Room Occupancy Sensing Mat

Design Document

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Group 83
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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

BLOCK DIAGRAM

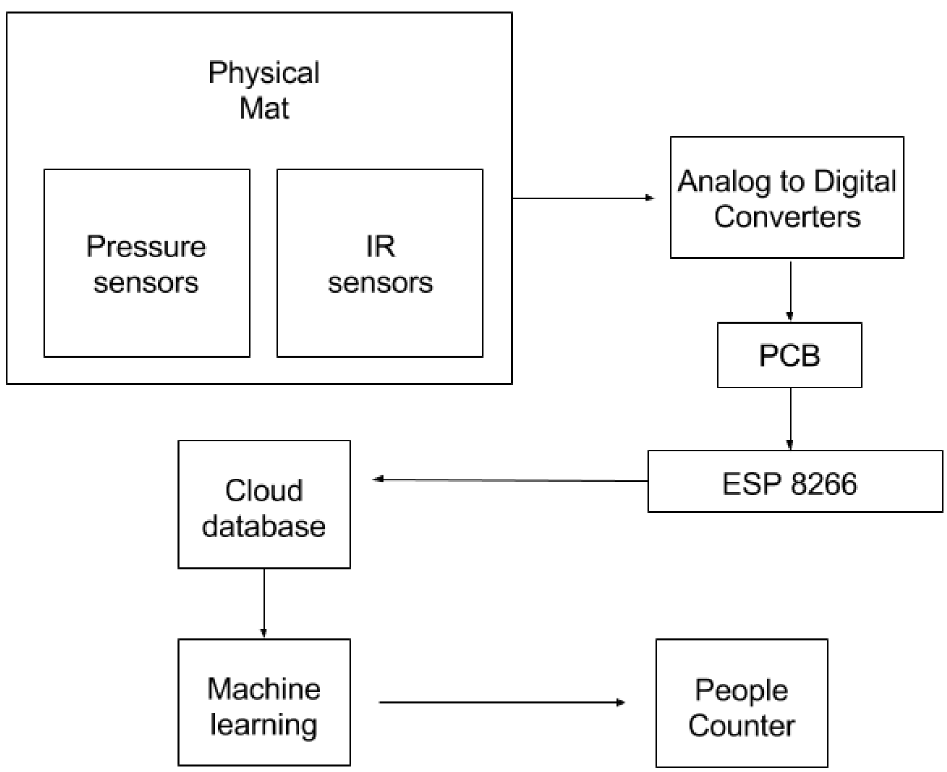


Figure 2.1.1 Block diagram

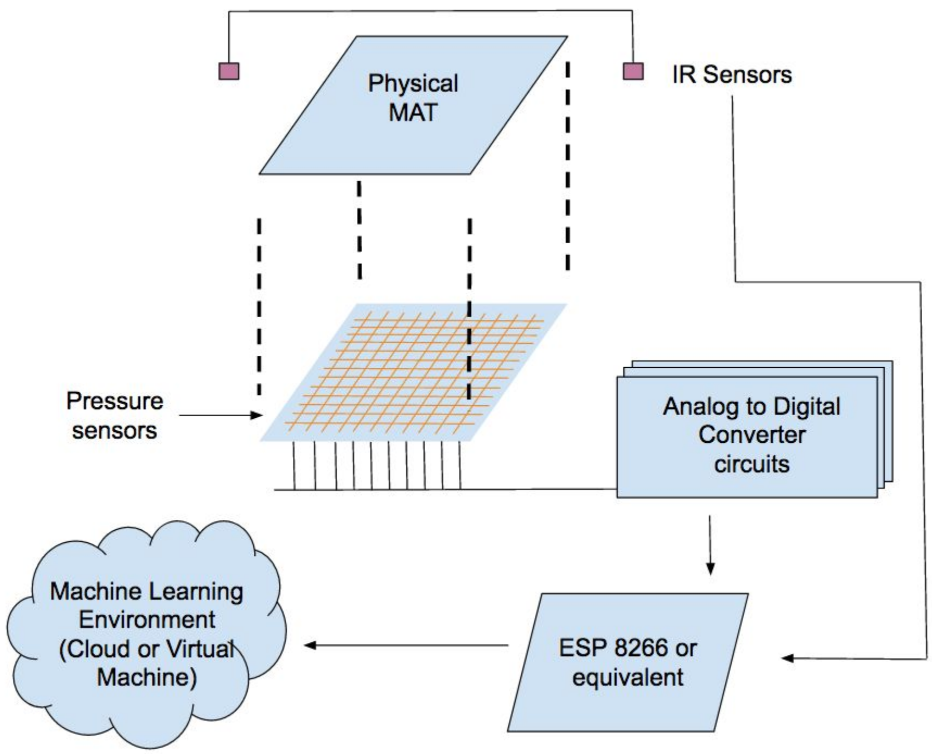


Figure 2.1.2 High level block diagram showing the flow of data between each module.

