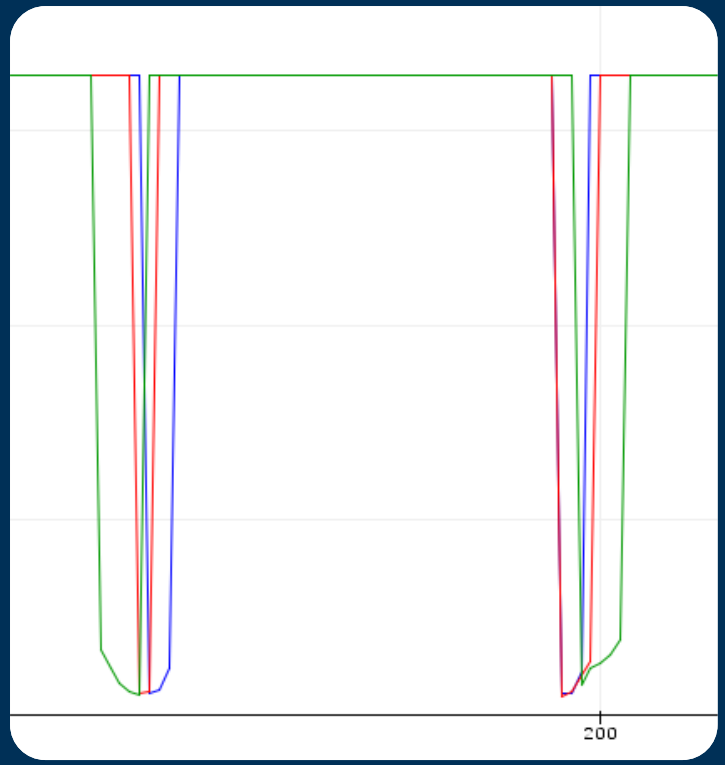
Validation

Testing revealed that the crosstalk issues present in the ultrasonic system made it **too noisy for use**. The IR system produced a **clean signal** with very **clear transit direction**.



Ultrasonic



Infrared

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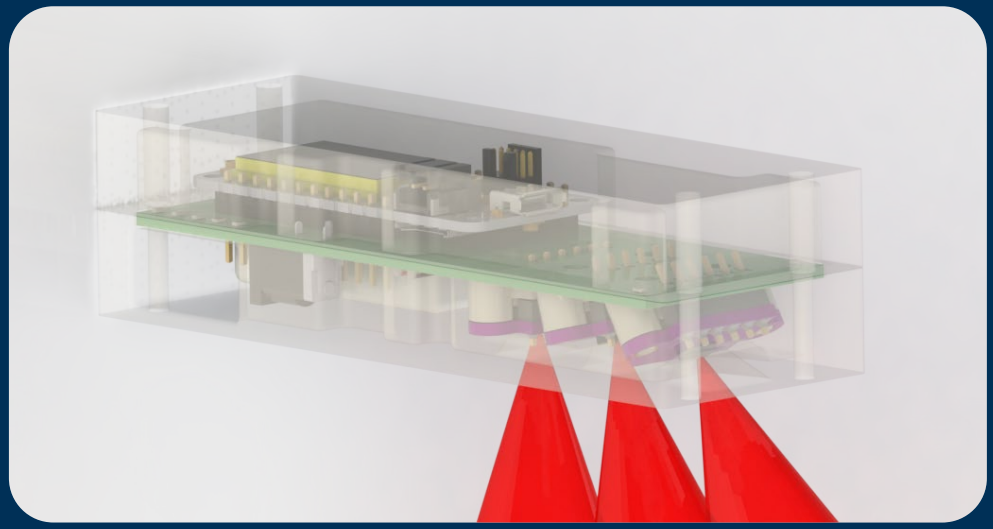
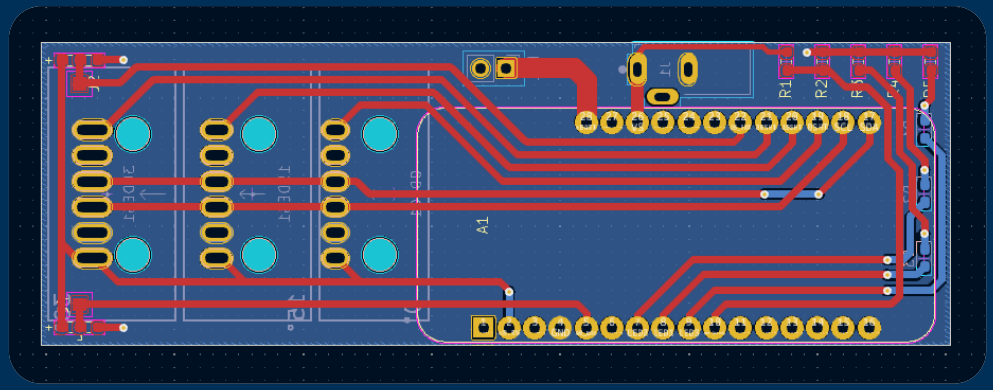
Refined Hardware - Design

