Developing a Low-Cost Building Occupancy Sensor

Daniel Wochnick

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Georgia Tech Aerospace Systems Design Laboratory

Background & Motivation

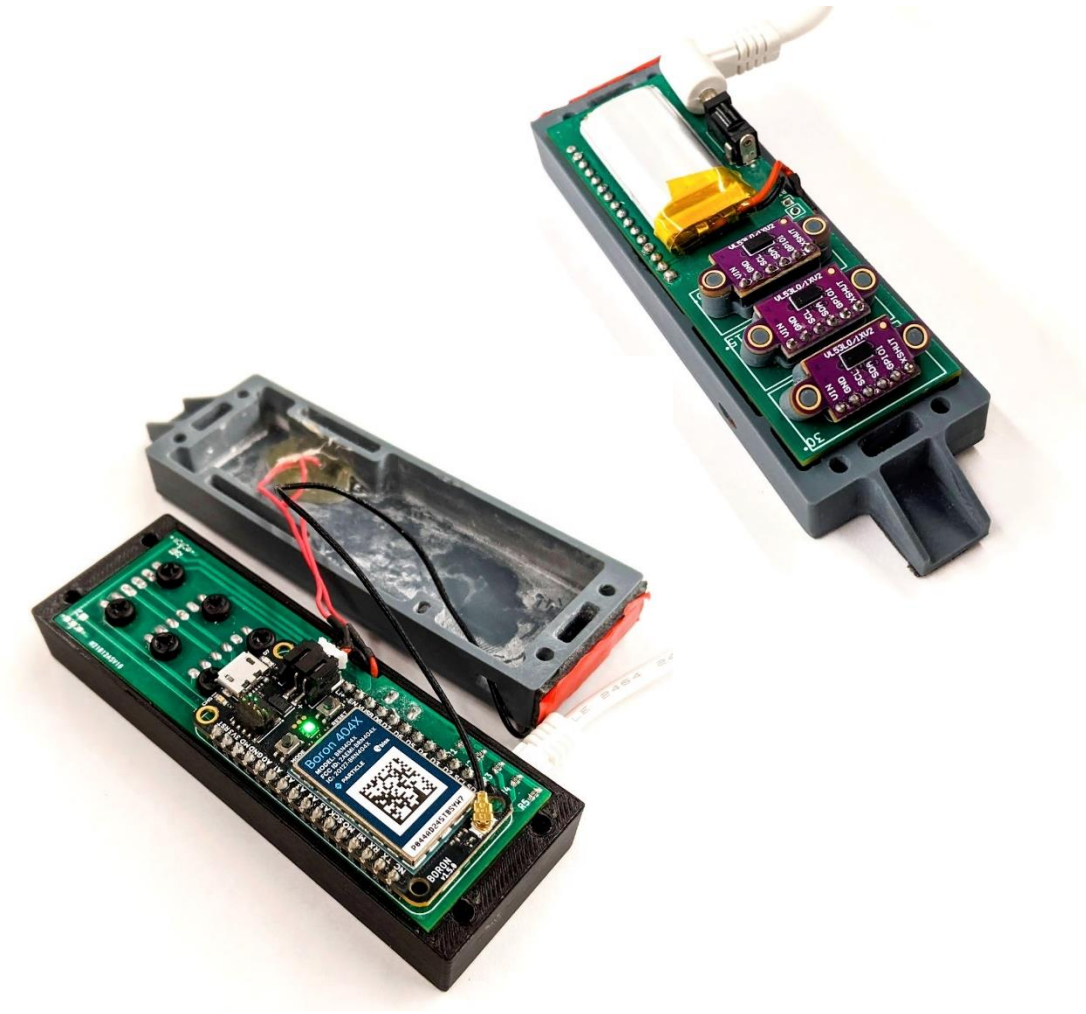
- Broad applications of people-counting
  - Public buildings, libraries, places of worship, and other community applications
  - Retail, restaurants, and other commercial applications
  - Measuring a key variable in energy use modeling
- Sustainability-focused benefits of people-counting
  - Understand user/customer base behavior
  - Distribute resources more efficiently – HVAC systems
  - Improve energy use modeling capabilities
- Our goal: Make this technology accessibly to more communities
  - Current systems are unaffordable ($500+), we will develop a low-cost device
  - Maintain essential data collection and uploading capability
  - Non-invasive design
- Previous ASDL Research
  - Previous prototype developed