1) The Mat - This contains an array of pressure sensors sewn into a physical mat that people step onto.
2) The ADC circuits - These converts all the analog pressure sensor signals into digital signals for transmission to our machine learning
3) IR Sensors - These are coupled so that we can learn the direction of people crossing the mat.
4) ESP 8266 or equivalent chip - This is a minimalistic chip that has wireless capabilities which will help get our data onto a virtual machine or into the cloud
5) The machine learning - This machine learning uses the snapshots obtained from the sensors along with data from the IR sensors to count how many people are in the room.

2.2. Force Sensing Velostat Mat

2.2.1. Functional Overview

The first element of our design is a floor mat made primarily of Velostat, which is a carbon-impregnated Polyethylene film [3] generally used to protect items from electrostatic discharge, but also has a 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 foam. Below the foam 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 2.3.3.4 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.

We tested several types of conductive thread for resistance; the results of which are shown in table 2.3.1.1. Additionally, we measured the high-frequency voltage response of each material to see if there were any significant delays in voltage changes.

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 2.3.3.5 shows the schematic for our sensing method. This design is capable of digitally reading the voltages of 64 separate sensor locations and outputting each as a byte of information.

2.2.2. Requirements and Verification

Requirement	Verification
Must have a sensor density of at least 2 sensing points per square foot	Measure the output of the mat without any object on its surface. Compare that data with the data produced when a test object one square foot in size is placed on the sensing surface. Repeat this action starting at the top left corner and moving half a foot to the right each time, and restarting a half a foot below when the end of the row is reached.
Each sensing location must be able to produce a ‘pressed’ voltage for objects heavier than 15 lb, and a ‘non-pressed’ voltage	Measure the output of the mat without any object on its surface. Compare that data with the data produced when a test object weighing 15 lb is placed on the sensing surface. Repeat this action starting at the top left corner and moving half a foot to the right each time, and restarting a half a foot below when the end of the row is reached.
The data for all sensing locations combined must have a collection time of less than 1 second	Count the number of clock cycles required for every sensor value to output once from the mat. Multiply the cycle number by the period of the clock.
The rectangular sensing surface must have a total area of at least 6 square feet, with the smallest side having a length of at least 2 feet.	Measure the dimensions of the sensing area on the mat and calculate its area.

2.2.3. Supporting Documents

Table 2.3.1.1 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

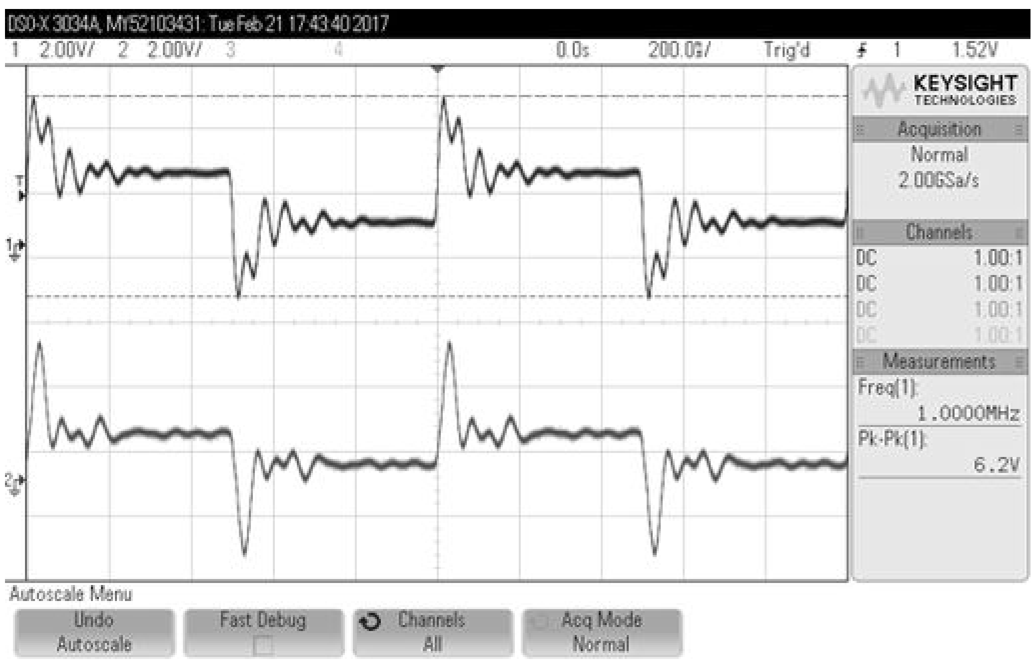


Figure 2.3.3.1 Voltage response of 12 in. of conductive yarn exposed to square wave at 1Mhz, Pk-Pk 6.2V, Offset 2.5V

