Crowd Monitoring Device

By

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Design Review for ECE 445, Senior Design, Fall 2016

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Project No. 20

Contents

1 Introduction

1.1 Motivation

Computer vision is limited by a camera viewing objects from an angle, not top-down. Because of this, targets may overlap, preventing distinction. Spherical cameras are available for viewing nearby, cramped scenes, but they are commercially available, but expensive. They also require a heavy software and mathematical effort to map a spherical projection to a plane. Faces and shapes of bodies, a big part of some computer vision, can get distorted.

We would like to create a modular tile that hook together on a ceiling and save researchers money they would have otherwise spent on chaining together Microsoft Kinects. Ideally we could provide information on human clusters moving through space and tell computer vision algorithms running on a professor's laptop where to look in his high definition camera's frame.

1.2 Objectives

We seek to make an array of sensors which will be directly above our targets. This way we can track motion across a space on a 1:1 scale without worrying about targets overlapping. This could be used in conjunction with installed computer vision to determine boundaries between people in a frame. We will group activated pixels into blobs to follow the trajectory of a human blob through space. Ideally we could incorporate data collected by our array processed with machine learning into computer vision.

Our project is a step toward sensor fusion of a ceiling-mounted sensor array and cameras placed at multiple viewing angles in a room. The goal of such a system is to track a target better than any individual sensing.

By the end of the project, we want to accurately count the number of people passing through a doorway – up to three at a time. We then assure we can accurately count the number of people within an area as long as we cover all entrances and exits. If a user were to tile an entire ceiling, they could map motion of specific individuals throughout a room.

2 Design

We seek to take snapshot of the surface below a square area, detect whether distinct human figures are walking through the area, and report this information to assist in other computer vision projects. Our design effort is comprehensive. At a broad scale, it covers signal processing, digital systems, circuit design, and machine learning. We see it as a refreshment for past coursework and a culmination of our undergraduate understanding of electrical engineering. As the reader will notice, evolution from our initial Piazza post and Request for Approval to our current design review is evidence of a continually evolving design process.

2.1 Block Diagram

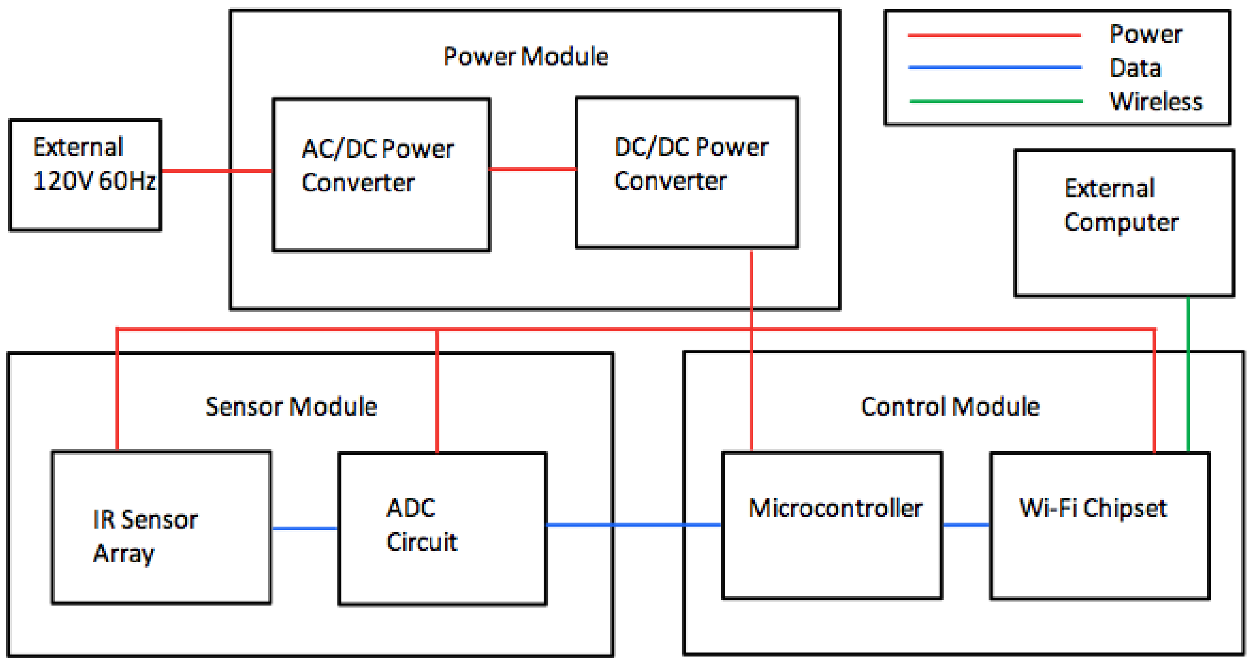

Figure 1: Block Diagram

2.2 Block Descriptions

2.2.1 Sensor Module

The sensor module is an active device meant to sense the height of a surface above the ground. It consists of two submodules: the infrared (IR) illuminator and the receiver array. The purpose of the IR illuminator is to flood the area beneath the receiver array with infrared light at an intensity such that reflected power $P_{reflected}$ seen at the receiver array reaches the ambient IR power $P_{ambient}$ of the room. We define this threshold as $P_{reflected} = P_{ambient}$. This ensures we can sense the distance to objects between the floor and the array. An object between the floor and array will increase $P_{reflected}$ above $P_{ambient}$. The purpose of the receiver array is to sense an increase in $P_{reflected}$ relative to $P_{ambient}$. The increase is proportional to the square of the distance to the floor $R_{ambient}$ divided by the distance to the object $R_{reflected}$. That is,

$$P_{reflected} = P_{ambient}(\frac{R_{ambient}}{R_{reflected}})^2 \qquad (1)$$

Because the module uses infrared light as an indicator, it should be deployed indoors, away from direct sunlight which would increase $P_{ambient}$. It is housed on a panel which should be mounted parallel to the floor to maximize sensing of reflected power.

