Room Occupancy Sensing Mat

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Abstract

Sensing the number of people in a room is a very pertinent problem in the Internet of Things today. The go to methods includes the use of cameras for image recognition but in the current times where privacy is a growing concern when it comes to our devices, most people don’t want to be recorded walking in and out of conference rooms, department stores, etc. Our solution is to use a doormat which has the ability to distinguish a foot-fall from other things by sensing pressure.

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1. Introduction

1.1. Objective

Our objective is to solve the issue of monitoring the number of people entering and leaving the room. Our solution is to create a floor mat that can be placed in front of an entrance or exit and count the number of people entering and leaving. First, we will check to see whether an object is a person by looking at the shape it makes when moving across the surface of our device; a person will create a foot-like shape when they step onto the surface, while a cart or rolling luggage will create a smaller impression that does not lift up from the surface from edge to edge. Second, we will look at the direction the person is going in using infrared sensors placed on the edges of the mat and sensing across its width; the order that the sensors trigger determine the object's movement direction. Lastly, we combine the collected data and use it to estimate the change in the number of people occupying a room.

1.2. Background

Sensing the occupancy of a room is a prevalent problem in modern Internet of Things scenarios. There are a lot of applications for a device that can deliver the number of people in a room, from trivial applications like attendance in a classroom or customer numbers at a business, to monitoring foot traffic at conventions and festivals. Room occupancy data trends can be used to optimize better resource allocation for dynamic air conditioning or heating in large buildings.

Current solutions to occupancy sensing include RFID badges, mechanical turnstiles and face detection using cameras. Face detection is largely considered an intrusive task especially in the workplace which is what our mat is targeted towards. Turnstiles are very inconvenient especially in an environment which has small hallways and doorways. RFID badges are not the most efficient since they require constant Radio Frequency communication and if trying to judge the occupancy of two adjoining spaces, the line becomes blurry.

Our solution is aimed at being less intrusive with no requirement of cameras and a minimal spatial locality of sensors. The only region we need sensors is in the 2x3 ft space occupied by the mat! Our solution is meant to be a prototype and is limited to handling one person passing over the mat at any given time.

1.3. High-Level Requirements

1) The mat must be able to identify the difference between a foot-fall, and any number of objects that are instead rolled across the mat.
2) The mat must be able to tell the direction in which a person or object is moving across its surface.
3) And lastly, it must be able to keep track of the total of number of people who have entered or left the room and have an error rate of less than 20% (missed persons or false positives) over the course of 1 hour.