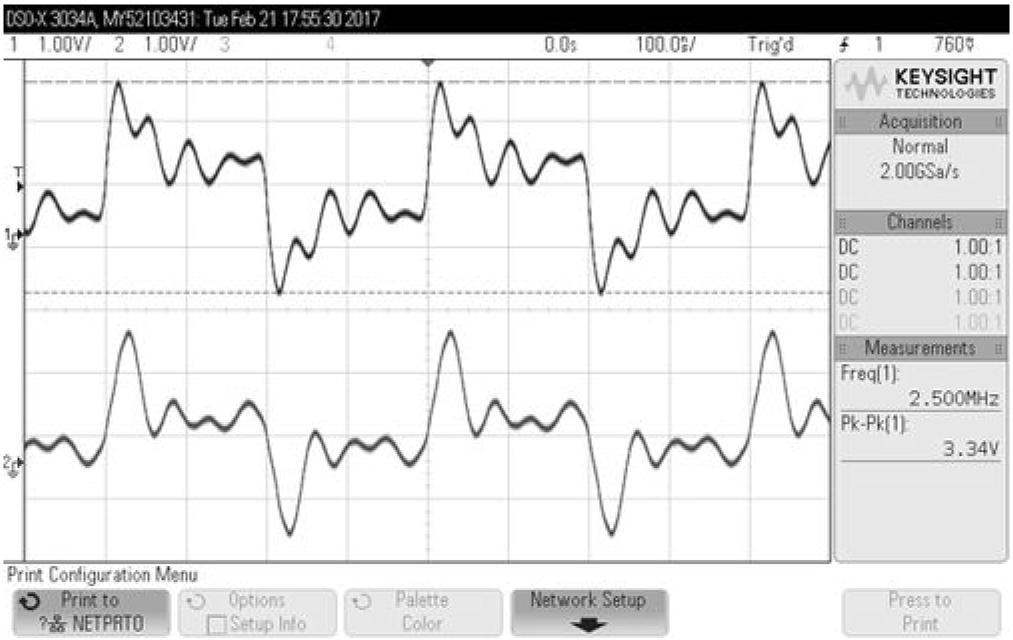


Figure 2.3.3.2 Voltage response of 12 in. of 2-ply conductive silver thread exposed to square wave at 2.5Mhz, Pk-Pk 3.34V, Offset 2.5V

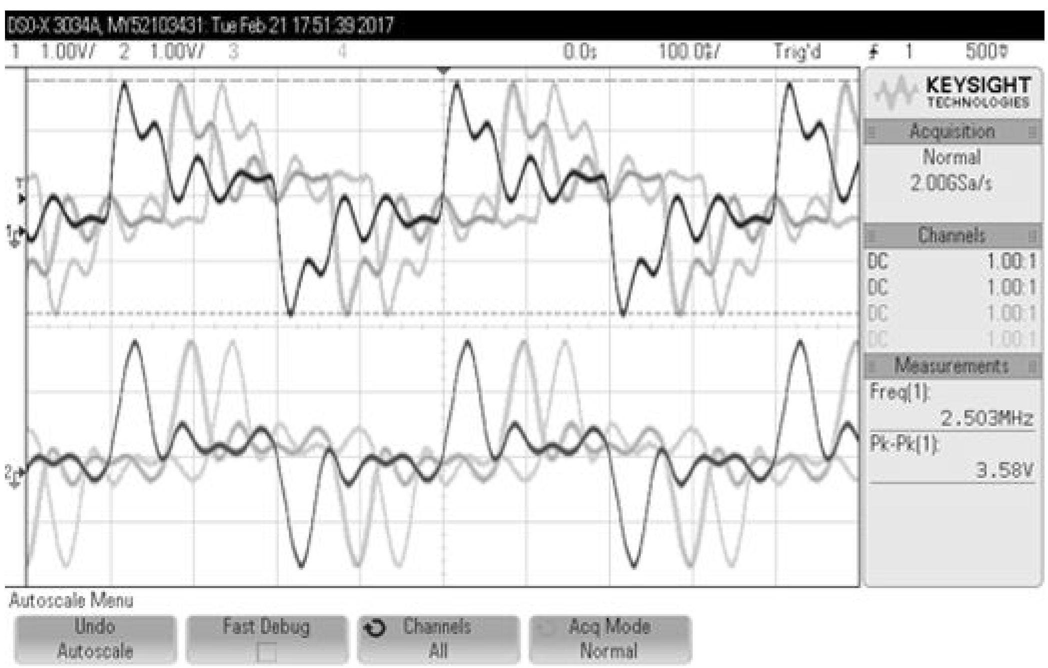


Figure 2.3.3.3 Voltage response of 12 in. of 3-ply conductive silver thread exposed to square wave at 2.5Mhz, Pk-Pk 3.58, Offset 2.5V

