ECE 445

Spring 2020

Senior Design

House Light Sensing System

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1 Introduction

1.1 Objective

It is very easy to accidentally leave a light on in the home when you are either going outside or going to sleep. Whenever this occurs, a person's electricity bill can rise by a large amount depending on the amount of lights that were kept on and their duration. Our goal is to allow for the user to see what lights are on in their home and to be able to control those lights remotely. We aim to solve this problem by using a board that contains LEDs and switches. The LEDs indicate what lights are on in the home, and the switches turn off the light. To monitor whether a light is on we will create a light sensing module which will be mounted in close proximity to the light source. To control the light we will make a relay module that can turn off the light source.

1.2 Background

The concept of monitoring what lights are on in the home and being able to turn them off remotely is not a new concept. Numerous different brands of smart lights are on the market and each one can be monitored and controlled wirelessly by the user. The problem with this solution is that the bulbs are very expensive; for example, the starter kit for the Philips Hue bulbs which contains 4 lights has a price of 200 dollars [1]. Very quickly buying these bulbs and making an entire house's light system 'smart' can cost a lot of money. Our solution will allow for the user to monitor and control their lights at a much cheaper price. Along with this unlike smart bulbs our system is not tied to the bulb so if the bulb dies then the user can just buy a cheap bulb to replace the dead one without having to worry about wireless monitoring and control.

The way that our project differs from the previous group is that they proposed a solution using a sensor via a door hanger to indicate whether a light is on or off by utilizing a pressure device and a z-wave light switch. This is different to our proposed design which is a modular based approach using light sensor units across the whole house that communicate via a WiFi signal to control what lights are activated on the LED board.

The advantage of using the original solution to the project is that the lights will be automatically turned off when a coat is no longer on a hanger, while our solution just indicates to the user that a light is on in their home and it is up to the user whether to turn off that specific light. The benefit of our design is that the user can decide if certain lights need to be on, for example if in the past the user wants to turn off their child's room light if they go outside this may not be desired if their child chooses to stay home as the child's light will turn off when the hanger is manipulated. Also if it is hot outside the user will most likely not need to use a coat so they need to manipulate the hanger in a way to turn off excess lights.