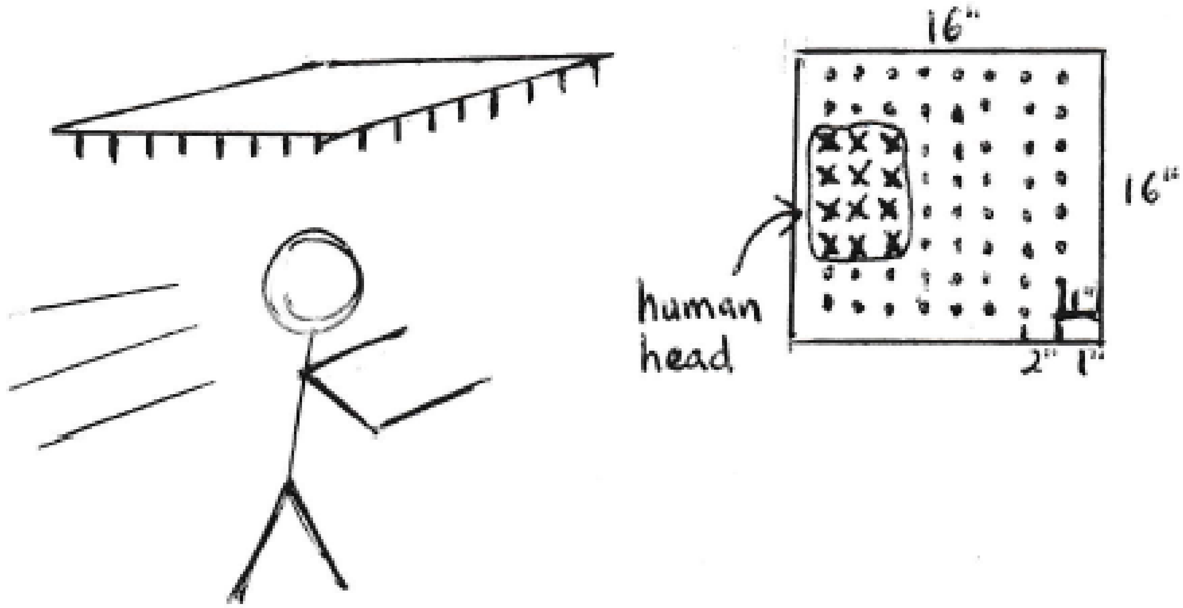

Figure 2: Person under sensor module and bottom view of sensor module

IR Illuminator: Every receiver cell in the receiver array has a 940nm LED to splash the ground beneath it. Experimentation with free LTE-5228 LEDs from the ECE Service Shop demonstrates 16 LEDs at 2 inch spacing and 1.25V forward voltage already increase $P_{reflected}$ above $P_{ambient}$.

Receiver Array: The array is a square grid. We choose a square grid for accuracy in production. We can measure the distance between rows and columns instead of measuring the distance between each pixel, which could introduce human error.

To detect a human head, we want to see a rectangle where length is not equal to width. Then we can determine the line from forehead to back of head, the head length line. The line across shoulders will be perpendicular or oblique to the head length line. This gives a good starting point for looking for shoulders. Certain activations do not provide a rectangle: 1 pixel is a point, 2 pixels is a vector, 3 pixels is a triangle. With 4 pixels, we have a square. With 6 pixels we have a clear indication of a shape with length greater than width.

We choose 2 inch spacing between receivers so the smallest anticipated human head will span at least a 6 pixel rectangle. In the first percentile of the population, the human head is 5 inches wide by 7 inches long[2]. When the head length line is parallel to our grid's columns, we want a 2 by 3 pixel activation. Minimum spacing for width is $\frac{5inch}{2} = 2.5$ inches while minimum spacing for length is $\frac{7inch}{3} = 2.33$ inches. We round down to 2" spacing to satisfy both requirements. As Figure 3 demonstrates, we can also detect a head length line if the head is oblique – in the worst case, diagonal – to the grid's columns.

A single array is 16 by 16 inches, containing 8 by 8 pixels. This is small enough to be portable. The design

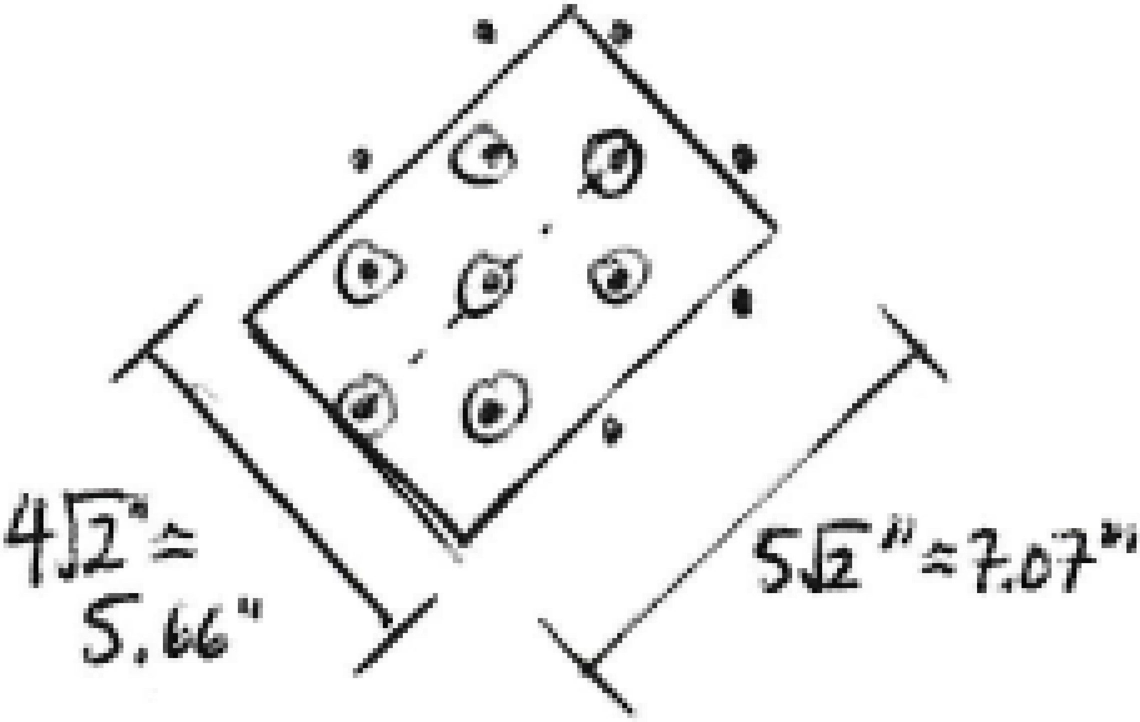

Figure 3: Head length line still detectable in diagonal case

is modular so, for the purposes of our demo, two arrays are connected for a 32 by 16 inch configuration, which fits between a standard 34 inch door frame with the door open.

Receiver Cell: Each receiver is an NPN phototransistor which conducts its highest current when exposed to 940nm light. The collector of the phototransistor is connected to Vdd, the emitter is connected to a resistor R_E, and the R_E is connected to ground. This constitutes a common collector configuration. Resistor sizing is discussed in the ADC Circuit subsection. $P_{reflected}$ causes a directly proportional collector-emitter current[1]. Current through the emitter resistor creates a voltage drop. This voltage $V_{reflected}$ is the signal we measure to represent $P_{reflected}$ so

$$V_{reflected} = V_{ambient}(\frac{R_{ambient}}{R_{reflected}})^2 \tag{2}$$

In order to minimize ambient infrared which would contribute to a higher $V_{ambient}$ reading, we will cover each phototransistor with a Plastidip-coated straw.

