POWER OFF: AN ARDUINO BASED COUNTER USING LOW-POWER DUAL LASER TRIPWIRE SYSTEM TO REDUCE ELECTRICITY WASTAGE AND ENVIRONMENTAL POLLUTION

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Abstract:

Humans have been using switches for controlling lights, and other power sources, for a long time. 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. This will result in cost savings by avoiding electricity wastage, as well as reduce environmental pollution from unneeded electricity generation from fossil fuels.

My solution is an inexpensive device that accurately tracks the number of people in a room by monitoring its entrance. This small device, installed invisibly, includes two low-power laser beams shining on two photoelectric sensors. The data from the two sensors are outputted to an arduino microcontroller which monitors the people count in a room. The arduino knows whether to increment or decrement the people count in the room based on the sequence in which the two photoelectric sensors gets tripped. The arduino then communicates with a relay which controls the state of the power sources (on or off).

I installed and tested this device at a local school restroom. Analysis of the data collected supported my hypothesis stating that the restrooms were vacant during large portions of the day, although the lights were on during these periods. Further analysis showed that the Chapel Hill School district would save over $10,000 per year by reducing wasted electricity consumption. I also estimated that my device will lead to savings of more than 160 million dollars per year if it was installed in all public school restrooms in the United States. My device was also tested at a University and the fitting rooms of a major retail chain to verify its accuracy and gather more data. The amount of wasted electricity would decrease significantly if my device is implemented in numerous locations including homes, schools, public restrooms, offices, retail stores, etc., thus also lowering the environmental impact due to wasted power consumption.

keywords: Sustainability and environment, electricity wastage, electric circuits, arduino micro-controllers

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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].

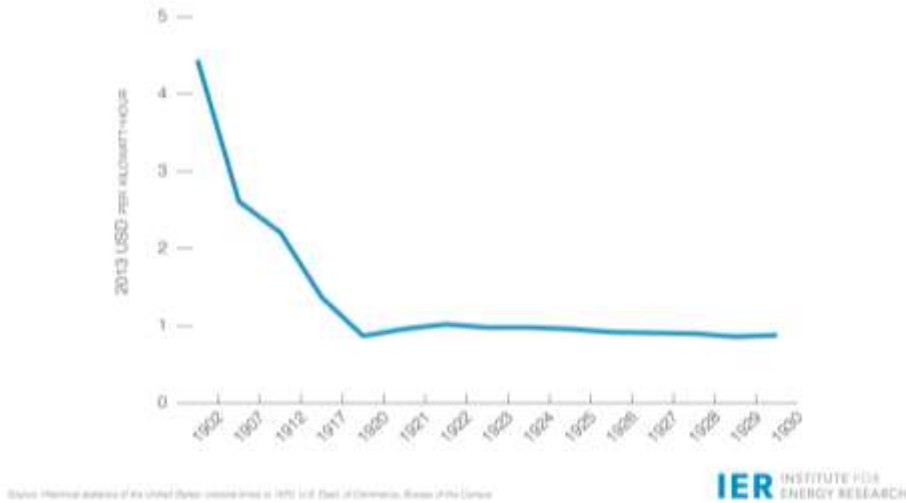

Figure 1.1: *Average Price for Electricity Energy, 1902-1930 (In Real 2013 US Dollars)*[1]

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 class periods, making the restrooms vacant for a large portion of the day.

Hypothesis 2: Large cost savings can be achieved by automatically switching off lights when the room is empty and, thus, the resulting wastage of electricity can be avoided.

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.

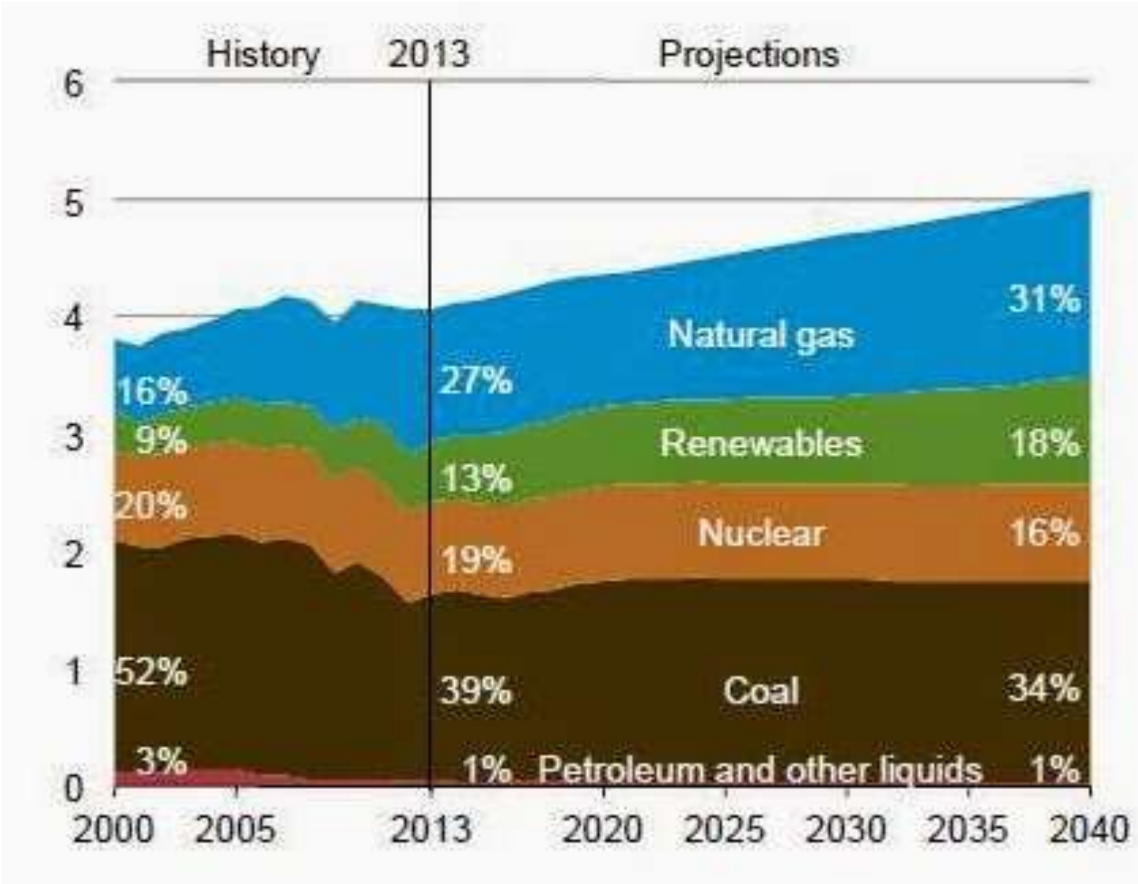

Figure 1.2: *Electricity Source Percentage vs Year*[6]

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.