1.3 Physical Design

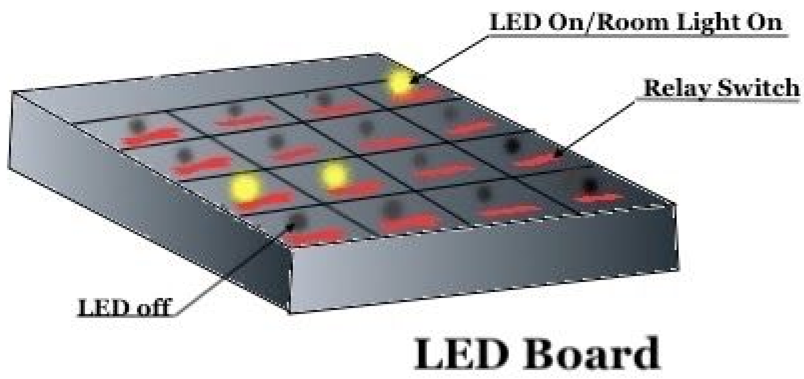


Fig. 1.3.1

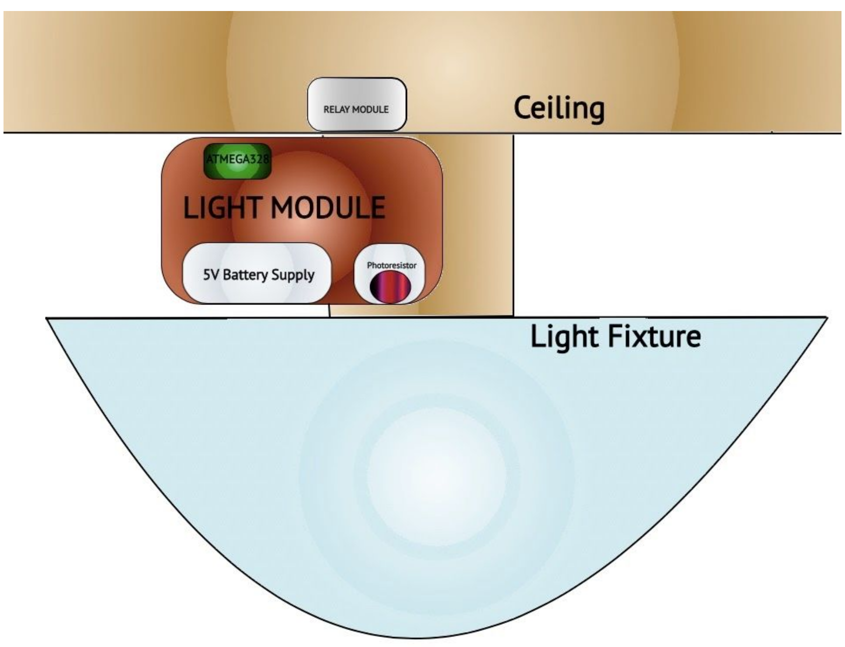


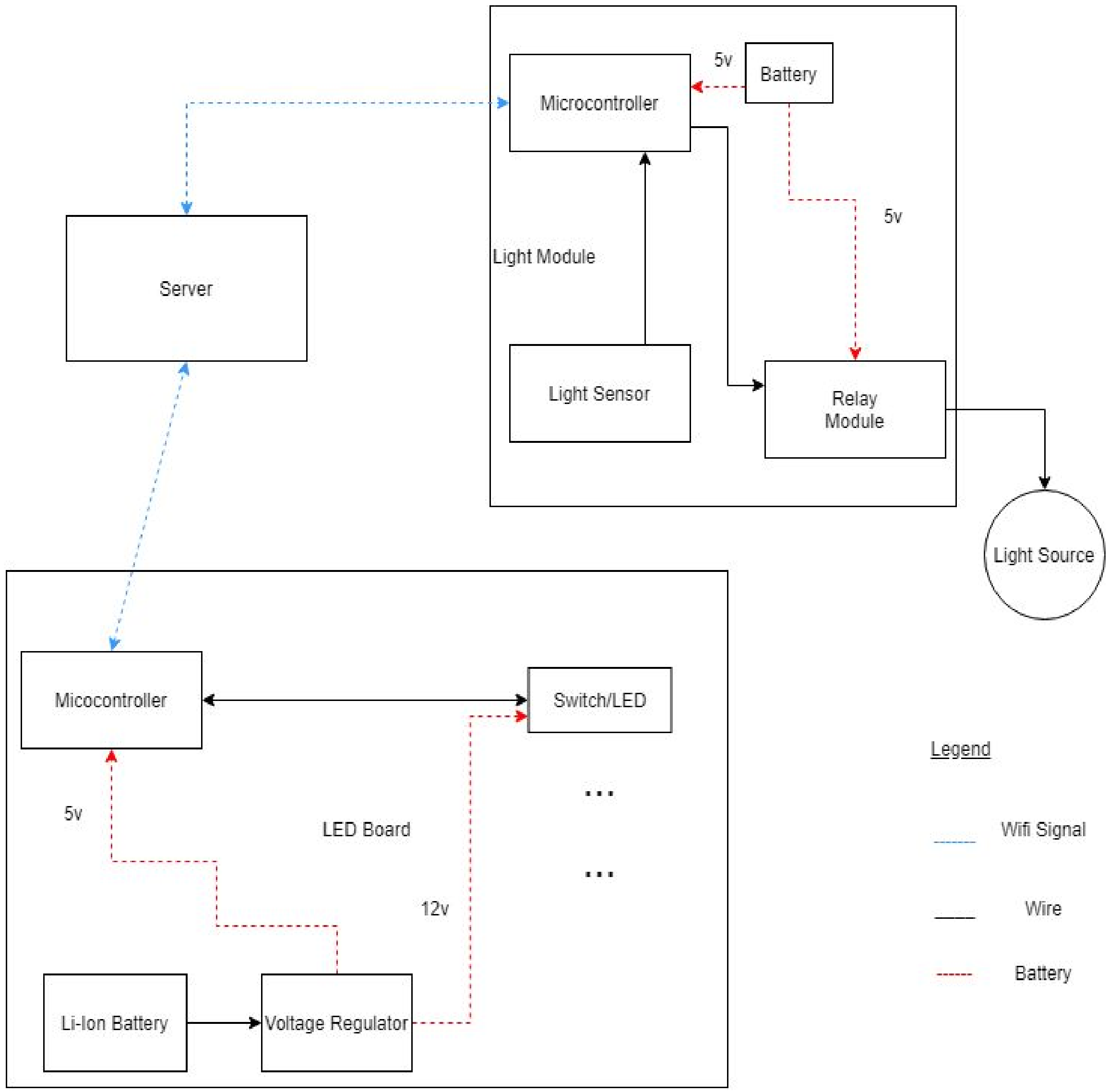
Fig. 1.3.2 Light Module

1.4 High-Level Requirements

- A Light Module signals a light is on only when the OPT3001 detects light of intensity equal to or greater than the luminosity threshold determined from its main light source.
- The microcontroller must be able to interpret light sensor data wirelessly and turn the correct board LEDs on or off.
- The User must be able to turn off individual lights from the LED board.

2 Design

2.1 Block Diagram



Light modules can be expanded similarly with the blueprint above adding another switch/LED and installing another light module on a Light Source

2.2 Block Requirements & Functional Overview

2.2.1 Control Unit

The control unit is responsible for taking in data from each of the light sensors and then stores this data and performs logic which gets sent to the LED board to activate certain lights on the device. Along with this the control unit also takes in information from the LED board on what light the user wants to turn off and stores this data and performs logic on it so that it can be used by the light modules which will then control whether the relay will be activated or not. The logic that will be performed on the server's data will be done through a python script.

2.2.1.1 Web Server

For the project we will use Amazon Web Services (AWS) ec2 as the server for the project. The server will contain the current state of each light module and then return true or false to the LED board which indicates if a light on the board needs to be illuminated. To do this the server will take in data from each light source and return true or false when the light fixture's status has changed. The server will also monitor if any switch on the LED board has been pressed and indicate this with a binary value. We will download the appropriate certifications for each module from the AWS website along with the public and private key.