Figure 4 shows an early prototype of a single receiver cell with the IR illuminator.

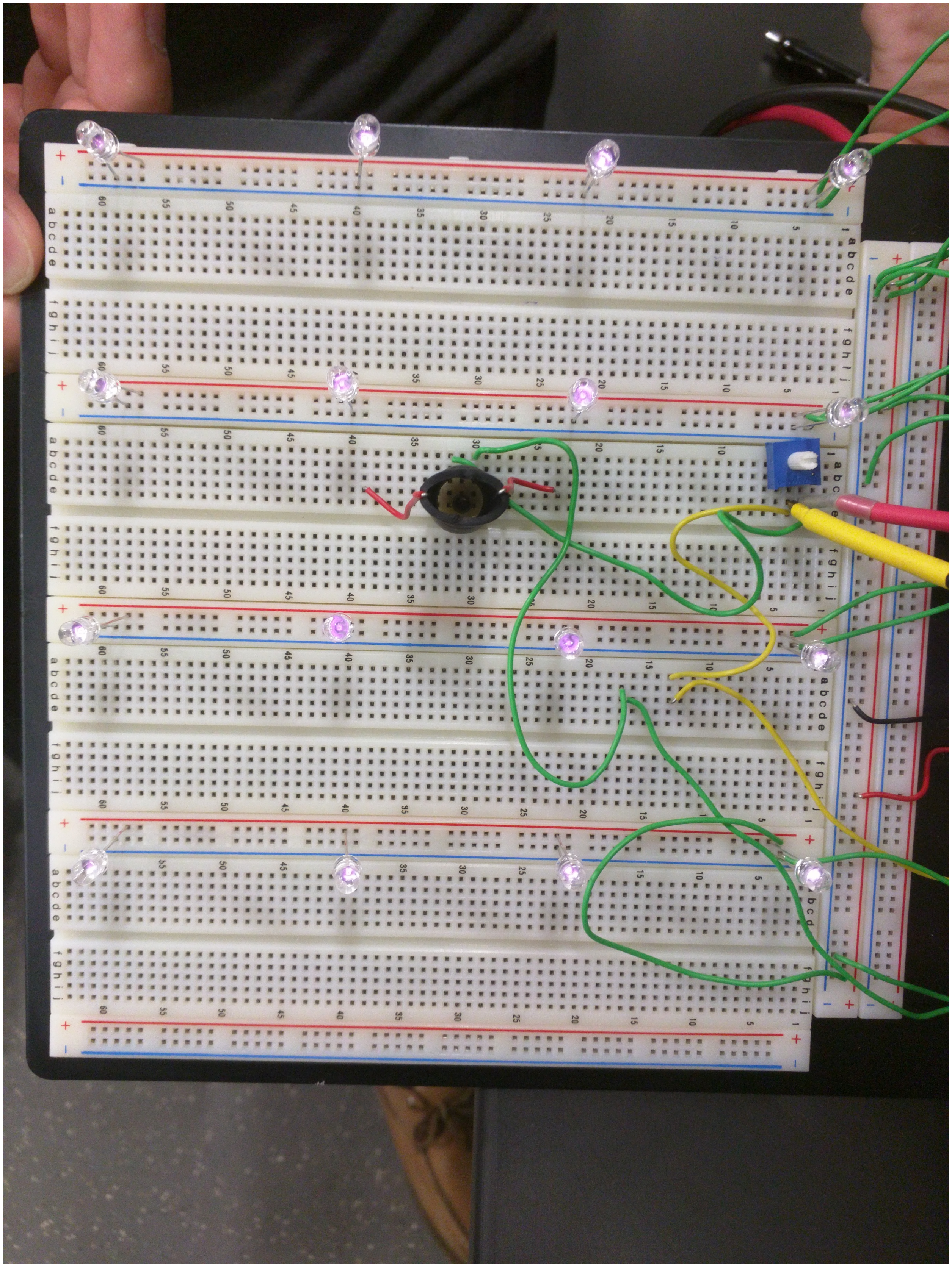

Figure 4: Prototype 6" by 6" Array, Single Receiver. Used for testing whether our $V_{reflected}$ at 1.2V across 16 LEDs is greater than $V_{ambient}$. It is!

