PowerOff: Leveraging IoT using an Arduino and ESP wifi module based dual tripwire to reduce electricity wastage and environmental pollution

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Abstract:

Scientists recently reported that 2015 was the hottest year for Earth in the historical record by far, breaking a mark set only the year before. 67% of electricity generated in the United States relies on fossil fuels and is a large contributor of CO2 emissions. Thus, there is an urgent need for more efficient use of electricity that is being generated.

I set a goal of building a device that will automatically turn lights and other powered devices off when a room is empty, and be implementable in every room in every building. This can only happen if the device is cheap, accurate, safe, small, easily installable, and be low maintenance. The impact can be amplified by leveraging the Internet of Things by allowing the devices to communicate with each other and the internet, so that it can be operated from anywhere in the world.

My solution is a functional device that I have prototyped, called PowerOff, which accurately tracks the number of people in a room by monitoring its entrances. This small device includes infrared waves projected on two infrared sensors. Unlike a motion sensor, the data from the two sensors in PowerOff are outputted to an Arduino microcontroller which monitors the people count in a room by using my innovative dual tripwire method. The Arduino then communicates with a relay which controls the state of the light bulb (on or off), as well as other devices and the internet.

Data collected using my device at a local school supported my hypothesis stating that the restrooms were vacant during a large portion of the day, although the lights were on during these periods. The device was also tested at a University and the fitting rooms of a major retail chain. Analysis of this data shows that my device has a potential to save billions of dollars per year in wasted electricity spending if it is implemented in numerous locations including homes, schools, restrooms, offices, retail stores, etc., and would lower the environmental impact of wasted power consumption.

keywords: Sustainability and environment, electricity wastage, electric circuits, Arduino micro-controllers, Internet of Things

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1. *Introduction:*

1.1 Motivation: Can you imagine a world without light bulbs, the modern computer, or other appliances? Electricity which powers modern devices and is cheap and reliable is fundamental to modern life. The invention of the light bulb in 1879 by Thomas Edison drastically changed the world, allowing people to have a reliable bright light source during the night time unlike candle light. Large amounts of electricity was needed when people started using the light bulb, resulting in the dawn of the coal fired power plant. The power plant was designed to burn coal to create electricity because coal was relatively cheap and abundant. Once the importance and demand for electricity was established, a vast array of appliances were created relying on electricity for its main power source. In September 1882, Edison opened the United States' first central power plant in lower Manhattan, called the Pearl Street Station. The demonstration of a working and feasible power plant generating electricity for local areas, unlike the time where every building had a small generator, enticed the consumer, generating demand for the power plant. Within decades other inventors created inventions helping advocate the widespread use for electricity. One such inventor, named Samuel Insull, used high-voltage transmission lines to spread electricity to the suburbs and then to the countryside. Other inventors created larger and more efficient generators, bringing the price of a kilowatt-hour down. Within three decades the price of electricity of a kilowatt-hour was merely quarter of the original value (Figure 1.1)[1]. Due to cheap and abundant availability of electricity the use of electricity has exploded over the last century. In 2012, the International Energy Agency (IEA) estimated that the world electricity generation was 22,668 terawatt-hour (TWh) of which 67% was from fossil fuels[2].

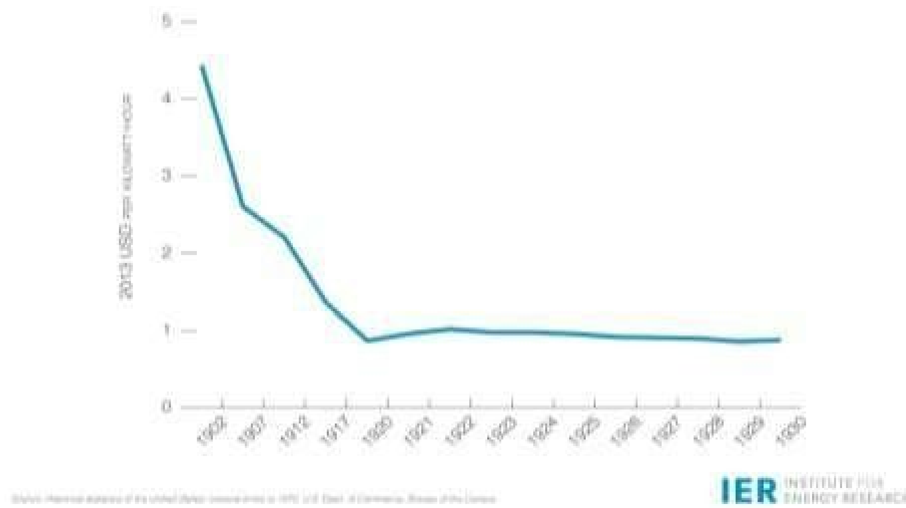


Figure 1.1: *Average Price for Electricity Energy, 1902-1930 (In Real 2013 US Dollars)*[1]

During the dawn of era of electricity, the increased demand for electricity had a small impact on the environment as few power plants existed. Today, with such a populous planet using electricity which is the largest source of carbon dioxide emissions, the United States alone produces 2,043 million metric tons of Carbon dioxide solely due to coal fired power plants[3]. In 1750, before the steam engine and coal fired power plant were created, there were 250 parts per million of carbon dioxide in the atmosphere. Today there are 400 parts per million of carbon dioxide in the atmosphere. Currently scientists estimate that the planet is warming at the astronomical rate which is 10,000 times faster than ever in history[4]. If we want to slow down the rate at which our planet is heating, we must become more efficient in our consumption of electricity.

Humans have been using switches for controlling lights, and other power sources, for a century. When people leave their rooms, they often forget to turn off these switches resulting in the wastage of unimaginable amount of electricity. There is a need for a new cheap technology that counts the number of people in a room and automatically turns off lights and other powered devices when a room is vacant, allowing us to become more efficient with our electricity consumption.

Given the large amounts of electricity wastage due to lights and other powered devices remaining ON while a room is vacant, I set the goal of building a device that accurately counts the number of people in a room in real-time by monitoring its entrance and, thus, can turn lights/devices on/off as desired.

1.2 Hypotheses

While working on another science project long after school had ended, I observed that lights in our school restrooms are ON throughout the day even while the restrooms are vacant including after school hours. At my home, lights and other powered devices remain ON while no one is in a room, as we often forget to turn off lights/devices[5]. School teachers often consider using the restroom during class hours a large disruption and heavily discourage the action, thus students tend to use the restrooms during a five minute time period between class periods. Classes in United States middle and high schools are 50 minutes long with 5 minute change over periods. This means a large fraction of the day will most likely be vacant, thus wasting electricity while the light are on. During this large portion of the school day when the restrooms are vacant, the lights can be automatically turned off to save electricity. Hence, I wanted to test two hypotheses at my school:

Hypothesis 1: School restrooms will be primarily used during the five minute delay between periods, making the restrooms vacant for a large portion of the day.

Hypothesis 2: The resulting wastage of electricity can be avoided by automatically switching off lights when the room is empty.

Hypothesis 3: The first two hypothesis also naturally extend to the wastage of electricity in other types of rooms such as classrooms, rooms in homes, and rooms in commercial buildings. A small amount of electricity consumption saved in each room in each building can add to large savings in electricity consumption

1.3 Research:

Prior to developing a solution, I conducted extensive research to fully understand all the current solutions to this problem to also understand the impact of electricity wastage in buildings in the United States. While reading the report by the US Energy Information Administration[6], I was surprised to find that, although renewable energy generation has increased in recent years, 67% of electricity generated in the United States still relies on fossil fuels. I was even more surprised to read that this fraction is not projected to decline significantly by the year 2040 (Figure 1.2). This means that it is extremely important to increase efficiency in the usage of this electricity, so that less electricity must be produced in order to complete the same tasks.

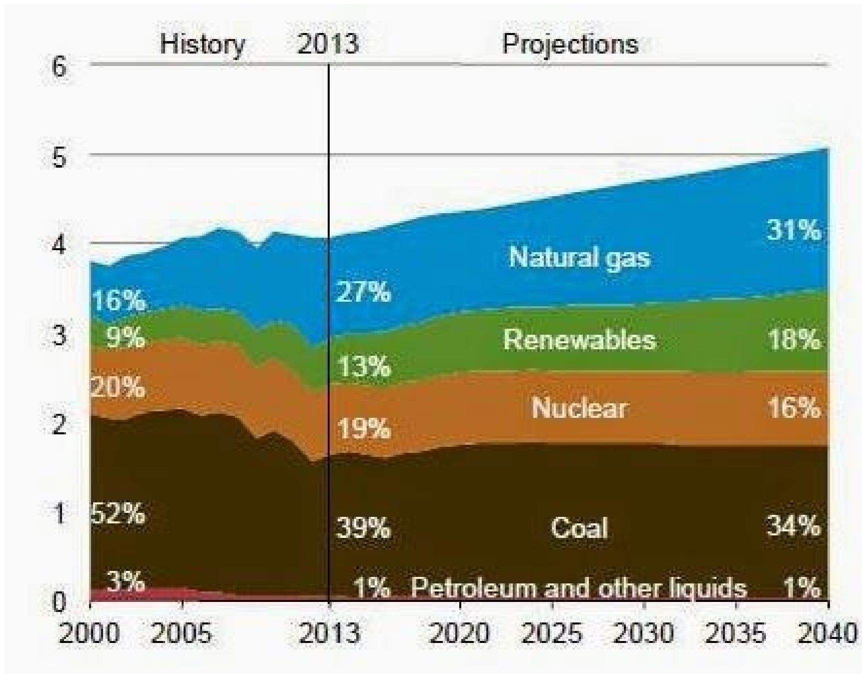


Figure 1.2: *Electricity Source Percentage vs Year*[6]

This report also mentioned that residential and commercial energy use leads to 37% of CO_2 emissions, and buildings consume 72% of all electricity that is generated. A McKinsey report[7] wrote that about 11 $GtCO_2$ emissions per year of abatement opportunities carry a net economic benefit. These opportunities largely consist of energy efficiency measures in the buildings and transport sectors. I also visited the website of the US green building council [8] where I read about their Leadership in Energy & Environmental Design (LEED) framework for green building design [9]. The LEED framework promotes sustainability by creating incentives for green buildings. These certified building save money and resources and have a positive impact on the health of occupants. To become certified, a building must reach a certain number of points, gained by completing certain tasks, such as fitting areas of a building with motion sensors. During one of my conversations with a LEED commissioning agent, he mentioned that some commercial contractors have uninstalled motion sensors from buildings due to safety issues. Due to set time intervals that lights stay on when using motion sensors, lights are often turned off while people are still in the room causing some elderly people to trip.

From this research, I concluded that it is going to take decades for electricity generation from renewable resources to be a significant source. Hence, we need to do a better job of using electricity that is primarily generated from fossil fuels. By improving the efficiency of our buildings and cutting electricity consumption, we can significantly reduce CO_2 and other greenhouse gas emissions.

1.4 Current Solutions:

I then researched all current technologies designed to solve the current problem: 1) motion detector, 2) the visible light camera, and 3) the thermal camera.

The motion detector[10] is comprised of a receiver and an emitter, both usually side by side. The emitter broadcasts a low power infrared wave, while the receiver monitors the intensity of waves being reflected by objects. As an object gets closer to the emitter and receiver, the intensity of waves being reflected back to the receiver increases. The receiver can detect motion by monitoring the values of the intensity of waves. Motion Sensors are ineffective in counting traffic due to the fact that they are able to detect motion but not the direction of a moving person, meaning that it cannot detect the number of people in a room. Current motion sensors attempt to compensate for errors by guessing the amount of time the person will be in a room (e.g. restrooms). In the application of toggling lights in a room with a motion sensor, the installation could have undesirable consequences due to the fact that is very likely that the device would turn the lights off while the person is still in the room. Thus, a key drawback of motion sensors is that it cannot turn lights on/off based on the count of number of people in a room. Also, motion sensors cost $50 to hundreds of dollars. As a result, they are currently not installed in every room in every building. A ubiquitous solution needs a device that is cheap.