Requirements	Verification
1. The AWS server will be able to monitor values and update these at set intervals.	1. We will make a test circuit using the wifi module and arduino along with a photoresistor. We will create test code that returns the resistance value of the photoresistor and uploads it to AWS. We will then verify that this value is on the page.

2.2.2 Light Module

Light modules are responsible for determining the status of a light and communicating on/off light source data wirelessly to the server. Additionally, a module receives relay commands from the server and communicates those commands to the relay module.

2.2.2.1 Light Module

Each room's main light source will have its own light sensor module. Individual Light Modules consist of a wifi-module (Atmega328), and an OPT3001 Digital Ambient Light Sensor [8]. The ATMEGA will be powered using 5V portable batteries. A TC1262-3.3VDB Voltage Regulator [12] will power the light sensor. The design must work for both day and night. Sunlight and natural light during the day should not affect the light sensors. In order to meet these conditions, the OPT3001 will be enclosed in a plastic casing directed at the light source for a normal-angle incidence of light. Placing the device close to the room's main light source will make sure the room light is the main source of luminosity for the light sensor.

Once powered the light sensor will be able to communicate data, the current lux level, to its microcontroller. The Atmega will then communicate this data to the server.

Each light module has a wired connection to its corresponding relay module. If the user requests a light to be shut off, the server will communicate this information to the correct light module. The light module then sends the appropriate signal to the relay.