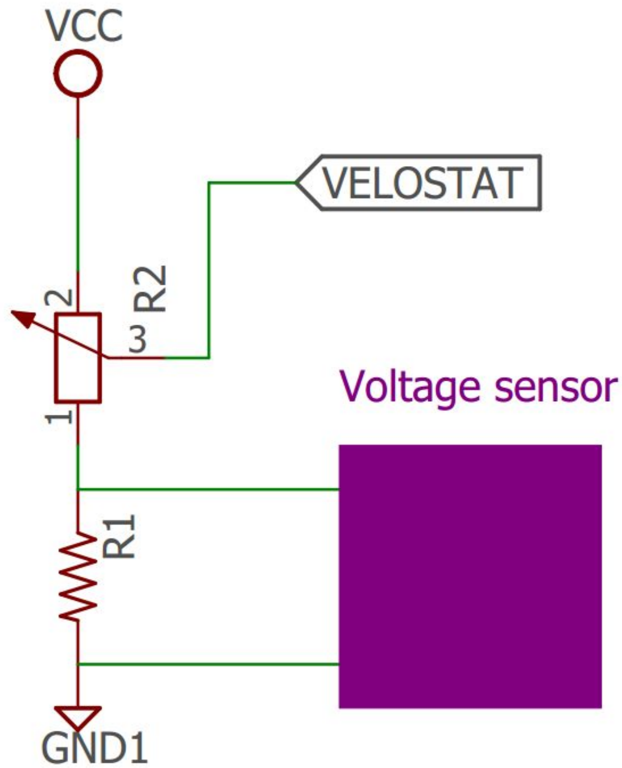


Figure 2.2.3.4 High level functional overview of Velostat surface and voltage sensor