Image Credit: Untied Nations (online)

Prototype Device Architecture

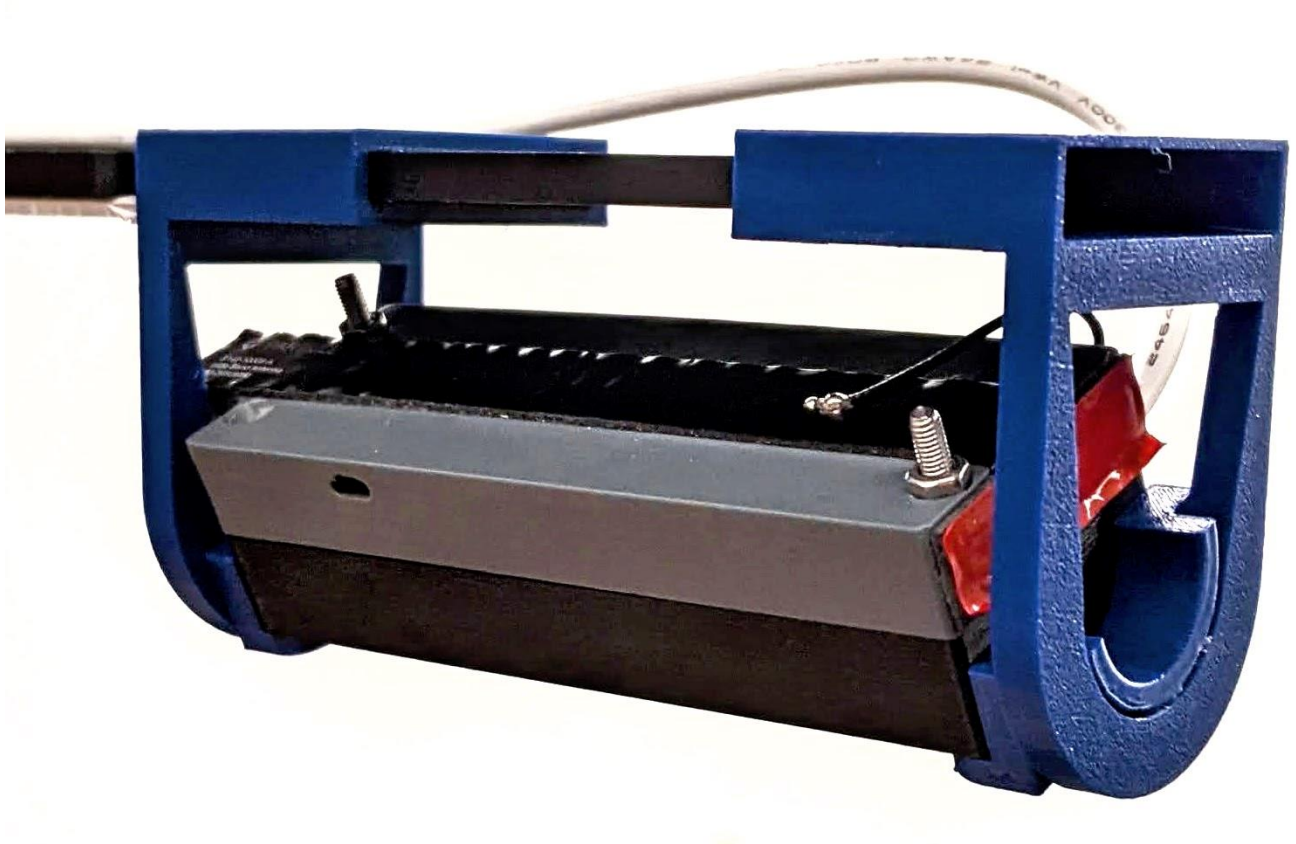
Component	Capability	Cost
3D-Printed Mount and Enclosure	Attaches to door frame	$7
Custom PCB	Connects electronic components	$7
Onboard Battery	Provides power	$5
LTE-enabled Microcontroller*	Runs algorithm and publishes data	$60
3x Time-of-Flight Distance Sensors	Detects people moving through door in each direction	$10
Total		<$90