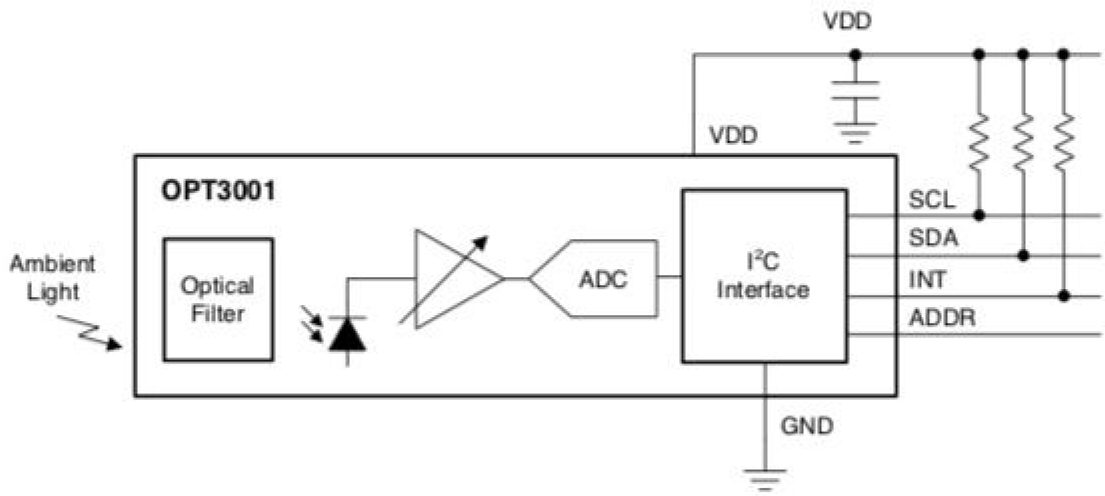


Fig. 2.2.2.1 OPT3001 Ambient Light Sensor

Requirement 1: The OTP3001 must be able to detect the lux level of the light source during both day and night conditions.
Requirement 2: The light module must be able to communicate information from the server to its relay module.

Requirements	Verification
1. Luminosity Threshold With an FOV of 15 degrees the	1. (1) Measure the output of the room during daylight conditions with the

luminosity threshold is high or low enough to accurately detect whether a light is on or off during both day and night conditions. 2. OPT3001 Sensing Range The light sensor can detect levels ranging 0.01 to 20000 lx.	main light source off. Record the data. (2) Secure the module to the light source at a normal incidence angle. (3) Measure the output during daylight conditions with the main light source off. Record data and make sure daylight levels do not reach the minimum luminosity threshold. (4) Measure the output during daylight conditions with the main light source on. Record data and make sure the light source reaches the minimum luminosity threshold. (5) Measure the output during nighttime conditions with the main light source off. Record data and make sure light levels do not reach the minimum luminosity threshold. (6) Measure the output during nighttime conditions with the main light source on. Record data and make sure light levels do reach the minimum luminosity threshold. 2. (1) Connect the OPT3001 to a 1.6-3.6 V DC power supply. (2) Measure light levels outside on a clear, bright day. These conditions should reach maximum lux values in our range. Measure light levels in a dark room. Record the data. (3) Using a torch light, illuminate the sensor at various incidence angles. Record the data.

2.2.3 Relay Module

The relay module is a relatively simple subsystem. This subsystem only contains a relay which will take in information from the web server. The way that the relay module takes in data from the server is from the light module which will have a wired connection to the relay module which contains information on if that particular light will be turned off.

2.2.3.1 Relay

The relay will be installed by the user to the light that they want to control. Once this is done then the relay will take in input from the web server. The only time that this occurs is if the user presses a switch on the LED board. When this occurs the relay will deactivate so that the light will shut off. We will use the Tolako 5v relay module [4] for the project due to how it is compatible with the ATMega IC in the light module. Along with this the relay can take up to 220v AC at 10 amps which can control lights. We will configure the light so that it is connected to the normally closed end of the relay. Due to this when the relay receives a high input the light will turn off.

Requirements	Verification
1. The relay must be able to handle 120 Volts AC. 2. When desired the relay must be able to switch a load off when activated and on when deactivated.	1. Using a function generator we will generate a 120v sinusoidal wave, which will imitate the input to a light source, and we will input one end into the middle pin of the relay. We will also input GND to the control pin. Using a voltmeter we will verify that the voltage at the NC pin is 120v AC. 2. For this the configuration will be similar to verification 1 the main difference is that we will use an arduino pin to output high to the control pin of the relay and verify that the voltage at the NC pin is much less than 120v.

2.2.4 LED Board

The Led board will have an led for each light in the house that a light module has been installed. As well as containing a switch that will enable the user to turn on or off a light in the house without physically going there. A microcontroller will be utilized in order to wirelessly communicate that a light must be turned on or off to a server.

Requirement 1: A wireless signal must be sent when the switch is activated or deactivated.
Requirement 2: The led and switches and microcontroller closest to the led board must be powered by a small portable battery that supplies 5 volts for the microcontroller.