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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 current solutions cannot count number people in a room. In order for the device to have a greater impact, the device must be ubiquitous. For this to happen, based on the microeconomics demand curve, the device must be low cost. To prove that the devices is an improvement over all current solutions, it must be accurate. The device should have a 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 be not obtrusive and it should be long lasting (> 1 yr), as frequent errors and reinstallations would be dissuasive to the consumer. I used these constraints as a checklist for designing my device.

2.2 Innovation: The innovation in my device is the use of a dual-laser trip wire system that is a connected to an Arduino, an open source Italian microcontroller built with Atmel Corporation electronic chips[12, 13]. Refer to Figure 2.1 for diagram of device setup after installation. The device is comprised of an emitter module (number 4 in Figure 2.1) and receiver (number 5 in Figure 2.1). The emitter module emits two concentrated beams of continuous waves (e.g., low powered laser beams), while the receiver is comprised of two sensors, which the continuous waves are aimed at, monitor the intensity of incoming waves. The device compares the incoming wave intensity with that of a benchmark wave (e.g. background light) similar to a tripwire[14]. If the incoming wave intensity is lower than a specific calibrated value (threshold), it is understood that the path of the beam has been obstructed/tripped. This calibrated value is set between the intensity of the benchmark wave and the normal intensity of the incoming wave. The direction of the motion can also be deduced based on the order in which both parallel beams are obstructed. If the path A (number 2 in Figure 2.1) was obstructed before path B (number 3 in Figure 2.1), the person must have moved from region A (number 6 in Figure 2.1) to region B (number 7 in Figure 2.1). If the device was keeping track of the number of people in region A (number 6 in Figure 2.1), it can now deduct one person from its total count. In the event path B (number 3 in Figure 2.1) was obstructed before path A (number 2 in Figure 2.1), the person must have moved in the opposite direction, from region A (number 6 in Figure 2.1) to region B (number 7 in Figure 2.1), allowing the device to add one person to the total number of people in region A (number 6 in Figure 2.1). Based on this new method, the device can track movement in two directions. 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 keeping a total count of person entrances and exits. The device communicates with a relay[15] which controls the state of the power sources (on or off). For the purpose of gathering data, instead of triggering the state of lights with the device, the timestamp, number of people, and other significant details were recorded automatically to an SD Card[16, 17]. After testing is completed this SD card can be removed from the device, and inserted into a computer for data extraction. Figure 2.2 shows a circuit diagram of my design and I built a prototype for the receiver.