*A future development goal is to replace with a $5 “spoke” chip to connect to central hub. This inexpensive chip would use the ZigBee communication protocol, which has the potential to reduce device cost to less than $40



Hardware Improvements

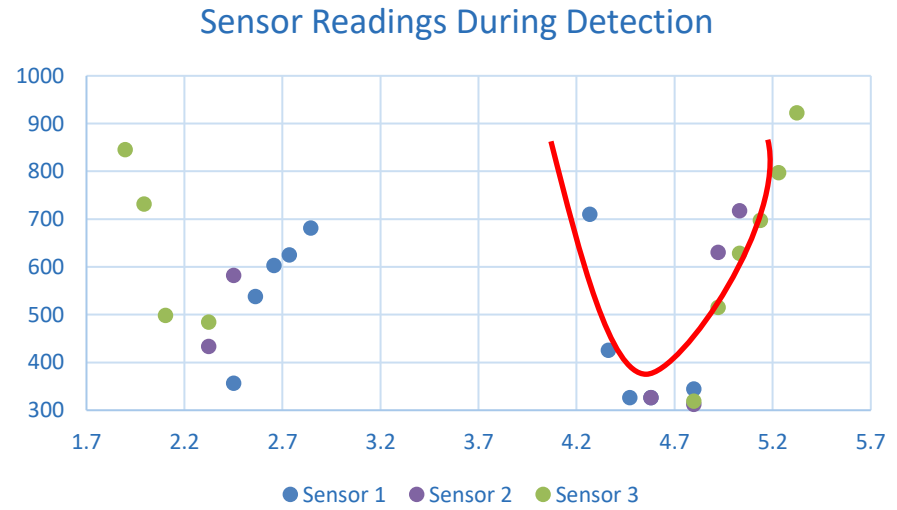
- Emphasis on flexibility for future development
- New enclosure with access to microcontroller USB
  - Allows for real-time serial data
- 3D-printed variable angle mount
  - Interfaces with existing mounting hardware
  - Allows for testing of different sensor positions without new PCB or casing
  - Testbed for double-door design
  - 3D printer-friendly design



Software Improvements

- Laying groundwork for future development
- Connectivity troubleshooting
- Rewrote algorithm using basic state machine
  - Increased human readability
  - Allow for additional modularity
- Experimented with active thresholds
  - Sensors can be triggered based on relative thresholds in addition to static thresholds as before
  - Would improve detection of groups
  - Ultimately unsuccessful
- Wrote serial port reader in MATLAB
  - Parses sensor measurement and people counting data
  - Exports data to a .CSV file for plotting and analysis
  - Attempted to include real-time plotting
    - Ultimately decided to focus elsewhere

```
switch(countingState) {

    // IDLE STATE: The sensor is waiting to detect people
    case IDLE:

        // If the "in" sensor is triggered, set the state to WALKING IN
        if(sensorTripped(1)) {
            countingState = WALKING_IN;
            peopleWalkingIn = 1; // Count a single person walking in

        }


        // If the "out" sensor is triggered, set the state to WALKING OUT
        if(sensorTripped(3)) {
            countingState = WALKING_OUT;
            peopleWalkingOut = 1; // Count a single person walking out
        }


        break;
```



Testing and Results

- Small-scale device testing assessed the responsiveness of the sensors and algorithm in a controlled environment
  - The device performed extremely well, but testing conditions were idealized
  - The device can work well with the correct algorithm and physical implementation
- Results did not translate to real-world device testing at the Kendeda building
  - The sensor performed poorly and inconsistently in these test conditions
- Qualitative and quantitative findings suggest several factors are to blame
  - Limited effective range of the sensor (~1 m) combined with a tall door frame
  - Door mechanism obstructions and off-center mounting location
  - Measurement frequency is limited by hardware and loop time, leads to data blips

Small-Scale Test Data			
Manually Counted In	**Sensor Detected In**	**Manually Counted Out**	**Sensor Detected Out**
101	100	101	100
Error In	1%	**Error Out**	1%

Real World Test Data			
Manually Counted In	**Sensor Detected In**	**Manually Counted Out**	**Sensor Detected Out**
94	36	98	34
Error In	62%	**Error Out**	65%

Next Steps

- Conclusions
  - The device hardware has the necessary capability to meet design requirements
    - Low cost
    - Adequate sensor performance
  - The current device is not performing as expected in a real-world environment
  - More work is needed to improve the mounting and algorithm of the device

- Future Work
  - Reduce algorithm complexity and minimize loop time
    - Optimize using sensor library code documentation
  - Systematically test different mounting locations
    - Device angle relative to ground
    - Mounted on the side of the doorframe
  - Assess feasibility of current design after tuning
  - Assess scalability of the device
    - Optimize design for final production
  - Develop dual-array variant for double doors
  - Research and consider implementing a ZigBee chip
    - Replace most expensive component
    - Cut device cost in half
    - Leverage central hub of internet-of-things (IoT) network

Closing Remarks

- Thank you all for your support!
  - Kendeda Building Advisory Board
  - Aerospace Systems Design Laboratory
  - Dr. Jung-Ho Lewe and Dr. Scott Duncan
  - Michael Peña and Hruday Shah
  - Alex Lomis and previous ASDL researchers
- Any questions?

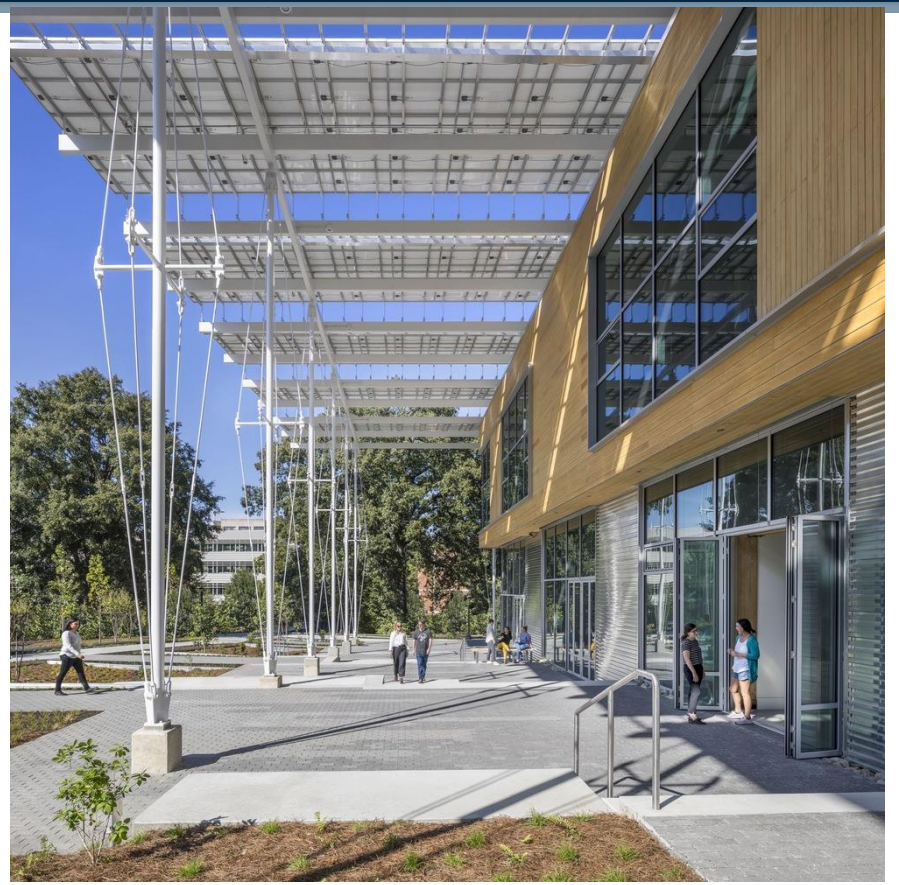


Photo Credit: Jonathan Hillyer (online)