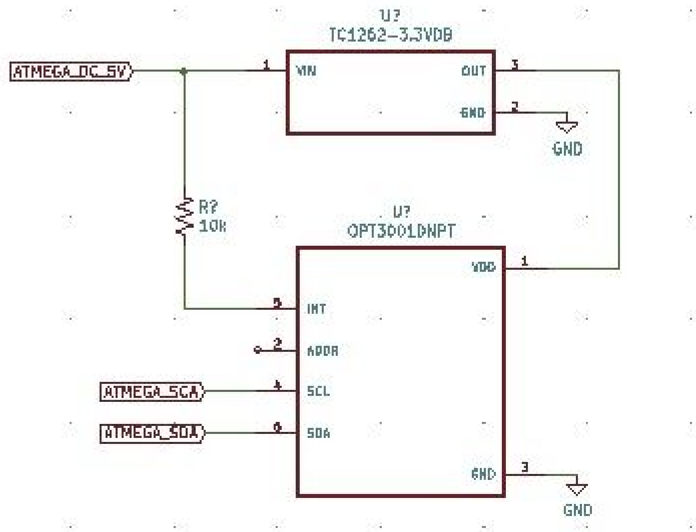
Requirements	**Verification**
1. A wireless signal must be sent when the switch is activated or deactivated 2. The led should change when there is a response from the server saying that the light was changed without using the led board's switch.	1. Using python, we will utilize print statements to check whether the wifi module and switch are properly sending a message to the server. 2. We will test this by turning on/off the corresponding light without the board and first check if the light module is sending a signal to the server appropriately, then check whether the led board's wifi module is transceiving this signal properly.

2.3 Risk Analysis

The main risk of this design is that our wireless communication is an integral part in the functionality because it needs to successfully communicate back and forth from led board to server and then to each light sensor, and in reverse direction as well. Another section that might cause significant risk to our project is our installation of each light sensing module onto an existing bulb/lamp in the home. This area is a challenge because there is a possibility that if not careful we may short circuit a component and cause the existing light to be ruined.