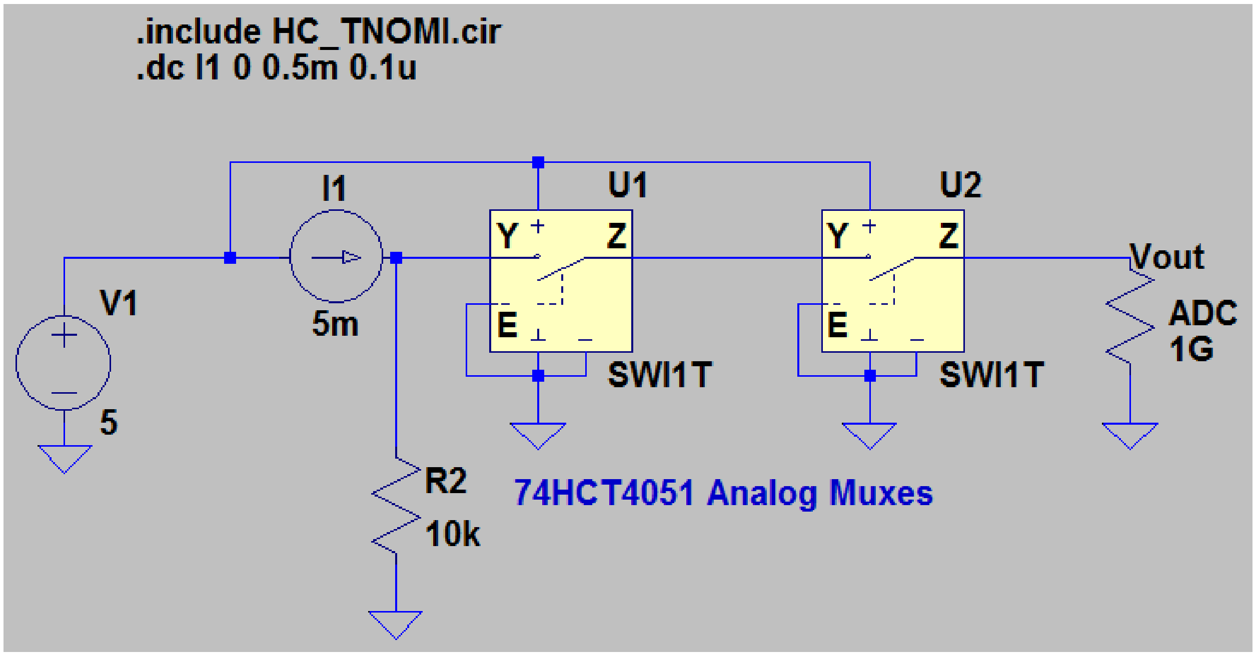

Figure 5: Individual IR Sensor Cell Receiver Circuit

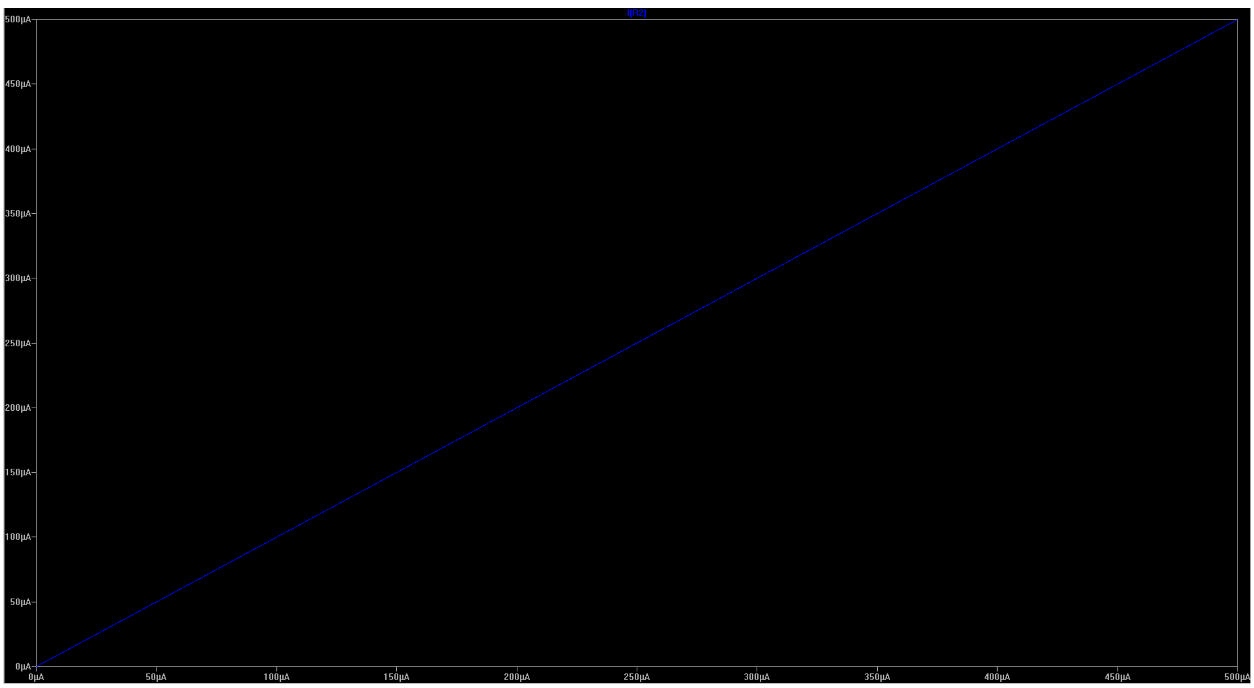

Figure 6: Individual IR Sensor Cell Receiver Circuit - Current Through Cell Resistor

ADC Circuit: The array has 8 rows and 8 columns. To route $V_{reflected}$ at a single pixel to the ADC for sampling, we need to select pixel at a particular row and column. To select a column from all rows, we use eight 8:1 analog multiplexers. We index each of these muxes with the 3 bit column address. Next we have to choose a particular row of this column. We could use another 8:1 analog multiplexer, but we instead use an 8 channel ADC to save cost. Figure 5 simulates the receiver cell with a current source I1 substituted for

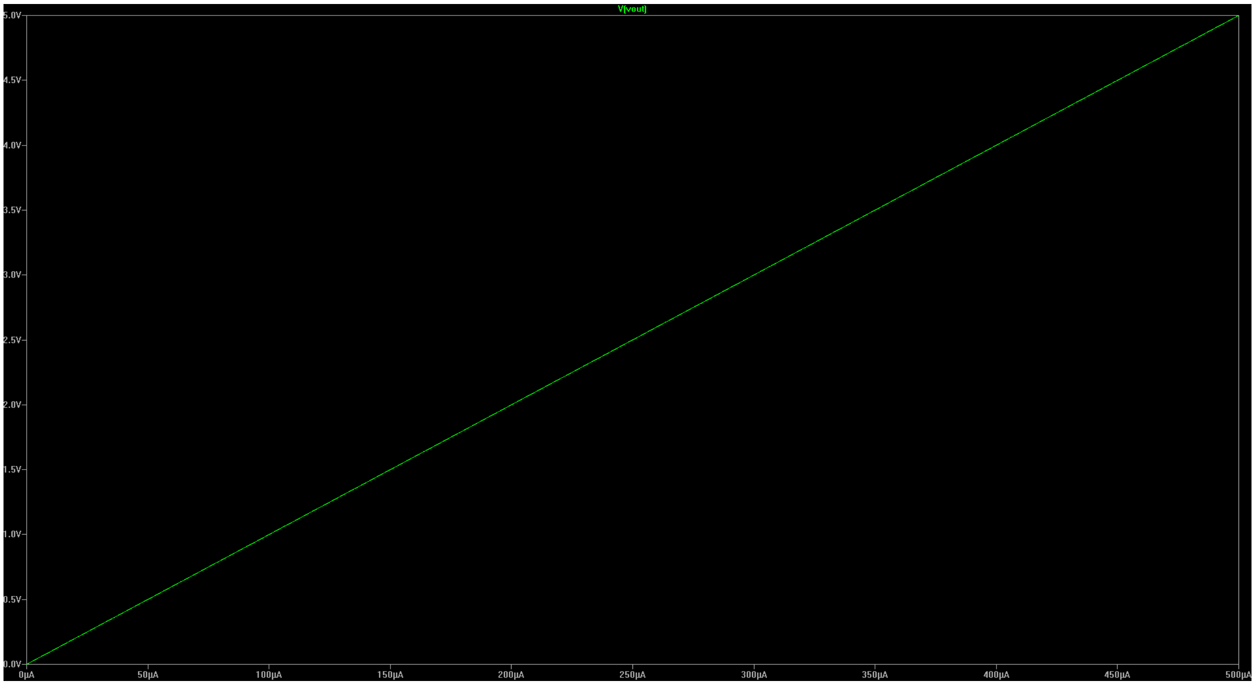

Figure 7: Individual IR Sensor Cell Receiver Circuit - Output Voltage (Seen by ADC)

the phototransistor and an emitter resistor R2. Next, two levels of analog multiplexing (one on an external mux and one inside the ADC) are loaded by the $G\Omega$ resistance of the ADC's sample/hold unit. Figure 6 demonstrates nearly all of the phototransistor current flows through the emitter resistor due to R_E being much smaller than the sample/hold resistance with which it's in parallel. Therefore, as Figure 7 shows, R_E determines the Vout.