- In parallel with the development of a robust counting algorithm, a more refined version of the hardware prototype was produced.
  - It uses a dedicated printed circuit board to decrease hardware size, and improve manufacturability
  - Has an on-board battery to be more resistant to power failures
- Uses a new microcontroller, one that connects wirelessly over 4G-LTE or Wi-Fi
  - This special microcontroller and a basic overview of the 4G backend system will be discussed later





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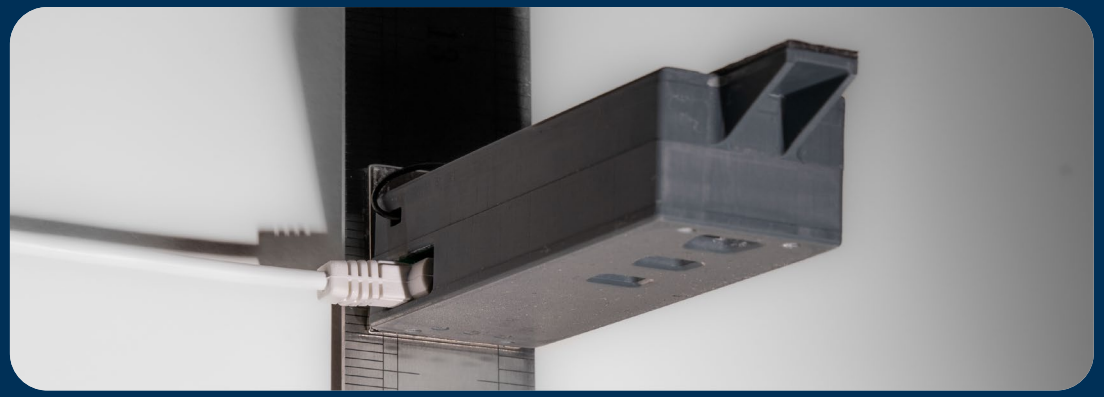
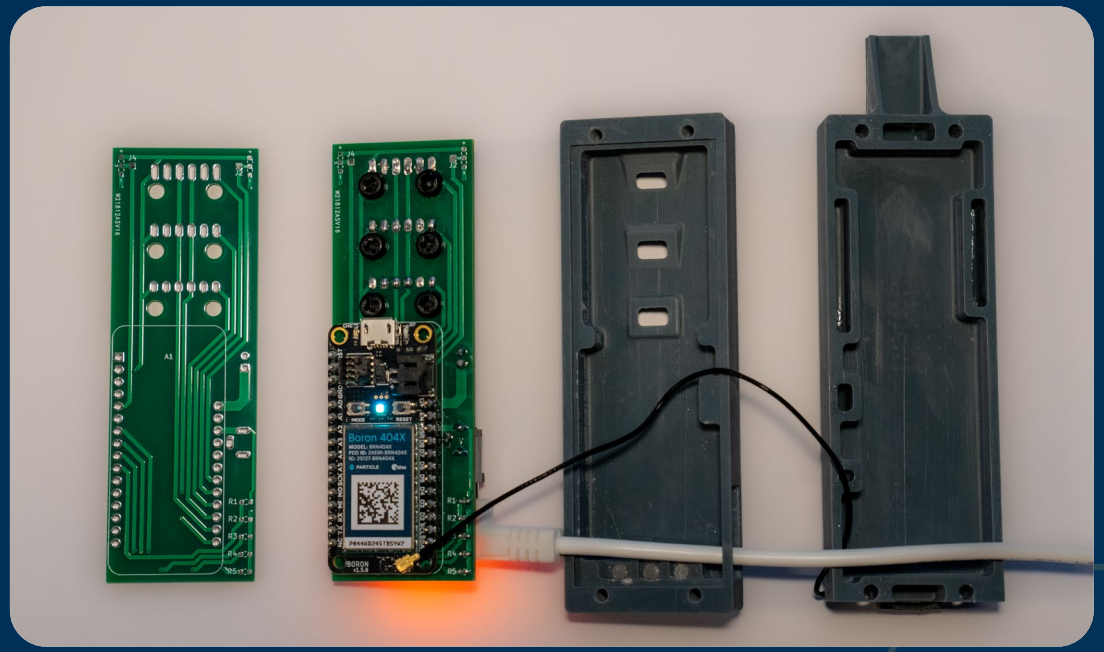
Refined Hardware - Assembly

- The production-ready version was ordered and assembled while the firmware was being completed
  - Features an SLA-printed outer enclosure, status LEDs, and magnet for wall-mounting.



