Exploring the Development of Novel Sensor Systems for Human Occupancy Detection

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Overview

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3. Experimental Design
4. Analysis of Results
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1. Introduction

What is occupancy detection and why is it useful?

- Any kind of system that can autonomously detect someone in the vicinity
- Depending on the application of the system:
    - Some systems only detect some motion
    - Others may count and track targets in the environment
- The kinds of applications are endless:
    - Building automation
    - Safety precautions
    - Autonomous navigation

What are some challenges in this field?

- Occupancy detection systems require the use of a sensor (or some combination of sensors)
- Sensor design is often a balance of:
  - Accuracy - how consistent is the device in detecting humans?
  - Power - how much energy does this device consume?
  - Cost - how expensive is this device?
- The goal of this thesis is to design a hybrid sensor system that is comparable to vision

2. Background Research

The different kinds of sensors for occupancy detection

- There exists a wide variety of sensors that utilize the electromagnetic spectrum to detect humans:
  - Vision
  - Audio
  - Ultrasonic
  - Infrared
  - Millimeter wave
- We'll discuss some of the sensor types considered for this thesis in more detail over the next few slides

Optical Camera

- Captures image on a light-sensitive surface
- Ubiquitous in our world, from personal phones to surveillance systems
- Can run standard computer vision algorithms
- But there are concerns over power consumption and privacy
- Used the Arducam as a baseline

Passive Infrared (PIR)

- Looks for differences in the infrared heat signature of an environment
- Initializes to a baseline heat signature, then able to detect changes based on motion in the scene
- Can come as low-powered devices
- But can’t track someone or distinguish between multiple targets
- Used the HC-SR501 for hybrid system

Infrared Camera

- Also utilizes the infrared spectrum
- Uses a thermopile array to convert thermal → electrical energy
- Yields a pixel-by-pixel map of an environment's heat signature
- Not as high-quality resolution as an optical camera
- But more useful than a PIR sensor for target tracking
- Used the AMG8833 for hybrid system

Millimeter Wave (MMW)

- Radio-frequency antenna system which transmits energy and receives reflections using the MMW spectrum
- Robust - not as affected by environmental conditions such as lighting compared to other sensors
- Used the IWR6843 for hybrid system
  - RF antenna integrated with on-chip ARM MCU + TI DSP chip
  - Transmits point-cloud data over USB

Comparisons

- **Below is a table that compares the different sensor devices discussed, comparing the sensors in their outputs, power consumption, and cost in dollars:**

Sensing Type	Output	Power	Cost
Vision (Arducam)	1080p (USB)	300 mA	$34.99
PIR (HC-SR501)	Digital Signal (Pin)	50 µA	$9.99 for 5
IR Camera (AMG8833)	8x8 Pixels (I2C)	4.5 mA	$40.95
MMW (IWR6843)	Point-Cloud Data (USB)	50-2000 mA	$125.00

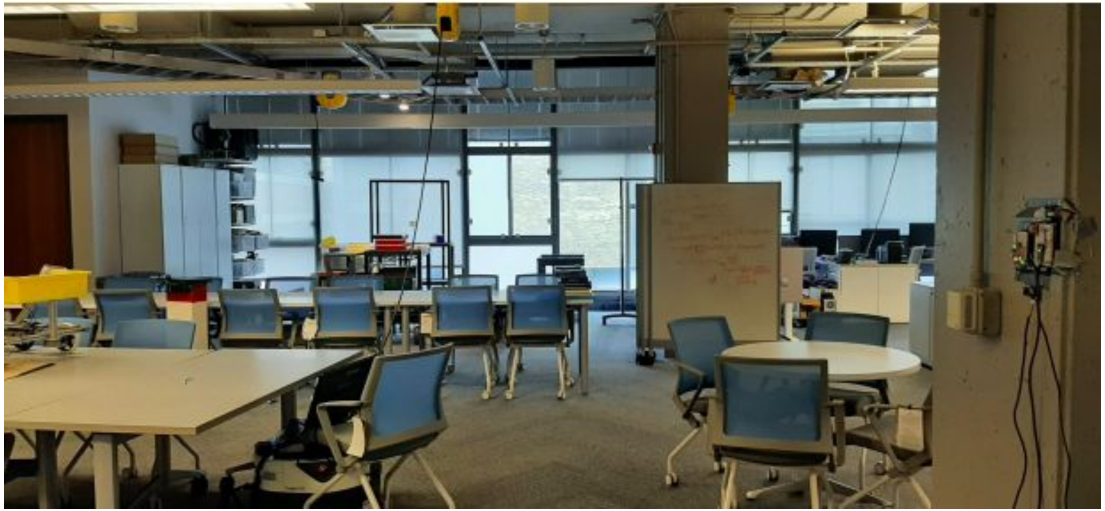
Past research in the area of occupancy detection