The second method, the visible light camera[11], is able to count traffic by looking at differences in pixels in the background and a person. The difference in pixel colors, the location in which these differences are found, along with the direction in which these differences are moving from each frame the camera takes, allows the camera to monitor traffic. Visible light cameras are ineffective due to fact that their measurements are error prone when majority of a person's body is a similar color as its background. For example, if a person were to wear white clothing and the background around the person is white, the motion sensor would have difficulty detecting a person. Visible light cameras are also expensive hindering its ability to become versatile and ubiquitous. Currently, visible light cameras are only used in high traffic business areas such as retail stores.

The third and final method for traffic counting and monitoring utilizes a thermal camera. This device is placed inside of a room in a manner so that the full room is visible with a single camera. The thermal imaging camera sees the world with colors between purple to red. All cold areas are displayed as purple while warm areas are displayed as red. This allows all humans to be displayed as bright yellow, orange, or red objects unlike the background around them which is violet or blue. The difference in pixel colors again is able to differentiate humans from the background, allowing the camera to count the number of people in a room. The thermal imaging camera is ineffective due to the fact that multiple people standing close together would be counted as one person. In crowded rooms, the device would be reviewing extremely inaccurate data. This would impair the device's ability to perform other functions dependent on the traffic count. The thermal imaging camera is also astronomically expensive hindering its ability to become versatile and ubiquitous. Hence, there is a need for a new technology that automatically counts the number of people in a room effectively and is cheap.

2. Method:

2.1 Design Criteria: Based on my research, I concluded that a successful solution must be able to track the number of people in an area in real-time by monitoring its entrance and communicate this to a relay switch to turn it on/off as desired, unlike current solutions which rely on the assumption that a person will only stay in the room for less than a set amount of time, approximately equal to five minutes, because the current solutions cannot count number people. In order for the device to have a greater impact, the device must ubiquitous. For this to happen, based on the microeconomics demand curve, the device must be low cost. In order for the device to become ubiquitous, it must be able to be implemented in all rooms. Thus, the device must be able to communicate with other devices in order to track the number of people in rooms with multiple entrances. To prove that the devices is an improvement over all current solutions, it must be accurate. The device should be significantly lower in power consumption than the lights in controls otherwise there would be marginal to no gain in implementing the device, thus the device must be low-power (<1 Watt). Finally, the device should be small (hidden in walls) in order to not be obtrusive and long lasting (> 1 yr), as frequent errors and reinstallations would be dissuasive to the consumer. I used these constraints as a checklist during the designing of possible solutions.

2.2 Innovation: The innovation in my device, PowerOff, is the use of a dual trip wire system that is a connected to an Arduino, an open source Italian microcontroller built with Atmel

Corporation electronic chips[12, 13]. PowerOff is comprised of an emitter module and a receiver. The emitter module emits beams of continuous low power infrared waves, while the receiver is comprised of two infrared receiver sensors, which the continuous waves are aimed at. The infrared receivers monitor the pattern and intensity of the incoming waves. Due to the fact that the infrared LEDs are low power, they do not pose any health or safety concerns. If an infrared receiver does not receive the IR pulse from the emitter module, it is understood that the path of the beam has been obstructed/tripped.

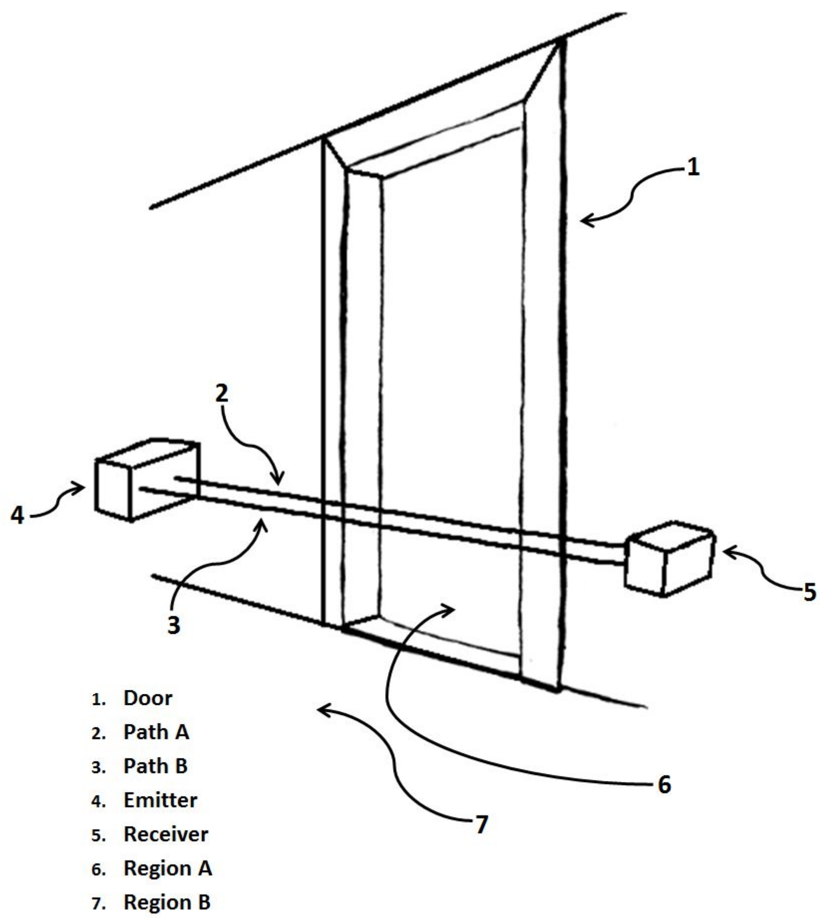


Figure 2.1 *Dual Trip Wire System Isometric Diagram*

The direction of the motion can then be deduced based on the order in which the two beams are obstructed, as illustrated in Figure 2.1 above. If path A shown in Figure 2.1 above was obstructed before path B, the person must have moved from region A to region B. If the device was keeping track of the number of people in region A, it can now deduct one person from its total count. In the event path B was obstructed before path A, the person must have moved in the opposite direction, from region A to region B, allowing the device to add one person to the total number of people in region A. Based on this new method, the device can track movement in two directions. The device communicates with a relay [14] which controls the state of the power sources (on or off). In scenarios where traffic must be tracked in closed regions with multiple entrances, a device can be installed at each entrance and the devices can communicate with each other using the inter/intranet to keep a total count of person entrances and exits. In order to utilize intra/internet capabilities, the arduino microcontroller is connected to the cheap yet powerful ESP8266 wifi IoT module. For a room with multiple entrance, the Power Off device, consisting of the emitter module and receiver module pair, will be mounted at each entrance. During installation, the user will set one of the devices as the “master” and the rest of the devices as “slaves”. If the slave devices detect changes in the number of people at the entrance that it is monitoring, it will report that change (+1 or -1) to the master in the form of a Null Response Get Request. This specific type of get request is sent by the slave to the master in the form of a link which contains the data. The master does not respond to the request, and the slave does not wait for an answer, thus it can be considered “Null Response”. When the master receives the data, it changes the data it holds by incrementing or decrementing the number of people as specified by the slave. Note that the slaves are not relayed the changes from the master, so they do not store the running count of the number of people. While the slaves monitor the entrances they are attached to, the Master also monitors the entrance that it is attached to and is able to change the people count accordingly when there is a change in the number of people at its entrance. When using the ESP module, the Master can also respond to HTTP requests sent from wifi enabled devices such as smartphones, computers, servers,etc. Upon request, the Master will retrieve all the data (number of people and timestamp) and relay the information to the device that requested it. Data can also be gathered without the ESP module by using an SD Card attached to the Arduino[15, 16]. The data from the SD Card will also contain the timestamp, number of people, and other significant details can be recorded automatically to an SD Card. A preliminary patent search showed that no such device/patent exists. In the next year, I intend to file for a patent on this technology. Figure 2.2 below is an IoT diagram that shows the connections between the wifi devices.

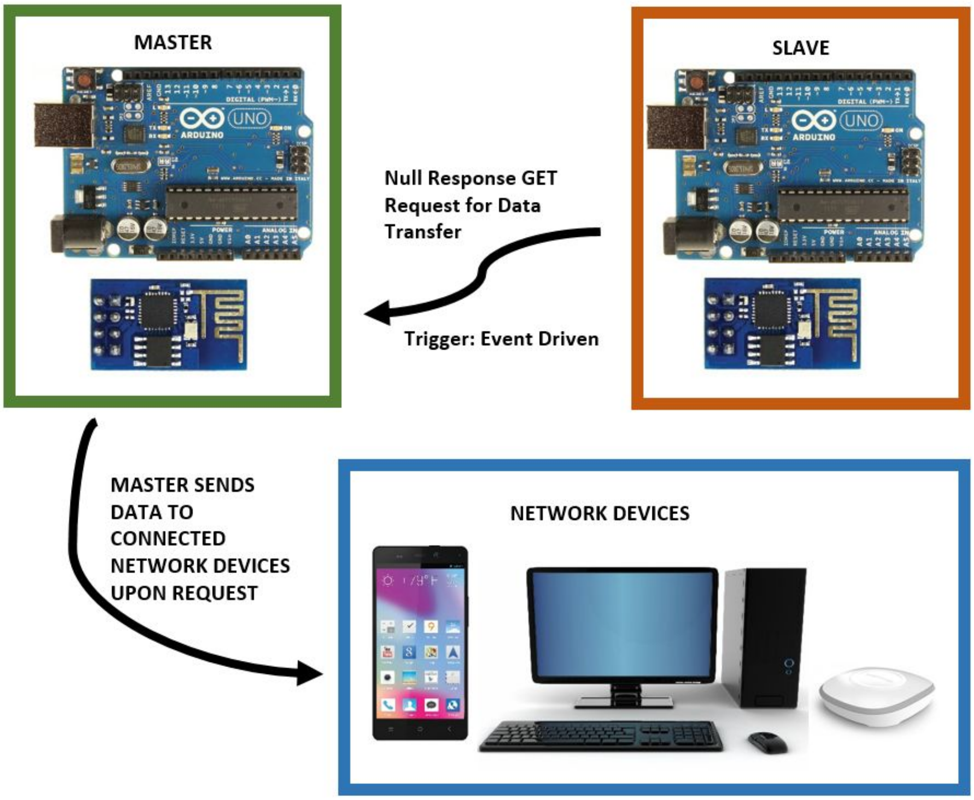


Figure 2.2: *IoT diagram*

<u>*2.3 Prototyping:Infrared technology*</u> There are some strong sources of infrared light such as the sun, which can possibly confuse the device. The solution to this problem is to have the infrared LED send a pattern that is not produced by any other naturally occurring or commonly used (e.g., TV remotes) infrared producing objects. The pattern sent by the device is a square wave, with different periods, oscillating within a half a sine wave [17]. This method has been scientifically proved to be very accurate for transferring data through infrared, and has been adopted by many companies and integrated into infrared remotes.