We have three considerations when sampling. First, we need to index and sample all 64 pixels multiple times before a person moves 2 inches on the grid. This allows us to take a moving average. The mean human running speed is 6.7 m/s, approximately 7 m/s, according to Reference 3. It would take 7.3 milliseconds to cover a 2 inch distance. If we want 3 samples at each pixel, we must index and sample the entire array in 2.43 milliseconds, or .038 milliseconds per pixel. This yields a sampling rate of 26.316 kHz. Second, the samples we store in microcontroller memory should not prevent us from also normalizing pixels, filtering pixels over time, and running our machine learning algorithm to find clusters of pixels at different heights. The MCP3008 eight channel ADC can sample up to 200 kHz, satisfying our requirement, at 10 bit resolution. The memory footprint is $3samples \times \frac{10bits}{sample} \times 64pixels = 1920$ bits $= 240$ bytes. Third, we want our ADC to have a high impedance for minimal impact on $V_{reflected}$ when sampling. The chosen ADC has a high impedance sample/hold unit.

10 bit resolution at a 5V swing provides a 4.88 mV step. Knowing this is our finest voltage step for detecting a change in distance, we consider the power difference over 1 inch at the furthest intended distance from our array. A door is 7 feet tall, or 84 inches. Moving from 84 to 83 inches increases $V_{reflected}$ by 102.4% by Equation (2). We expect an ambient current around 1 uA, a number verified experimentally with a prototype board at 7 feet above the ground, so a 2.4% change means $\triangle I = .024$ uA. Then the R_E needed to detect a 1 inch change in distance from the top of the door frame to the ground is $\frac{4.8mV}{.024uA} = 0.2\text{M}\Omega$.

2.2.2 Power Module

DC Power Supply: This power supply will convert the standard 120Vac 60Hz signal to 5A 10Vdc. Its purpose is to provide a DC voltage that can be stepped down with a Buck converter (DC/DC power converter). The maximum power dissipation of all the components in one sensor module is 20W. To demonstrate modularity, we will build two sensor modules and therefore the maximum power dissipation becomes 40W.

Figure 8 shows our DC power supply configuration. We started by finding a transformer in the ece service shop that was rated for 50W or above to accommodate all of the components used for this project. We plan on using MBR1045 diodes for our full wave rectification since they are available at the ece service shop (MBR745 shown for simulation purposes). Finally, we used a linear regulator (LT1084) to output 10Vdc. Figure 9 shows the output voltage of the DC power supply.

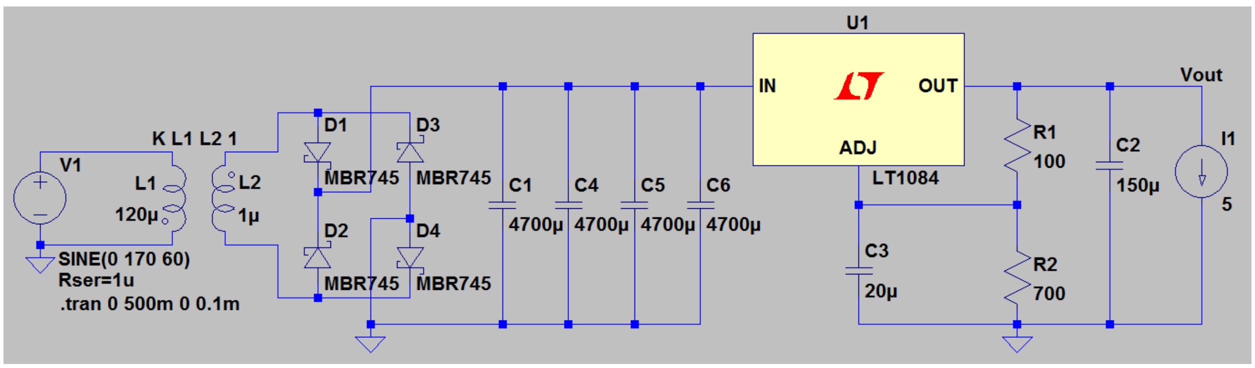

Figure 8: DC Power Supply

Figure 9: DC Power Supply - Output Voltage

Buck Converters: Two buck converters will be used to convert the 10Vdc produced by the DC power supply to 1.2Vdc and 5Vdc. The 1.2Vdc rail will be used to power the IR illuminator submodule while the 5Vdc rail will be used to power the control module, IR receiver submodule, and ADC circuit submodule. The purpose of the buck converters is to efficiently step down the DC power supply voltage to the operating component level voltages.

Figure 10 shows a buck converter we initially considered building. Figure 11 shows the expected output voltage of 5Vdc since we are applying a 50% duty cycle with a 10Vdc input voltage. However, when varying the load we were getting inconsistent simulation results and were advised to purchase buck converters.

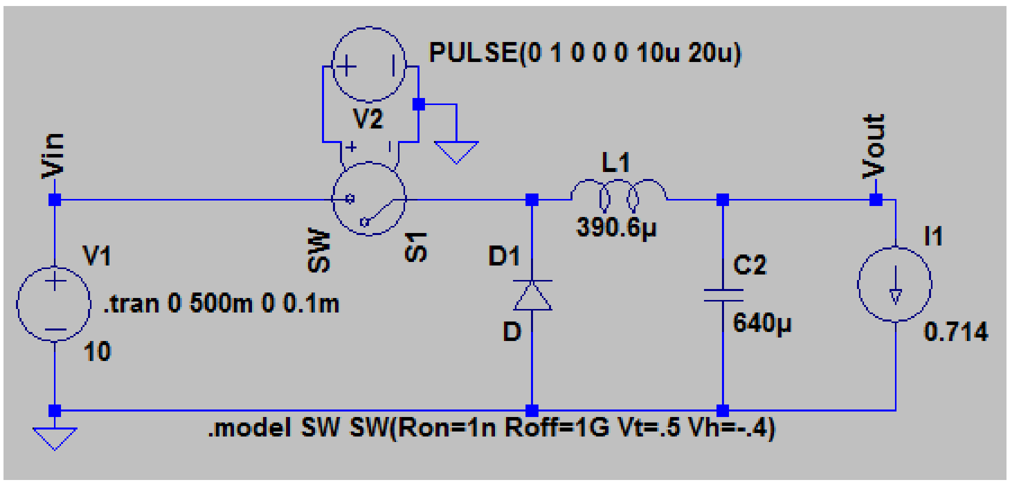

Figure 10: Buck Converter Example

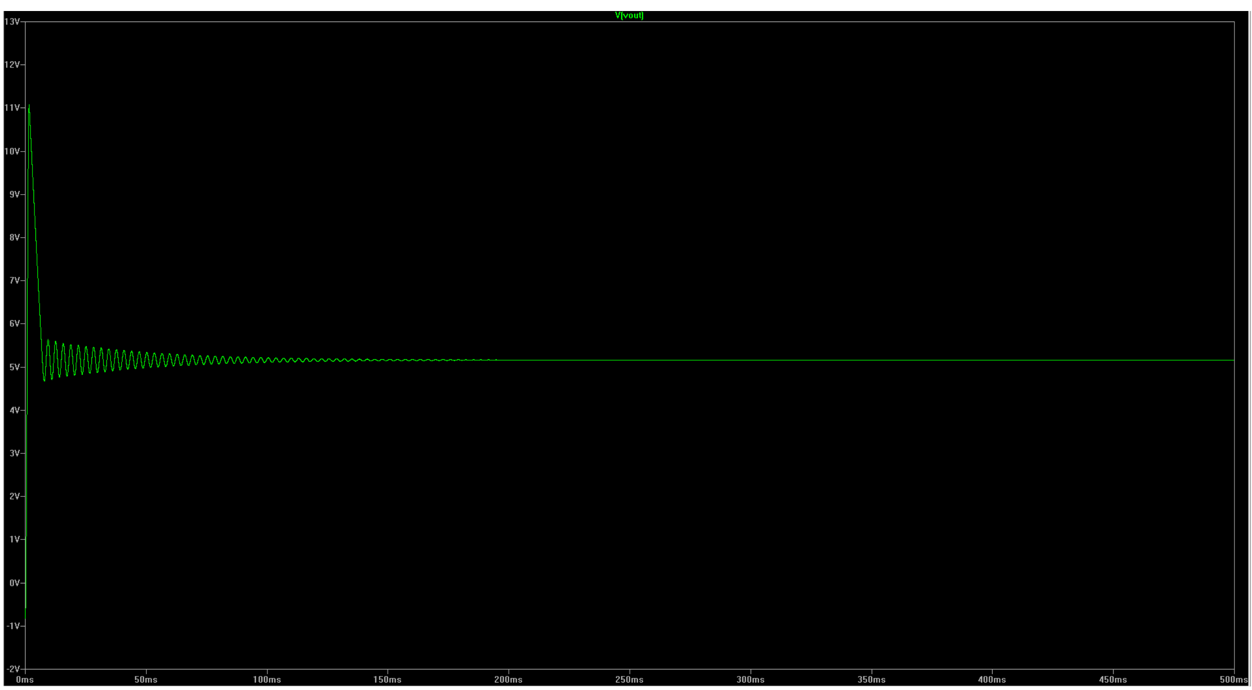

Figure 11: Buck Converter Example - Output Voltage

2.2.3 Control Module

Microcontroller: The microcontroller provides a clock signal to the ADC to set the sample rate. It communicates on a serial bus with the ADC to read each receiver cell's $V_{reflected}$ sample and write it to microcontroller memory. Then it uses the raster scan algorithm to identify clusters of pixels corresponding to a person's head and shoulders. It transmits this cluster data over an OTG to USB connector to the Wi-Fi chipset. Figure 12 demonstrates the software procedure necessary to accomplish sampling and clustering on the microcontroller.

