Towards a Low-Cost, Non-Invasive System for Occupancy Detection using a Thermal Detector Array

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Introduction

Energy prices are rising. Occupancy detection, the ability to count people, offers one way to increase energy efficiency and save money, as knowing the number of people in a space allows more efficient heating and cooling.

Aim

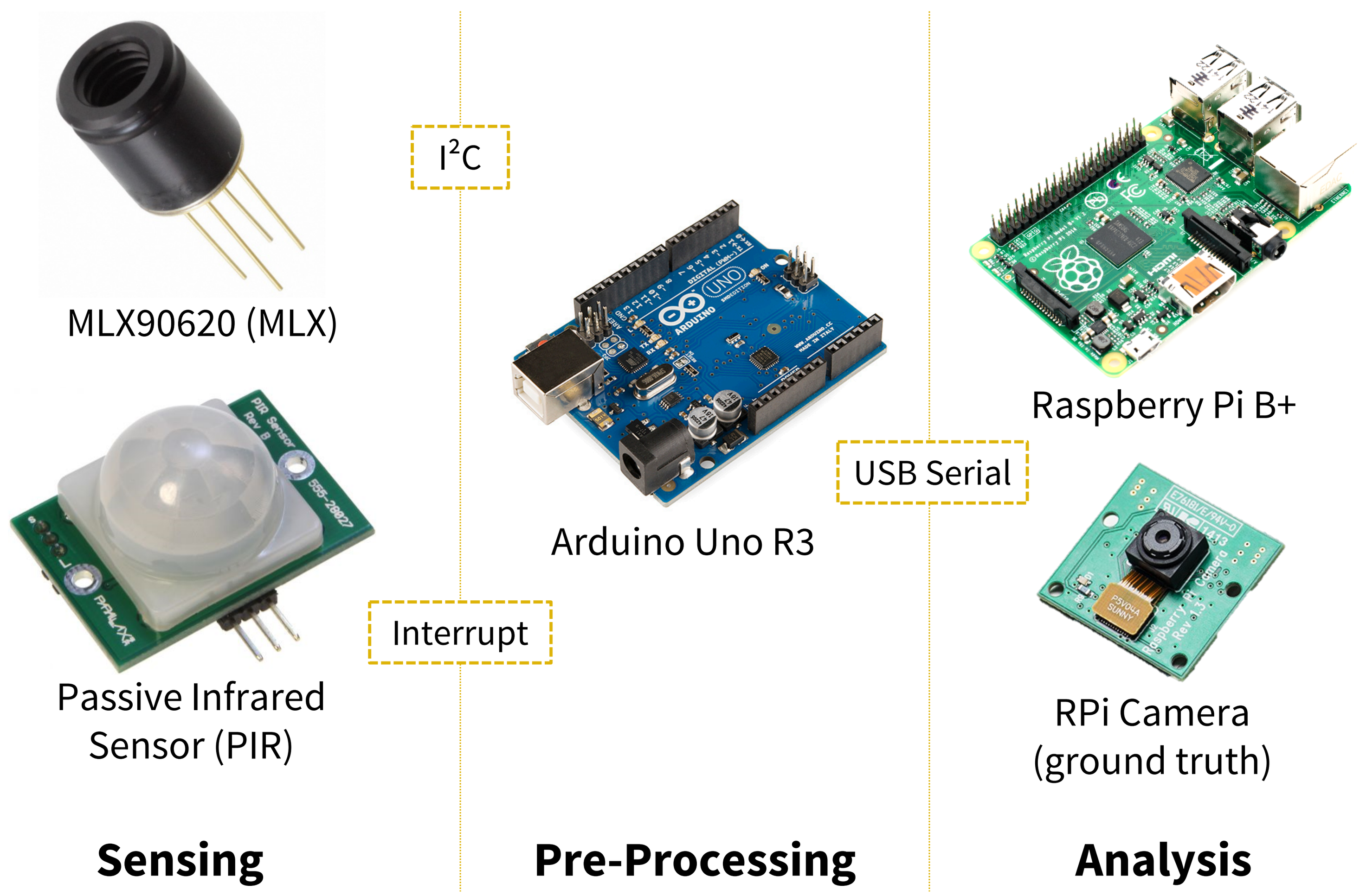
We aimed to make an occupancy detection system that is;

- Low Cost: Less than $300 in prototype stage.
- Non-Invasive: Collects minimal data to perform goal.
- Reliable: At least 75% accurate.
- Energy Efficient: Can last more than 7 days on battery.