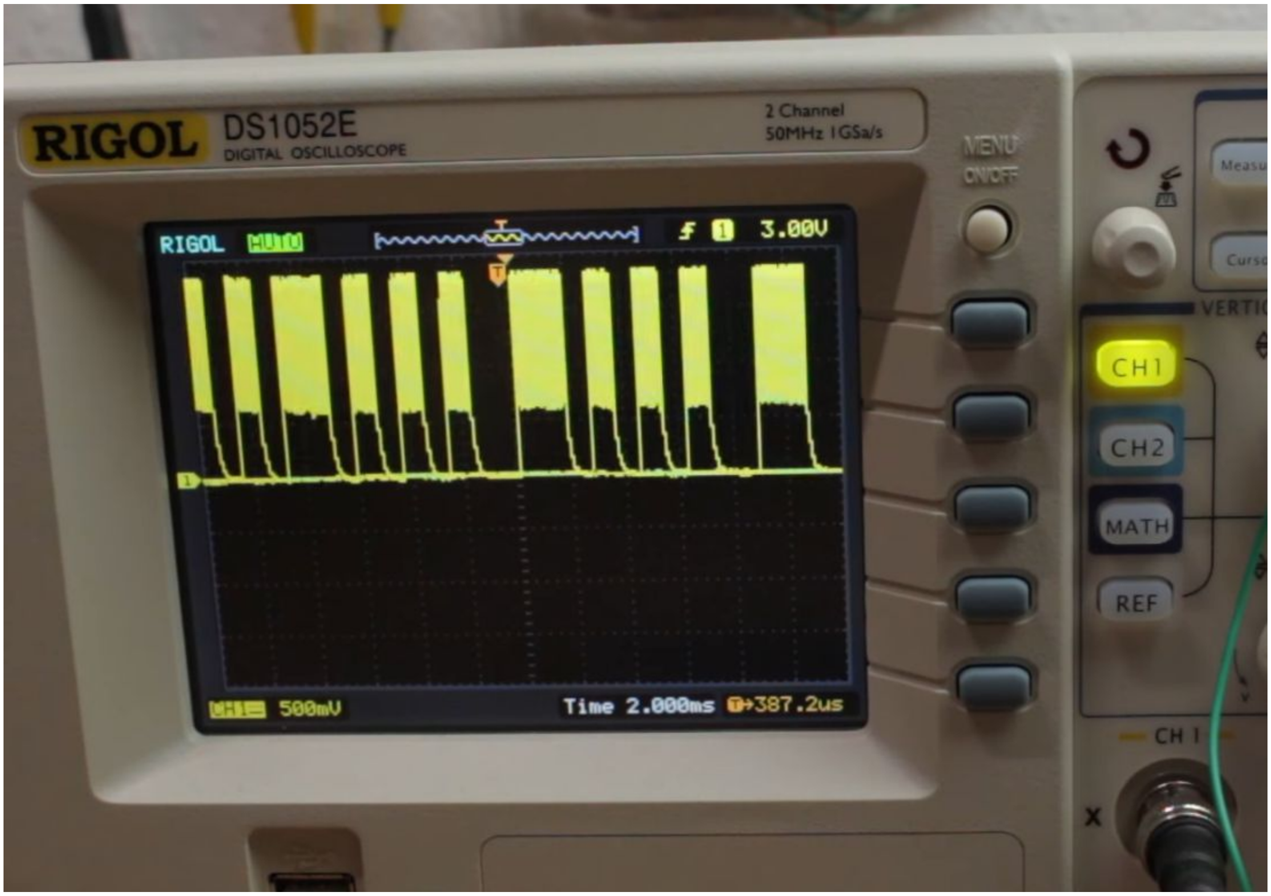


Figure 2.3: *Infrared Wave Pattern*

The picture above show the 38kHz waves for a hexcode data transmission when the x axis (time) is zoomed out. Many “packets of data” look solid yellow on the screen because of the astronomical number of oscillations within each packet of data. Clearly, this data stream is very different than any other natural infrared emitting object.

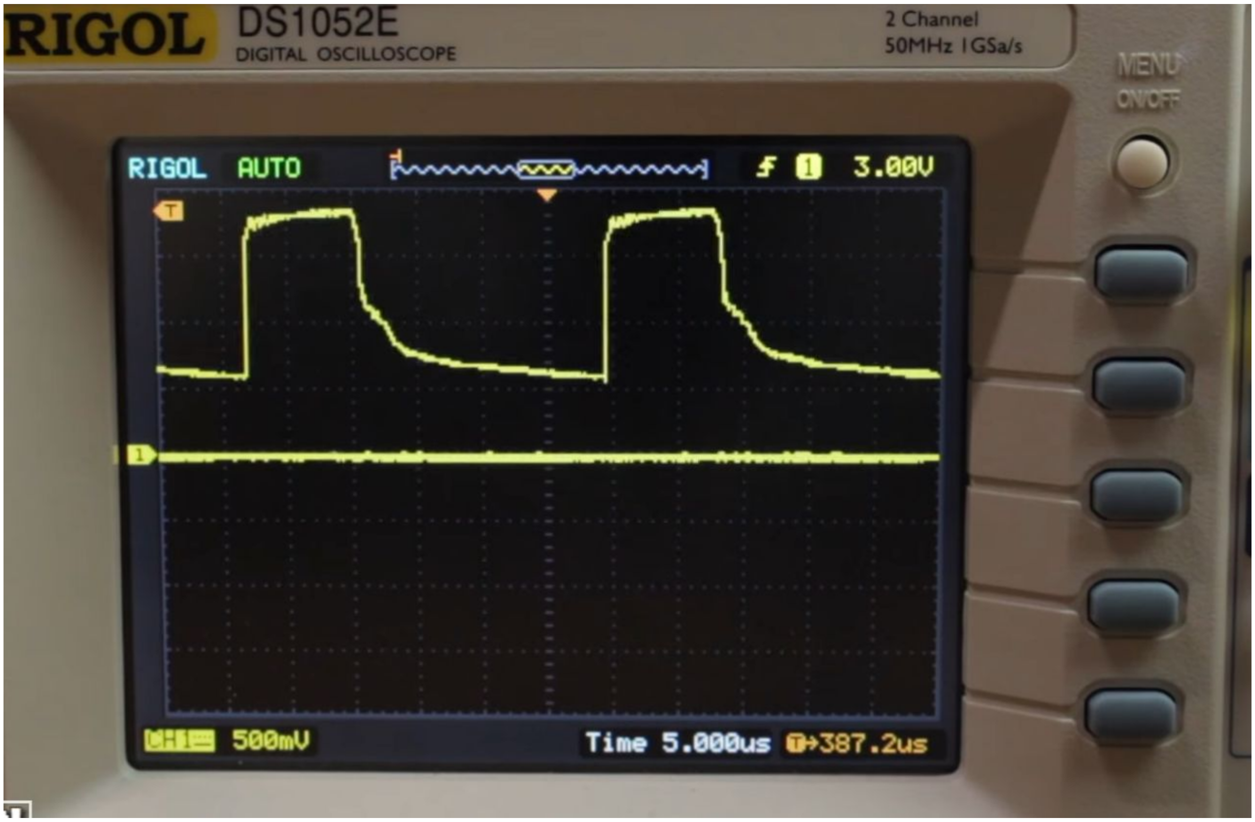


Figure 2.4: *Infrared Wave Pattern (Magnified)*

The picture above shows one squarewave within the sine wave oscillation inside of a packet of data for the same hexcode. The data sent through the infrared is determined based on the period between these square wave oscillations within each packet of data.

<u>*2.4 Prototyping: Receiver Module:*</u> Figure 2.5 below shows the Receiver module schematic. The module has an ATMEGA 328-20P[18], coded in the Arduino Software IDE, hooked up to two Vishay 4838 continuous sensing IR receivers and the ESP8266 wifi IoT module. Rather than use the arduino board, which is relatively large, an arduino standalone was created. This allowed all extra unneeded features to be removed without affecting the device.

The ATMEGA chip was hooked up to a 16MHZ clock crystal resonator, two infrared receivers (Vishay 4838), and the ESP8266 wifi modules. The pin guide of the ESP module was used to make sure the Transmit and Receive lines (TX and RX) were hooked up to the Arduino's Software Serial TX and RX lines[19].

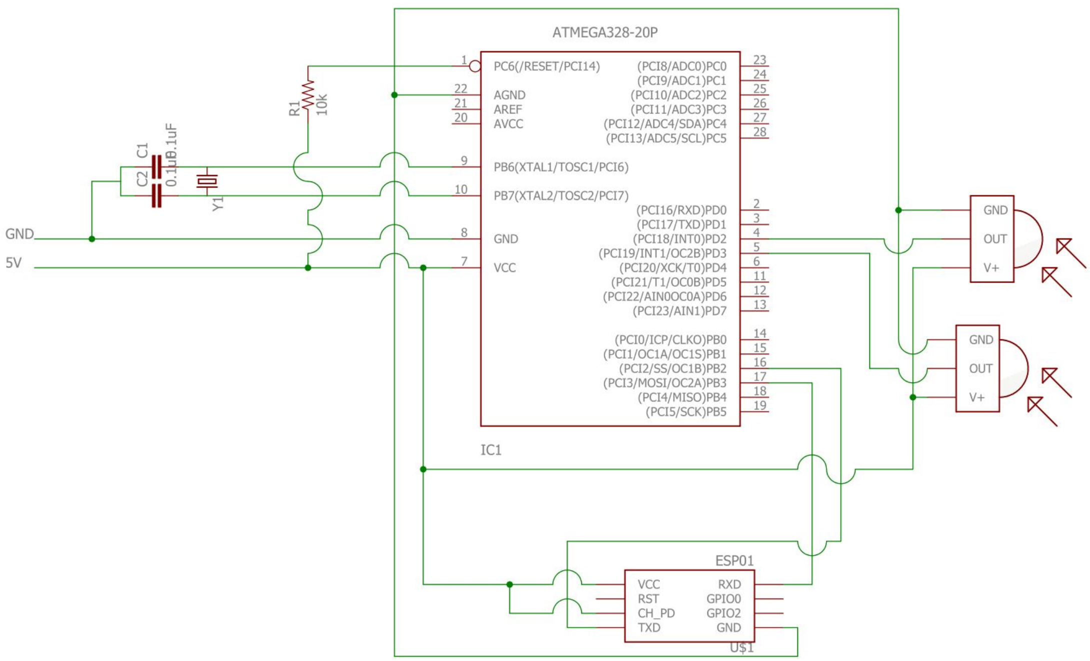


Figure 2.5: *Receiver module schematic*

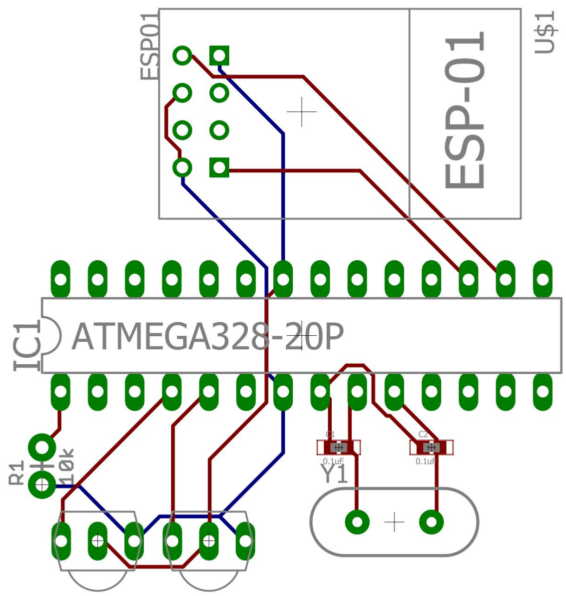


Figure 2.6: *Receiver module printed circuit board (PCB)*

The PCB design [20] above shows the same parts as in the schematic, but instead on a layout to be printed and etched onto a PCB board. The layout includes surface mount resistors and capacitors to shrink the size of the board. The size of the device can be shrunk significantly by using a PCB instead of a perf board with hand soldered wires.

<u>*2.5 Prototyping: Emitter Module:*</u> The emitter module includes an Arduino (ATMEGA 328-20P) which creates the modulated 38kHz infrared wave. Similar to the receiver module, a standalone arduino was built allowing all unneeded parts to be removed. The standalone arduino was created with the Atmel ATMEGA 328 chip, 2 capacitors, and a 16 MHZ clock crystal resonator. Because the Arduino Infrared library can only supply a small amount of current to the Infrared LED pin, an NPN transistor was used to amplify the current going through the IR LED.

