Modular Light Control System

ECE 445 Design Document

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1. Introduction

1.1 Objective

Modern home automation has been popular lately thanks to the internet, which wirelessly pulls the strings so we do not have to. People love convenience and simplicity, which the internet provides. However, with convenience comes a cost.

Smart light systems can take time, expertise, and much money to install. Our goal is to design an affordable, modular, wifi-capable sensor system solution in order to automatically control zonal lighting and help lessen power consumption. The system will be easy to install with minimum effort applied and little to no professional help required. It should be able to detect movement and human presence by sensor fusion between a passive infrared (PIR) sensor and an amplified microphone, and to change specified and grouped lights. Sensor fusion will be beneficial in reducing false negatives in a case where the room is occupied and the PIR sensor does not detect movement, the microphone may detect sounds made by the occupants. Having multiple sensors can also eliminate false sensor positives, in cases such as where the HVAC system might trigger the PIR, in order to improve accuracy. One potential reach goal would be having a user interface to easily control sensor and switch groupings and policies and to add new sensors.

1.2 Background

If you've ever been in a room with motion sensing lights, you may be familiar with how frustrating it can be when the lights turn off whilst you're still occupying the room. You have to periodically stand up, move around, possibly even wave your arms, and go back to where you were. What if the room is very large and you want to control a set of lights in a certain portion of the room where the switch is far away? Who would want to move across a large room every twenty to thirty minutes?

Other systems require a hefty initial investment since they require multiple pricey smart switches all around the house, the majority linked together with a required standalone smart hub for control. Each switch can cost upwards of $50 [1], and hub, potentially up to $100 [2]. Outfitting an entire house may run over one thousand dollars! [3] In some switches, they are limited by having the sensor mounted on the switch itself, which can be potentially far from the lights.

Our system will address these issues by being cost effective and not requiring any major rewiring other than replacement of switches. The modularity of the sensors and the ease of mounting (using 3m double sided tape) will allow for the sensors to be at any location. Our system will also be able to group multiple sensor units to one or more switches using an app based user interface. Once setup, the system will work in the background with no required human intervention, unless the user overrides the sensors by a manual toggle on the switch.

1.3 High-Level Requirements

- Modularity to add and adjust the switches and sensors without requiring any professional help or tools
- Zonal Lighting through grouping of sensors and switches which can be changed with ease.
- Run the microcontrollers in the sensors using an interrupt driven approach in order to reduce power consumption