- A 2019 paper, *A novel occupancy detection solution using low-power IR-FPA based wireless occupancy sensor* (Mikkilineni et. al), influenced the system design of this thesis
- They used a variety of sensors including PIR, ambient light, and longwave infrared
- They had two tiers of sensors - the first tier was always active and triggered the second tier once some activity was detected
- This idea will show up in our experimental design

3. Experimental Design

Experimental Layout

- We utilized the 4th floor Levine GRASP Laboratory
- Provided an open space to walk in front of the sensors for testing
- Devices were mounted onto pillar in center of room



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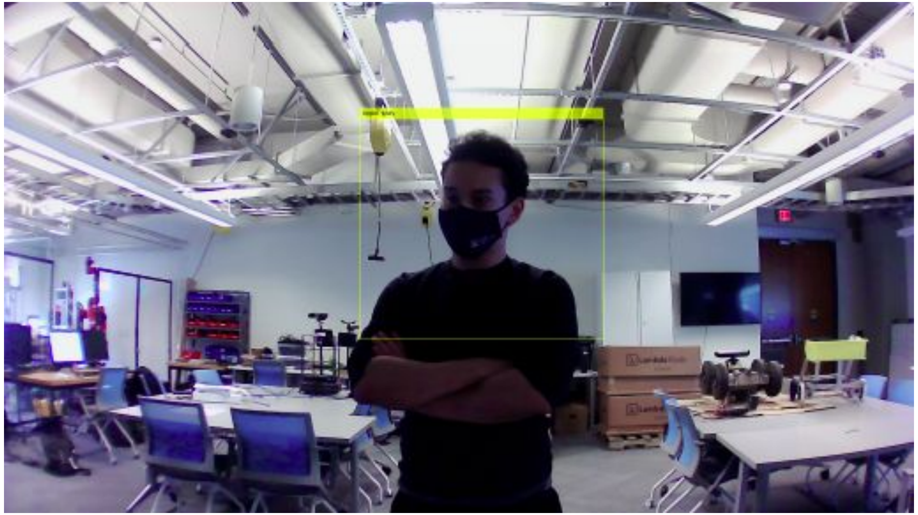
Camera Baseline

- Used Arducam to stream data over USB into MATLAB
- Within MATLAB, utilized the Cascade Object Detector (from the Computer Vision Toolbox)
- Used the Viola-Jones algorithm to detect and label the upper body within the frame