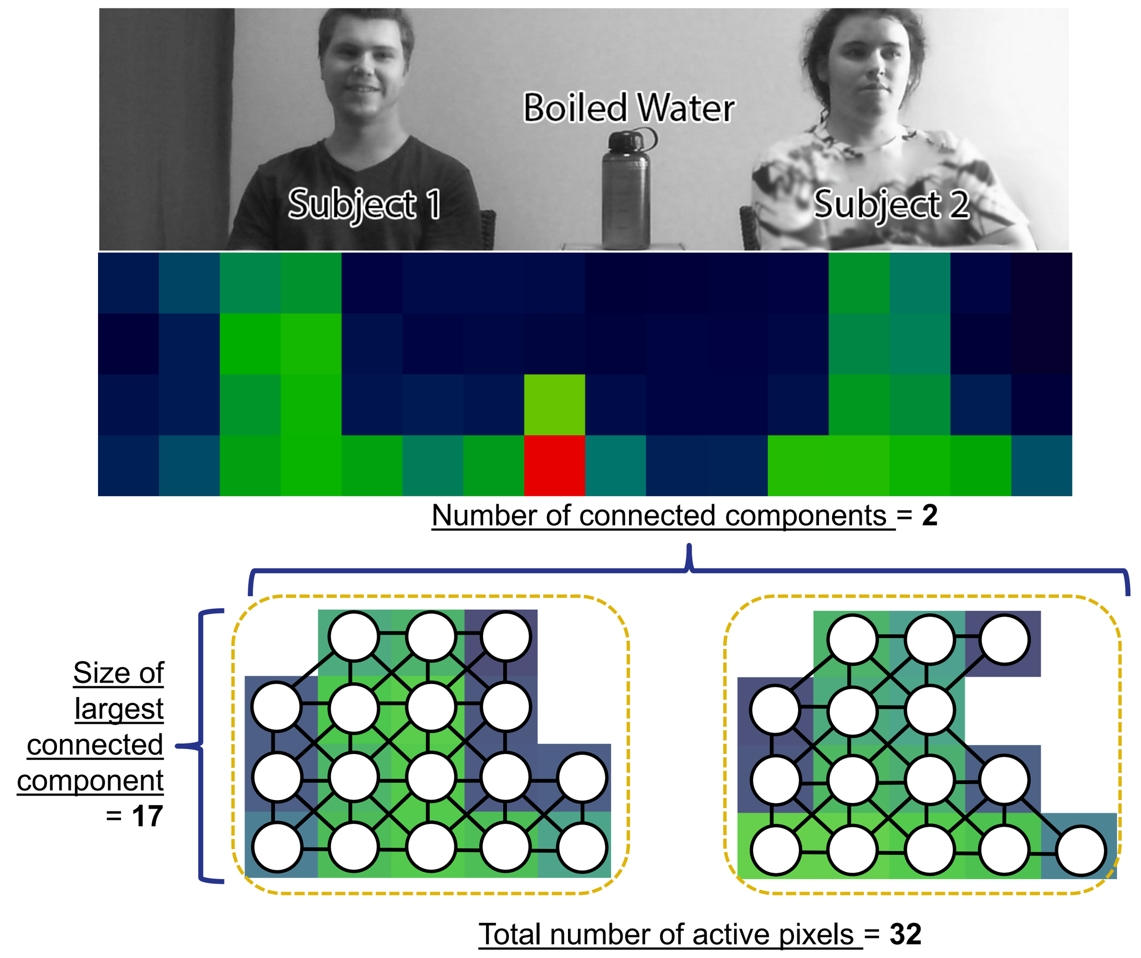
"ThermoSense," a recent paper, used a low resolution thermal sensor to count occupants with acceptable accuracy. We based our algorithmic approach off this paper.

Prototype

A hardware prototype was constructed with a three-tiered architecture to investigate these criteria, costing $185. We used a sensor which has a narrower, rectangular field of view when compared with ThermoSense's sensor.