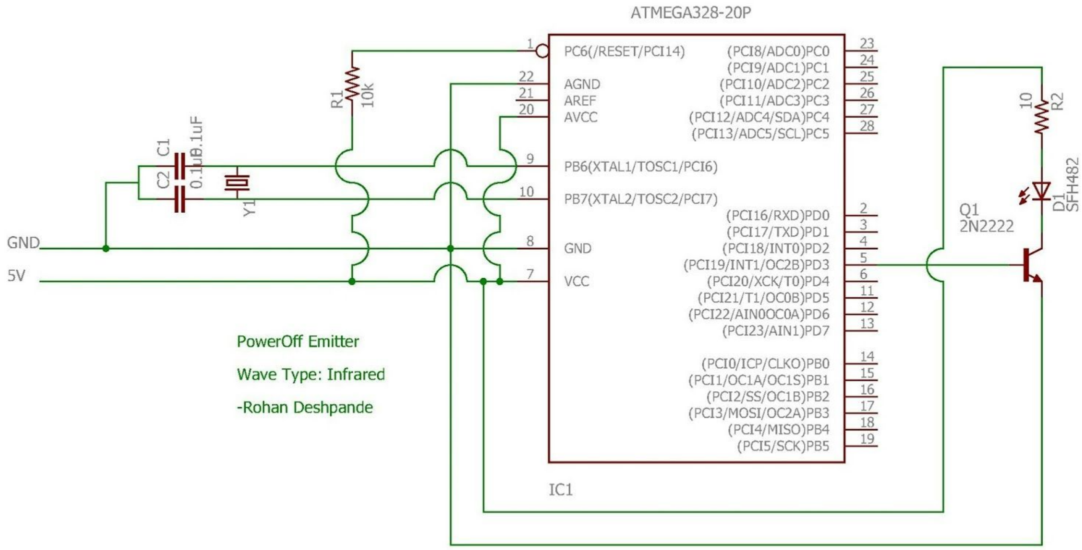


Figure 2.8: *Emitter module schematic*

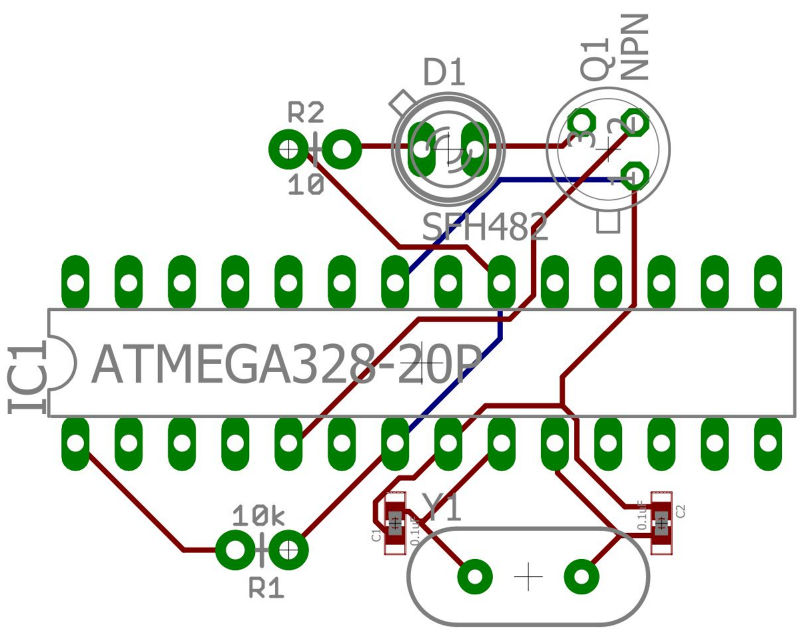


Figure 2.9: *Emitter module printed circuit board (PCB)*

The PCB design [20] above shows the same parts as in the schematic for the emitter, but instead on a layout to be printed and etched onto a PCB board. The layout includes surface mount resistors and capacitors to shrink the size of the board.

2.6 Code: I created and debugged multiple versions of arduino code before I settled on the final version. The code starts by defining a variable (ctr) that tracks the number of people in a room and initializes it to zero, as there are zero people when the device is installed. The boolean variable writenow, which is triggered HIGH after the device senses a change in the people count, is set initially to zero. The device starts the stopwatch to be able to timestamp data. At this instant the device will start a loop repeating on the order of milliseconds. The state of both IR Receivers are stored at variables stateA and stateB during the beginning of each loop. Next, if stateA=0 and stateB=1 and writenow=0, the device decrements the number of people in the room because it has determined that someone is coming out of the room. Else, if stateA=1 and stateB=0 and writenow=0, the device increments the number of people in the room because it has determined that someone is going into the room. The device waits for the person to pass both beams completely (if stateA=0 and stateB=0 and writenow=1),. When this happens the device checks whether it was initially set as a slave or a master. If it was set as a slave, the device will send a Get Request to MASTER with data (+1 for increment or -1 for decrement). If the device is a master it will check if the number of people in the room is greater than zero. If this is true, the device turns the lights on, while if it is false, the device know that there are no people in the room and turns the lights off. Also if the device is a master it will check its ESP Buffer for incoming data which was sent by the Slaves. If there is incoming data, the master will change its data accordingly. The loop cycles back to the start after this point. As a safety protocol the device turns lights back on and keeps it on until the device resets if it accidently records a negative number of people in a room (This never happened during my numerous tests). A pseudo-code of the algorithm used is provided below. A complete code loaded on the Arduino micro-controller is provided in the appendix.

Infrared Device Pseudo-Code

```
//Let the number of people in the room be called ctr
//start time
//Loop cycle begins
//Let the state values at the two IR Receivers be stored at variables stateA and stateB
//check if stateA=0 and stateB=1 and writenow=0
        // then decrement ctr and writenow=1
        // and if device is SLAVE, Change=-1
// check if stateA=1 and stateB=0 and writenow=0
        //then increment ctr and writenow=1
        // and if device is SLAVE, Change=+1
// if stateA=0, stateB=0 and writenow=1
        // if Device is SLAVE
        // then Send Get Request to MASTER with   data(+1 for increment or -1 for decrement)
```

// if Device is MASTER

//check if ctr>0

// then turn light on

// else turn light off

// writenow=0

//if Device is MASTER

//Check ESP Buffer for incoming data

// ctr= ctr+change and writenow=1

//Loop cycle ends

2.7 Building the prototype:

I bought parts for the circuits from SparkFun electronics, Radio Shack, and Lowe’s. I then assembled the Receiver and the Emitter for the device at home using my experience building circuits. The total cost of all the parts for the device was less than 20 dollars. The code was uploaded onto Arduino microcontroller to be debugged. By following the schematic (FIG X) and code (Appendix 1), one can easily reconstruct the device. Pictures of the assembled prototype that I built are shown below in Figures 2.10 and 2.11..

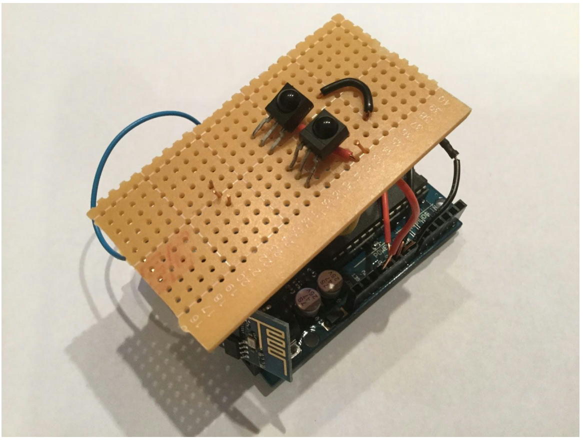


Figure 2.10: *Emitter Module*

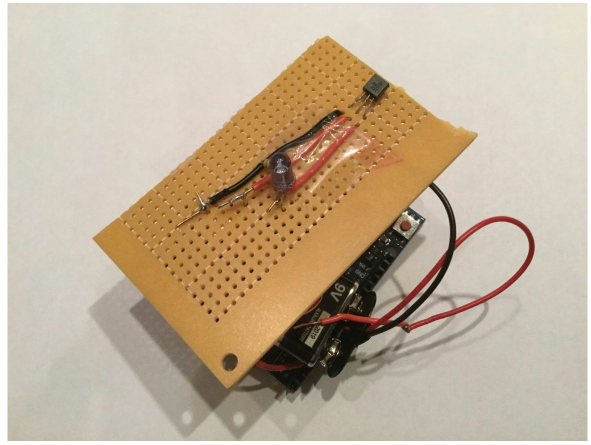


Figure 2.11: *Receiver Module*

2.8 Device Testing and Refinement: Finally, I performed extensive calibration and testing at home under different conditions and rooms. The device was installed in one of the rooms of my house and multiple people walked in different orders in and out of the room. After the device was deemed fully functional, the device was uninstalled and reinstalled into a new room which had a new ambient light level for further testing. The device was fully functional in very dim rooms, a completely dark room, a normal brightened room, and an extremely bright room. Thus, different levels of ambient light was used as a control while testing my device. Next the device was tested in areas of naturally occurring infrared light. As predicted the receiver was able to decode the unique pulses created by the emitter. Thus, the accuracy of the device was not compromised.

2.9 Implementation: Once I was convinced that the device was working properly, I installed the device outside one of the restrooms at my local school, Guy B. Phillips Middle School, to gather data on restroom usage. The device was installed at the entrance of the restroom approximately 25 minutes before school starts, a time when only teachers are inside the building. Data was collected at the same entrance for multiple days. I also tested the device at a local University restroom to gather additional data under a different environment. The device was coded so that the data was written from the device to an SD Card. The file on the SD card can be later extracted when plugged into a computer. I was thrilled that a major retail chain, who requested to stay anonymous, agreed to let me test the device to count fitting room traffic. This third trial is unique as it creates an environment which includes high frequency traffic. Finally, I tested the device multiple times in a classroom in my school. This allows one to determine the accuracy of the device when compared to a human who manually counts the traffic. Thus, I was able to test the device in four real world settings: a local school restroom(Figure 2.12), a university (Figure 2.13), a major retail chain (Figure 2.14), and a school classroom (Figure 2.15). The data obtained from these tests, which includes information such as the number of people in the room along with the corresponding time, was then analyzed to calculate the potential benefit of the device.

Testing at Local school

Testing at local University

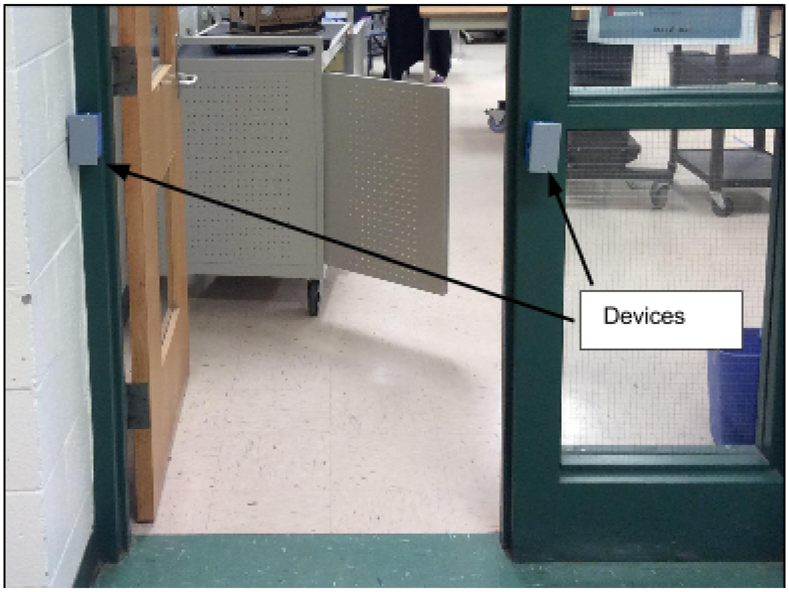
Figure 2.12

Figure 2.13

Pictures from retail chain implementation

Figure 2.14

Figure 2.15: *PowerOff Device Mounted in School Classroom:*



3. Results:

<u>*3.1 Data:*</u> I analyzed the data collected by the device from the tests that I ran at the local school, university, and a major retailer. The device provided me with time-stamped data for every entry or exit from the room. It also gave me count data on the number of people in the room over time.