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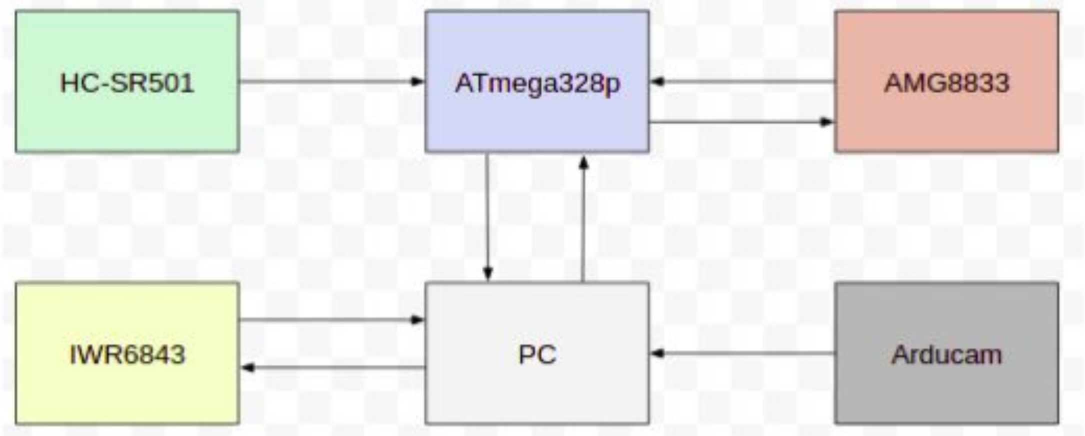
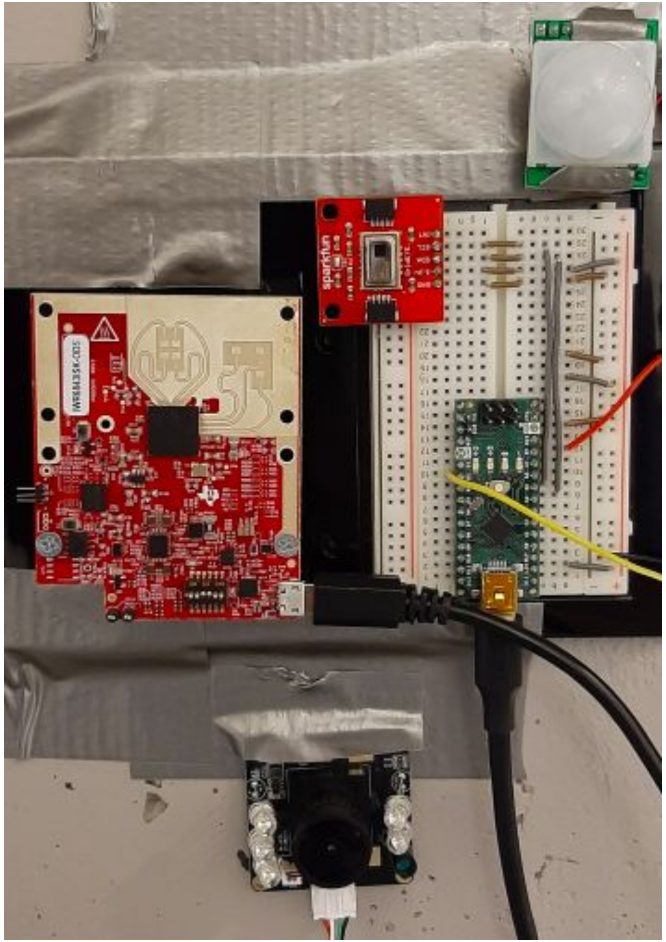
Hybrid Sensor - System Design

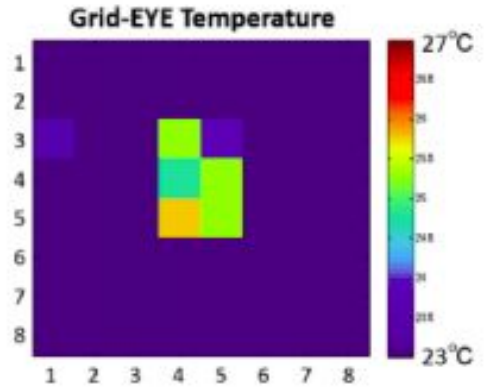
- Used an ATMega328p MCU to read the PIR sensor + IR camera & send data over USB
- MMW also sent its data over USB
- MATLAB processed the data streams and determined whether someone was in the scene
- PIR sensor was used to trigger IR camera, then IR camera triggered MMW sensor - more efficient to use a tiered system rather than have devices constantly on


HC-SR501
ATmega328p
AMG8833
IWR6843
PC
Arducam



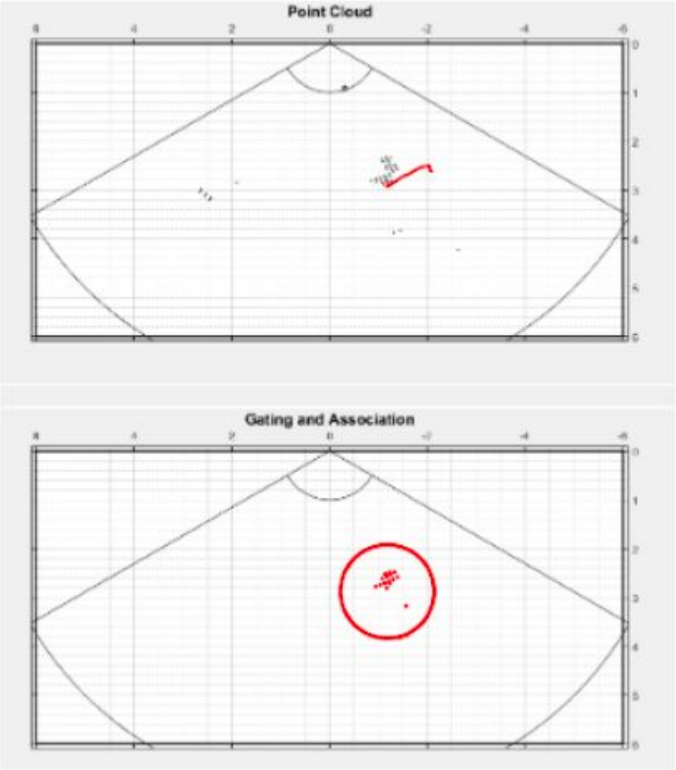
Hybrid Sensor - Target Detection for IR Camera

- IR camera produces a temperature heatmap - we can use image segmentation on this
- Interpolate image from 8x8 to 32x32, then turn into a binary image using a threshold value
- Run connected components algorithm - effectively groups together pixels that are adjacent to each other to yield a number of blobs



Hybrid Sensor - Target Detection for MMW Sensor

- **MMW sensor uses a signal processing algorithm on the front-end data coming from the radar**
- **Signal processing includes using an FFT, removing false detections in the scene, and grouping together points to label a target in the range**



4. Analysis of Results

Method of Evaluation

- Based off an evaluation method from Texas Instruments, used the following metrics:
  - Good Measurement Rate (GMR) - percentage of measurements with no errors
  - Miss Detection Rate (MDR) - Ratio of individuals missed to total individuals across all measurements
  - False Detection Rate (FDR) - Ratio of false positives to total individuals across all measurements
- And tested three different scenarios:
  - Scenario 1: Individual enters the scene and remains in the vicinity of the sensor, standing still, until the end of the trial
  - Scenario 2: Individual enters the scene and remains in the vicinity of the sensor, moving around the scene, until the end of the trial
  - Scenario 3: Individual enters the scene and exits the scene before the end of the trial

Camera Baseline

- Vision algorithm began to struggle when target was consistently moving or came too close to camera
- Lighting may have been an issue for the camera
- Algorithm was triggering on environmental cues
- Could refine vision algorithm to deal with motion better

Scenario-Trial	GMR	MDR	FDR
1-1	0.80	0.30	0.20
1-2	0.70	0.78	0.66
1-3	0.65	0.25	0.10
1-AVG	0.72	0.44	0.32
2-1	0.40	0.63	0.10
2-2	0.70	0.32	0.11
2-3	0.55	0.42	0.05
2-AVG	0.55	0.46	.09
3-1	0.60	0.78	0.78
3-2	0.75	0.50	0.70
3-3	0.65	0.63	0.50
3-AVG	0.67	0.64	0.66

Hybrid Sensor System

- **System struggled when target sat motionless, as MMW may have removed them as static clutter**
- **Did a better job of tracking the target when they kept moving, compared to camera**
- **IR camera handles stationary targets well + MMW handles targets in motion well - could optimize system based on this**

Scenario-Trial	GMR	MDR	FDR
1-1	0.40	0.60	0.00
1-2	0.40	0.60	0.00
1-3	0.40	0.60	0.00
1-AVG	0.40	0.60	0.00
2-1	0.40	0.60	0.00
2-2	0.65	0.35	0.00
2-3	0.60	0.60	0.20
2-AVG	0.55	0.51	0.06
3-1	0.25	0.00	1.87
3-2	0.20	0.43	0.71
3-3	0.80	0.33	0.00
3-AVG	0.42	0.25	0.86

5. Conclusion

Possible Improvements

- Hybrid sensor system could identify a target similar to the camera, but there is room for improvement:
  - Better sensors - another IR camera (or higher resolution) could help with tracking
  - Better integration - using a more powerful MCU such as a Raspberry Pi so that all computation occurs on the same platform
  - Better algorithm - perhaps using more advanced sensor fusion, such as Kalman filtering

Looking Forward

- As discussed at the start, the applications of occupancy detection sensors are endless
- This project was originally inspired by discussions with Dr. Taylor, Dr. Madhu Annapragrada (of Automation Research Group), and Michael Wong and Dayo Adewole (of Instahub) - for the purpose of automatic lighting control
- This technology could also be useful in the pandemic era of social distancing
- These are just a few of many examples
- My hope is that this work has helped provide some insight into the technology and tools available in this field!

Thank you so much for your time and attention!