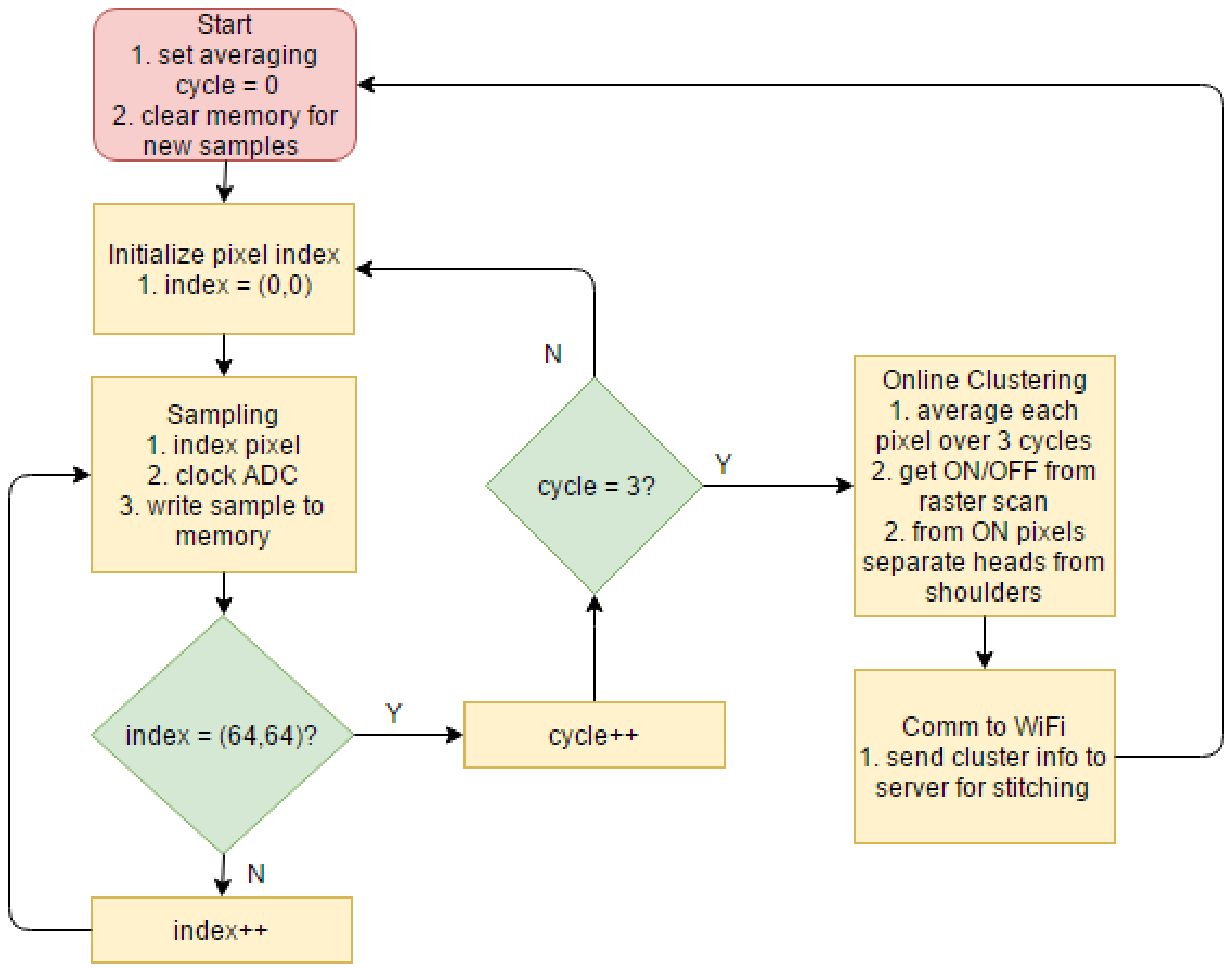

Figure 12: Microcontroller Software Flowchart

Wi-Fi Chipset: The Wi-Fi chipset will transmit the head and shoulder cluster data received from the microcontroller to a central location. Since our device is modular, the central server stitch the data received from multiple arrays to act as one larger array.

3 Requirement and Verification Table

Table 1: System Requirements and Verifications

Requirement	Verification	Points
1. Submodule: Receiver Array (a) Receiver rows are spaced 2 inches apart. Columns are spaced 2 inches apart. (b) Array mount should support 4 pounds of force.	1. Submodule: Receiver Array (a) Measure 2 ± 0.2 inches between rows and columns with tape measure. (b) Mount does not fail.	5
2. Submodule: Receiver Cell (a) Resistor R_E is greater than $.2M\Omega$. (b) Output voltage $V_{ambient}$ when IR illuminator is off is 0.2V ± .1V. (c) Cell has 5V supply.	2. Submodule: Receiver Cell (a) Test 2-wire resistance from output node to ground with DMM. (b) Test voltage from output node to ground with DMM. (c) Probe voltage at collector of each cell's photoransistor with DMM. It should be 5V ± 0.1V.	10
3. Submodule: ADC Circuit (a) Mux can select output node at each of 64 pixels. (b) We must sample array data at 26.316 ± 1kHz.	3. Submodule: ADC Circuit (a) Do this for every pixel with aid of microcontroller testbench. Apply 5V to cell output node, apply corresponding column index to mux select pins, output voltage reading with DMM on proper row mux output should be 5V ± 4.88 mV. (b) In microcontroller code, write timestamp before sampling the 64 pixels and after sampling the pixels. The output time should be 2.43 ms.	30
4. Module: Control Unit (a) Microcontroller reads samples from ADC into memory. (b) WiFi chip needs sends/receives cluster data to and from central server.	4. Module: Control Unit (a) Start sampling of array according to microcontroller flowchart in ambient conditions and write 240 characters to memory. Start sampling again with metal underneath array. New 240 character values should be at least double. (b) Connect WiFi chip to central server. Send test byte back and forth.	30

Continued on next page

Table 1 – continued from previous page

Requirement	Verification	Points
5. Submodule: IR Transmitter (a) IR LEDs receive 1.2 - 1.6 V.	5. Submodule: IR Transmitter (a) Probe voltage across LED terminals with DMM. It must be greater than 1.2V and less than 1.6V.	5
6. Submodule: Buck Converters (a) Vout = 1.2Vdc $\pm$ 0.024Vdc with output current limited to 5A (b) Vout = 5Vdc $\pm$ 0.1Vdc with output current limited to 5A	6. Submodule: Buck Converters (a) Place load resistor at output, use a multimeter to measure the output voltage. The voltage should be 1.2Vdc $\pm$ 0.024Vdc. Use an ammeter to measure the current drawn through the load. The max current should be 5A. (b) Place load resistor at output, use a multimeter to measure the output voltage. The voltage should be 5Vdc $\pm$ 0.1Vdc. Use an ammeter to measure the current drawn through the load. The max current should be 5A.	10
7. Submodule: DC Power Supply (a) Vout = 10Vdc $\pm$ 0.2Vdc with output current limited to 5A	7. Submodule: DC Power Supply (a) Place load resistor at output, use a multimeter to measure the output voltage. The voltage should be 10Vdc $\pm$ 0.2Vdc. Use an ammeter to measure the current drawn through the load. The max current should be 5A.	10

4 Tolerance Analysis

We believe the most important part of our system is making sure we don't operate the panel in an environment flooded with IR. Ambient conditions could cause erroneous activations and therefore the data we process could produce false positives. Ambient conditions with high intensity IR could saturate our sensors. We need a wide dynamic range between a signal identifying someone's head and shoulders. We don't want both the head and shoulders to provide the highest signal value possible.

To make sure we keep a dynamic range in an average, nonflooded environment, we normalize the ambient IR readings in software.

We have also sized R_E with our ADC's minimum voltage step in mind to maximize our ability to see changes in distance to objects below the array.

5 Ethics and Safety

Our device directly addresses the first tenet of the IEEE Code of Ethics[4]: "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment." One purpose of crowd monitoring is to perceive threats in a crowded environment and attend to them before they cause harm. Another purpose is to gauge congestion over an area for properly staffing this area.

One danger posed by our project is shining people with too high an intensity IR light. IR, though it is not detected by rods and cones in the retina, is still focused onto the back of the retina and can cause tissue damage if it is high power. Our chosen LEDs will not transmit a high enough intensity to damage the eye.

Another danger is our panel falling from its mount and hitting a passerby. We limit this risk by demonstrating our panel without mounting the heavy transformer we scavenged from the ECE Service Shop to our PCB. This way we lessen the weight on our mount.

When working on our transformer, we will follow the course safety policy carefully. This includes never working with main voltage unless a TA is present.