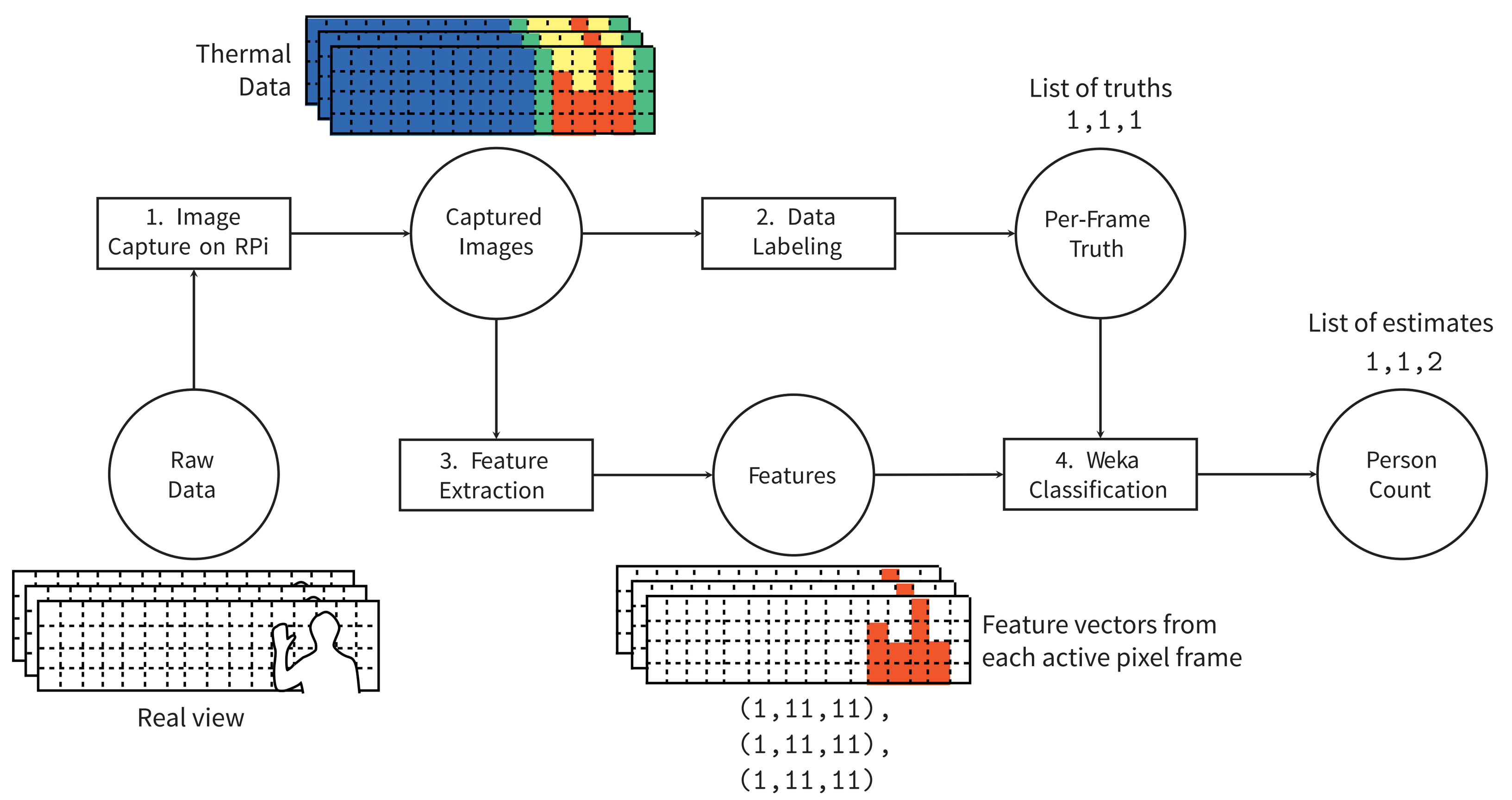
Prototype Architecture



Taking a raw thermal image and extracting its three features

Algorithm

1. When no motion is detected, use thermal frames to calculate a background mean and standard deviation.
2. When motion is detected, any pixel >3 standard deviations above the mean is considered "active."
3. Convert "active" pixels to a graph, using adjacency as edges, and extract three feature vectors:
   - Total number of active pixels.
   - Number of connected components. (pixel "islands")
   - Size of largest connected component.



Processing Pipeline

Evaluation

To evaluate our reliability and energy efficiency criteria, a series of experiments were required. To that end, we created a software processing pipeline for converting raw data into occupancy predictions.

We collected ~1,000 frames of data with corresponding ground truth using a roof-mounted prototype with a floor-facing sensor. We imported this data into Weka to run a series of machine learning classification experiments.

The following algorithms were trailed:

- *Numeric Multi-Layer Perceptron*
- *Linear Regression*
- *K-Nearest Neighbours*
- Nominal Multi-Layer Perceptron
- K*
- C4.5
- Support Vector Machine
- Naive Bayes

Algorithms in *italics* were used in the ThermoSense paper.

We found that our best performing techniques were C4.5 and K*, which were both ~82% accurate. We were unable to replicate the high accuracies of ThermoSense's classifiers, suggesting differences in our experimental setups.

When capturing, the prototype drew ~255 mW, suggesting it would last 8 days with a 50 Wh battery. With modifications, draw could theoretically be reduced to only ~0.4 mW, increasing life to several years.

Conclusions

- ☑ Low Cost? $185 is sufficiently low, with the price of all components trending downwards in the future.
- ☑ Non-Invasive? Low resolution thermal imaging gathers sufficiently little information to be non-invasive.
- ☑ Reliable? 82% accuracy is sufficient for our purposes.
- ☑ Energy Efficient? Current prototype predicted to last 8 days. With modifications, it could last several years.

Beltran, A., Erickson, V. L., and Cerpa, A. E. ThermoSense: Occupancy thermal based sensing for HVAC control. In *Proceedings of the 5th ACM Workshop on Embedded Systems For Energy-Efficient Buildings* (2013), ACM, pp. 1–8.