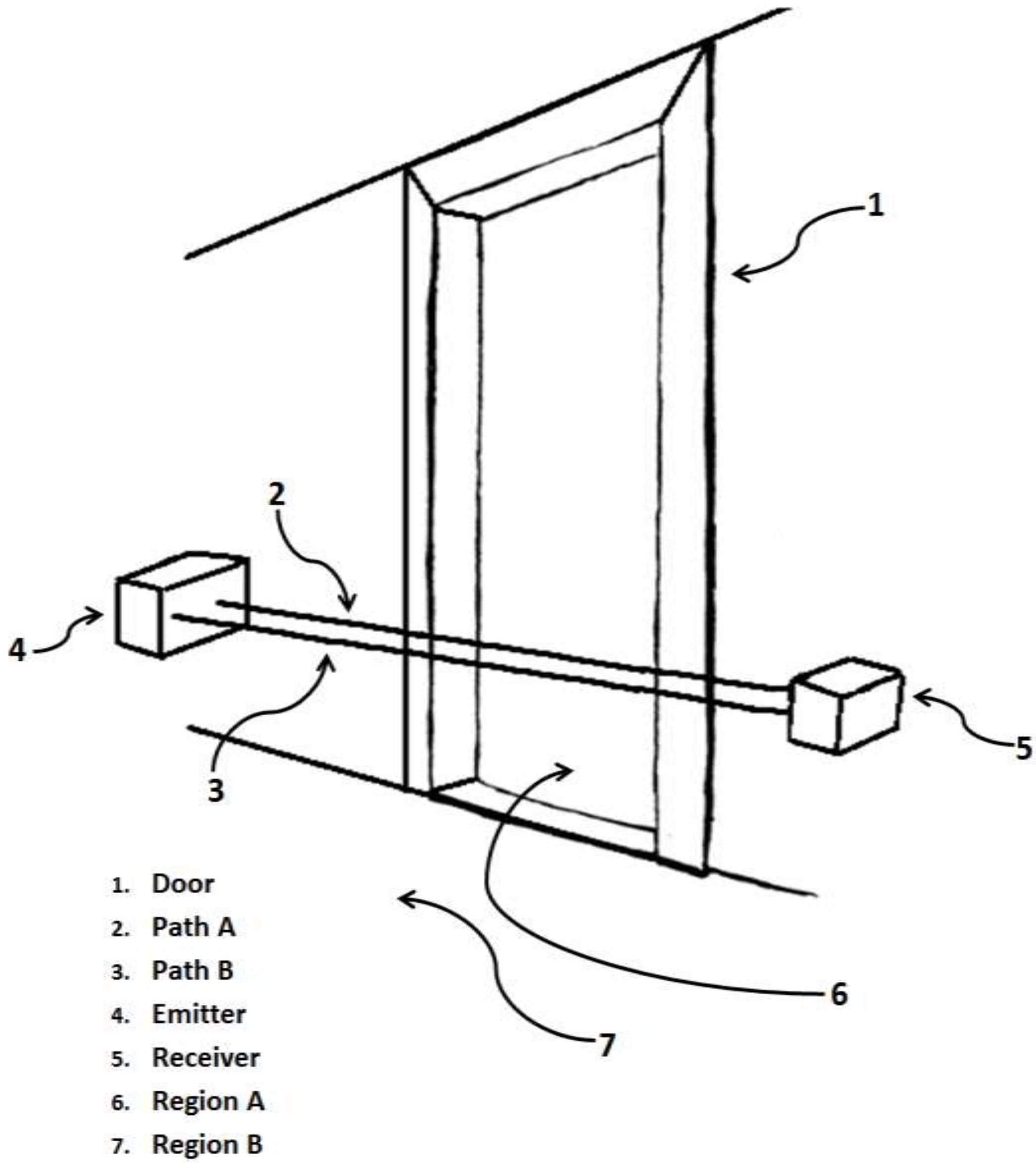

Figure 2.1: *Diagram of Device Installation Setting*

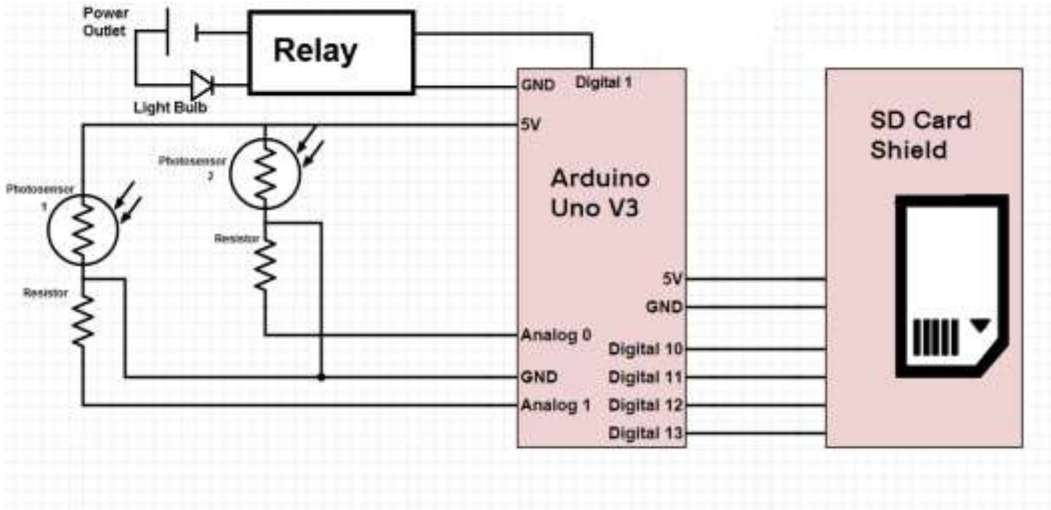

Figure 2.2 *Receiver Module Schematic*

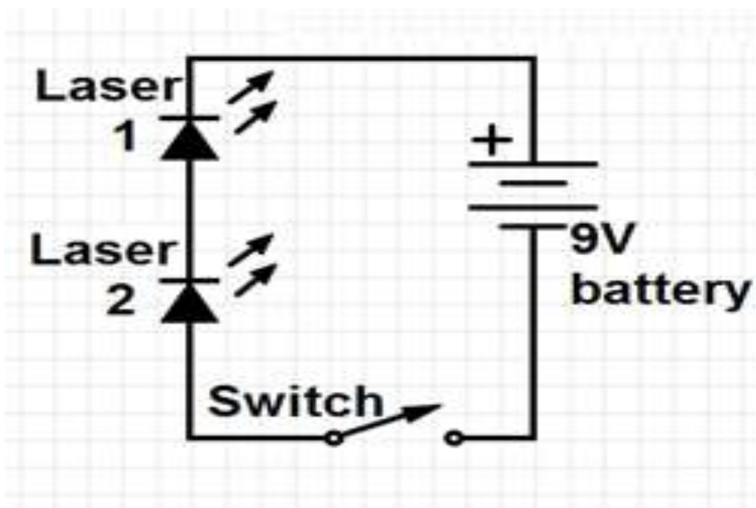

Figure 2.3 *Emitter Module Schematic*

2.3 Arduino Code: Multiple versions of arduino code were created and debugged before I settled on the final version. The code starts by defining the number of people and setting it to zero, as there are zero people when the device is installed. Next the threshold value is defined. This value varies depending on the amount of ambient light. This number must be changed during the setup after installation manually. The device starts the internal stopwatch to be able to timestamp data. At this instant the device will start the loop. The light intensity values for each sensor are stored at two variables called sensA and sensB. The device sets the last number of people as the current number of people. Later this information to find changes in the number of people in the room. The device will compare the values of the sensors to the threshold value. If sensB has a value less than the threshold and sensA has a value greater than the threshold the device increments the number of people in the room because it has determined that someone is going into the room. If the device finds that sensB is greater than the threshold and sensA has a value less than the threshold the device decrements the number of people in the room because it has determined that someone is going into the room. If the last count is not equal to the current number of people in the room, the device will print the timestamp and the number of people into the SD card. The device checks for the difference between the last and current numbers to make sure the device does not continuously record the number of people even if there is no change. If the number of people in the room is greater than zero, the device turns the lights on, while if the number of people is zero, the device know that there are no people in the room and turns the lights off. 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 there are a negative number of people in a room. This is because a negative number means that the device made an error. The pseudo-code of the code that was loaded on the device is given below.

Device Pseudo Code:

```
//Let the number of people in the room be called ctr
//create value called thresh, variable compensates for ambient light
```

```
//start time
//Loop cycle begins
//Let the values at the two photosensors be stored at variables sensA sensB
//Let the last number of people be called lastcnt
//check if sensA>thresh and sensB<thresh
//        then increment ctr
//check if sensA<thresh and sensB>thresh
//        then decrement ctr
//check if ctr is not equal to the last count
//        then write time to SD card
//        then write ctr to SD card
//check if ctr>0
//        then turn light on
//else turn light off
//Loop cycle ends
```

The full Arduino Code for the device is found in the appendix.

2.4 Build: I bought parts for the above circuit from SparkFun electronics, Radio Shack, and Lowe's. I then assembled the Receiver and the Emitter at home using my experience building circuits. The total cost of all the parts for both modules was less than 20 dollars (Appendix B provides a list of all parts used for assembling the device). The code was uploaded onto Arduino microcontroller to be debugged. By following the schematic (Figure 2.1) , code (Appendix A), and the parts list (Appendix B), one can easily reconstruct the device. Figures 2.4 and Figure 2.5 provide pictures of the fully assembled emitter and receiver respectively.