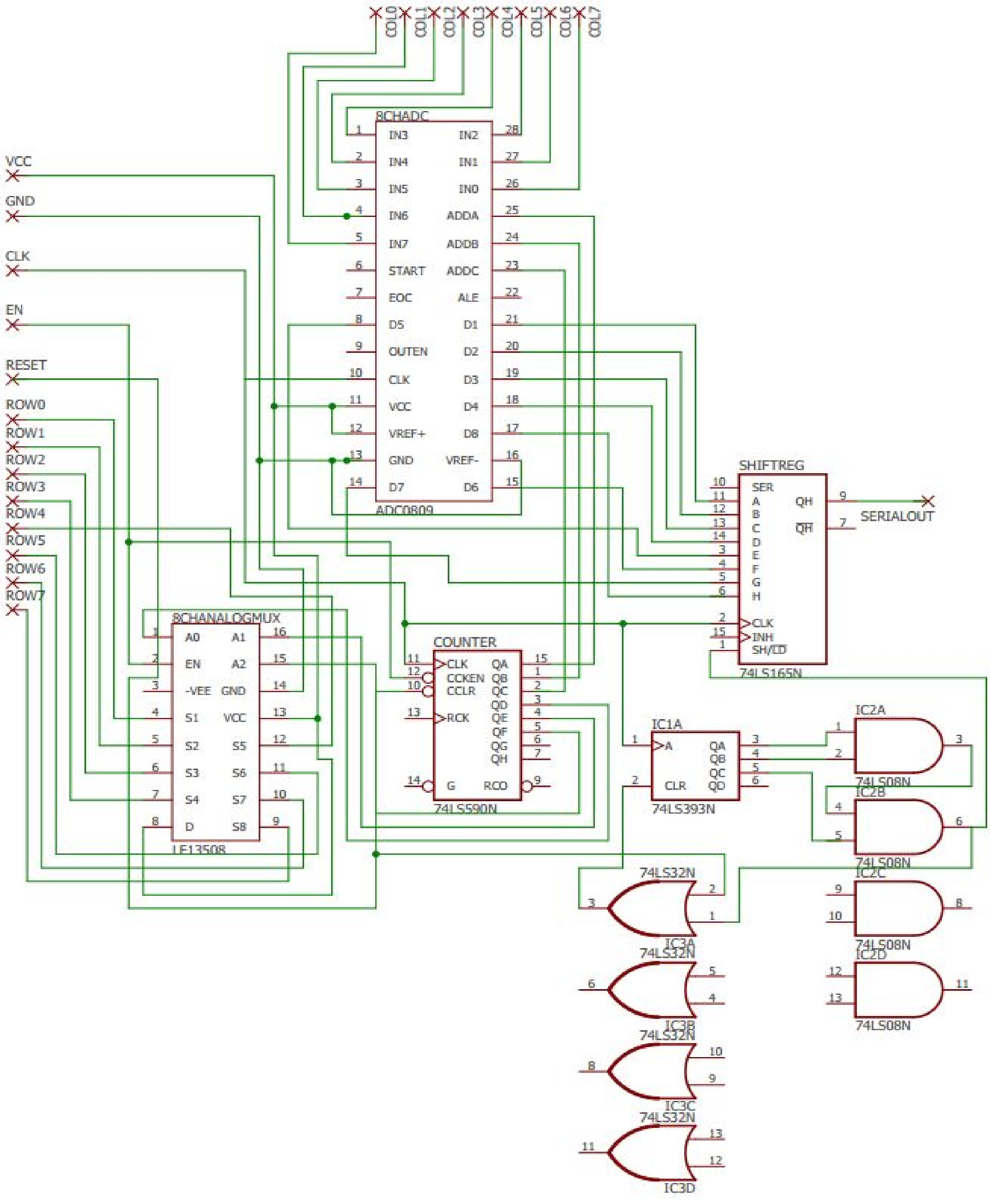


Figure 2.2.3.5 Version 1 of our analog voltage to digital data sensing circuit

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. 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-receiver couple should be able to detect a human even if no part of the foot is on its horizontal axis. Thus it should be able to detect object at heights up to 3 inches.	The IR emitter-receiver must be mounted at a height of an inch so that the total height equals 3inches.
The IR emitter-receiver couple should be able to operate at room temperature (defined at 23 + - 10 ^{o}C).	Have the temperature of the room as a controlled variable. Most purchasable IR sensors can work between 0 to 50 ^{o}C. Under the controlled temperature the LED test is performed.
The emitter peak current should not exceed 12.0 mA.	Check the current using voltage probes to measure the voltage. The resistance of the emitter is around 35 ohms.
The emitter-receiver must be joined to the mat.	The emitter and receivers can be soldered onto a component of the mat. The soldering temperature must not exceed 250^{o}C
Power consumption of the receiver should be less than 10mW.	Control the power source and constantly measure the power consumption
Voltage supply on the emitter should be less than 6V.	Power the emitter with a 6V source.
The receiver-emitter should not be accidentally stepped on.	The IR receivers and emitters can be encased so that they are protected.
The IR should not cause a flame.	We are dealing with small currents and voltages. The current can be constantly measured. Also the IR will not be inside the mat so it is not incident on the electrical equipment inside the mat.

2.3.3. Supporting Documents

The figure 2.4.3.1 is the schematic of the IR receiver we are planning to use.

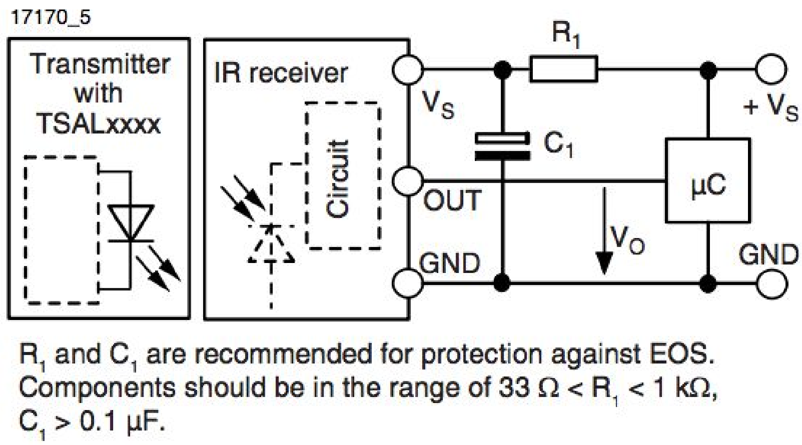


Figure 2.4.3.1 Circuit schematic of the IR Receiver[6]

Figure 2.4.3.2 are the schematics of the IR emitter that we plan to use.

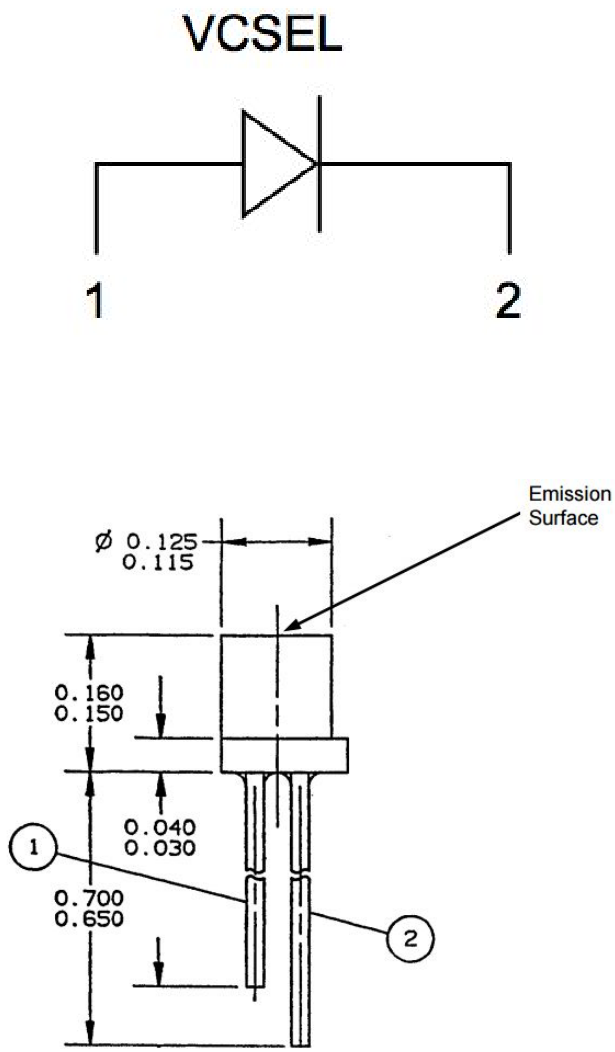


Figure 2.4.3.2 Vertical Cavity Surface Emitting Laser (VCSEL) packaged in a flat lens lateral package [7]

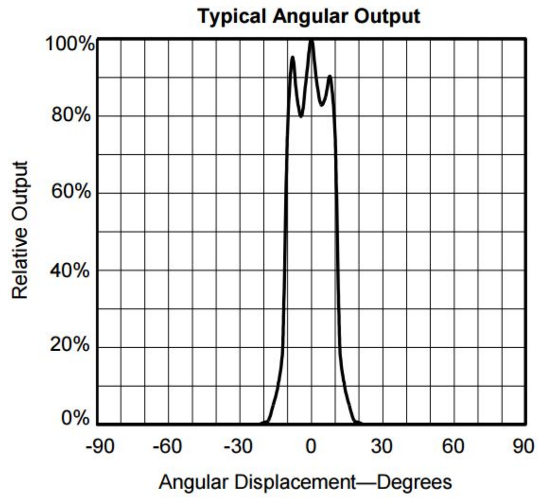


Figure 2.4.3.3 Angular Output described in a Relative Output vs Angular Displacement [8]

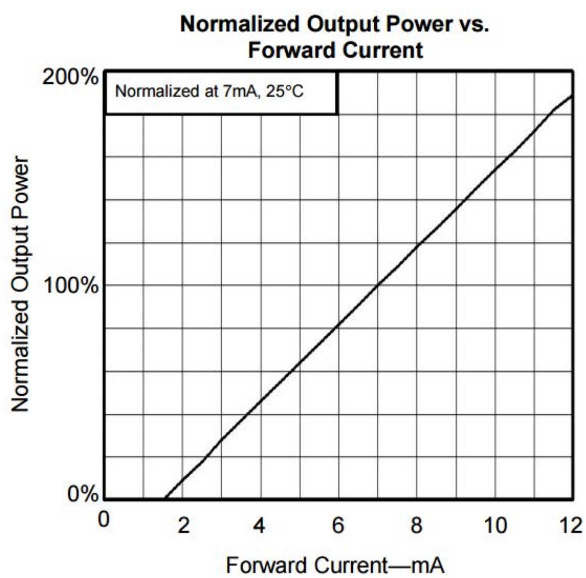


Figure 2.4.3.4 Normalized Output Power vs Forward Current [9]

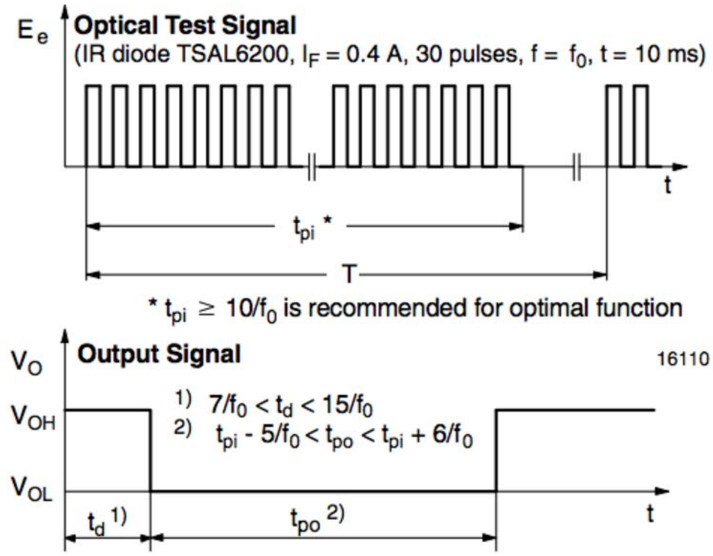


Figure 2.4.3.5 IR Output Active low [10]

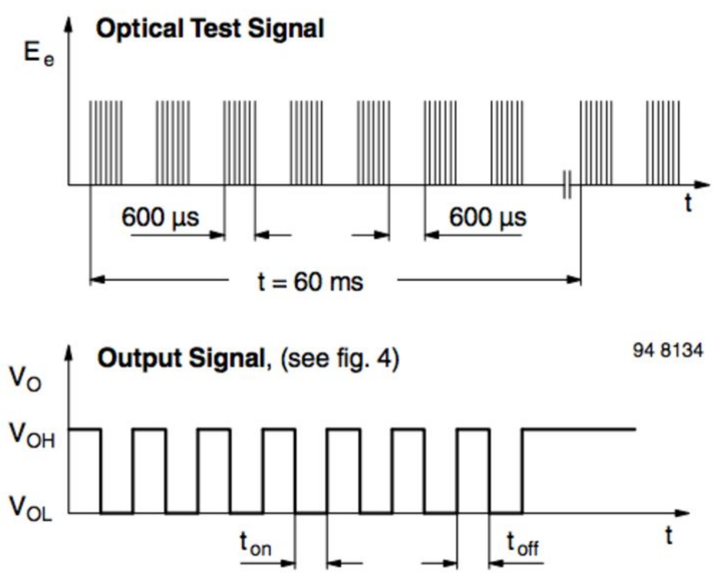


Figure 2.4.3.6 IR Receiver Output Function [11]

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.