6 Cost and Schedule

6.1 Cost Analysis

6.1.1 Labor

Table 2: Labor Costs

Name	Hours Invested	Hourly Rate ($)	Total * 2.5 Engineering Factor ($)
Armando Juresic	250	34.00	21,250.00
William Schellhorn	250	34.00	21,250.00
Total	**500**	**68.00**	**42,500.00**

6.1.2 Parts

Table 3: Parts Costs

Part	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)	Status
PT204-6B IR Phototransistor	1 @ 0.34	100 @ 0.1315	13.15	ordering
Raspberry Pi Zero	1 @ 5.00		5.00	ordering
LTE-5228A IR LED	1 @ 0.50	100 @ 0.28	free	ordering
CD74HCT4051E 8:1 Analog Mux	1 @ 0.63	10 @ 0.536	5.36	ordering
MCP3008 ADC	1 @ 2.19	25 @ 1.82	2.19	ordering
Resistors			free	ordering
PL-8188EUS WLAN USB adapter	1 @ 5.29		5.29	ordering
NEMA power plug			free	ordering
2x20-pin Strip Dual Male Header	1 @ 0.95		0.95	ordering
USB to OTG	1 @ 0.95		0.95	ordering
Wire			free	ordering
4G microSD			free	ordering
P6458 AC/DC Transformer			free	ordering
LM2679 Buck Converter	1 @ 5.96	10 @ 5.355	11.92	ordering
LT1084 Linear Regulator	1 @ 1.90	25 @ 1.75	1.90	ordering
Tile				ordering
Straws				ordering
MBR1045			free	ordering
Black Plastidip	1 @ 6.00		6.00	ordering

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Table 3 – continued from previous page

Part	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)	Status
Total			**52.71**	

6.1.3 Grand Total

Table 4: Project Total

Labor Cost ($)	Parts Cost ($)	Grand Total ($)
42,500.00	52.71	42,552.71

6.2 Schedule

Table 5: Schedule

Week	William	Armando
09/18/2016	Simulate movement through a grid using python.	Draft AC/DC, DC/DC power conversion and ADC circuits.
09/25/2016	Design IR Sensor Cell, surrounding circuit, and muxing	Design FSM for Control Unit
10/02/2016	Write machine learning algorithm	Build Sensor Cell prototype
10/09/2016	Prototype array	Program control module with FSM, interact with WiFi chip
10/16/2016	PCB layout	Continue prototyping sensor module
10/23/2016	Write code for central server stitching	Assemble first array with power module
10/30/2016	Assemble second array with power module	Revise PCB layout if needed
11/06/2016	Testing and Debugging	Testing and Debugging
11/13/2016	Testing and Debugging	Testing and Debugging
11/20/2016	Thanksgiving Break / Testing and Debugging	Thanksgiving Break / Testing and Debugging
11/27/2016	Demo	Demo
12/04/2016	Presentation	Presentation

7 References

1. "PT204-6B." Everlight Electronics Co Ltd. N.p., n.d. Web. 04 Oct. 2016.

2. "Human Head." Wikipedia. Wikimedia Foundation, n.d. Web. 04 Oct. 2016.

3. "What Is the Average Human Running Speed?" Reference. N.p., n.d. Web. 04 Oct. 2016.

4. "IEEE IEEE Code of Ethics." IEEE. N.p., n.d. Web. 04 Oct. 2016.

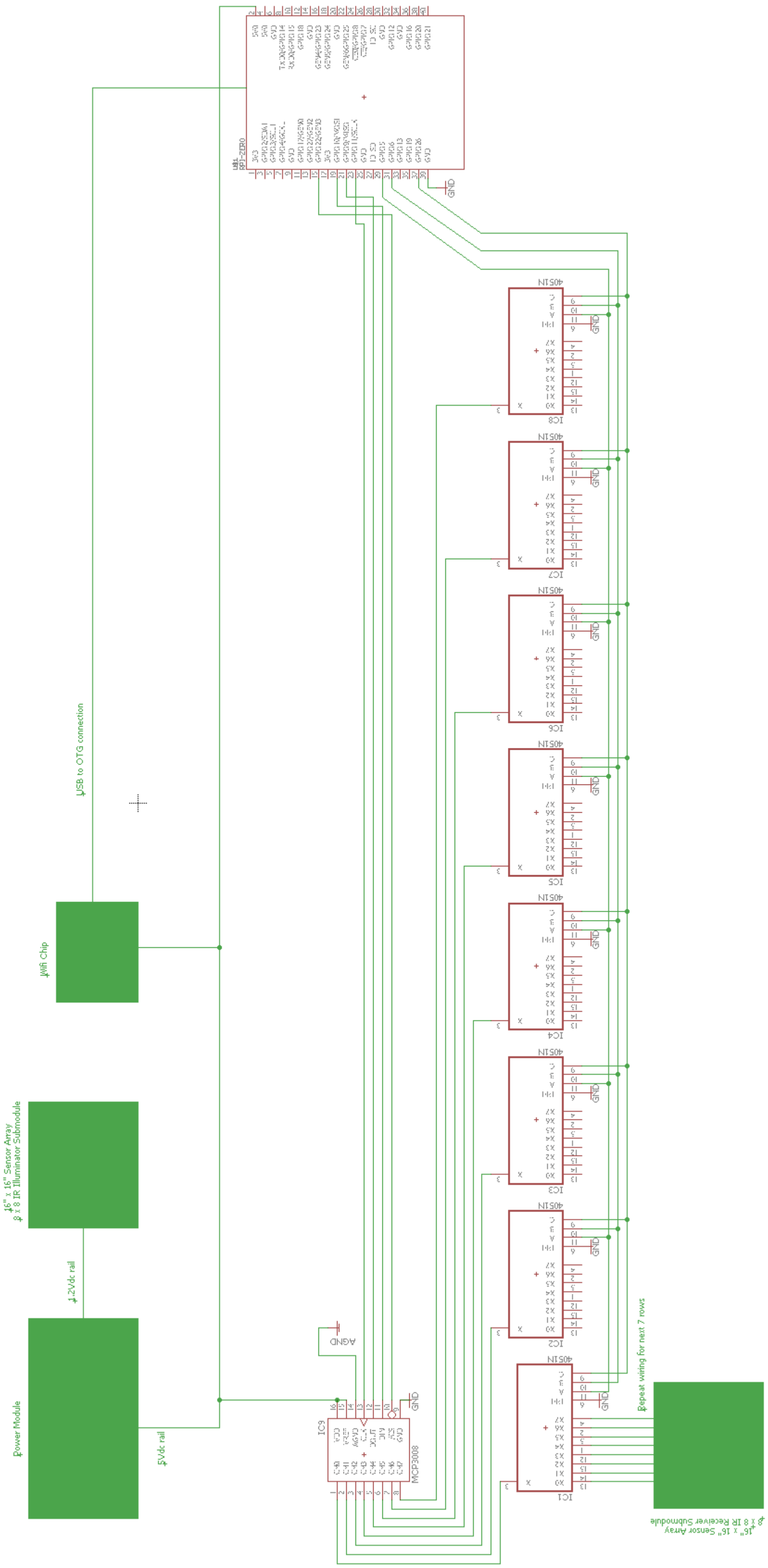

Figure 13: Overall Schematic