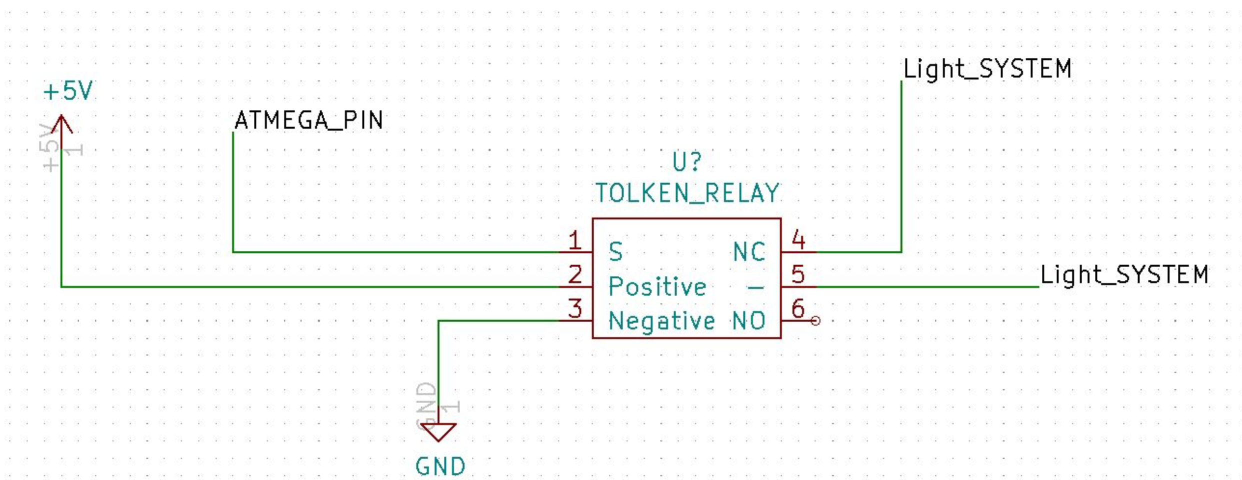
2.4 Schematics

2.4.1 Light Module



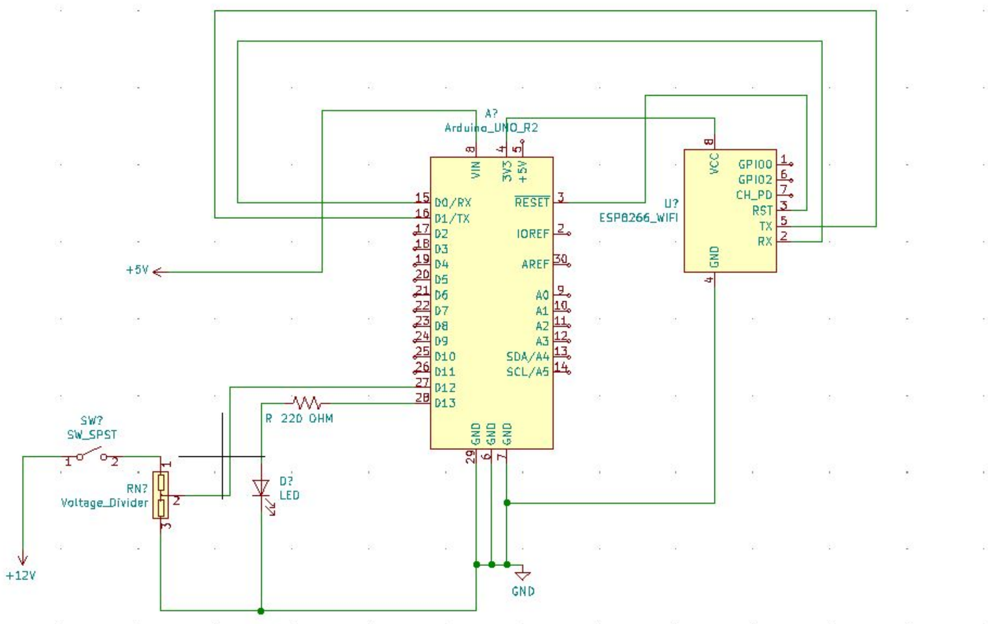
2.4.2 Relay Module

The relay module is used to control a light fixture. This device takes in input from the microcontroller that is in the light module, thus the two systems are connected via three wires. The three wires transmit data, power, and ground to the relay. As stated above we will use a Tolako 5v relay.



2.4.3 Led Board Schematic

The Led board schematic relies primarily on the esp8266 wifi module to communicate with the ec2 server. The switch is connected to a 12 volt battery and uses a voltage divider circuit to convert the voltage from 12v to 5v to allow the connection to the digital pin on the atmega328p. The led requires no such division and connects to a digital pin directly.



2.5 Software

The software will involve the use of a EC2 instance through aws services that will host our python3 script.

Pseudocode:

We will be using three primary signals to accomplish our software goals.

Each Switch and LED will be associated with a number and will be True/False variables.
Signal 1: LIGHT - signal comes from the Light module, depending on photoresistor

Signal 2: SWITCH - signal comes from the LED Board, depends on switch state

Signal 3: LED - signal sent to the LED board from server to switch on

EC2 server:

Case 1: Light is turned on/off without use of led board

```
if(LIGHT):
    Send signal to Led Board to change the LED signal to be True,
    which turns on the led indicator on the board.
elif(NOT LIGHT):
    Send Signal to Led Board to change the LED signal to be False,
    which turns off the led indicator on board.
```

Case 2: Light is switched on/ off from LED board

```
if(switch_num):
    Send signal to Light Module to change SWITCH signal to True,
    effectively signaling the Relay to switch on the light source.
elif(not switch_num):
    Send signal to light Module to change SWITCH signal to False,
    signaling relay to switch off the light source.
```

Led Board Microcontroller:

```
Case 1: led_num signal received from server on some change.
    if(led_num):
        Turn on the led indicator on board.
    elif(NOT led_num):
        Turn off the led indicator on board.
```

Light Module Microcontroller:

```
Case 1: Photoresistor detects light:
    if(detects_light):
        Send signal to server that LIGHT is true
    Else:
        Send signal to server that LIGHT is false
```

2.6 Tolerance Analysis

2.6.1 Light Sensing Accuracy

A Light Module signals a light is on only when the OPT3001 detects light of intensity equal to or greater than the luminosity threshold determined from its main light source. The varying lux levels between light sources should not affect the functionality of our design. Ideally the sensor will only detect light from its main light source and it will not be affected by varying daylight conditions in the room. Light from night conditions is negligible, however, we need to prevent daylight from interfering with sensor reading.

According to [11], average light levels in a home range from 500-1000 lx. On a clear day light levels from a window may be 25-30 lux in the middle area of a room. Setting the minimum luminosity threshold of the OPT to be 350 lx in a bedroom with a light source of 450 lx gives a normalized response of 0.778. This is within tolerance since the OPT3001 has a normalized response of 0.96 at $\pm 15°$ and the sensor should not detect lux levels below 336 lx.

2.6.2 Window Casing Calculation

The OPT3001 has a field-of-view of approximately $\pm 45°$, where 50% or more of the incident light is detected [10]. Since our design is a targeted application, a smaller FOV can be used. To keep outside light from reaching the sensor, the device should be situated so that the main light source is at a normal incidence angle to the sensor. We are able to adjust the window casing for the OPT3001 so that its FOV is $\pm 15°$. This should prevent detection of luminous flux from outside sources. Below is the window casing calculation.

Relevant equations and variables obtained from [10]:

- $W = (SensorWidth(XorY)) + 2 * (WFOV + \Delta W)$
- $WFOV = h' * \tan\Theta1$
- $h' = h - hs$
- $\Theta1 = \pm FOV°$
- $\Delta W = t * \tan\Theta2$
- $\sin(\Theta2) = \frac{n1}{n2} * \sin(\Theta1)$
- $\Theta2 = \arcsin(\frac{n1}{n2} * \sin(\Theta1))$

h_s = sensor height above the PCB, typically 0.38 mm [8]

h = product casing height above the PCB

W = width of window

W_{FOV} = window dimension defined by FOV angle and distance from sensor

ΔW = window dimension defined by light bending as a function of window refractive index and thickness

N_1 = refractive index of material between sensor and bottom of window (air)

N_2 = refractive index of window material

t = glass thickness

Sensor X = measurement (in mm) of sensor in the X direction [8]

Sensor Y = measurement (in mm) of sensor in the Y direction [8]

Θ_1 = angle from surface normal to the incident light ray

Θ_2 = angle from surface normal to the incident light ray in material of refractive index N_2

System Level Requirements:

- Desired FOV is ±15°
- Thickness of window is 1 mm
- Height from the PCB to the bottom of the window (h) is 5 mm

- Index of refraction of the window material (N2) is 1.5
- Sensor Width X is 0.49 mm, Sensor Width Y is 0.39 mm

Prototype Design Requirements:

- $\Theta 1 = 15°$
- $h' = 5\text{ mm} - 0.38\text{ mm} = 4.62\text{ mm}$
- $WFOV = 4.62\text{ mm} * \tan(15°) = 1.238\text{ mm}$
- $\Theta 2 = 9.936°$
- $\Delta W = 1\text{ mm} * \tan 9.936° = 0.175607\text{ mm}$
- $Wx = (0.49\text{ mm}) + 2 * (1.238\text{ mm} + 0.175607\text{ mm}) = 3.317\text{ mm}$
- $Wy = (0.39\text{ mm}) + 2 * (1.238\text{ mm} + 0.175607\text{ mm}) = 3.217\text{ mm}$

3 Project Differences

3.1 Original Project Solution

The original project sought to automate light operation via a coat hanger which would turn off its connected light fixtures when the hanger is no longer holding anything. To accomplish this the hanger had a pressure sensor, delay circuit, and a Z-wave hub. Each light fixture that was connected wirelessly to the hanger was controlled by a Z-wave switch. Thus when the user takes an item off the coat hanger the pressure sensor will read a low value which will then activate the delay circuit. After a set amount of time the Z-wave hub will interact with the various Z-wave switches and turn off each light.

3.2 Differences in Approach

The past project used a coat hanger to turn off every connected light when the hanger is no longer holding an item. Our solution varies in the sense that we are using a board that tells the user exactly what lights are on in the home via LEDs and labels, which the user would have to make. This board also contains switches that allows the user to toggle on/off that certain light. The past project used a Z-wave hub which then controlled Z-wave switches in order to automate the light fixtures. In our project we are using AWS which stores the status of each light module, via the wifi module in each light module, and uses this to transmit to the LED board. The AWS system for the project also takes in data from the LED board, via the wifi module in the board, on what switch was pressed and it will use this to turn off that particular light fixture. Essentially the past project sought to limit light usage by having a main kill switch for each connected light while we have decided to have independent control over each light that is connected to our light module and relay.

3.3 Improvements and Trade-Offs

The main improvement with our project is that our design allows for the user to know what lights are on in the home and they can control each one independently. Due to this if the user is leaving the home but they know that a family member is in an upstairs room then they can turn off each light but that one. In the past project when the user lifts their item off the coat hanger then each connected light gets shut off, which can be annoying if someone was in that room. Also our LED board can be placed anywhere in the home whilst a coat hanger can only be placed in closets. Because of this the user can control their lights from their bedroom or in their garage. Another issue with having a coat hanger is that using a coat is not always necessary so when a person leaves their home they might forget to manipulate the hanger since they do not need a coat in July.

A major tradeoff in our design is that after being switched off the light fixture cannot be activated by a room switch until the user switches the light on from the LED board. This is due to the relay configuration which will turn off the light when the board’s switch is pressed. Because of this, if the switch is pressed then the light can only be controlled by the board until the user presses the switch to the off position. This can be annoying as the user may forget if they recently controlled a specific light with the board and they may think that their light is broken when it really is not.

4 Cost and Schedule

4.1 Cost

Part	Cost
Tolako 5v Relay (x5)	27.5
ATMEGA328p IC (x6)	12.48
OPT3001dnpr (x5)	6.585
LEDs	0
Various Resistors	0
12v Battery	19.00
5v Batteries (x5)	129.95
ESP8266 Wifi Module(x6)	39.3
TC1262-3.3VDB (x5)	2.55
Test Light fixture (x1)	29.99

Housing for light modules and relay (x5)	To be determined
Housing for LED board (x1)	To be determined
Total	**267.26**

Name	Hourly Rate	Hours/Week	Total Over 7.5 Weeks	Total x 2.5
Julia Luzinski	$40.00	10	$3,000.00	$7,500.00
Rajiv	$40.00	10	$3,000.00	$7,500.00
Amrit	$40.00	10	$3,000.00	$7,500.00
			Total	$22,500.00

4.2 Schedule

Week	Rajiv	Amrit	Julia
4/13	Design Document, designing led board circuits.	Setup EC2 server and run EC2 server certifications on test wifi module. Purchase a light fixture for testing.	Design Document, Research electrical components for light modules and order parts
4/20	Design Review	Make a test circuit involving an arduino, ESP8266, and relay to verify that the relay module can be controlled wirelessly by EC2 server. Connect relay to test light fixture.	Design Review
4/27	Test wifi module and make sure connection can be made, then work on	Assist with OPT3001 testing and verify that the current light module circuit will be	Mechanical part design and OPT3001 testing

	testing sending data back and forth from server to led board	able to send data to the EC2 server. Verify that the current LED board test circuit can interact with the server.	
5/4	Test led board circuit, switch and leds work properly.	Begin writing python script.	Finalizing schematic and ‘Early Bird’ PCB design
5/11	Assist with python code.	Finalize python script	Mechanical and electrical part testing for the LED Board.
5/18	Work on pcb design.	Begin testing the script on the current PCBs for the LED board and light modules, verifying that the system works as expected.	PCB prototype 2
5/25	Testing software	Make any necessary adjustments to the code as needed.	Test PCB prototype 2
6/1	Testing hardware	Begin to set up each of the five light modules and the led board with the server and verify that the system works as intended.	Finalize PCB design
6/8	Use if needed	More testing	Functional and implementation testing
6/15	Work on Report	Start the final report.	Begin working on the Final Report.
6/22	Final report and Final presentation	Work on final presentation and final report	Prepare Final Presentation and Final Report

5 Ethics and Safety

5.1 Ethics

Our design is in compliance with the IEEE Code of Ethics [2] and the ACM Code of Ethics and Professional Conduct [3]. To prevent any harm done to the user and the environment, as stated in ACM, code 1.2, and in IEEE code of Ethics, code 1, we will make our design process and the final product as sade as we can. Additionally we will strive to make the highest quality product that we can make which is in accordance with ACM code 2.1.

5.2 Safety

One issue that could occur would be if the LED board, light sensor module, or relay modules short. This would be a major issue since many of these devices handle high voltage and can potentially harm the user if they fail. For example if the light sensing module or the relay module short they could create a fire. As the number of sensors increases the potential for failure also will increase, so a major concern that we will work on is to make the modules as safe as possible so that this will not be a major issue. We will work on adding fuses wherever possible in the modules to avoid this problem.

The user is also responsible for installing the relay to their lighting fixture so there is an inherent danger where the user did not properly set up the relay module and this system may shock the user. Since the relay can control a 120 Volt device this shock can be deadly. For this reason the product should only be installed by people that have experience with installing electrical systems.

6 References

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[2] “IEEE Code of Ethics,” *IEEE*, Jun-2019. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 03-Feb-2020].

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