A	B
0:33:02	0
0:33:02	1
0:34:40	1
0:34:40	0
0:36:50	0
0:36:50	1
0:38:25	1
0:38:25	0
1:19:44	0
1:19:44	1
1:20:25	1
1:20:25	2
1:21:13	2
1:21:13	1
1:23:00	1
1:23:00	0
1:47:30	0
1:47:30	1
1:48:46	1
1:48:46	0
2:07:48	0
2:07:48	1
2:09:00	1
2:09:00	2
2:10:05	2
2:10:05	3
2:10:53	3
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2:13:01	1
2:13:01	0
2:41:00	0

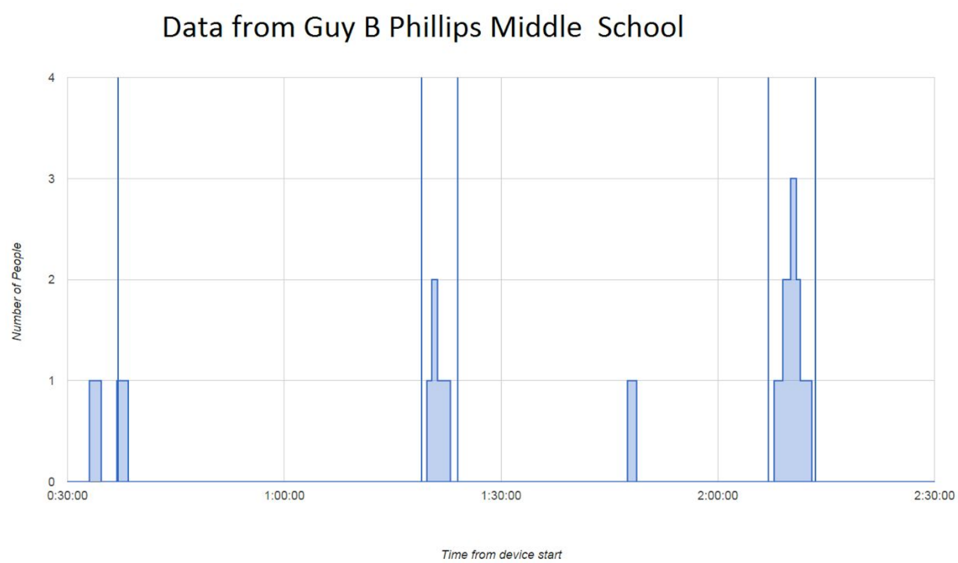

Figure 3.1: *People Count in the restroom at local school vs Time*

The above graph (Figure 3.1) reveals that, apart from a few exceptions, most restroom usage happens during class changeovers, similar to my previous prediction (Hypothesis 1). Further analysis revealed that our school restroom was empty 91% (Figure 3.4 :1) of the time while the lights were always ON. I also plotted similar graphs for the data collected from a local university and a major retail chain as shown below.

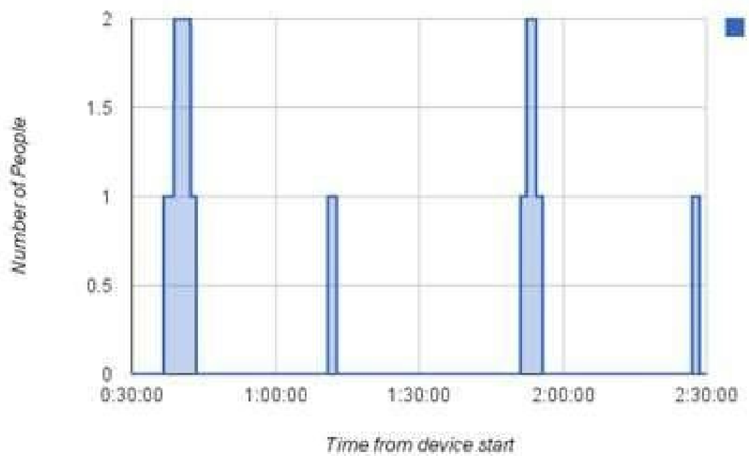

Figure 3.2: *People Count in the restroom vs Time at University*

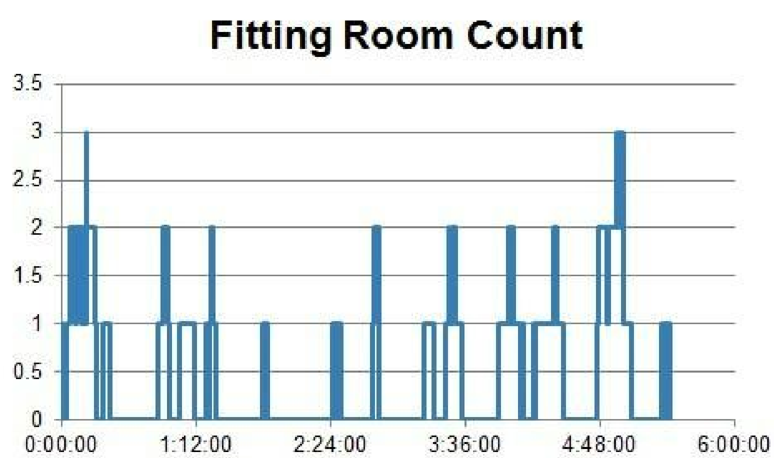

Figure 3.3: *People Count in the fitting room vs Time at Local Retail Store*

Graph, Figure 3.2, collected from the university restroom shows that, while there is no predictable pattern to when the restroom gets used, the restroom is empty 90% of the time, while the lights were always ON. Figure 3.3 shows data obtained under high traffic conditions in the fitting room of a major retail chain. This data was used to verify the accuracy of the device.

While my device was collecting the data, a research assistant manually monitored the fitting room usage (Figure 3.4). The figure shows data starting at time 14:08:10 and ending at 16:39:08. Every time the device recorded a change in the number of people in the room, the time was recorded. The assistant also recorded the time, but instead the assistant treated groups of people as one. Review showed that the missing times recorded in the human recorded category were caused due to treating each person separately. Further analysis revealed that my device was 100% accurate, and my device recorded no erroneous entry or exits.

Device	Human Recorded	Device	Human Recorded
14:08:10	14:09	15:40:41	15:40:38
14:25:13	14:25:00	15:43:38	15:43:24
14:25:17	14:28:34	15:44:53	14:45:00
14:28:46		15:45:45	14:45:53
14:28:48		15:51:20	15:51:00
14:52:42	14:53:00	15:51:58	
14:58:10	14:58:27	15:52:22	15:52:00
15:03:44	15:04:00	16:02:16	16:03:20
15:05:49	15:06:00	16:03:39	16:02:00
15:05:59		16:07:14	16:07:00
15:07:17	15:08:18	16:24:54	16:25:00
15:09:18		16:26:10	16:26:00
15:12:58	15:13:11	16:30:39	16:30:32
15:32:14	15:32:00	16:31:11	16:31:00
15:37:43	15:38:00	16:36:06	16:37:00
15:38:32		16:36:11	
15:39:18		16:37:02	
		16:39:03	16:39:08

Figure 3.4: *Device Recorded time vs Human Recorded time*

<u>*3.2 Analysis:*</u> To estimate the savings from my device, I first obtained CHCCS (Chapel Hill Carrboro City Schools) electricity cost and usage data from our school district sustainability director. My data analysis showed 91% electricity wastage from 7:30am to 7:30 pm (Figure 3.1). I observed that our school restrooms have 10 bulbs at 32 watts each. This results in a total of 320 Watts of electricity for every restroom in the school (number 2 in Figure 3.5). The data collected was from 7:30 am to 7:30 to PM, or a full 12 hour time period. Thus, the estimated wasted electricity per day is 3,494 Watt hours, every day, for each restroom in the school (number 3 in Figure 3.5).

The schools in our school district have 12 public restrooms (student and faculty), and are open 180 days (also known as one school year). There are 18 schools in our school district. Using these numbers, I estimated that our school district wasted 135,862 kiloWatt hours for every school year (number 4 in Figure 3.5). Using the cost usage data of our school district, given by our district sustainability director, I found that the cost of electricity for our school district is 8 cents/kWh. Thus, our district wastes $10,869 in annual electricity expenditure (number 5 in Figure 3.5). My device was built at a cost of less than $20/device, and if it was installed in every restroom, it will pay for itself in less than 6 months.

To find the possible impact of this new solution, I then projected the benefits of this device if it was installed in all public schools in the United States. Assuming 98,817 Public schools in the United States (source: National Center for Education Statistics), and an average electricity cost of 12 cents per kWh (source Energy Information Administration (EIA)), I calculated that my device would save $167 million annually by reducing wasted electricity consumption (Figure 3.6) across all public school restrooms in the United States. While this number is an estimate, my calculation shows that the impact of my device can be huge! To understand the impact of such as device in non-monetary terms, I entered these numbers in EPA's greenhouse gas equivalencies calculator[21]. The savings for my school district would be equivalent to 100,627 lbs of coal burned to create this electricity. The saved electricity is equivalent to saving 93.7 metric tons of carbon dioxide from being released into the atmosphere. The equivalent impact across all public school in the United States is much larger. The electricity saved is equivalent to 1,035,800,262 pounds of coal burned for the electricity or saving 964,330 metric tons of carbon dioxide from being released into the atmosphere (Figure 3.10). These numbers could be even larger if the device was installed in every home and building in the United States.

To calculate the impact of my device if it was installed in offices in the United States, data from the US Energy Information Administration was used. One of their recent reports states that office building lighting consumes approximately 80 billion kWh annually in the United States[28]. Research from many university and EPA reports document savings in office lighting with occupancy sensors to be between 15% to 75%[22](See Figure 3.7). Even though my device is more accurate that current motion sensors, I conservatively assumed that the PowerOff device saves only 15 percent in office lighting (the smallest number in the range). Data from the EIA shows that the average price for electricity for Offices in US is 10.36 cents/kWh[23]. Combining the numbers yields an annual office building savings of $1.25 billion on lighting alone in the United States. Using similar data from the same agencies (EIA and EPA) for home lighting, which consumes 150 billion kWh annually at a price of 12.48 cents/kWh and savings percent of 10% (see Figure 3.9), yields an annual residential savings of $1.8 billion on lighting[22], [23], [24]. Thus, based on data that I collected and based on data collected by EPA and Universities, I conservatively estimated that my device could potentially save billions of dollars annually in wasted electricity consumption.

To understand the environmental impact of wasted electricity consumption, I projected the impact of these savings using the EPA Greenhouse Gas Equivalencies Calculator. The projected possible impact includes savings of 20 billion pounds of coal used to create the electricity wasted. This number also translates to 18.5 million metric tons of carbon dioxide that will not be released into the atmosphere (See Figure 3.11) by saving this wastage of electricity.

$$t_U = \sum t_f - t_i$$

$$t_U = (0{:}34{:}40 - 0{:}33{:}02) + (0{:}38{:}25 - 0{:}36{:}50) + (1{:}23{:}00 - 1{:}19{:}44) + (1{:}48{:}46 - 1{:}47{:}30) + (2{:}13{:}01 - 2{:}07{:}48)$$

$$= 98s + 95s + 196s + 76s + 313s$$

$$t_U = 12.967min$$

$$p = 1 - \frac{t_U}{t_T}$$

$$t_T = (2{:}41{:}00) = 161min$$

$$p = 1 - \frac{12.967min}{161min} = 92\%$$

$$\frac{10bulb}{restroom} * \frac{32Watts}{bulb} = \frac{320Watts}{restroom}$$

$$.91 * 12hours * \frac{320Watts}{restroom} = \frac{3{,}494Watt * hours}{restroom * 1schoolday}$$

$$\frac{3{,}494Watt * hours}{restroom * 1schoolday} * \frac{kW}{1000Watts} * \frac{12restrooms}{school} * \frac{180days}{schoolyear} = \frac{135{,}862KWh}{schoolyear * school}$$

$$\frac{135{,}862KWh}{schoolyear * school} * \frac{\$0.12}{kWh} = \frac{\$10{,}862}{schoolyear * school}$$

Figure 3.5: *Calculations for Impact Analysis at CHCCS Schools*

91% electricity wastage from 7:30am to 3:30 pm
restroom have 10 bulbs at 60 watts each = 600W
Lights on for 12 hrs/day on school day = 12 hours
wasted electricity = .91 * 12 * 600 = 6552 Wh/Day/restroom
12 Public restroom /school = 6552 * 12 = 78624 Wh/Day/School
180 school days/ year = 78624*180 = 14152320 Wh/School Year/School
1000W = 1 KW = 14152.32 KWh/School Year/ School

At 14152.32 kWh wasted during the School Year by **One School**
98,817 **Public schools in the United States** (source: National Center for Education Statistics)
= 1398489805 **kWh/School Year/ US** Schools
= $167,818,776.70 wasted spending

Figure 3.6: *Calculations for nationwide impact by reducing electricity wastage in restrooms in public schools*

Space type	CEC	Esource	EPRI	Novitas	Watt Stopper
Private office	25-50	13-50	30	40-55	15-70
Open office	20-25	20-28	15	30-35	5-25
Classroom	-	40-46	20-35	30-40	10-75
Conference	45-65	22-65	35	45-65	20-65
Restroom	30-75	30-90	40	45-65	30-75
Warehouses	50-75	-	55	70-90	50-75
Storage	45-65	45-80	-	-	45-65

Fig 3.7: *Industry estimates of potential energy savings from occupancy sensors (in %)*[22]

Impact calculations for all homes in USA

Estimated U.S. residential electricity consumption for lighting in USA was 150 billion kWh in 2014 (Source: Energy Information Administration).

Of this amount 10-75% is wasted depending on home and usage (Source: US EPA and RPI report, IES Paper #43).

A conservative estimate is that my device would save 10% of this consumption = 15 billion kWh

The average residential price of electricity is 12.48 cents/kWh

This is equivalent of saving $1.872 billion dollars by avoiding electricity wastage from all homes in the US

Figure 3.8: *Calculations for nationwide impact by reducing electricity wastage in homes*

Impact calculations for all offices in USA

Estimated U.S. office building electricity consumption for lighting in USA was 275 billion BTU which is equivalent to 80 billion kWh in 2014 (Source: Energy Information Administration).

Of this amount 15-75% is wasted depending on office type and usage (Source: US EPA and RPI report, IES Paper #43).

A conservative estimate is that my device would save 15% of this consumption = 12 billion kWh

The average commercial building price of electricity is 10.36 cents/kWh

This is equivalent of saving $1.25 billion dollars by avoiding electricity wastage from all homes in the US

Figure 3.9: *Calculations for nationwide impact by reducing electricity wastage in offices*

Calculated using "Greenhouse Gas Equivalencies Calculator." *EPA*. Environmental Protection Agency, n.d. Web. 24 Feb. 2015.

Figure 3.10: *Projected Impact across schools in US*

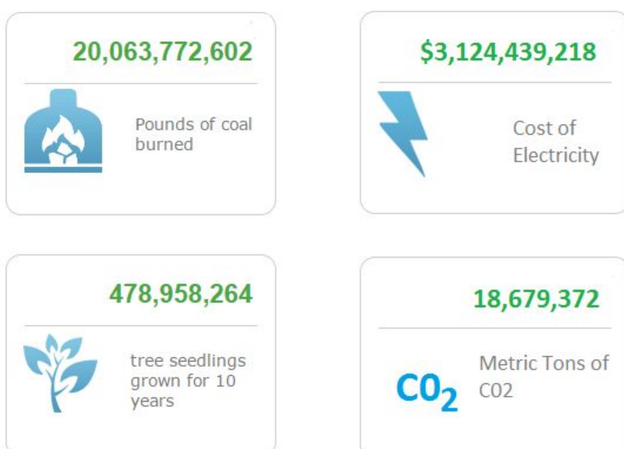

Figure 3.11: *Projected Impact across all Homes and Offices in the US*

Calculated using “Greenhouse Gas Equivalencies Calculator”, EPA.

4. Discussion:

<u>*4.1 Summary:*</u> In this project, I invented a novel device using an Arduino microcontroller, and a low-power dual infrared tripwire system with an ESP8266 wifi module, to count the number of people in a room with single or multiple entrances by monitoring its entrance and communicate this to a relay switch to turn lights/devices on/off as desired. I built this device from parts obtained locally for less than $20, and tested it extensively at home. I then deployed this device at a local school restroom, a school classroom, a University, and a major retail chain. Analysis of data collected from these experiments show that my device may have a huge impact, both economically and on the environment. My data showed that our school restrooms were empty 91% of the time, while the lights were always on. This data provides support for my first hypothesis that school restrooms are empty for a large portion of the day. My calculations also showed that our school district can potentially save ten thousand dollars annually if my device was installed at all school restrooms. If installed at all restrooms in all public schools in US, my device can potentially save $167 million annually from reducing wasted electricity consumption. Analysis from EPA equivalencies calculator shows that this is equivalent to reducing one billion pounds of coal burned, thus reducing CO_2 emissions by one million metric tons. Across all homes and offices in the US, the projected possible impact includes more than 3 billion dollars in wasted electricity spending and savings of 20 billion pounds of coal used to create this wasted electricity. This number also translates to 18.5 million metric tons of carbon dioxide that will not

be released into the atmosphere. Thus, my analysis provides support for my second and third hypotheses that the savings from installing a device that automatically switches off lights when the room is empty can be significant.

4.2 Device Feasibility: To understand implementation issues and feasibility of my device, I presented results of my project to the Sustainability director of CHCCS Schools. I also received feedback from a LEED commissioning agent who installs motion sensors in commercial buildings. Finally, the retail chain fitting-room experiment provided further feedback. I have concluded that, for my device to be feasible, the device needs to be hidden in a wall so that it can be invisible. Also, it should require minimal rewiring and needs to connect to existing wiring. A preliminary PCB layout was created to show significant size reductions to the device (Appendix E). One of the problems that could arise with other types of devices which consist of emitter and receiver modules is that both modules could lose alignment easily. Because the PowerOff device uses low power infrared waves, which emits a small cone rather than a concentrated beam, the two modules will not lose alignment. Thus, maintenance checks do not need to be performed frequently, allowing the device to be implemented more ubiquitously.

4.3 Other Applications: My device has many other potential applications. As demonstrated by my experiment at a major retail chain, my device can be used as a real-time traffic counter in fitting rooms and other areas in retail stores. This data can be used by the retailer for staffing the fitting rooms in order to provide customer service. Another application for my device would be using it as a security device. The device could not only raise alarm when there is an intruder, it can also provide additional information like where the intruder is located by using the people count information in every room made available by my device. My device can be installed in Smart automated homes / Green buildings to reduce the environmental impact of wasted electricity consumption, and, thus, can potentially be used to earn credits for LEED certification of buildings. It can also be used in elderly homes/hospitals for fall detection in bathrooms by monitoring restroom usage and sending signals about abnormal usage. It can also be used in schools to monitor abnormal restroom usage while classes are on, by making restroom usage data available over the intranet on a real-time basis to school administrators.

I fully intend to pursue commercialization of my innovative device. A preliminary patent search showed that no such device/patent exists. In the next year, I intend to file for a patent on this technology. I am excited that a simple device that I invented has the potential to have such a large impact in reducing electricity costs, as well as helping the environment by reducing pollution caused by unneeded electricity generation.

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5. Acknowledgements:

Thanks to Anagha Kalvade for being parent supervisor/ mentor and providing financial support for the project. I also thank Guy B. Phillips middle school principal and vice principal for approval of installation and testing the device at the school. Thanks also to UNC Kenan Flagler business school for approving the testing of the device in their facility, allowing for the collection of data at the University. Finally, a big thank you to an anonymous large domestic

retail store chain for approval of testing the device, allowing for high traffic testing of the device to measure its accuracy.

—

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7. Appendices:

Appendix A: Emitter and Receiver module Code

Full Arduino Uno Code (Infrared Receiver):

```
#include <SoftwareSerial.h>
#include <Time.h>

#define DEBUG true

SoftwareSerial esp8266(10,11); // make RX Arduino line is pin 10,
make TX Arduino line is pin 11.


#include <IRremote.h>

#define PIN_DETECTA 2
#define PIN_DETECTB 3

#define interuptpinA 0
#define interuptpinB 1

int transactions[200];  //empty array that will store ctr and time
int trannum=0;  //current array element id
String time="";
String webpage="";

boolean stateA;
boolean stateB;
int ctr=0;  //number of people
int writenow=0; //1= stop changing ctr and write data

int se = 0; //seconds
int mi=0; //minutes
int ho = 0; //hours

String hubid="";  //Each device has a unique id. At the beginning the
Device id is the same as hubid
```

```
int devstate=0;//1 is master, 2 is slave
String devid="PowerOffA9DH";

int changeM;  //integer change Master receives
String changeS; //String change Slave sends


void setup()
{
  Serial.begin(9600);
  esp8266.begin(9600); // your esp's baud rate might be different
  sendData("AT+RST\r\n",2000,DEBUG);// Reset Module
  sendData("AT+CWMODE=3\r\n",1000,DEBUG);   //set as acess point
  sendData("AT+CIPMUX=1\r\n",1000,DEBUG);
  sendData("AT+CIPSERVER=1,80\r\n",1000,DEBUG);
  sendData("AT+CIFSR\r\n",1000,DEBUG);
  Serial.println("Server Ready\r\n");
  while(esp8266.available()==0)
  {
    delay(100);
  }
 if(esp8266.available()){
  if(esp8266.find("+IPD,"))
    {
     delay(1000);
     esp8266.find("?devid=");
     for(int i=0; i<12;i++){
     hubid+=(char)esp8266.read();  //read the device id
    }
  while(esp8266.available())
    {
     esp8266.read();
    }
  delay(500);
  sendData("AT+CIPCLOSE=0\r\n", 1000, DEBUG);  //close connection
    }
  }
    if(hubid.equals(devid)==0){// if the hubid is not the same as the
device id, the device is a slave
      devstate=2;
      sendData("AT+RST\r\n",2000,DEBUG);
      sendData("AT+CWMODE=1\r\n",1000,DEBUG);
```

```
      String connectssid="AT+CWJAP=\"";
      connectssid+=hubid;
      connectssid+="\",\"password\"\r\n";
      sendData(connectssid,10000,DEBUG);  //connect to the hub
    }
    if(hubid.equals(devid)==1){//if the device id and hub are the
same, the device is the master
      devstate=1;
      Serial.println("You are the Hub");
    }
  delay(5000);
  attachInterrupt(interuptpinA, changeIR, RISING);
  attachInterrupt(interuptpinB, changeIR, RISING);
}


void changeIR(){// triggered on rising intterupt (either pins go 0 to
1)
  noInterrupts();
  stateA = digitalRead(PIN_DETECTA);
  stateB = digitalRead(PIN_DETECTB);
  if(stateA==1 && stateB ==0 && writenow==0){// when A is tripped and
B is not add 1
    ctr+=1;
    writenow=1;
    changeS="1";
  }
  if(stateA==0 && stateB ==1 && writenow==0){// when B is tripped and
A is not, subtract 1
    ctr-=1;
    writenow=1;
    changeS="-1";
  }
}



void loop()
{
  int ho = hour();  //set the hour, minute, and seconds
  int mi = minute();
  int se = second();
```

```
  stateA = digitalRead(PIN_DETECTA);// check the current states
  stateB = digitalRead(PIN_DETECTB);
  if(stateA==0 && stateB==0 && writenow==1){  //person has walked
through, time to write the data
    Serial.print(stateA);
    Serial.print(", ");
    Serial.print(stateB);
    Serial.print(", ");
    Serial.println(ctr);
    transactions[trannum]=ctr;
    trannum+=1;
    transactions[trannum]= ho;
    trannum+=1;
    transactions[trannum]= mi;
    trannum+=1;
    transactions[trannum]= se;
    trannum+=1;
    writenow=0;
    if(devstate==2){
        String CIPSTART="AT+CIPSTART=\"TCP\",\"192.168.4.1\",80\r\n";
        sendData(CIPSTART,1000,DEBUG);
        String GetReq="GET http://192.168.4.1/?change=";
        GetReq+=changeS;
        GetReq+=" HTTP/1.0";
        int GetLen= GetReq.length();
        String CIPSEND="AT+CIPSEND=";
        CIPSEND+=GetLen;
        CIPSEND+="\r\n";
        sendData(CIPSEND,1000,DEBUG);
        delay(500);
        sendData(GetReq,1000,DEBUG);
        delay(2000);
        changeS="";
     }
  delay(750);
  interrupts();
  }
  if(devstate==1){
  if(esp8266.available()) // check if the esp is sending a message
  {
    if(esp8266.find("+IPD,"))
    {
```

```
    delay(1000);

    int connectionId = esp8266.read()-48; // subtract 48 because the
read() function returns
                                          // the ASCII decimal value
and 0 (the first decimal number) starts at 48
    if(esp8266.find("?change=")){// if esp finds "?change==", it has
received a get request. Else it must serve the webpage
        String changestr;
        int stopread=0;
        while(esp8266.available())
        {
         String addletter;
         addletter=(String)esp8266.read();
         if(addletter==" ")//adding letters one at a time. if the
added char is not a space, append to string. Else, end reading
process.
         {
           esp8266.find("HTTP/1.0");//find the end
         }
         else{
           changestr+=addletter;
         }
        }
        changeM=changestr.toInt();
        ctr+=changeM;  //change the running count
    }
     else{     //serve the webpage
    webpage="";
    for(int i=0; i< trannum;){//print out the data in format ctr,
hour:second:minute
      webpage+="<p>";
      webpage+= transactions[i];
      webpage+=", ";
      i++;
      webpage+= transactions[i];
      webpage+= String(":");
      i++;
      webpage+= transactions[i];
      webpage+= String(":");
      i++;
      webpage+= transactions[i];
```

```
        i++;
        webpage+= "</p>";
      }
      String cipSend = "AT+CIPSEND=";
      cipSend += connectionId;
      cipSend += ",";
      cipSend +=webpage.length();
      cipSend +="\r\n";

      sendData(cipSend,1000,DEBUG);   //send data size
      sendData(webpage,1000,DEBUG);   //send data

      String closeCommand = "AT+CIPCLOSE=";
      closeCommand+=connectionId; // append connection id
      closeCommand+="\r\n";

      sendData(closeCommand,3000,DEBUG); //close connection
     }
     }
   }
   }
}

//function for sending data to ESP
String sendData(String command, const int timeout, boolean debug)//
method for sending data to ESP
{
    String response = "";

    esp8266.print(command); // send the read character to the esp8266

    long int time = millis();

    while( (time+timeout) > millis())
    {
      while(esp8266.available())
      {

        // The esp has data so display its output to the serial
window
        char c = esp8266.read(); // read the next character.
        response+=c;
```

```
      }
    }

    if(debug)
    {
      Serial.print(response);
    }

    return response;
}
```

Full Arduino Uno Code (Infrared Emitter):

```
#include <IRremote.h>

#define PIN_IR 3

IRsend irsend;
void setup()
{
  irsend.enableIROut(38); //create 38kHz IR signal
  irsend.mark(0);
}

void loop() {
}
```

Appendix B ***Project Parts List (Infrared):***

Part Name	**Quantity**	**Cost ($)**
Relay SPDT Sealed	1	1.95
Infrared Receivers (38kHz)	2	2
Arduino Clone (Uno and Pro Mini)	2	5.8
Resistor 330 Ohm 1/6th Watt PTH	2	0.5
Infrared LED	1	1
9V Battery	1	1.25
CARLON 1-Gang Blue Plastic Interior New Work Standard Switch/Outlet Wall Electrical Box	2	2.4
CARLON 1-Gang Rectangle Plastic Electrical Box Cover	2	1.2
ESP 8266 Wifi Module	1	3.1

Total Cost: $19.20

Appendix C ***Device Installation Pictures***

Device is not visible when entering the room at local retail store

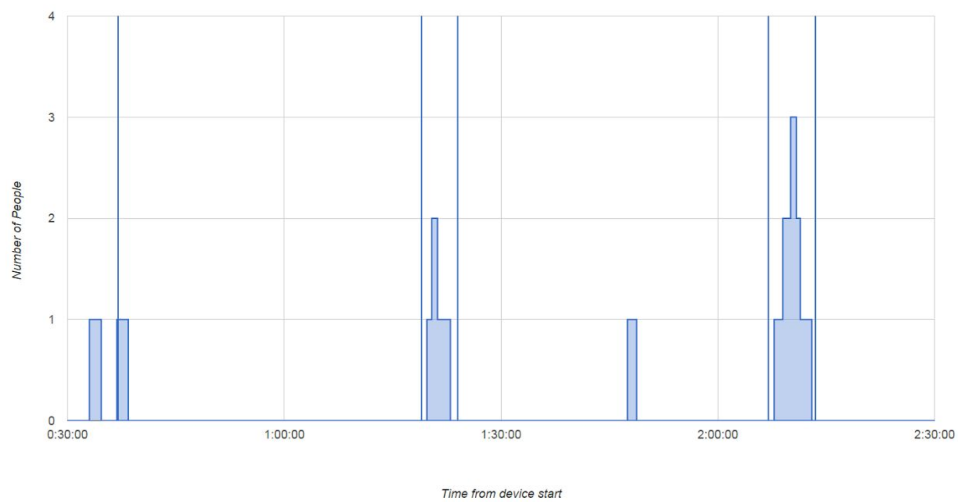
Device installation at Phillips Middle School.

<u>*Appendix D*</u> *Data:*

People Count in the restroom at local school vs Time

Data from Guy B Phillips Middle School

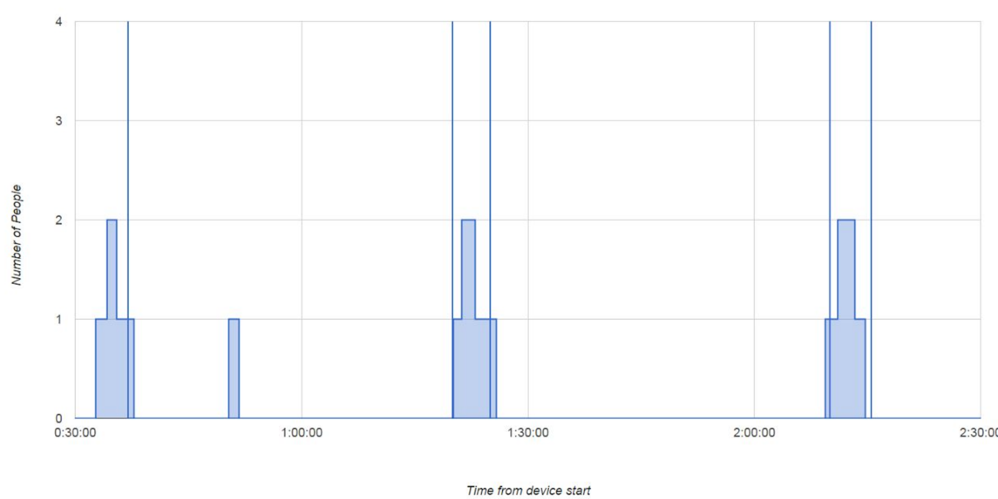
A	B
0:33:02	0
0:33:02	1
0:34:40	1
0:34:40	0
0:36:50	0
0:36:50	1
0:38:25	1
0:38:25	0
1:19:44	0
1:19:44	1
1:20:25	1
1:20:25	2
1:21:13	2
1:21:13	1
1:23:00	1
1:23:00	0
1:47:30	0
1:47:30	1
1:48:46	1
1:48:46	0
2:07:48	0
2:07:48	1
2:09:00	1
2:09:00	2
2:10:05	2
2:10:05	3
2:10:53	3
2:10:53	2
2:11:25	2
2:11:25	1
2:13:01	1
2:13:01	0
2:41:00	0



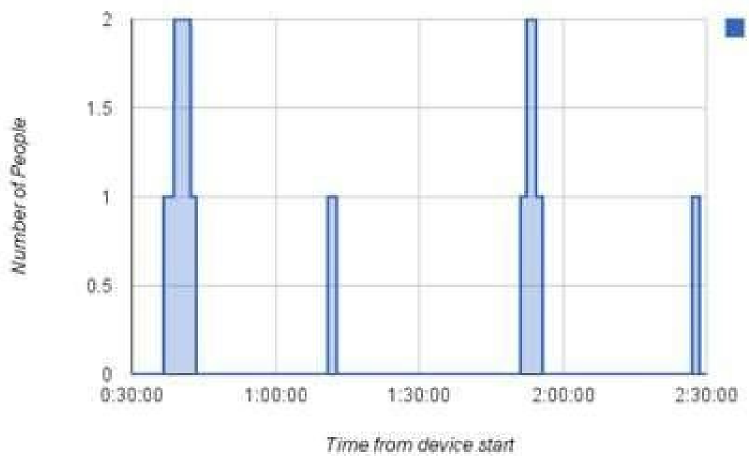
People Count in the restroom at local school vs Time

Data from Guy B Phillips Middle School

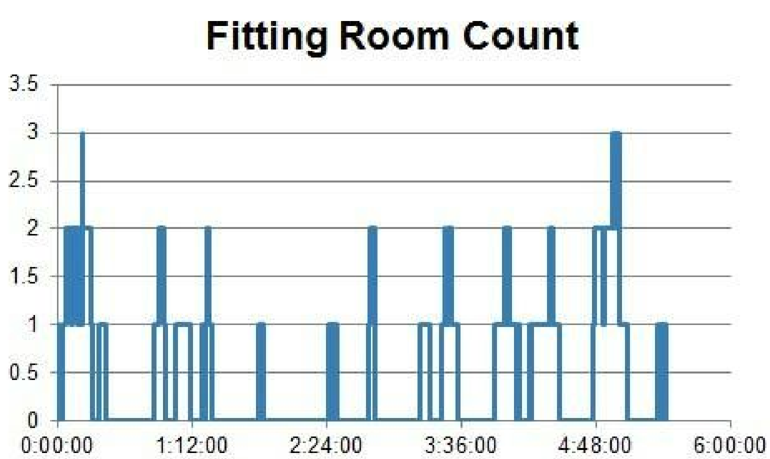
A	B
0:32:43	0
0:32:43	1
0:34:13	1
0:34:13	2
0:35:29	2
0:35:29	1
0:37:47	1
0:37:47	0
0:50:21	0
0:50:21	1
0:51:42	1
0:51:42	0
1:20:07	0
1:20:07	1
1:21:13	1
1:21:13	2
1:23:00	2
1:23:00	1
1:25:48	1
1:25:48	0
2:09:25	0
2:09:25	1
2:11:03	1
2:11:03	2
2:13:19	2
2:13:19	1
2:14:42	1
2:14:42	0
2:45:00	0



People Count in the restroom vs Time at University



People Count in the fitting room vs Time at Local Retail Store



14:08:10		14:09
14:25:13		14:25:00
14:25:17		14:28:34
14:28:46		
14:28:48		
14:52:42		14:53:00
14:58:10		14:58:27
15:03:44		15:04:00
15:05:49		15:06:00
15:05:59		
15:07:17		15:08:18
15:09:18		
15:12:58		15:13:11
15:32:14		15:32:00
15:37:43		15:38:00
15:38:32		
15:39:18		

15:40:41		15:40:38
15:43:38		15:43:24
15:44:53		14:45:00
15:45:45		14:45:53
15:51:20		15:51:00
15:51:58		
15:52:22		15:52:00
16:02:16		16:03:20
16:03:39		16:02:00
16:07:14		16:07:00
16:24:54		16:25:00
16:26:10		16:26:00
16:30:39		16:30:32
16:31:11		16:31:00
16:36:06		16:37:00
16:36:11		
16:37:02		
16:39:03		16:39:08

Device Recorded time vs Human Recorded time at local retail store

Raw Data (text document created by device) from UNC Chapel Hill

RAW Data

Time, Number of People

0:00:19,1

0:00:26,0

0:36:41,1

0:38:52,2

0:42:19,1

0:43:29,0

1:10:59,1

1:12:49,0

1:51:14,1

1:52:29,2

1:54:28,1

1:55:51,0

2:27:03,1

2:28:36,0

2:33:47,1

2:37:37,0

Raw Data (text document created by device) from Guy B Phillips Middle School

RAW Data

Time, Number of People

0:00:12,1

0:00:15,0

0:33:02,1

0:34:40,0

0:36:50,1

0:38:25,0

1:19:44,1

1:20:25,2

1:21:13,1

1:23:00,0

1:47:30,1

1:48:46,0

2:07:48,1

2:09:00,2

2:10:05,3

2:10:53,2

2:11:25,1

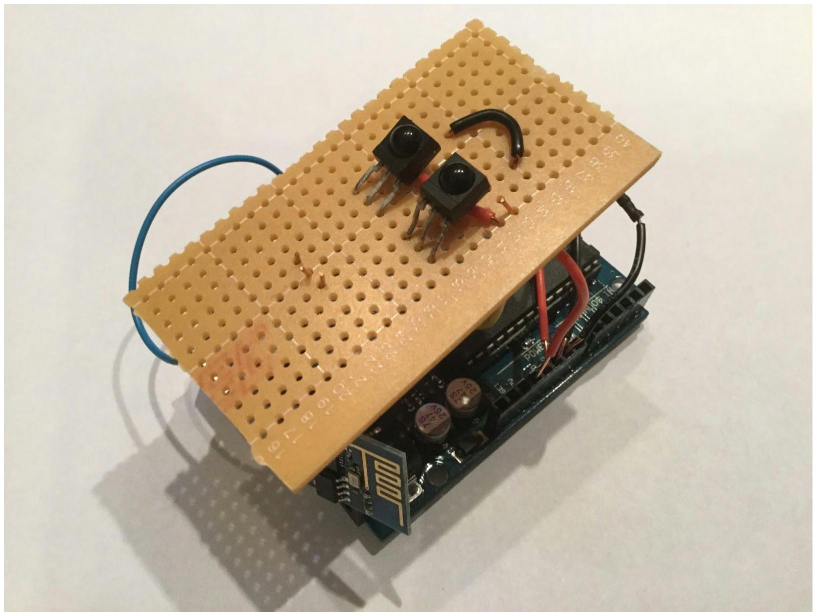
2:13:01,0

Appendix E ***Device Pictures:***

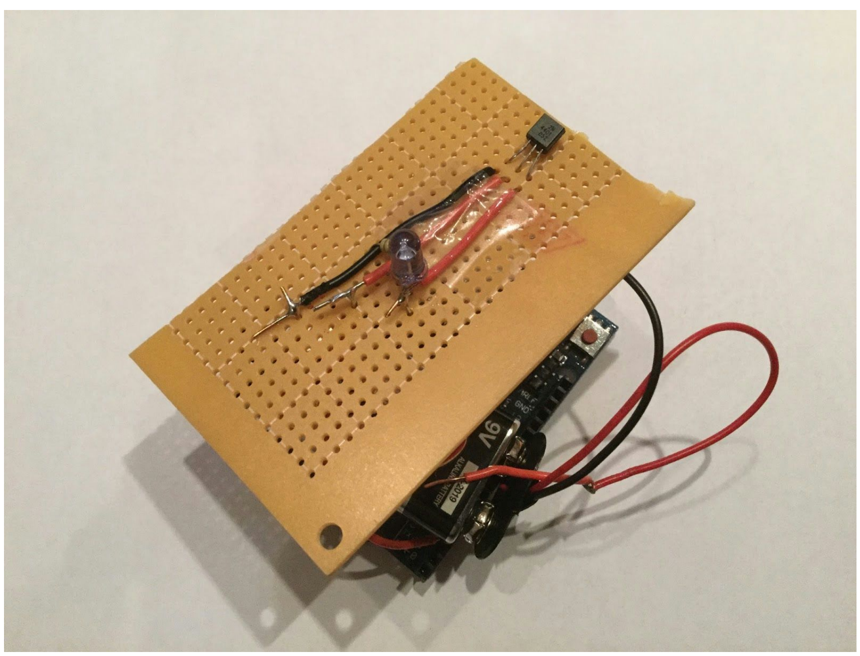
Receiver Module:

Emitter Module:

Receiver Module Internals Built:

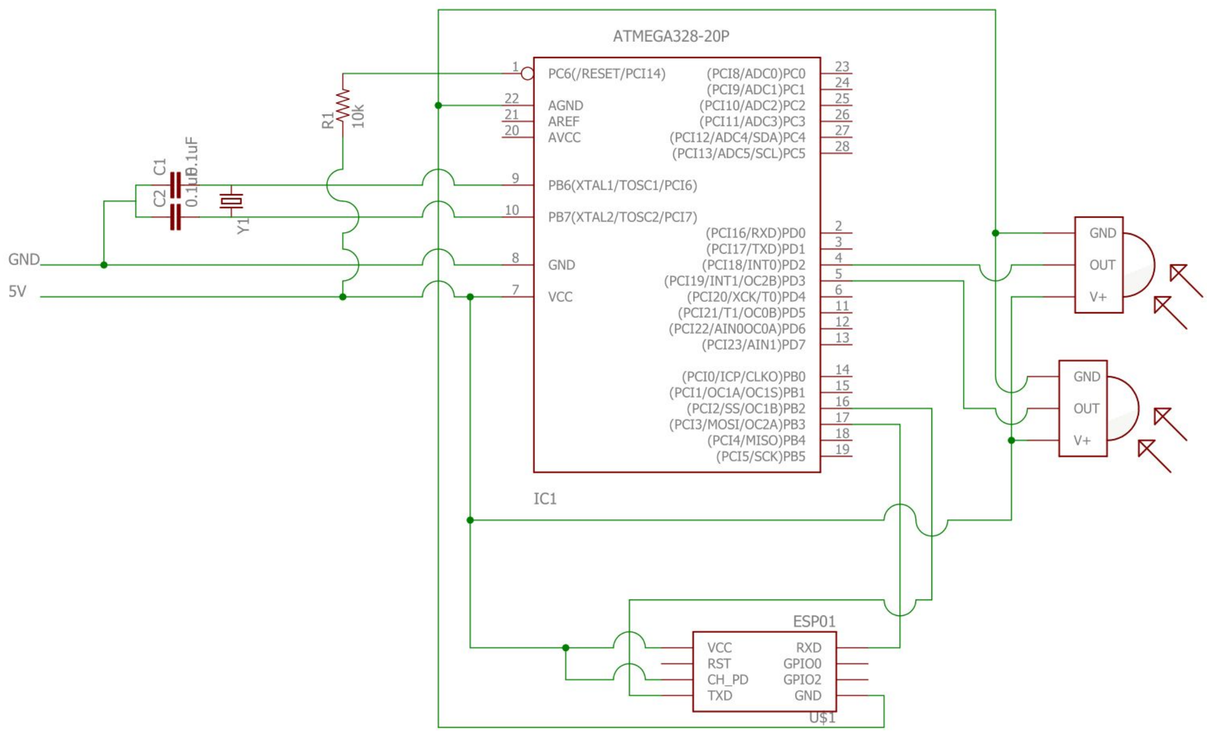


Emitter Module Internals Built:

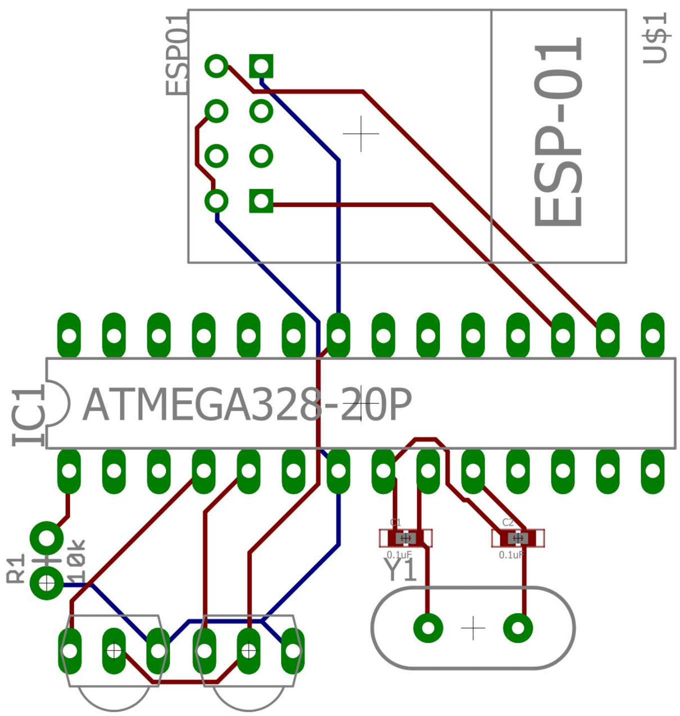


Appendix F: ***Device Schematics***

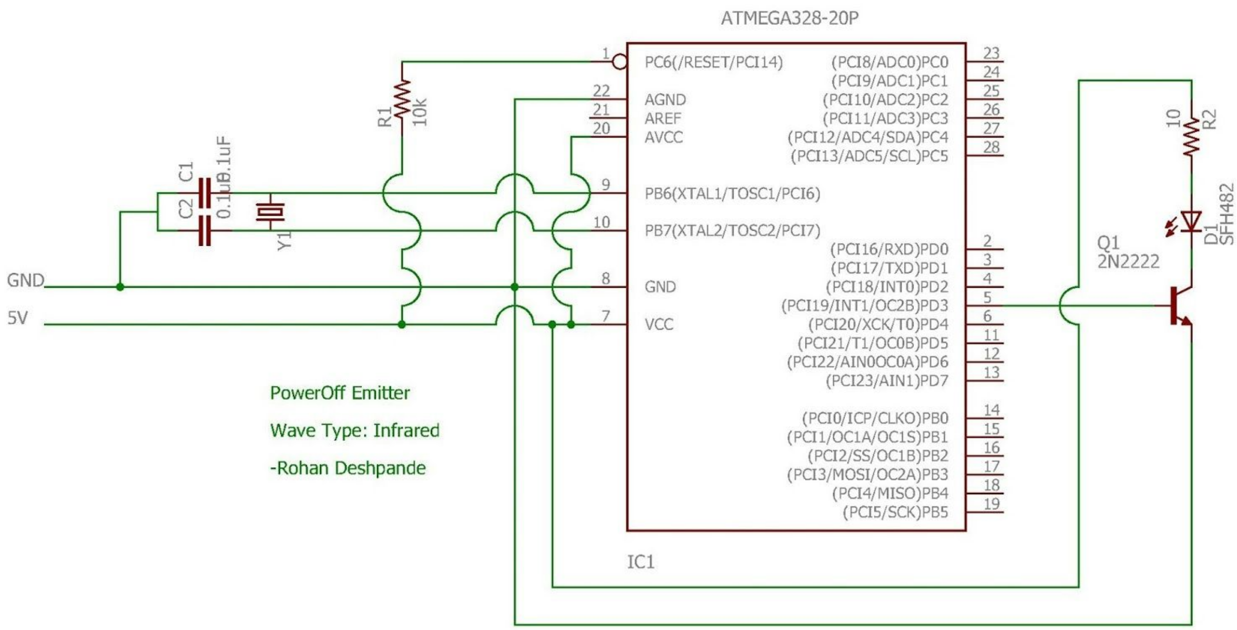
Receiver Module Schematic:



Receiver Module PCB layout:



Emitter Module Schematic:



Emitter Module PCB layout: