MODULAR AUTONOMOUS HOME LIGHT

By

Cary Chai (caryzc2)

Makomborero Tizora (mtizor2)

Samuel Darmamulia (sid2)

Design Document for ECE 445, Senior Design, Spring 2020

TA: Chi Zhang

13 February 2020

Project No. 52

Contents

1. Introduction

1.1 Objective

People love the convenience and the energy savings that automation can bring. It's for this reason that home automation is so prevalent today. One area that has seen developments in automation is lighting. Especially in the bustle of everyday life, it is often easy to forget to turn off the lights which wastes energy and money. On average, a household uses $200 a year for electricity on lighting, not including the cost of bulbs used overtime. [1] Modern commercial buildings often come built with some of these automation features pre-installed. For example, in ECEB, lighting is automated, but in many older buildings and especially in apartments and personal homes, automatic lighting is not implemented as there is currently no cheap, modular solution for autonomous lighting without having to hire an electrician and rewire the circuitry or purchase an entire expensive smart home ecosystem.

Our goal is to create a cheap modular solution which can be implemented on manual light switches to automatically control lights without needing to rewire a building's circuitry. This way, typical individuals and families can afford to have autonomous lighting installed without needing to hire an electrician to. This will be achieved through two modules. One that will attach externally to existing light switches and a second module that will hold a sensor unit consisting of two passive infrared (PIR) sensors. These two units will communicate with each other to provide low-cost, reliable automatic lighting to families. We will also have a phone app that will allow for manual control of the sensors as well.

In addition, current solutions for occupancy detection which focus on full room motion detection, there is a significant failure rate for still occupants. Therefore, we aim to implement our occupancy detection using a sensor unit focused on the entrance to detect as people enter and leave the room instead of the motion in the entire room. The sensor unit will communicate with a central computing unit through Bluetooth. After an entry is detected, the computer will increment its count by one. When someone leaves, the device will count down one. At zero, the device will know that there are currently no occupants in the room.

1.2 Background

There are companies such as SwitchBot which are working towards easy implantation of IoT homes. However, their products are focused on manual switches that can all be controlled from your smartphone and still require human input. In addition, their products are very expensive. For example, SwitchBot's Button Presser costs $29. You then need to purchase a SwitchBot Hub, and the Mini runs for $49. This is roughly $80 for just setting up a manual system for lighting which you can control from a phone app. [2] The environment is not integrated with existing motion sensors, and regardless, these would need to be purchased separately.

Other solutions use motion sensing to turn on and off lights in a room. However, these rely on constant motion and are prone to failure when there is little to no motion in rooms. Our solution aims to be an affordable, modular solution that will have the full capabilities to autonomously control lighting in a room. It will also implement occupancy detection based not on persisting motion in the room but instead on the number of people currently in the room based off a count from the entrance.