Figure 2.4*: Picture of Emitter Module prototype.*

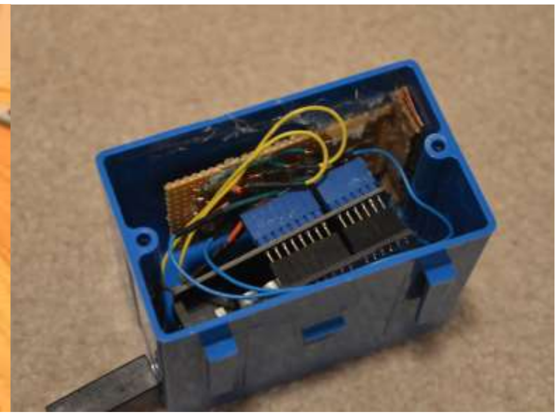

Figure 2.5*: Picture of Receiver Module prototype.*

<u>*2.5 Device Testing and Refinement:*</u> Finally, I performed extensive calibration and testing at home under different conditions and rooms. The device was installed 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 has 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. I calibrated the photosensor threshold trigger value based on ambient light, caused by different brightness levels of a room, for accurate count measurement. The variation in ambient light follows a normal distribution (Figure 2.6) for lighting unaffected by sunlight. Normally, the device must be manually calibrated by a human who compares the light level of the lasers to ambient light. This meticulous work process prompted me to refine the device, allowing for an auto-calibration method handled completely by the device. A standardized procedure, which uses information such as the mean and standard deviation of ambient light intensity, allows for the device to auto-

calibrate itself. To accurately determine the threshold value, one must find the light value with the lasers turned on, to simulated the beams with no obstructions (normal distribution 1), and also the light value while the lasers are turned off, to simulated the beams being obstructed (normal distribution 2). The threshold value can be determined using the six sigma method, a common statistical tool for eliminating defects during production. The threshold is half the distance between 6 sigmas of the mean of the normal distribution 1 and normal distribution 2.

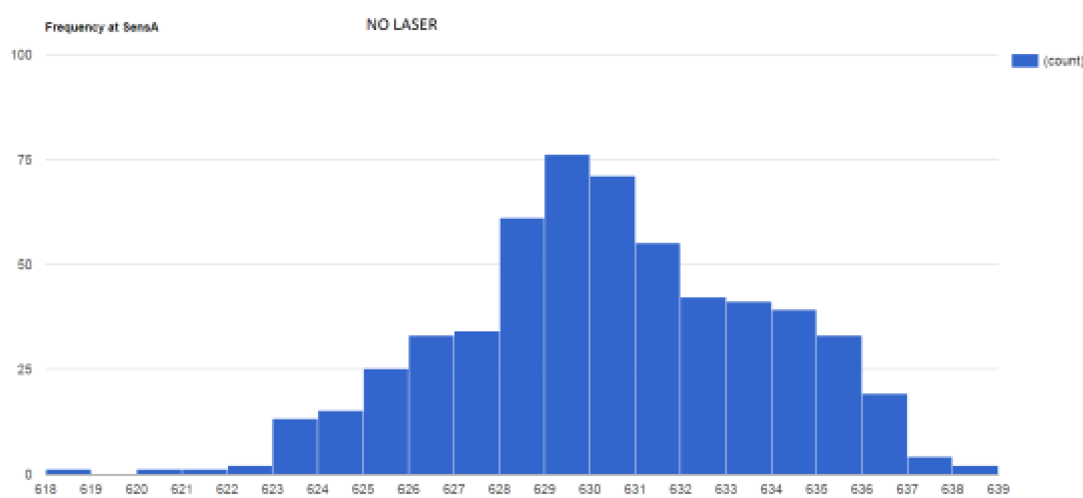

Figure 2.6: *Frequency of light variation on photosensor A with no laserbeam*

Figure 2.6 shows one such graph of the frequency of ambient light variation, gathered during the calibration process. The device converted this data into the mean and standard deviation values for the auto-calibration process which was then used to set the threshold value.

2.6 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. Finally, 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. 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 three real world settings: a local school (Figure 2.7), a university (Figure 2.8), and a major retail chain (Figure 2.9). 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 University

Testing at Local school

Figure 2.8*: Pictures from installation at Local University*

Figure 2.7*: Pictures from installation at Local School*

Pictures from retail chain implementation

Figure 2.9*: Pictures from installation at Major Retail Chain*

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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.

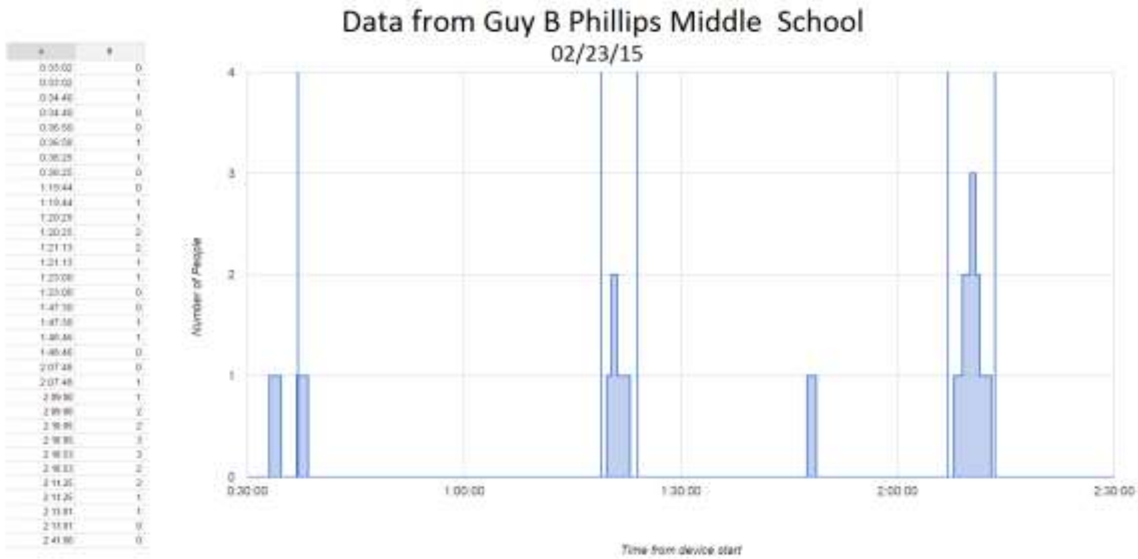


Figure 3.1: *People Count in the restroom at local school vs Time*

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.