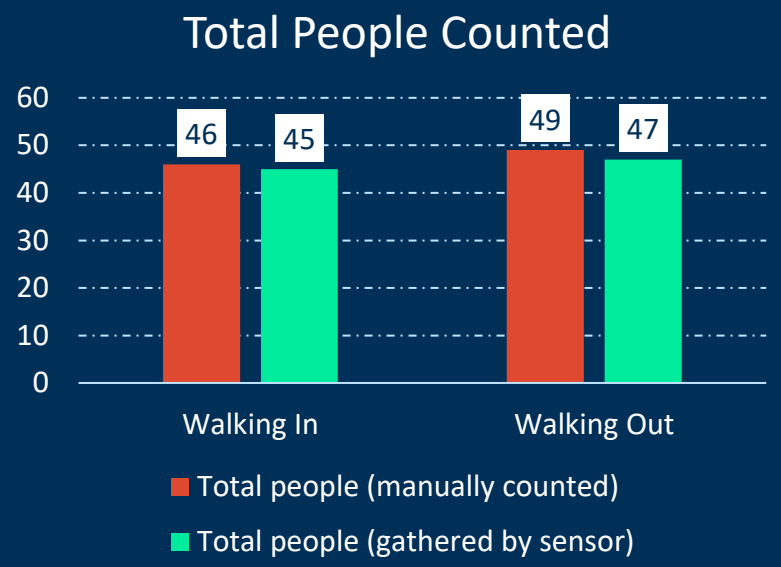


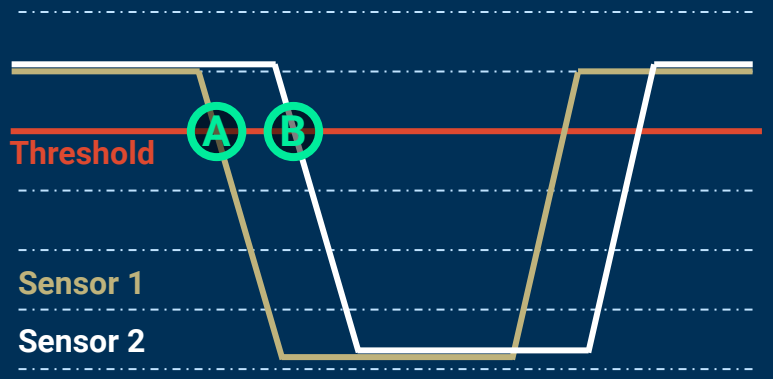
Devi Patel

Algorithm Design, Verification, and Validation

The algorithm takes the raw sensor data and converts it into estimates of “people in” and “people out”

- By comparing transit counts from the sensor to manually counted values (*N = 95*), the algorithm was shown to result in a roughly 2% to 4% error based on conditions
- The algorithm compares the falling time of the waveform output from each sensor. Depending on which sensor is set off first, transit direction can be determined





Very Simplified Falling Edge Detection Algorithm

```
if (time(A) < time(B)) {
      people_in + 1; }
else { people_out + 1;}
```

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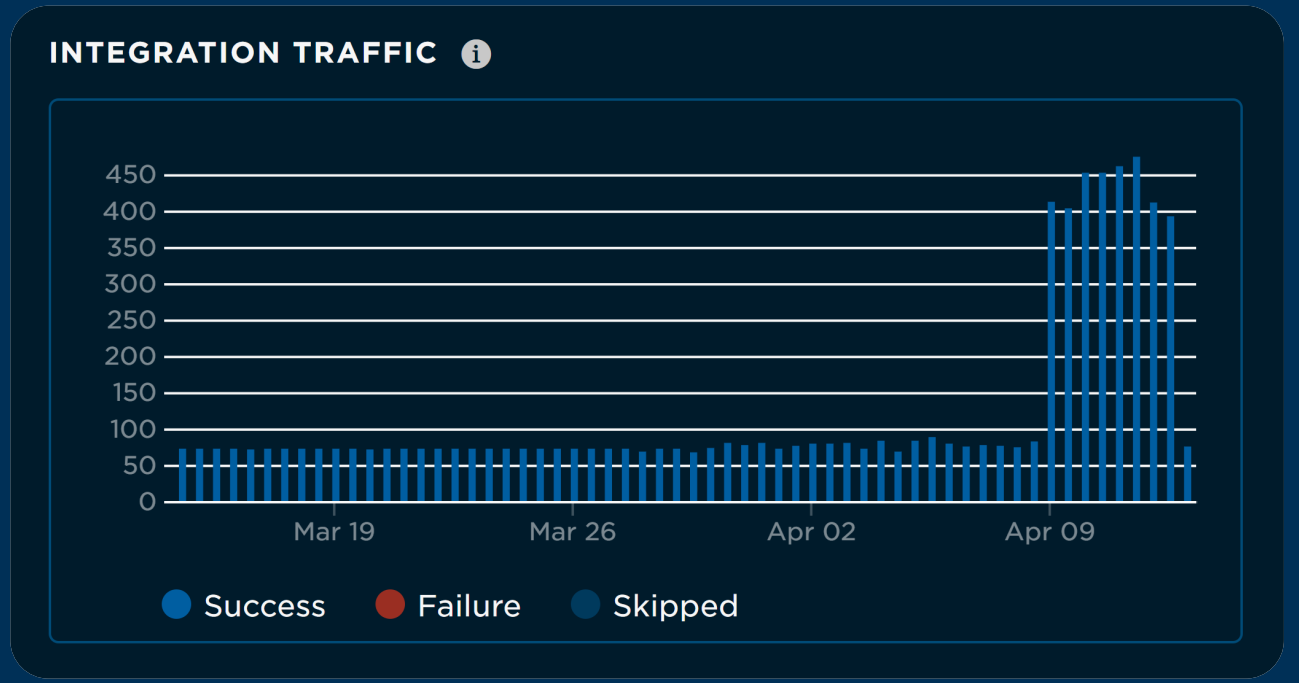
Cellular IoT

- Reliability is a **serious concern** with existing occupancy estimation systems
  - Cellular systems are reliable due to no dependency on complex communication or workmanship skills on site.
- By using a microcontroller with a built-in 4G-LTE modem, we can operate independently of building Wi-Fi, and even operate through power losses



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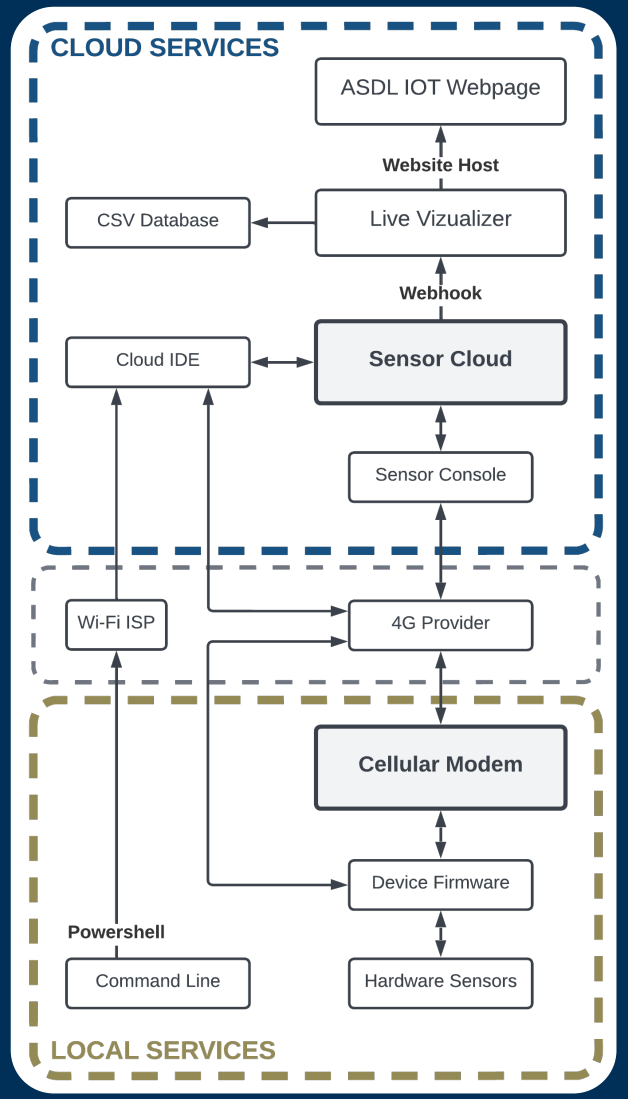
Cellular IoT - Architecture

- I don't have the time to go into the *full* details of how our 4G system works
- Very roughly, there exist two components of our system that are bridged by the cellular network
  - The **local** system reads the sensors and processes the raw data
  - The **cloud** system receives the processed information and publishes it to our visualization tools
- This system allows for rapid prototyping through over-the-air updates
  - Applicable in other projects as well