1.3 Visual Aid

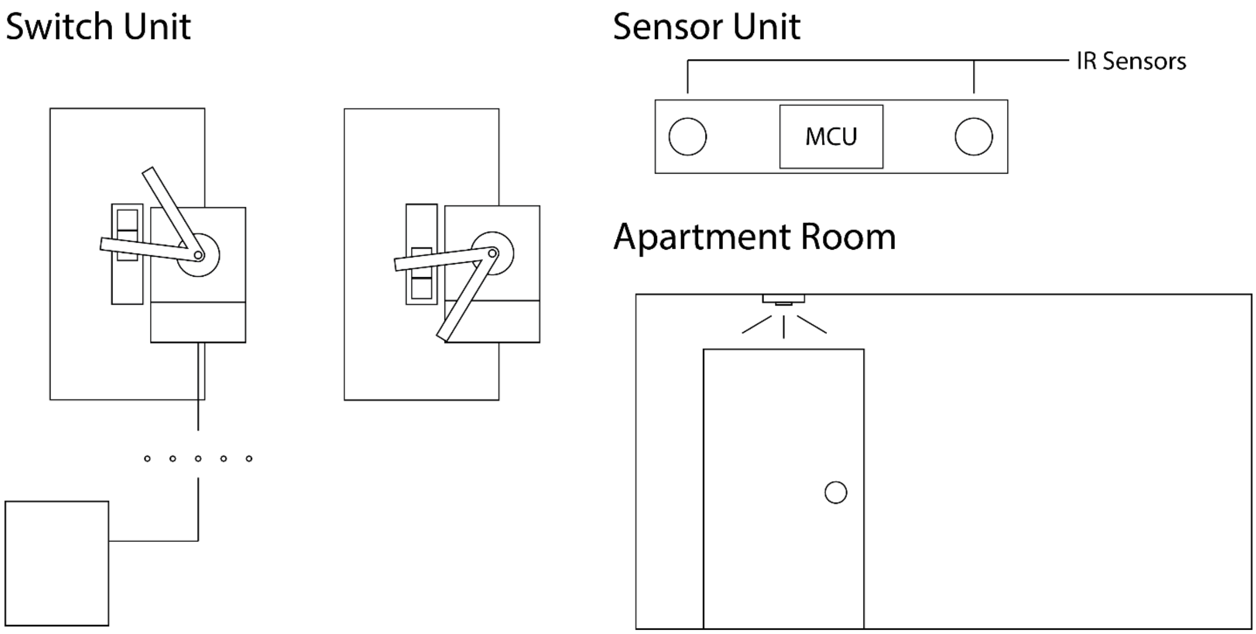


Figure 1: Visual Aid

On the left side of figure 1, we can see the switch unit and the design of how the motor will turn the switch on and off. On the top right of the figure is the sensor unit design. There are two infrared sensors on each side so the system will be able to figure out if the person left or entered the room based on which sensor triggers first. The placement of the sensor can be seen in the lower right side of the figure. The gap represents the door and the sensor unit will be placed near the door in order to detect people.

1.4 High Level Requirements List

- Both infrared sensors need to be able to detect people entering and leaving the room and send that signal to the main microcontroller, so the microcontroller can correctly send that Bluetooth signal to the mechanical component.
- The mechanical component must be able to receive the correct Bluetooth signal from the main microcontroller, and the servo motor must be able to have enough force to flip the switch.
- The phone must be able to communicate with the Wi-Fi module, so the main microcontroller can send the Bluetooth signal to the mechanical unit to flip the switch.