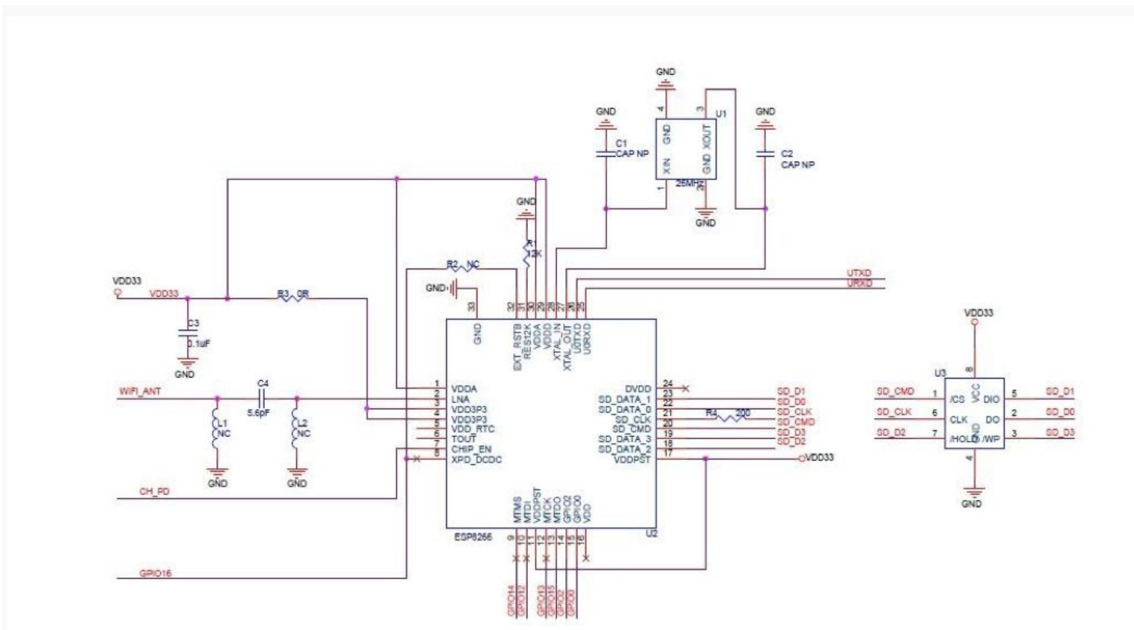


Figure 2.5.1.1 - THE ESP 8266 Schema [5]

2.4.2. Requirements and Verification

Requirement	Verification
Connect to PCB to obtain data coming from Pressure sensors at 20 Hz or better	Obtain an entire matrix of data and pass it forward to a database
Connect to IR sensors to obtain data at 20 Hz or better	Obtain coupled, time stamped, IR data and pass it forward to a database
Pass data to a database hosted on Azure using REST calls	Obtain a collection of IR and pressure sensor data in an entity framework sql database

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.

Feature Extraction

From the data received from the ESP8266 we will at least extract the following features:

1. Length of object imprint
2. Width of Object imprint
3. Radius of Curvature from center of imprint
4. Number of times object was on the mat

We will add more features after obtaining and studying training data.
The answer will be a 0 or a 1 (Foot or no foot) and is therefore a one dimensional answer.