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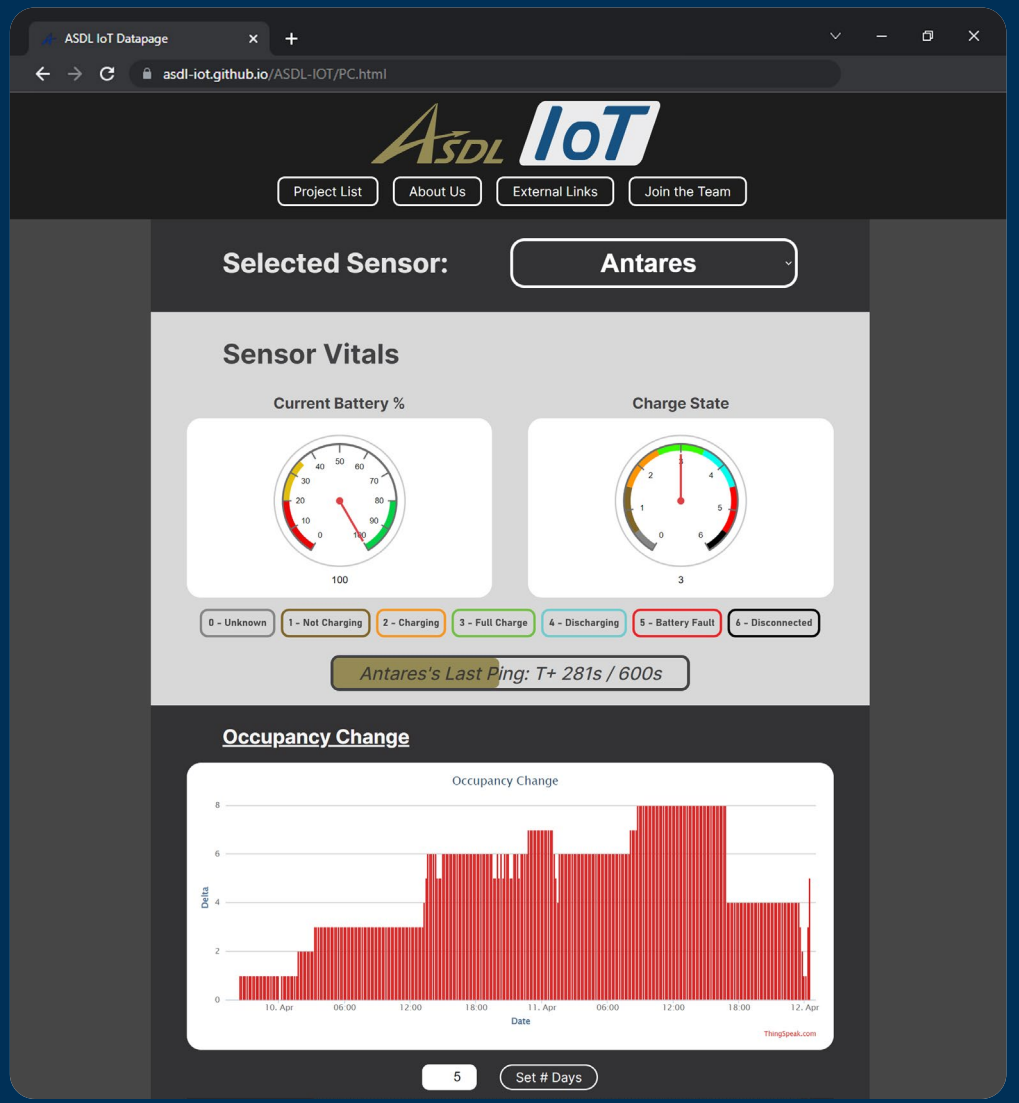
Data Visualization

- The website uses embedded ThingSpeak charts to display sensor vitals and data plots
  - The span of visible data can be adjusted to observe shorter or longer-term trends
- The website plots the counts in and counts out within the last 10 minute interval. It also shows the overall occupancy change as a running total



asdl-iot.github.io/ASDL-IOT/

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Next Steps

The current People Counter design is only suitable for single entry rooms/buildings. Future designs will link sensors across a building

- No current method exists for connecting sensor readings from multiple entryways and combining results
- Connecting sensors will require a custom backend and server-side processing, or a “master-board” that downloads data from others in an area

A more robust algorithm could be developed through the use of Machine Learning

- The microcontroller that drives this system is capable of running simple machine learning libraries that could further strengthen the robustness of the counting methods

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Thank You!

The funding provided by this microgrant helped make this project possible!

Any questions?