2. Design

2.1. Functional Diagram and Physical Design

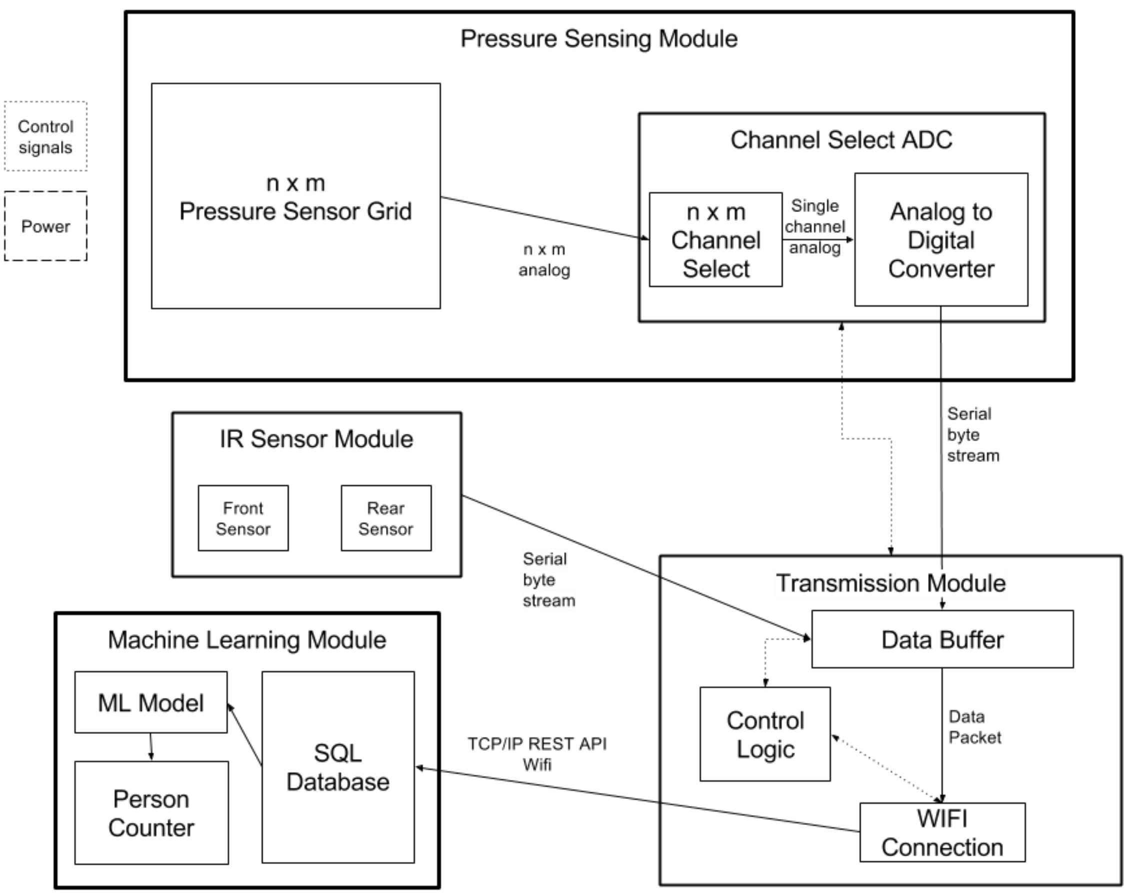


Figure 2.1.1 Functional Diagram

2.2. Pressure Sensing Module

2.2.1. Design Considerations

Our two basic options for the pressure sensing module are an array of piezoresistive sensors, or a method using a material called Velostat, which is a carbon-impregnated Polyethylene film [3] generally used to protect items from electrostatic discharge. The Velostat option has the advantage of being inexpensive and easy to set up in comparison to the many connections required to get our device working.

Velostat has the useful property of changing its resistivity when deformed. To utilize this property, we will check the resistivity of a sheet of Velostat at each point of a grid laid out on top of the material. Any changes is the shape of the Velostat will change the resistivity through its volume, and we will use this data to determine the overall shape of an object that is placed on the surface.

For the physical design of the mat, we have 8 rows of conductive thread going across the top of a sheet of square Velostat. Below the sheet will be 8 columns of conductive thread going perpendicular to the direction of the thread above the mat. For each sensor cycle, 5 V will be applied to one of the 8 conductive threads above the mat, and a connecting to ground will be applied to one of the 8 conductive threads below the mat. An ADC connected between the bottom thread and ground will measure any changes in the foam's resistivity at that location.

Figure 2.2.1.1 shows a high-level overview of how we are using the Velostat to sense objects that are placed on it. Resistivity of the Velostat has a direct relationship to its volume, causing the voltage measured by the voltage sensor to increase.

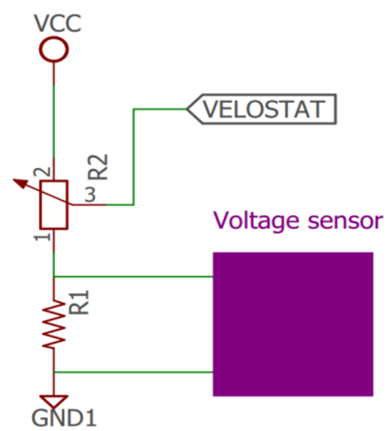


Figure 2.2.1.1 High level functional overview of Velostat surface and voltage sensor

We tested several types of conductive thread for resistance; the results of which are shown in table 2.2.1.1. Too large of a resistance, and there is a risk that the conductive thread we are using will degrade enough over time to affect the sensor readings. Additionally, we measured the high-frequency voltage response of each material to see if there were any significant delays in voltage changes. To calculate a worst case scenario, we sent a square wave voltage signal through 6 inches of each thread type. The frequency was then increased by an order of magnitude until there was a noticeable change in the response signal. As shown in figures 2.2.3.1 through 2.2.3.3, a signal with a frequency greater than 1 Mhz was required to affect the voltage response enough that it was noticeable.