2. Design

2.1 Block Diagram

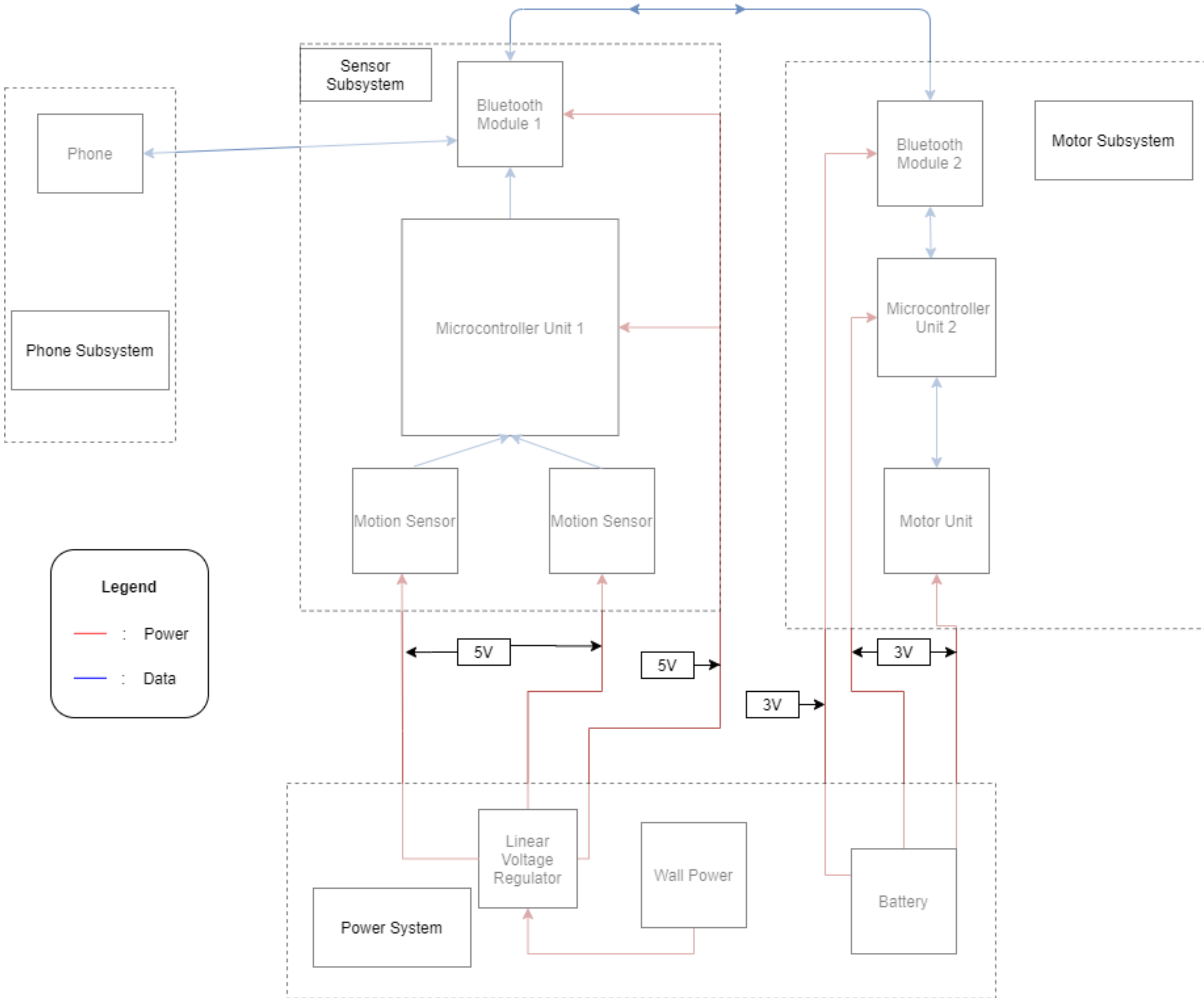


Figure 2: Block Diagram

Our block diagram has 4 subsystems - the phone subsystem, the power system, the sensor subsystem, and the motor subsystem. The power subsystem's job is to power up all the components of the other subsystems, except for the phone subsystem. There are 2 motion sensors that will be able to detect people entering or leaving and give that information to the Microcontroller Unit 1, which will then send a switch command to the Bluetooth Module 2 via Bluetooth Module 1. The motor subsystem will then flip the switch based on that information. The phone subsystem also can give commands to the Microcontroller Unit 1, which then will send a switch command to the motor subsystem. All of these subsystems are needed to fulfill our high-level requirements.

2.2 Functional Overview

Motion Sensor:

We will be using a HC-SR501 PIR Sensor. A PIR sensor is designed to detect infrared radiation. All objects with a temperature above Absolute Zero emit heat energy in the form of infrared radiation, including human bodies. The hotter an object is, the more radiation it emits. The responsibility of this sensor will be to track people entering and leaving the room.

1. Should be able to detect motion from 3-4 meters. 2. 2V - 15V	1. a. Connect PIR motion sensor to voltage source b. Connect Oscilloscope to Output pin c. Walk in front of the motion sensor and see if the output pin line goes high by using the oscilloscope.

Battery (1.5V per battery):

To power our motor subsystem we will be using 2 AA batteries for the motor subsystem. These two batteries will be put in series so we can have a total of 3 V and 2400 mAh.

Servo Motor:

A servo contains a small DC motor which is connected to the output shaft through gears. The output shaft drives a servo arm that is also connected to a potentiometer. The potentiometer provides position feedback to the servo control unit where the current position of the motor is compared to the target position. Then depending on the amount of error, the control unit corrects the actual position of the motor so that it matches the target position. This servo motor in conjunction with additional mechanical fixtures will be what turns the switch on and off.

Requirements	Verification
1. The servo motor needs to be able to generate at least 194 g of force. To convert to torque, we multiply 9.8 [m/s^2] * 0.194 [kg] * 0.0254 [m] = 0.048 [N*m] and we convert that to 0.4895 [kg-cm], which is below the torque given by the servo motor (2.5[kg-cm]) 2. 3V to 6V DC (4.8V nominal)	1. To verify this, we would place the servo motor near a light switch. 2. Run a code that will make the servo motor run. 3. See if the servo motor can turn on/off the light switch

Microcontroller 1 (Sensor Unit):

A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. In our block diagram we have two microcontrollers. The first one is used to process data from the motion sensors and send that data to the Bluetooth module which then transmit that data to another Bluetooth module. This Bluetooth module then sends that data to our second microcontroller which is responsible for controlling the servo motor. The first microcontroller unit will send motion sensor data to the Wi-Fi module which will then send that data to our mobile phone.

Requirements	Verification
1. Make sure that microcontroller unit 1 is properly able to process information coming in from the Bluetooth module and that it can send information to the Bluetooth module 2. Make sure that the microcontroller unit 1 can process information coming from the motion sensor 3. 2.7V - 5.5V	1. Run code that will send a test message to Bluetooth module and then from there send to the microcontroller and see if the microcontroller received the message 2. Run code that will continuously output the output of the motion sensor and the microcontroller a. Walk in front of the motion sensor b. Check the output line of the motion sensor changes to high when it detects motion c. Make sure that the microcontroller output changes with the change in the output of the motion sensor, which means that the microcontroller can detect change in the motion sensor

Requirements	Verification
1. Make sure that the microcontroller unit 2 can process information from the Bluetooth module. 2. Check to see if the microcontroller unit 2 can control the servo motor. 3. 2.7V - 5.5V	1. Run code that will send test messages from the Bluetooth module and see if microcontroller received them. 2. Run code that will send out voltage pulses from the microcontroller and see if the servo motor responds.

Bluetooth Modules:

We will be using the HC-05 module which uses a Bluetooth Serial Port Protocol which is designed for wireless serial connection setup. The Bluetooth module will be responsible for communication between the sensor subsystem and the motor subsystem.

Requirements	Verification
1. Needs to be able to connect to another Bluetooth module 2. Needs to be able to connect to a cell phone 3. 1.9V - 5.5V	1. Will test by running a code that will send test messages between Bluetooth modules and seeing if they can communicate with each other 2. Will test by trying to connect the cell phone with Bluetooth module and see if it is able to pair

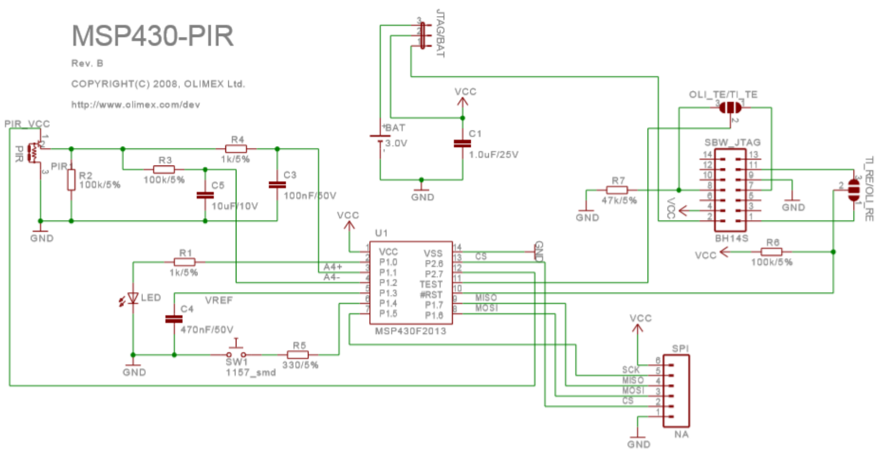
Linear Voltage Regulator:
We are using a L7805 voltage regulator. Our sensor subsystem will be powered from a wall outlet so the linear voltage regulator will make sure only 5V is outputted to our sensor subsystem

Requirements	Verification
1. Needs to be able to step down 110-130 V outlet from wall to 5V with an accuracy of ± 5 % 2. Have a max current of 1.5 A	1. Will input 110-130 V to the linear voltage regulator via wall output 2. Measure the output to make sure 5V ± 5 % is coming out and check also for the current to be less than 1.5 A

Phone App:
The mobile app that we create will allow users to track the occupancy levels of people in the room. From the phone, users can also turn on and off the lights.

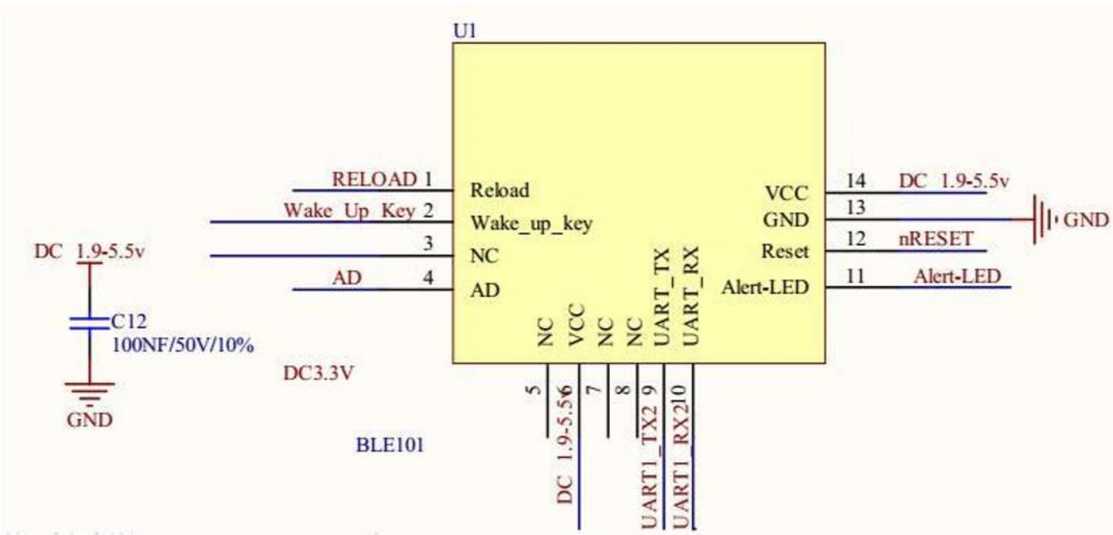
2.3 Schematics and Plots

2.3.1 Schematic for Motion Sensor [9]

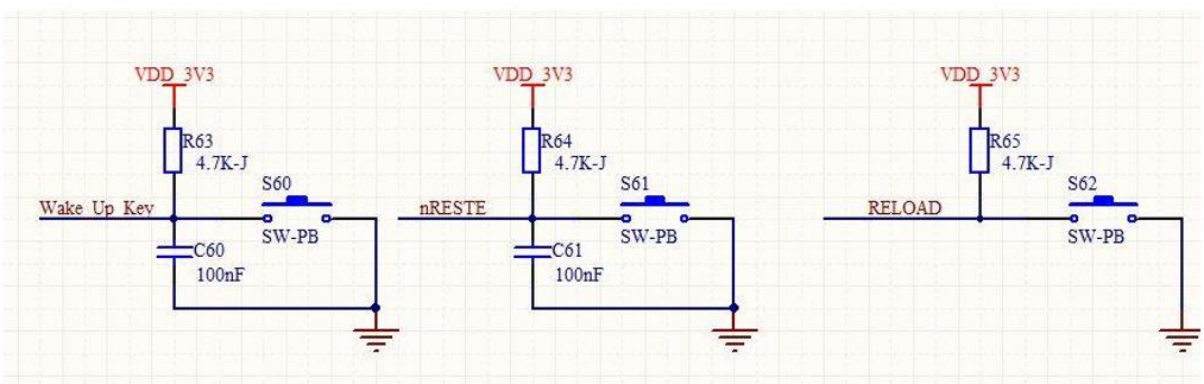


2.3.2 Bluetooth Module Schematic [8]

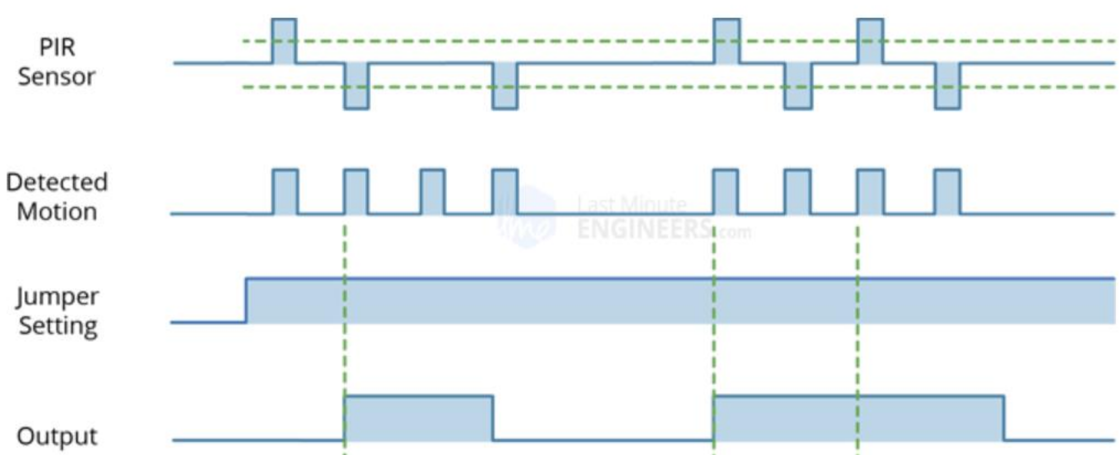
- Power Interface



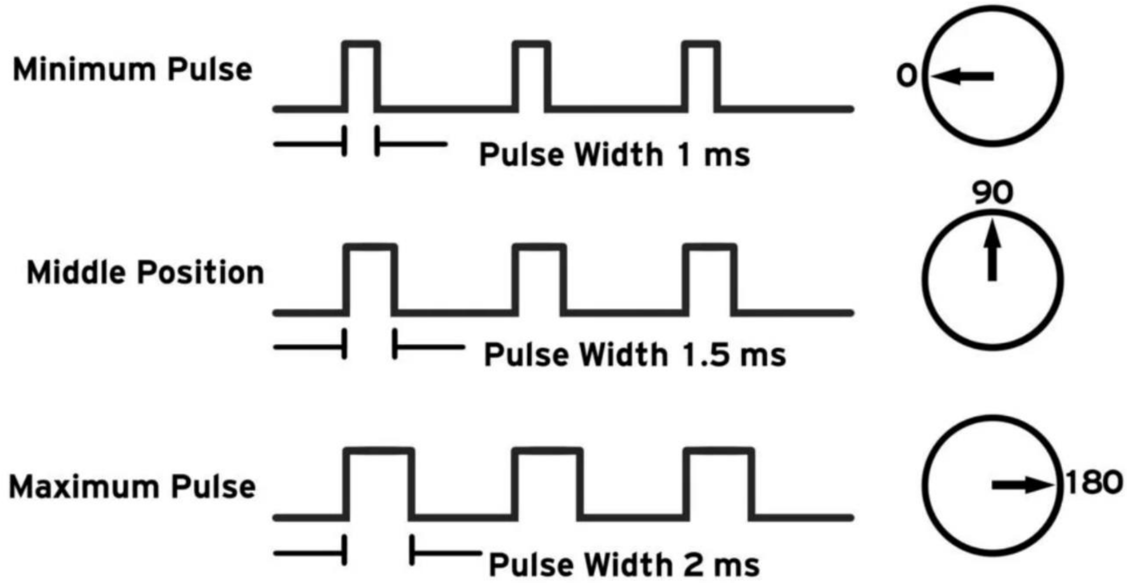
- Reset, Reload and Wake Up Interface



2.3.3 Timing Diagram for Motion Sensor [9]



2.3.4 Servo Motor Timing Diagram [7]



2.4 Calculations

Power Consumption of Sensor Unit:
ATmega = 1.5 [mAh]
Bluetooth Low Energy = 1.3 [microAh]
MSP430-PIR Motion sensor (Active Mode) (x2)= 220 [microAh] x 2 units = 440 [microAh]

Total power consumption = 1.9413 [mAh]

D batteries have 20500 [mAh] and we are planning to use 2 D batteries for a total of 41000 [mAh].

Therefore, 41000 [mAh] / 1.9413 [mAh] = 21119.86813 [hours] = 879.99 [days] = 2.4 [years]

3. Ethics and Safety

Regarding ethics and safety, we have identified a few potential ethics and safety risks. The first safety concern is the location of the PCB. Being an electrical device that will be present in rooms, there is a chance that the PCB could fry, and users could harm themselves. In order to protect against this, we must ensure that there are adequate measures in place against electrostatic discharge.

In addition, due to the multisystem aspect of our project, there are privacy considerations regarding the communication protocols between subsystems that we need to address in order to follow ACM's General Ethics Principles 1.6. For connection between the sensor and switch units, information is sent and received using Bluetooth. Steps should be taken to ensure that the Bluetooth unit cannot be eavesdropped on or be taken control of by a third party. Otherwise, they will have access to information on the comings and goings of people in their own homes. They would also be able to take control of the lights controlled by the switch unit. [3]

To secure our Bluetooth network, we can provide a pairing mode between the sensor units and utilize BLE's security mode 2. This is a service level security measure which will allow for authentication, encryption, and authorization of data sent between the devices. [4] In this way, third parties will be unable to connect with the sensor and switch units to receive information from them unless they have already previously paired with them. This will greatly mitigate the risk of unwanted connections as a user will need to be already in the apartment to activate the pairing mode of the devices.

For collaboration during the project, our group will adhere to IEEE Code of Ethics Rule 7: we will make sure throughout the entire design process that we will always seek honest feedback from one another. [5] In addition, being a project related to energy efficiency. Our project is following the ACM General Ethics Principle 1.1, which is to contribute to humanity and well-being, by helping the environment. [6]

References

[1] "How Much Money Can You Save by Turning Off the Lights?," Mr. Electric. [Online]. Available: https://mrelectric.com/blog/turn-off-lights-save-money. [Accessed: 14-Feb-2020].

[2] switch-bot.com. (2020). [online] Available at: https://www.switch-bot.com/bot [Accessed 24-Feb-2020].

[3] Mdpi.com. (2020). [online] Available at: https://www.mdpi.com/1999-5903/11/9/194/pdf [Accessed 14-Feb-2020].

[4] "Secure your Bluetooth wireless networks and protect your data," TechRepublic. [Online]. Available: https://www.techrepublic.com/article/secure-your-bluetooth-wireless-networks-and-protect-your-data/ [Accessed: 24-Feb-2020].

[5] "IEEE Code of Ethics," IEEE. [Online]. Available at: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 14-Feb-2020].

[6] "The Code affirms an obligation of computing professionals to use their skills for the benefit of society.," Code of Ethics. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 14-Feb-2020]

[7] "How Does a Servo Work?," ServoCity.com. [Online]. Available: https://www.servocity.com/how-does-a-servo-work. [Accessed: 24-Feb-2020].

[8] Usriot, "[Datasheet] USR-BLE101 Datasheet," USRIOT. [Online]. Available: https://www.usriot.com/support/downloads/usr-ble101-datasheet.html. [Accessed: 24-Feb-2020].

[9] Olimex, "MSP430-PIR," Olimex. [Online]. Available: https://www.olimex.com/Products/MSP430/Starter/MSP430-PIR/. [Accessed: 24-Feb-2020].