2. Design
2.1 Block Diagram

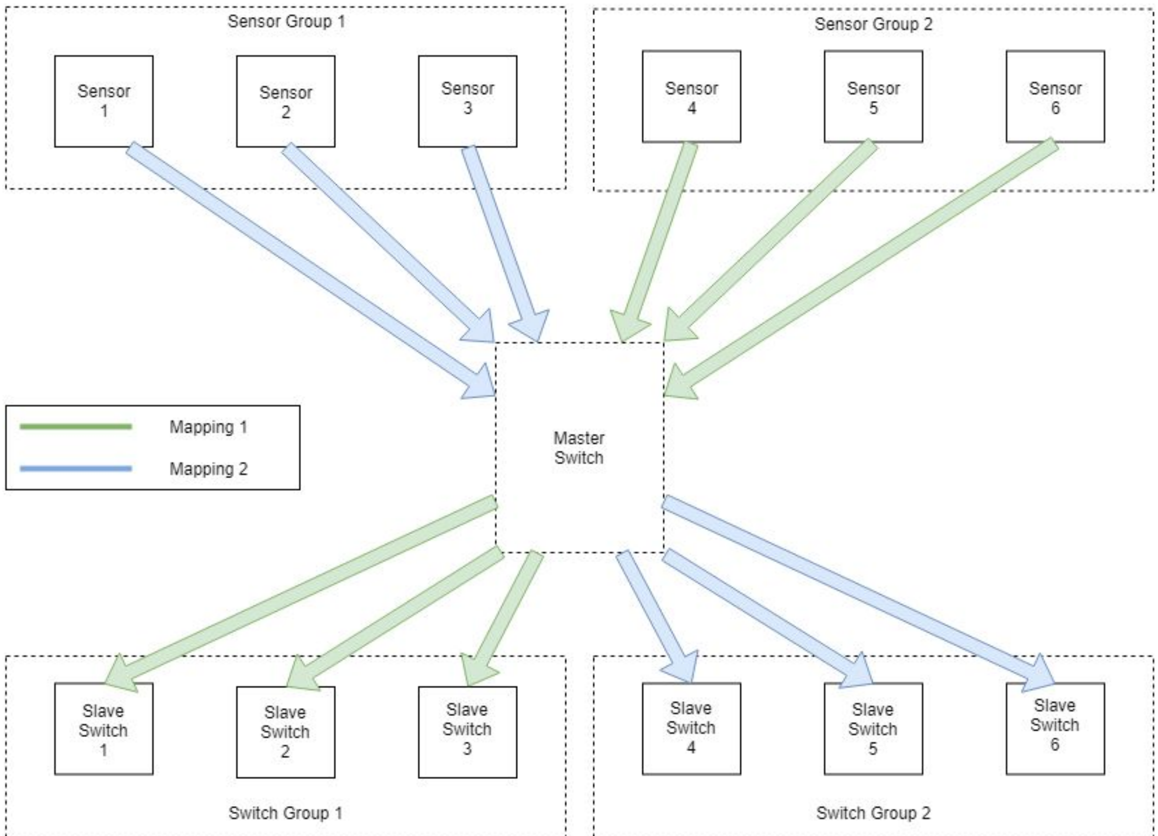

Figure 1

Switch Subsytem

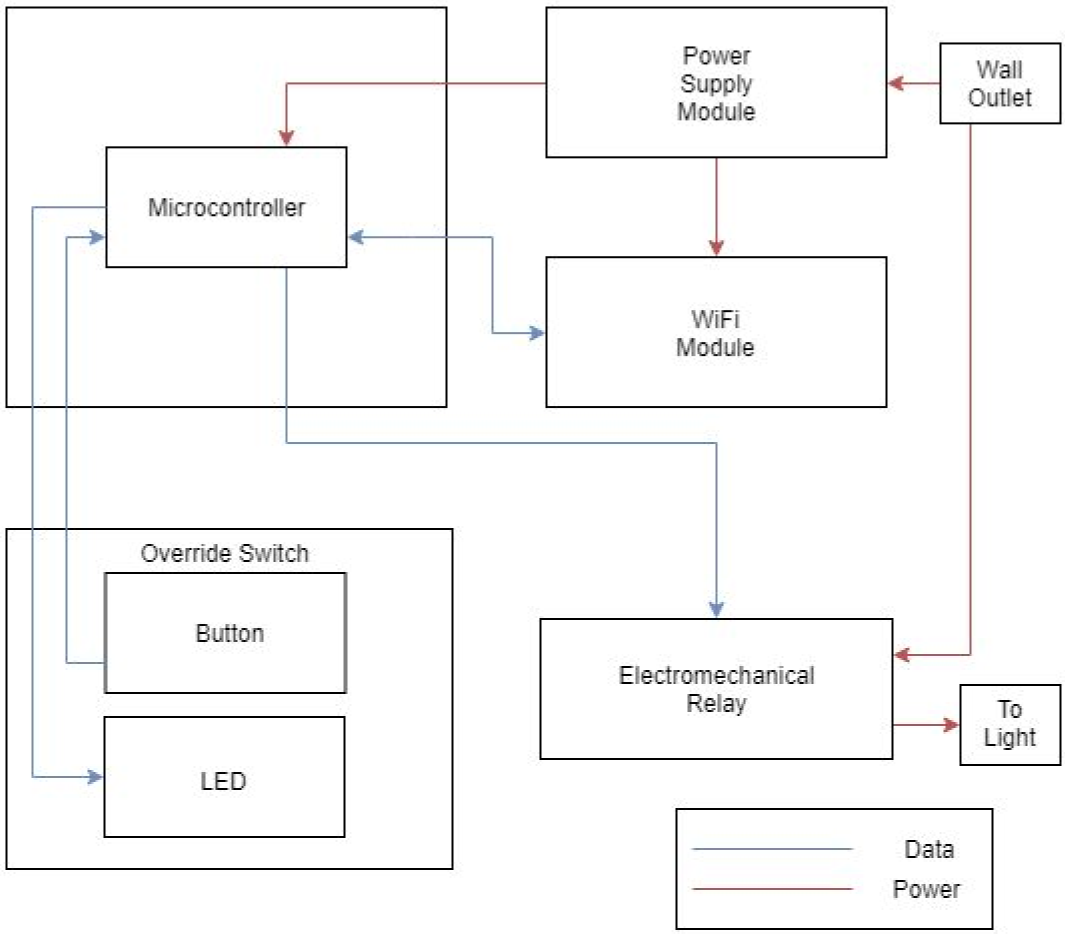

Figure 2: Switch Subsystem

2.2 Physical Design

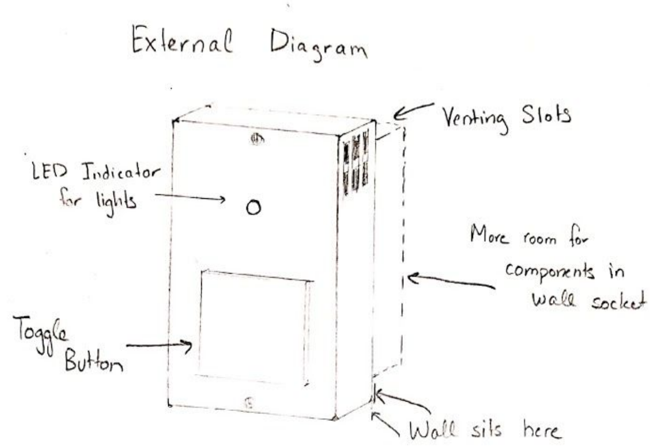

Figure 3: External Diagram

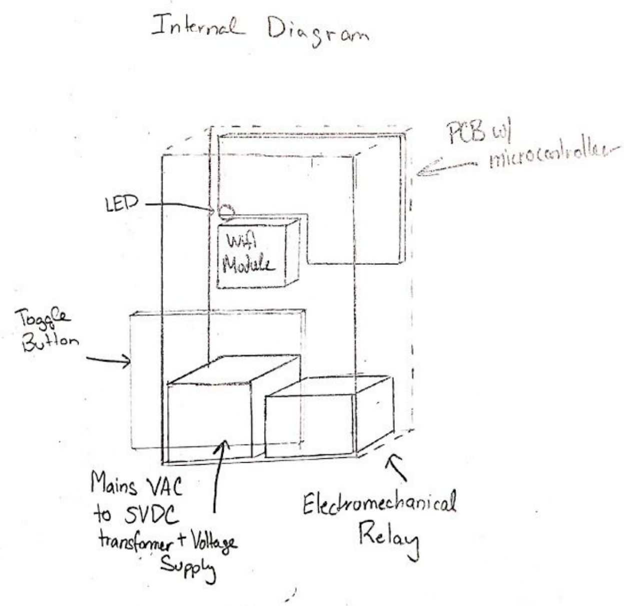

Figure 4: Internal Diagram

2.3 Block Design

2.3.1 Functional Overview and RV Table

2.3.1.1 Active Bandpass Filter

The microphone outputs a maximum RMS voltage of 0.398 V [4] and will thus need to be amplified before inputted into the Microcontroller. Along with this as the microphone output will be used to detect human voice, we will pass it through an appropriate band pass filter. The amplifier output must reach the peak to peak voltage of Vcc for maximum granularity in audio sensing. The filter must range from 85 Hz to 255 Hz, which is the fundamental frequency range of human voice.

No.	Requirements	Verification
1	Must filter the input signal with a -3dB bandwidth of 85Hz ± 10 Hz to 255Hz ± 10 Hz (the frequency range of human voice)	A voltage signal generated by a signal generator at 1.126V peak-to-peak (max output of the microphone) at the filter input must output 0.8 V ± 0.1 V at both 85 Hz and 255 Hz
2	Amplifier must amplify desired signals by proper gain of 2.9315 ± 0.1	A voltage signal generated by a signal generator at 1.126V peak-to-peak with a frequency of 177Hz at the filter input must output 3.3V ± 0.113V as recorded by an oscilloscope

Table 1

2.3.2 Circuit Schematics

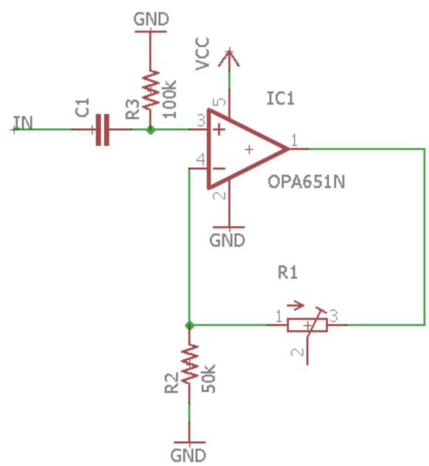

Figure 5: Audio amplifier circuit schematic

2.3.3 Calculations

2.3.3.1 Amplifier

Our microphone outputs a maximum RMS voltage of 0.398 V [4]. Our voltage into the atmega must have a peak value of $\frac{V_{cc}}{2}$ with a $\frac{V_{cc}}{2}$ in order for the analog pin to have its maximum possible input granularity while still maintaining the tolerances of the input. We calculate these values with a supply voltage of 3.3V. Our gain must be as follows.

$$A_v \equiv \frac{V_{out,peak}}{V_{in,peak}} = \frac{V_{cc}/2}{V_{in,peak}} = \frac{V_{cc}/2}{\sqrt{2}V_{rms}} = \frac{1.65V}{\sqrt{2}*0.398V}$$

$$A_v = 2.9315\ \frac{V}{V}$$

Therefore, our amplifier must have a gain of 2.9315. The feedback amplifier shown in figure 5 has a generalized gain of

$$A_v = 1 + \frac{R_1}{R_2}\,.$$

Therefore, our amplifier must have

$$\frac{R_1}{R_2} = 1.9315\,.$$

We will use an R2 value of 50k and a potentiometer for R1 for the sake of fine tuning.

2.3.3.2 Viewing Angle

To calculate the viewing range of our sensors, we take into account the viewing angle of the sensors and the height of the ceiling.

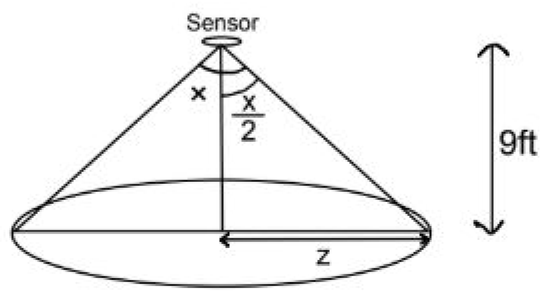

Figure 6: Viewing range diagram

Observing figure 6, x is the total viewing angle of the sensor, z is the radius of the detection zone, and we assume an average ceiling height of 9 feet. Given these values, we can calculate the z value as

$$z = 9 * tan(\tfrac{x}{2})\,.$$

3. Cost and Schedule

3.1 Cost Analysis

3.2 Schedule

4. Safety & Ethics

The electromechanical relay in our device will be connected to wall outlet power through one of its pins and will be conducting this wall power in its active state. This will pose a safety risk during our own testing procedures and during installation by any consumer. We would like to market this device as easy to install, but we will make the shock hazards abundantly apparent and will encourage support by others more familiar with the dangers for those who are entirely unfamiliar with rewiring electronics in order to maintain #1 of the IEEE code of ethics - “to disclose promptly factors that might endanger the public” [5]. We intend to include descriptions of proper safety practices regarding mains power with our product, and we will approach our design and test using the same safety practices. We will be following the OSHA standards for power safety [6]. Our ground and power rails on our device will be clearly marked so that polarities are not switched. When rewiring the circuitry, the power to the device will be off. In testing, we will use a ground-fault circuit-interrupter and insulating gloves to ensure no significant electric shock. We will use the “one hand rule” with one hand in pocket when working with the relays and transformers [7].

Since our device connects the modules through wifi, an ethical and safety concern arises with the possibility of unauthorized users who would be able to gain access to the network and control the lights manually and/or retrieve the sensor data to detect a person’s presence in the building in order to use this information for malicious intent, directly infringing upon #9 of the IEEE code of ethics - “to avoid injuring others, their property, reputation, or employment by false or malicious action”[5]. In order to prevent this, we will have identifying data associated with the sensor boards that will be encrypted along with the data read from the sensors, and this ID will be required for the switches to act upon the given command. We strive to take advantage of the utility of wifi while also accounting for the associated safety concerns.

5. Citations

[1] Amazon, ‘GE Enbrighten Smart Light Switch’, 2019. [Online]. Available: https://www.amazon.com/GE-Repeater-Extender-SmartThings-14291/dp/B01M1AHC3R/ref=sr_1_6?s=hi&ie=UTF8&qid=1550517975&sr=1-6&keywords=smart+switch+hub

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[3] Cnet, ‘5 Things To Consider Before Installing Smart Lighting’, 2018. [Online]. Available: https://www.cnet.com/how-to/things-to-consider-before-installing-smart-switches/

[4] https://www.invensense.com, ‘ICS-40180’, 2015. [Online]. Available: https://www.invensense.com/wp-content/uploads/2015/02/DS-000021-v1.22.pdf

[5] Ieee.org, "IEEE IEEE Code of Ethics", 2019. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: Feb 7, 2019].

[6] osha.gov, “Occupational Safety and Health Standards Subpart S: Wiring design and protection”, 2019, [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.304. [Accessed: Feb 7, 2019]

[7] UC Irvine, “High Voltage Electrical Safety Program”, 2015, [Online]. Available: https://www.ehs.uci.edu/programs/safety/hvoltageAppendixB.pdf. [Accessed: Feb 7, 2019]