Table 2.2.1.1 Experimental data on the resistivity of each type of conductive material

Thread type	**Resistance (Ohms/Inch)**
Copper Wire (control)	0.60
Conductive Yarn	1.75
2 Ply Silver Thread	2.00
3 Ply Silver Thread	1.20

Based on our collected data, we will be using 3 Ply Silver Thread as it has the lowest resistivity among our options. None of the material options created any significant delay, so it has no bearing on our material decision.

Figure 2.2.3.5 shows the schematic for our measurement circuit. This design is capable of reading the voltages of 64 separate sensor locations and serially outputting each as a byte of information. The ROWn signal provides the Vcc, and COLn probes the voltage in figure 2.2.1.1.

2.2.2. Requirements and Verification

Requirement	**Verification**
Must have a sensor density of at least 2 sensing points per square foot with uniform distribution	Add up the number of sensing points on the floor mat, and divide that number by the sensing area in square ft. to get sensors per square foot.
Each sensing location	Measure the voltage drop across the mat at each sensor

must be able to produce a ‘pressed’ voltage for an object as light as 15 psi, and a ‘non-pressed’ voltage when no weight is applied.	point without any object on its surface. Compare that data with the data produced when a test object applying 15 psi or less is placed on the sensing surface. The data comparison should show that the sensing point registered a change in voltage drop that cannot be attributed to noise.
The device is capable of reading the data of every sensing location consecutively for the entire sensing area in less than 1 second	Give a stable clock signal to the device and measure the amount of elapsed time between the data reading of the first sensing location and the last sensing location. Show that there exists a clock frequency that, when applied to the device, allows for the collection of data values from the entire sensing surface within 1 second.
The analog voltage values collected from each sensing point are converted to relative digital values and outputted to the transmission module	Apply a detectable weight onto the surface of the sensing area in a configuration that divides it into two clearly defined sections. One section will have high weight applied and the other section will have low or no weight applied. Signal to the device to collect all values from the sensing surface and output them to the transmission module. View the sensor data collected by the transmission module and check to see that there is a clear difference between the sensor values collected from the high weight section and the low or no weight section.

2.3. Infrared Receiver

2.3.1. Functional Overview

The IR module is an important module in our project. It is directly responsible for fulfilling two of the high level requirements of the occupancy sensing mat. The two high level requirements being: the ability to tell the direction in which a person or object is moving across its surface and keeping track of the total of number of people who have entered or left the room. The way it accomplishes these high level requirements is simple. We use a set of two IR receivers and emitters. One pair on each side of the mat. The receiver-emitter pair will be placed on a horizontal line along the length of the mat and the emitter-emitter pair on a vertical line along the breadth of the mat. The IR sensor will be triggered when an object is passed through the emitter-receiver line. We now consider two cases:

1) The Human Case: Human beings walk in such a way that the heel touches the ground at position x. Then at a time t+y, the toe touches position x+a. Both variables a and y are greater than zero. In other words the human foot triggers one IR sensor and then triggers the next one. This gives us the general direction of the movement of the human being. If IR sensor at position x gets triggered before the IR sensor at position x+a then we can conclude that the movement is in the forward direction relative to the sensor at position x.

2) The Inanimate Object Case: This case is very similar to the human being case. Here we consider any inanimate object like a trolley or a bag. It does not matter is the object is on wheels or not. If IR sensor at position x gets triggered before the IR sensor at position x+a then we can conclude that the movement of the object is in the forward direction relative to the sensor at position x.

The high level requirement of finding the net number of people is also accomplished here as the net number of people is people entering -people leaving. We have already described how the IR sensors provide information regarding the direction of movement. Thus we can consider the forward movement to be entry and the opposite direction movement to be an exit. Thus the number of people in the room at any given time is simply entry - exit (number of people).

2.3.2. Requirements and Verification

Requirement	Verification
The IR emitter should be able to emit over a distance of 2ft.	Test the emitter with the receiver with test distances. Start with 0.5ft and increment to 2ft with a step size of 0.5ft. A pin from the IR receiver is connected to an LED. When the LED is turned on the receiver is receiving a signal.
The IR emitter should emit IR	Use a cellular phone camera to check for IR rays
The IR receiver should be receiving the IR beam from the emitter	The LED attached in the detector circuit should light up
The module should be able to communicate to the ESP8266	The output values can be seen on the scope of the computer
The IR emitter should be able to emit upto 1ft	The mat length is 1ft so if the IR LED in the receiver circuit lights up then this req can be validated

Verification Images:

Figure 2.3.2.1 Image showing the IR emitter working

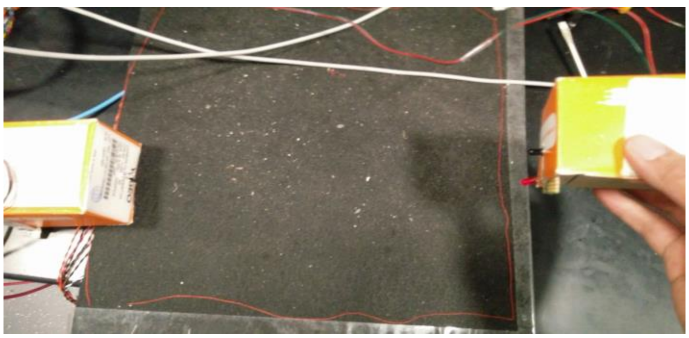


Figure 2.3.2.2 Image showing the IR receiver working for 1ft distance

2.3.3. Supporting Documents

The figure 2.3.3.1 is the schematic of the IR emitter circuit.

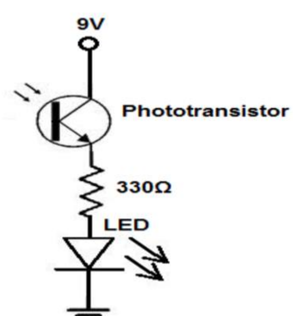


Figure 2.3.3.1 Circuit schematic of the IR Emitter [6]

Figure 2.3.3.2 are the schematics of the IR receiver circuit

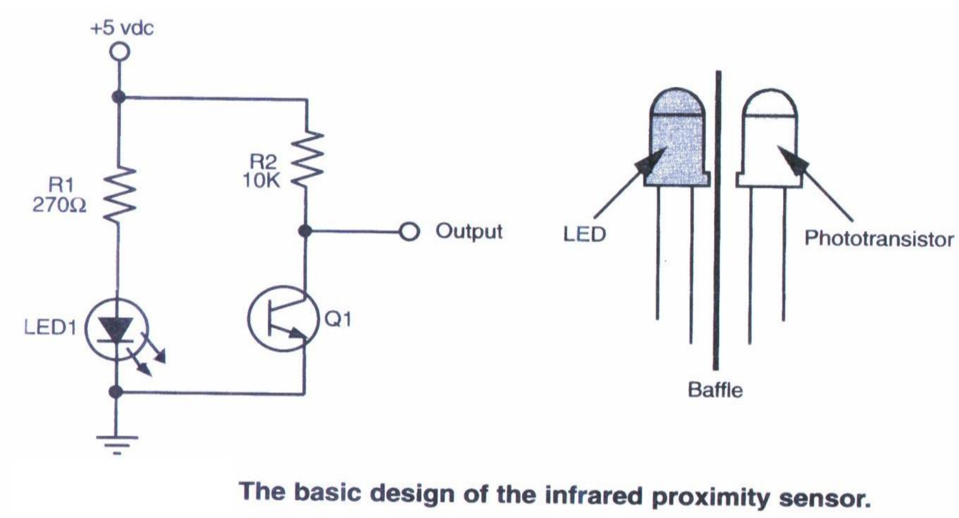


Figure 2.3.3.2 IR receiver circuit schematic [7]

2.4. Transmission Controller

2.4.1. Functional Overview

The job of the transmission controller includes obtaining data from the Analog to Digital Converter and transmitting them using wireless connectivity and REST API to the Azure cloud. The ESP8266 WiFi Module is a self contained SOC with integrated TCP/IP protocol stack. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. We will be using 512B flash storage to temporarily store input from the mat that hasn't been sent by the SOC. This storage size is enough to hold all of the sensor data obtained from a single capture.

2.4.2. Requirements and Verification

Requirement	Verification
Control timing pressure sensing by clocking the sensor mat	Use an Oscilloscope to show clock output from the ESP 8266
Obtain mat data at a sampling rate > 20 Hz	Use an Oscilloscope to measure output for IR sensors and pressure sensors.
Pass data using REST calls to an SQL database with end(Input to ESP 8266) to end(Successful completion of store operation) latency < 2 second.	Observe consecutive timestamp differences using REST monitoring software such as Postman

Timing Diagram:

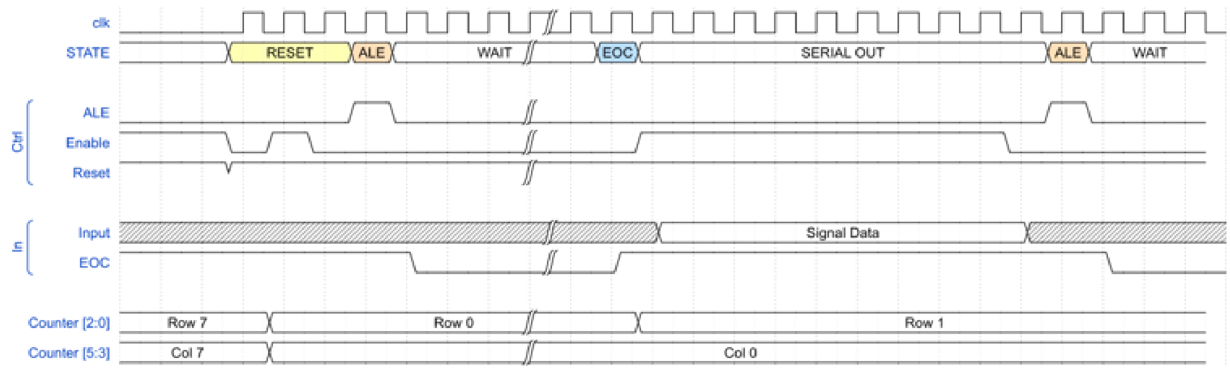


Figure 2.4.2.1 Timing Diagram

Clocking the circuit:

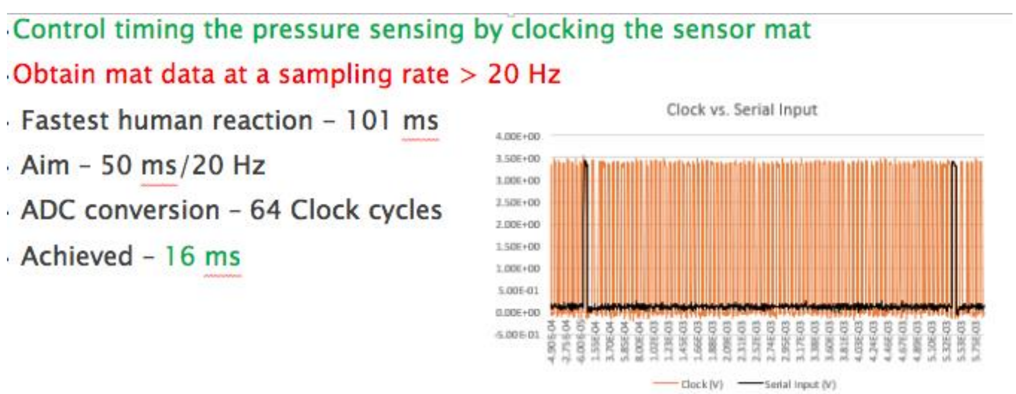


Figure 2.4.2.2 Image showing the mat sampling rate

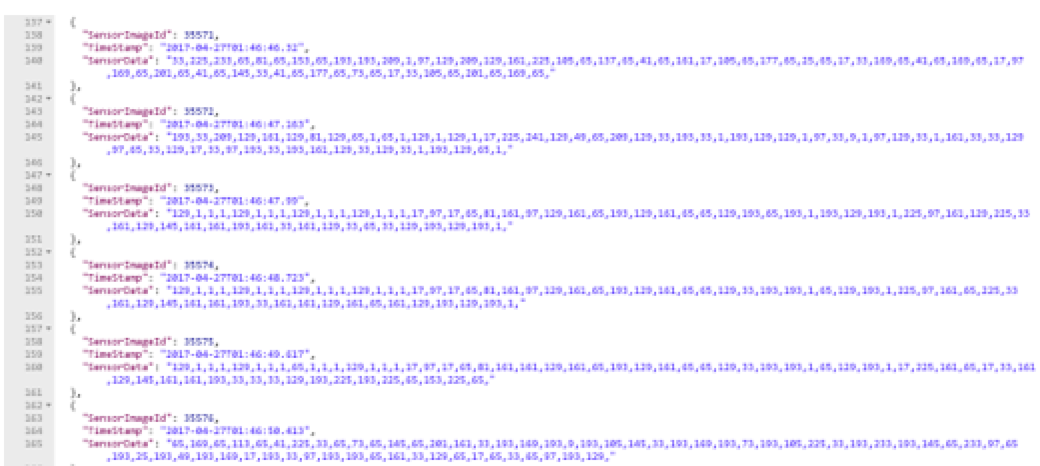


Figure 2.4.2.3 Consecutive timestamps on a REST client. Shows end to end latency < 2sec

2.5. Machine Learning Environment

2.5.1. Functional Overview

The machine learning environment is the portion of our design that takes the data aggregated from the Infrared Sensors and Force Sensors. It uses this information to decide whether an object crossing over the surface of the mat is a person, and it also determines what direction an object is going across. This is used to give the net number of people in the room. This module is intended to run the following way:

1. Collect and label training data(Manually or K-Means clustering) from use of the mat. We will aim to obtain at least 750 pieces of unsupervised data and 200 pieces of supervised data as part of data collection.
2. Run the following classifiers and choose the best based on a combination of hinge loss and 0-1 loss.
   a. Logistic Regression
   b. K-Nearest Neighbors
   c. Linear Discriminant Analysis
   d. Bayes classifier
3. Apply classifier to data received from the ESP8266 and output a count for the number of people that is within a 20% error margin.

The model training and verification process involves the following steps:

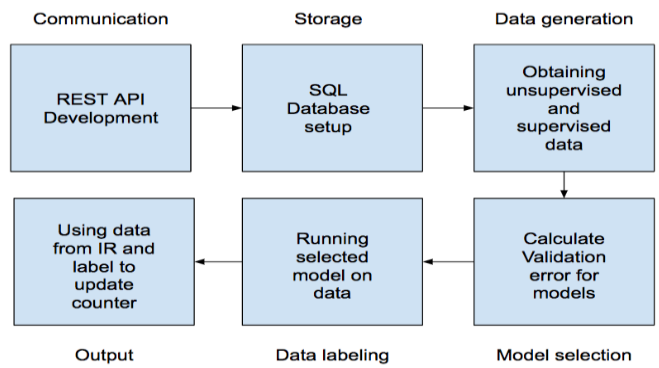
- Obtain unsupervised training data and obtain feature vectors
- Apply K Means clustering. Use graphs of J*(k) to k to identify number of labels.
- Obtain supervised training data and obtain feature vectors.

$$J^{*}(K) = \min_{z_1,\ldots,z_N,\mu_1,\ldots,\mu_K} \sum_{i=1}^{N} \|\boldsymbol{x}_i - \boldsymbol{\mu}_{z_i}\|^2$$

  ○

- Use the obtained label predictions along with human supervision to give labels to all unsupervised training data.
- Divide final aggregation of data into training, validation and test.

- Use training and validation data to identify the best model amongst

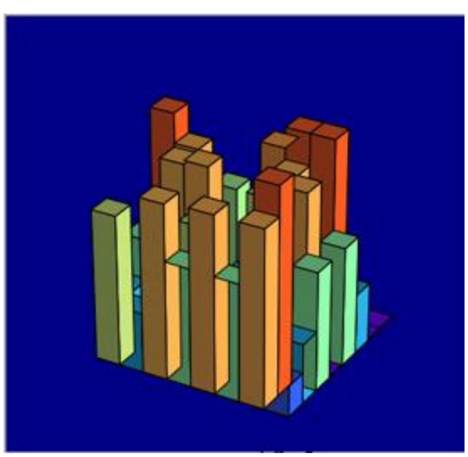


logarithmic regression, LDA, Bayes classifiers and K-nearest neighbors.

2.5.2. Requirements and Verification

Requirement	Verification
Produce a live output detailing whether a human or an object crossed the mat	Cross the mat and check the output. Roll a mail cart over the mat and check the output
Produce a counter every 2.5 minutes or less that gives a count of the number of people in a hypothetical room.	Manually count the number of people entering and leaving a room over the course of 5 minutes.
Show data coming from the sensor mat in a graphical format.	Produce surface plots and pixel images of live data

What the data looks like:



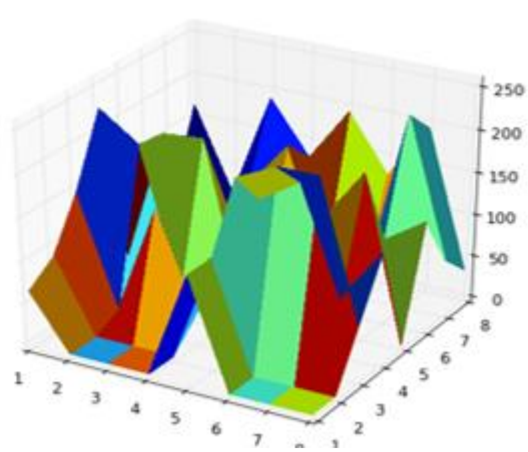


Figure 2.5.2.1 - Surface plots

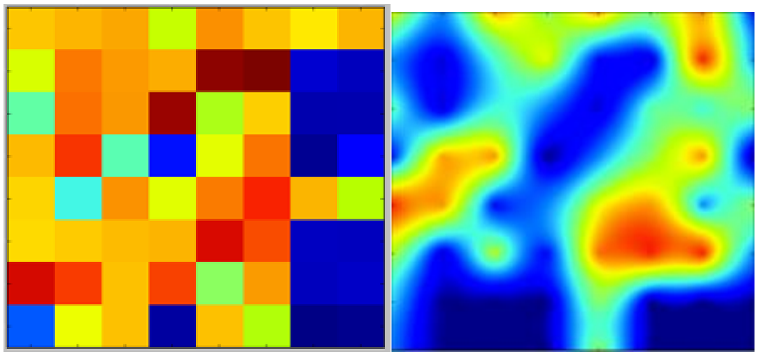


Figure 2.5.2.2 - Averaged pixel form (left) and 1000x1000 interpolated (right)

Classifier	**Validation error (0,1 loss)**
2 Nearest neighbor	0.432
Logistic Regression	~0.0 (Negligible)
Linear SVC	0.64835165
Bernoulli Naïve Bayes	~0.1 (Negligible)

Multinomial NB	0.51515152
Linear Discriminant Analysis	~0.1 (Negligible)

2.6. Tolerance Analysis

The IR sensors come with a range of operational values. The working temperature of the IR emitter is between 0ºC to 85ºC. As we expect to perform at room temperature this should not cause a problem in the tolerance of the IR system. The same thing goes for the IR receiver. The min irradiance for the receiver 0.15mW/m^2. Max irradiance is 30W/m^2. This is within the range of the emitter diode. The tolerance in terms of directivity for the receiver is +-45º. W are placing the emitter at an angle of 180º to the receiver and the emitter has a beam divergence of 20º thus the max error is still within the tolerance range. Thus I expect the IR sensor to work with 95% efficiency in conveying bit information of 1 or 0 conveying if the IR ray is inhibited or not (due to the case of some dust in the air inhibiting the irradiance conditions).

Since we are building a prototype we have given ourselves a tolerance on the final count of the number of people as ceil[true value + 20%] to floor[true value - 20%]This number will be calculated over the course of 60 minutes.

For example, if 20 people entered a room and 13 people left a room in an hour, the real number of people in the room = 7. The counter should read between ceil[7+1.4] = 9 and floor[7-1.4] = 5.

We are not putting a time constraint on our classifiers since the job of counting people in a room is not time sensitive. Therefore, time will also not be considered when choosing a model however a reasonable upper limit of 2.5 minutes per update is set.

3. Cost and Schedule

3.1. Cost Analysis

Table 3.1.1 Estimate of total number of labor hours and subsequent cost

Name	Labor Cost per hour	Hours per week	Total number of weeks	Total labor cost (labor cost per hour * total hours)
Aakarsh Sethi	$40	10	16	$6400
Yohann Puri	$40	10	16	$6400
Steve Wang	$40	10	16	$6400

Table 3.1.2 USD paid for each part

Part	Cost (USD)
ESP 8266	6.95
Azure Rest API and Entity Framework server	Free 25$ Credit from Azure
PCB	Free from University
8 to 1 MUX + Analog to Digital Converter	Free from University
IR (Infrared) Receiver Sensor	1.95
Vertical Cavity Surface Emitting Laser (IR Emitter)	5.34

4. Ethics and Safety

One safety consideration of this device is that it is a surface that people are meant to walk on. Adverse weather can lead to dirt and water that could compromise the integrity of the device. To help address these safety issues, the surface of the mat that people will walk on will be grounded; any electronic components that hold charge will be underneath this grounded surface. Additionally, the bottom surface of the mat will be made of rubber, effectively isolating the bottom of the device from any contaminants coming from below. Another safety concern to address is the possibility of a flame due to the IR emitter. This should not be a problem in our circuit because we are working with low voltages and currents. Also the IR module is over the mat and not inside it. Thus the IR rays do not interact with the electrical component of the mat.

The sensor array and data collection methods we implement might also be misused to collect biometric data from people without their consent by collecting and saving raw sensor data and performing analysis beyond simple object identification. This can include identification of heights, weights, gaits, etc. The ACM Code of Ethics (1.8 Honor Confidentiality) and IEEE Code of Conduct [8] state that personal information collected outside the scope of a project must be kept confidential. To avoid ethical breaches, no data we collect will be associated with any person's identity without their consent, and no data can be collected about any specific person using the hardware and software we provide. While dealing with the scalability of the project we plan on the mat being able to identify wheelchairs too. Thus handicapped people will not be exceptions to the mat sensing. Although we are not dealing with this case in our current project, our ML algorithm can be trained to identify wheel chairs. This is in accordance to the IEEE Code of Conduct that states that we must, "treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression"[9]

5. Conclusion

We were able to accomplish a good amount of work in our one semester. We were able to design a sensing material for the mat, build a mat from ground up and get it to communicate with the ESP8266. Additionally we were also able to process this information and apply machine learning algorithms to differentiate between humans and inanimate objects. We also built the IR module which works as we wished it to work. Looking towards the future we wish to first integrate the IR module into the rest of the system by having the the receiver output communicate to the ESP8266 and then get an exact count of the number of people. We are also trying to look into scalability issues involved in making a bigger mat. Some design uncertainties arise here involving vertical IR sensors to keep track of multiple humans on the mat at the same time. We want to integrate neural nets into our machine learning and eventually phase out the IR module thus giving the mat true omni directionality.

6. Citations

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