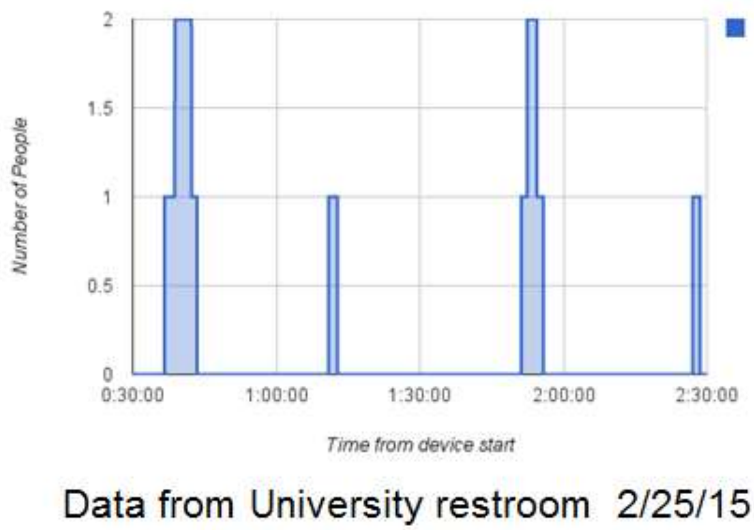


Figure 3.2: *People Count in the restroom vs Time at University*

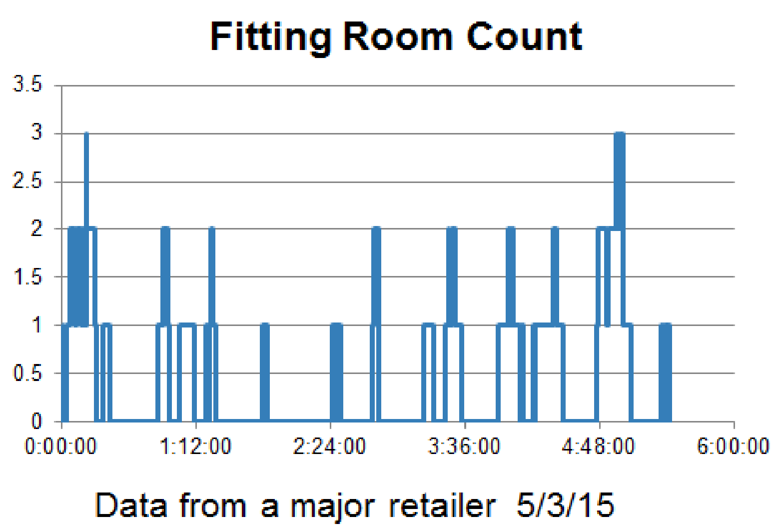


Figure 3.3: *People Count in the fitting room vs Time at Local Retail Store*

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*

3.2 Analysis: To estimate the savings from my device, I first obtained CHCCS (Chapel Hill Carrboro Schools) electricity cost and usage data from our school 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, I calculated that my device would save $167 million annually by reducing wasted electricity consumption (Figure 3.6). 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[18]. 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 3.7). These numbers could be even larger if the device was installed in every home and building in the United States.

$$t_U = \sum t_f - t_i \tag{1}$$

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

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

$$t_U = 12.967min$$

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

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

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

$$\frac{10bulb}{restroom} * \frac{32Watts}{bulb} = \frac{320Watts}{restroom} \tag{2}$$

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

$$\frac{3{,}494Watt * hours}{restroom * 1schoolday} * \frac{kW}{1000Watts} * \frac{12restrooms}{school} * \frac{180days}{schoolyear} = \frac{135{,}862KWh}{schoolyear * school} \tag{4}$$

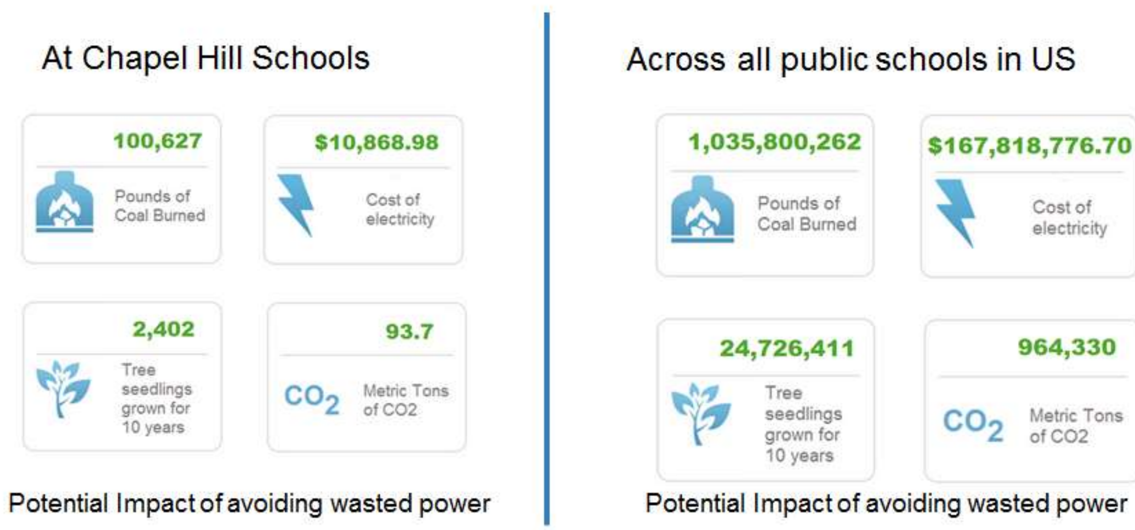
$$\frac{135{,}862KWh}{schoolyear * school} * \frac{\$0.12}{kWh} = \frac{\$10{,}862}{schoolyear * school} \tag{5}$$

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*



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

Figure 3.7: *Impact Analysis using EPA Greenhouse Gas Equivalencies Calculator*

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4. Discussion:

4.1 Summary: In this project, I invented a novel device using an Arduino microcontroller, and a low-power dual laser tripwire system, to count the number of people in a room 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, a University, and a major retail chain. Analysis of data collected from these experiments show that my device may have a huge impact. 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. Thus, my analysis provides support for my second hypothesis 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. The alignment of both lasers on the device needs to be simplified and device size needs to be shrunk using a PCB board for easy installation. A preliminary PCB layout was created to show significant size reductions to the device (Appendix E). The alignment of the two lasers can be fixed with a three axis rotation attachment, allowing the consumer to easily fine tune the alignment of the two lasers easily, and then lock it into place.

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. My device can be installed in Smart automated homes / Green buildings to reduce environmental impact of wasted electricity consumption, and, thus, can potentially be used to earn credits for LEED certification of buildings. It can be used in elderly homes/hospitals for fall detection in bathrooms. It can also be used in schools to monitor abnormal restroom usage while classes are on, by making restroom usage data available 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.