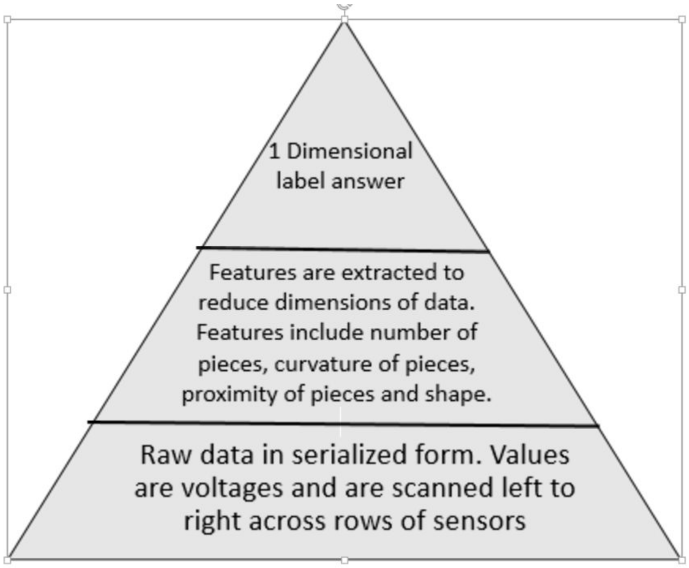
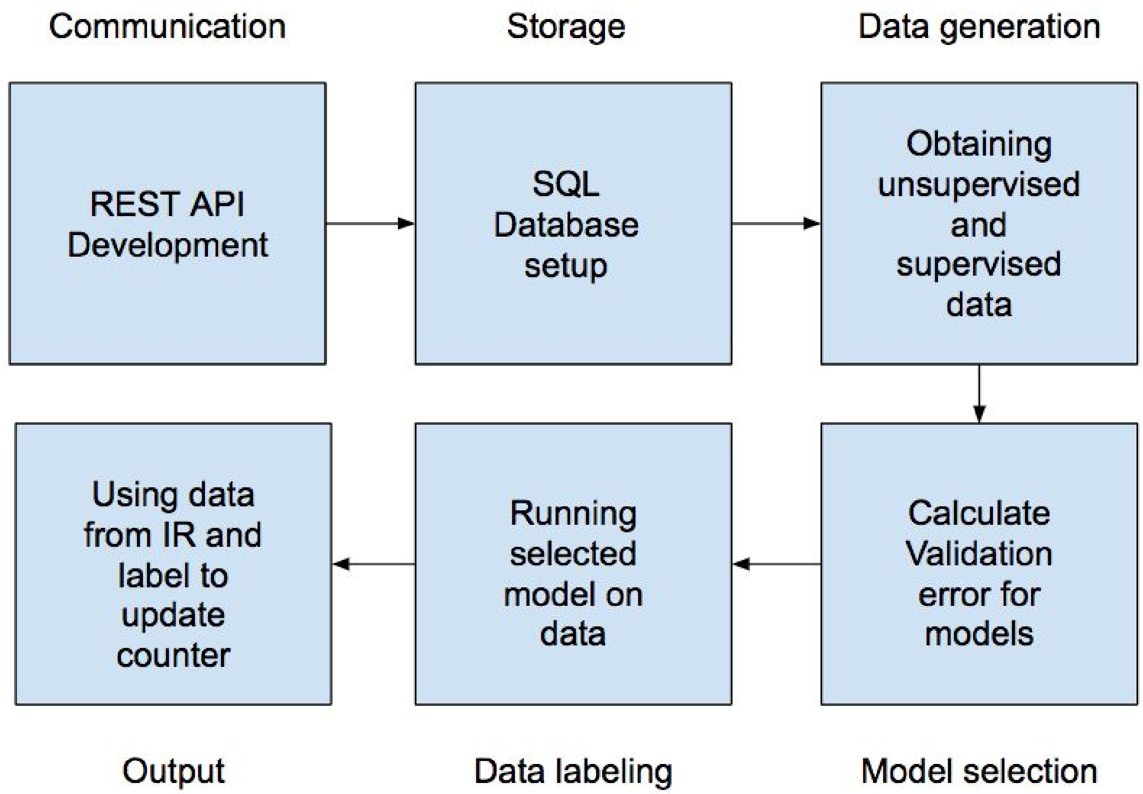


Figure 2.6.1.1 - The feature extraction pyramid

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
Obtain 750 sets of unsupervised training data and perform K means clustering.	Perform dimensionality reduction on data to create a feature set.
Obtain 250 sets of supervised training data	Perform dimensionality reduction on data to create a feature set.
Obtain a model of a choice by splitting data obtained from the aggregated set into training, validation and test	Performing a fit for each of logarithmic regression, K Nearest Neighbors and Linear Discriminant Analysis to obtain test error.

2.6. Tolerance Analysis

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 1 hour.

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 4 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

3.2. Schedule

Week	Task	Person Responsible
Week of February 20	1) Set up REST API and SQL database 2) Purchase Prototyping supplies; begin building test circuit	1) Yohann 2) Steve
Week of February 27	1) Create programs to validate models. Use dummy, self created data for this. 2) Order IR emitter and receiver 3) Finish building small-scale prototype of sensor mat; begin revision and verification 4) Program ESP 8266 to make POST calls with data to the API	1, 4) Yohann 2) Aakarsh 3) Steve
Week of March 6	1) Begin collecting training data from small-scale prototype of sensor mat. 2) Test the functional working of the IR receiver and emitter. 3) Finish revision and verification of small-scale prototype; begin building full-scale prototype	1) Yohann 2) Aakarsh 3) Steve
Week of March 13	1) Continue collecting training data 2) Build a prototype of the IR module and check for requirements. 3) Continue building full-scale prototype; begin integrating with transmission unit	1) Yohann 2) Aakarsh 3) Steve
Week of March 27	1) Continue collecting training data 2) Build a prototype of the IR module and check for requirements 3) Finish building full-scale prototype; begin revision and verification	1) Yohann 2) Aakarsh 3) Steve
Week of April 3	1) Choose model based on validation tests once data is available 2) Take care of external requirements such as encasing the sensors and soldering onto the mat 3) Finish revision and verification; begin external covering of mat	1) Yohann 2) Aakarsh 3) Steve
Week of April 10	1) Create program to perform labeling of data 2) Integrate the IR module to the mat/ integratable parts of the mat	1) Yohann 2) Aakarsh 2) Steve

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 [12] 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"[13]

5. Citations

[1] "DIT." *DIT School of Electronic and Communications Engineering*. Dublin Institute of Technology, n.d. Web. 15 Feb. 2017. <http://www.electronics.dit.ie/>.

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