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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6. Resources:

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7. Appendix:

Appendix A. ***Full Arduino Uno Code:***

```
//Dual Laser Tripwire Code    Version 4
//Rohan Deshpande

#include <SD.h> //Load SD card library
#include<SPI.h> //Load SPI Library
#include <Time.h>

int writenow =0;
int sensA;                          //    Declaring VARIABLES
int sensB;
int thresh;
int ctr=0;
int lastcnt=0;
int lights = 5;
int se = 0;
int mi=0;
int ho = 0;
int chipSelect = 4; //chipSelect pin for the SD card Reader
File mySensorData; //Data object you will write your sensor data to

void setup()
{
Serial.begin(9600);
pinMode(10, OUTPUT); //For SD Card
pinMode(5, OUTPUT);
digitalWrite(lights, LOW);
SD.begin(chipSelect); //Initialize the SD card reader
delay(1000);
}

void loop()
{
  int ho = hour();
  int mi = minute();
  int se = second();
 lastcnt = ctr;
sensA = analogRead(A0) + 29;    // READ SENSOR A AND B, and calibrate
sensB= analogRead(A1) -24;
thresh = 805;                          // BASED ON THE AMBIENT LIGHT

  if(sensA<thresh && sensB>thresh && writenow ==0)
  {
    ctr=ctr-1;                                      //   INCREMENT
    delay(500);
```

```
    writenow=1;
  }

  if(sensA>thresh && sensB<thresh && writenow==0)
  {
    ctr=ctr+1;                                      // DECREMENT
    delay(500);
    writenow=1;
  }

if(writenow == 1)
{
  if(ctr>0 || ctr<0)        //if number people are greater
{                          //or if there is a mistake have failsafe to
be ON
    digitalWrite(lights, HIGH);      //turn lights ON
  }
  if(ctr==0)                    //if there are zero people in the room
  {
    digitalWrite(lights, LOW);    //turn lights OFF
  }
if(sensA>thresh && sensB>thresh)
{
  Serial.print("sensA is :  ");                         // PRINT ALL
THE VALUES AND COUNTER
  Serial.print(sensA   );
  Serial.print("      sensB is :  ");
  Serial.print(sensB    );
  Serial.print("     counter :  ");
  Serial.print(ctr);
  Serial.print("     Time:");
  Serial.print(ho);
  Serial.print(":");
  Serial.print(mi);
  Serial.print(":");
  Serial.print(se);
  Serial.print(",");
  Serial.print(writenow);
  Serial.print(",");
  Serial.print("  thresh val : ");
  Serial.println(thresh);

  File mySensorData = SD.open("Project.txt", FILE_WRITE); //Open file
on SD card for writing
  if(mySensorData)
    {
    mySensorData.print(ctr);
    mySensorData.print(",");
```

```
    mySensorData.print(ho);
    mySensorData.print(":");
    mySensorData.print(mi);
    mySensorData.print(":");
    mySensorData.println(se);
    mySensorData.close();
    }
  writenow=0;
  }
}
}
```

Appendix B ***Project Parts List:***

Part Name	Quantity	Cost ($)
Relay SPDT Sealed	1	1.95
Mini Photocell	2	2
Arduino Uno Clone	1	4.1
Resistor 330 Ohm 1/6th Watt PTH	4	1
Laser Module	2	5.58
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

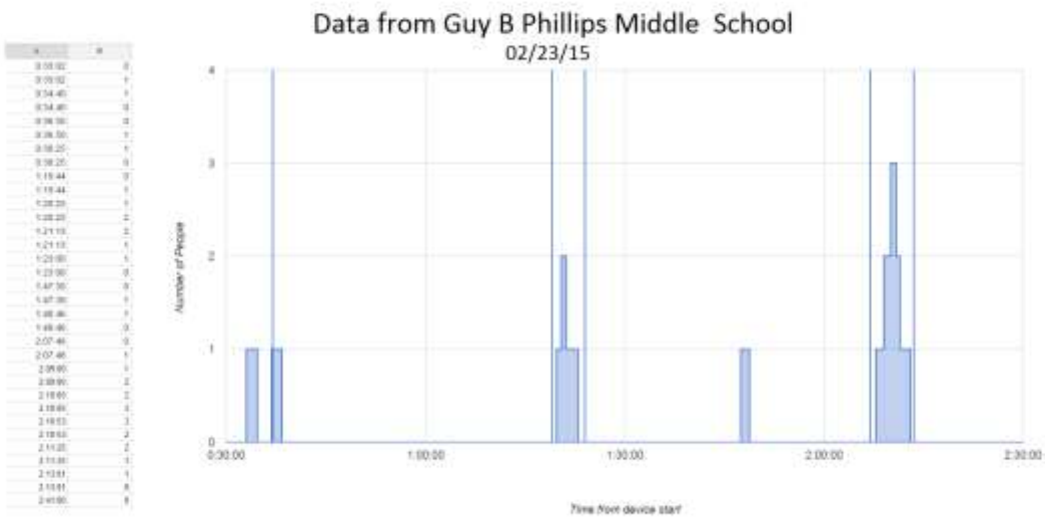
Total Cost: $19.48

<u>Appendix C</u> ***Device Installation Pictures***

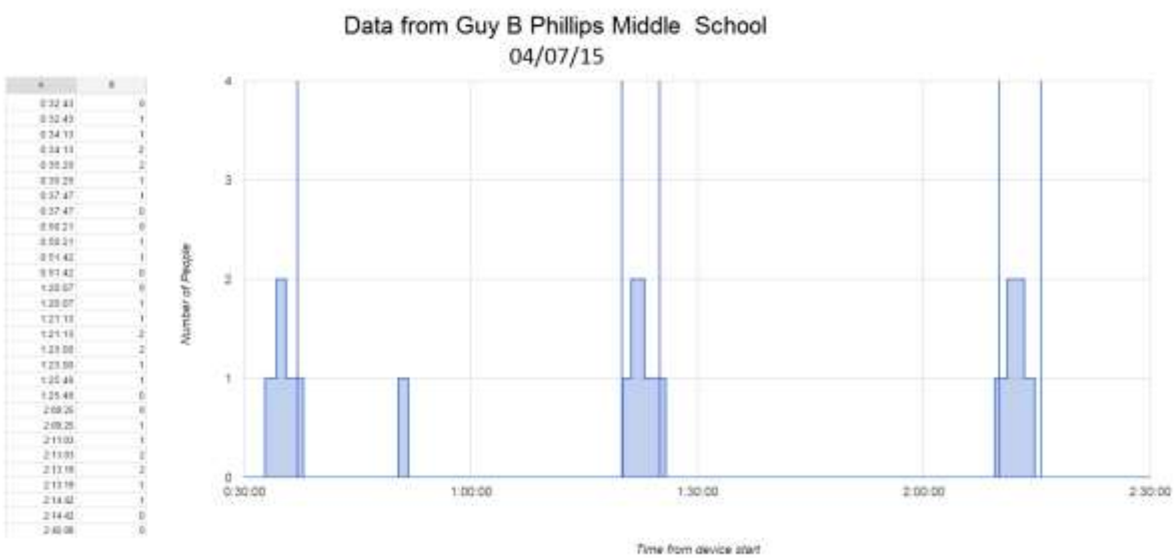
Device is not visible when entering the room at local retail store

Device installation at Phillips Middle School.

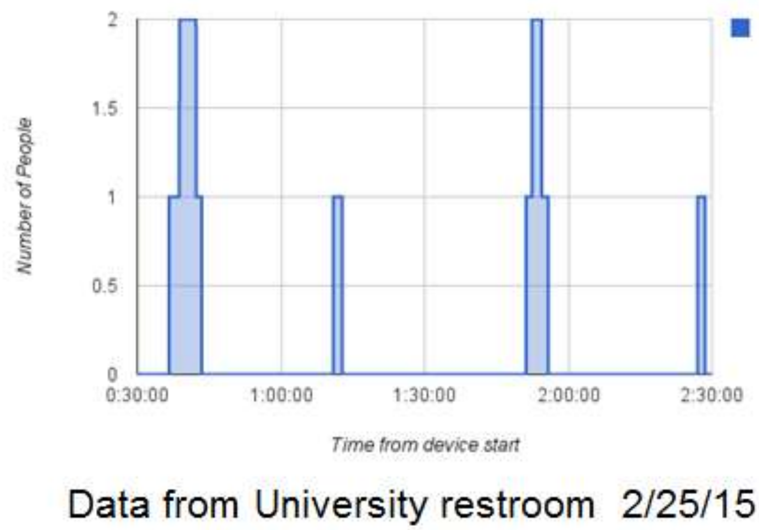
***<u>Appendix D</u>* Data:**



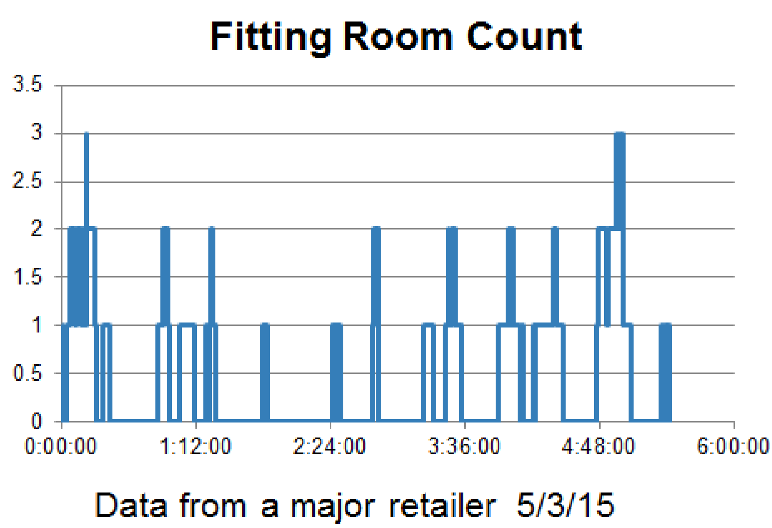
People Count in the restroom at local school (2/23/15) vs Time



People Count in the restroom at local school (4/07/15) vs Time



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

2/25/15

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

2/23/15

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

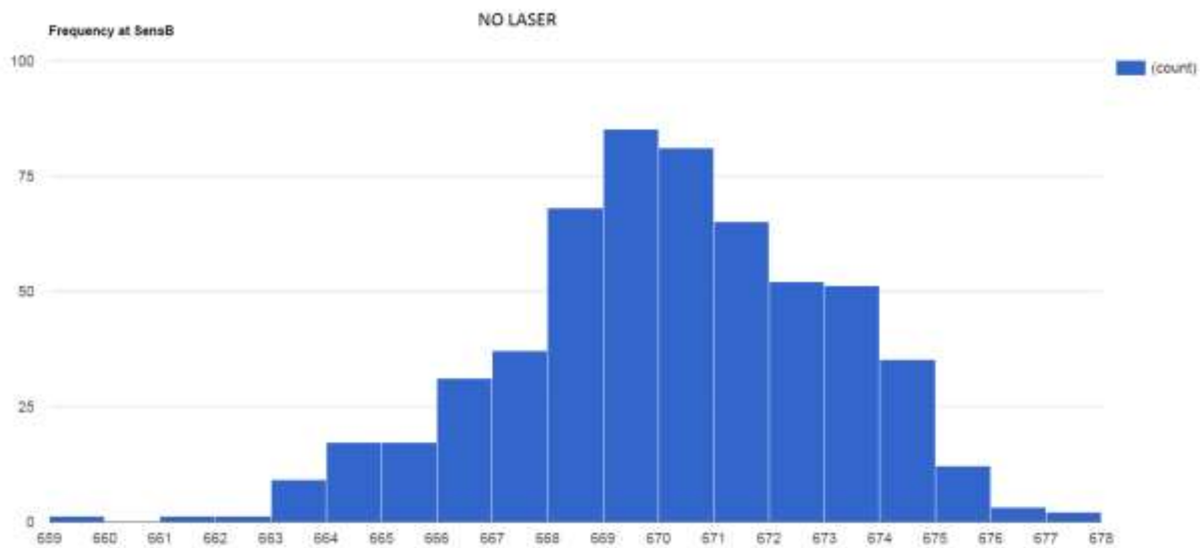
2:09:00,2

2:10:05,3

2:10:53,2

2:11:25,1

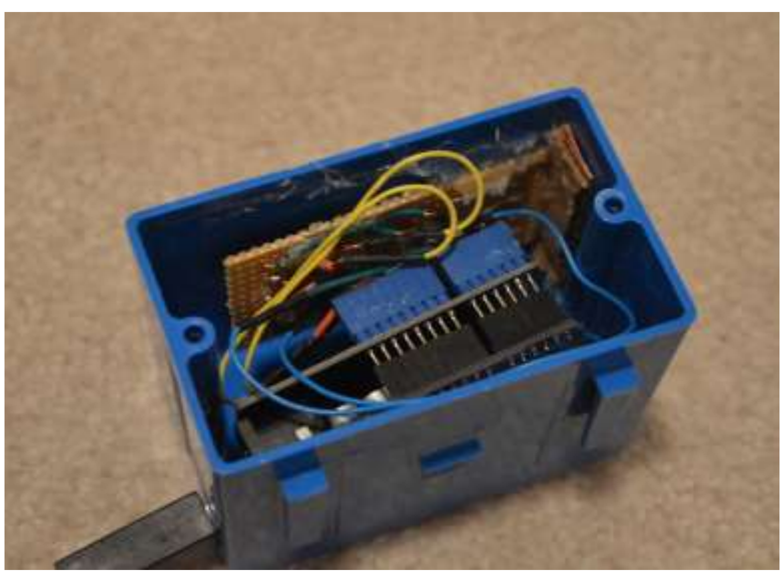
2:13:01,0



Ambient Light Variation during calibration process from Sensor B

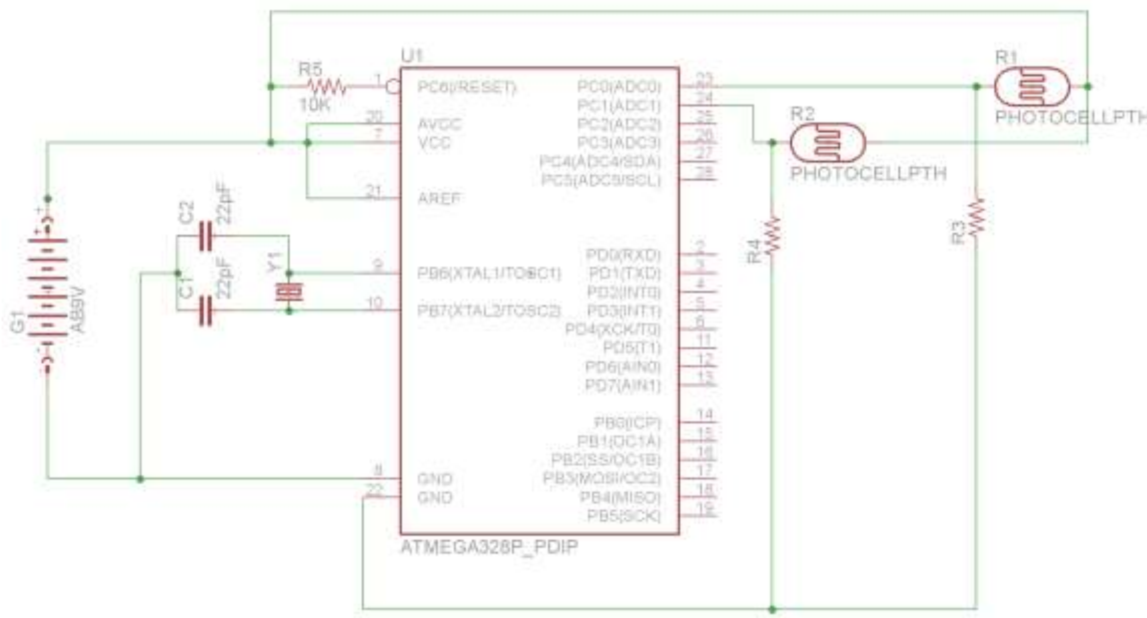
<u>Appendix E</u>   Device Pictures:

Receiver Module Internals Built:

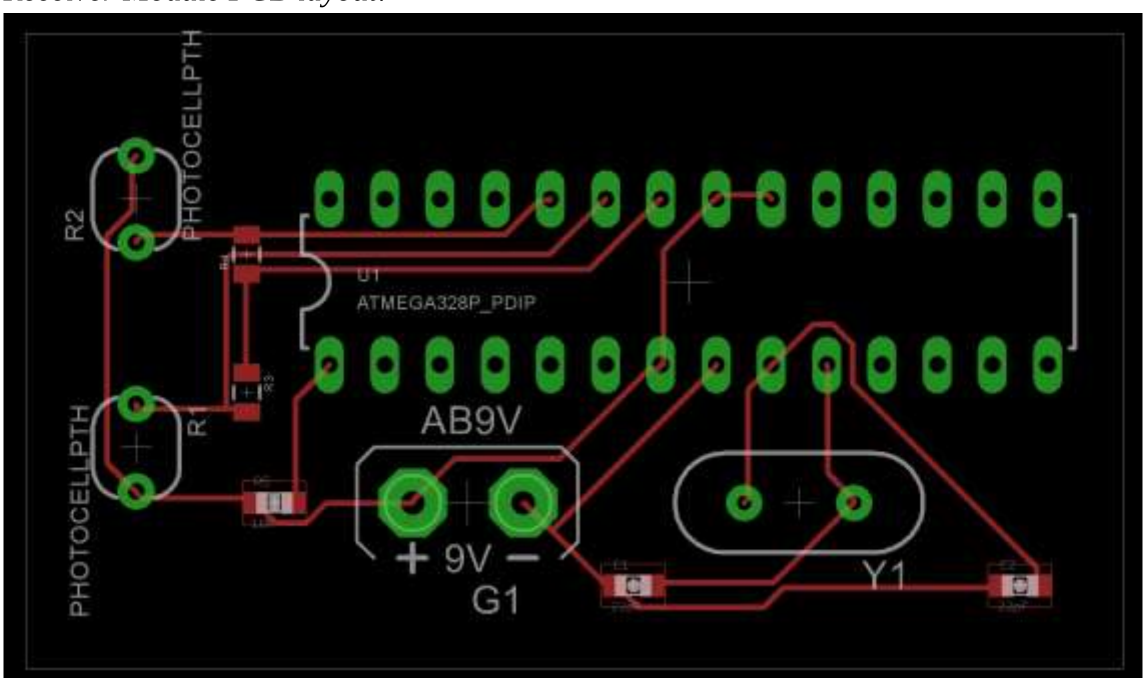


Appendix F: ***Device Schematics***

Receiver Module Schematic:



Receiver Module PCB layout:



Power Off
Rohan Deshpande
42

Emitter Module Schematic: