Modular Autonomous Light

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Team 11

Abstract

The Modular Autonomous Light seeks to provide a low-cost alternative to automatic light installation by way of augmenting a light switch box, as opposed to replacing it. The original solution to this problem sought to count the individuals in a room by detecting those entering/exiting with a pair of IR sensors, but would struggle to operate in a room with more than one entrance. Thus this model of the Modular Autonomous Light uses the number of detected cellular devices in the area, allowing it to work in rooms with multiple entrances or exits.

Contents

1. Introduction

1.1 Problem:

In commercial buildings with large rooms or offices, manual lights can be left on even when the room or office is not in use, which wastes power unnecessarily. Installing automatic lights that operate off of movement is one solution that currently exists for this problem, but the installation requires directing mains power to the switch, which requires a licensed electrician and has an accompanying expense in conjunction with the occupancy sensing system, which can cost 400$ or more per room for installation. To make an autonomous light switch, we want to design a switch that can be applied without the need for redirecting any wires within the building in order to operate a room's lights.

1.2 Solution:

By using Wi-Fi MAC Address tracking, the device will be able to count the number of devices connected to the Internet within the vicinity of the switch. A sniffer program, run on an ESP 8266 Wi-Fi module, will fetch information of local devices (MAC address and connected AP) and APs (SSID and MAC address). This information will be sent to a microcontroller chip, which will operate a connected motor to flick the light switch on if we detect a device connected to the local AP, and flick it off if there are no devices connected to the local AP. To improve energy efficiency, a phototransistor will test the ambient lux prior to flicking on the light switch, determining if the light provided naturally/elsewhere is sufficient for the workspace or gathering area. For commercial areas, we can assume that the number of people in a room is approximately equal to the number of devices tracked, due to the assumption that an individual will have their cell phone on them if they go to a location such as a school or office. These individuals are recognized as a unique MAC address on his/her phone. This deviates from the original solution done for this project, as its method of detecting occupants relies on detected cellular devices over a head count of those entering a room by means of the PIR sensors. This makes it more operable for large rooms with multiple entrances, and less prone to error caused by occupants entering/exiting the room in bulk.

1.3 High-Level Requirements

- Achieve within 1 m error (the error being the average Euclidean distance between the estimated location and the actual location) when locating clients to estimate occupancy of the room
- The light must be switched within 1 minute depending on occupancy of the room, and so long as detected illuminance is below 250 lux
- The device can last for at least 24 hours without need to switch batteries.

1.4 Visual Aids

The visual aid of the project is shown in the following figures. In Figure 1, we demonstrate the layout of our device in real life. It would be installed next to the light switch so the horns attached to the motor are able to switch the lights by sliding the light toggle. A closer view of the device is shown in Figure 2. In addition, the layout of different units inside the device is demonstrated in Figure 3.

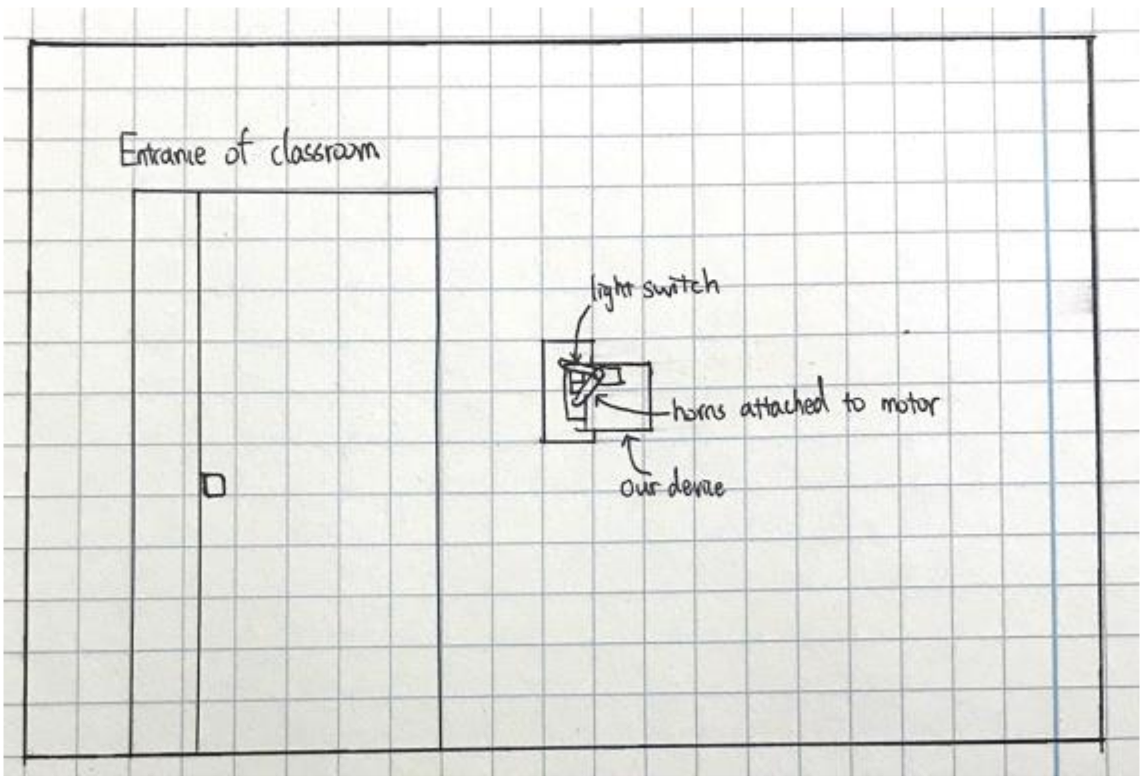

Figure 1. Visual Aid of the product on the wall

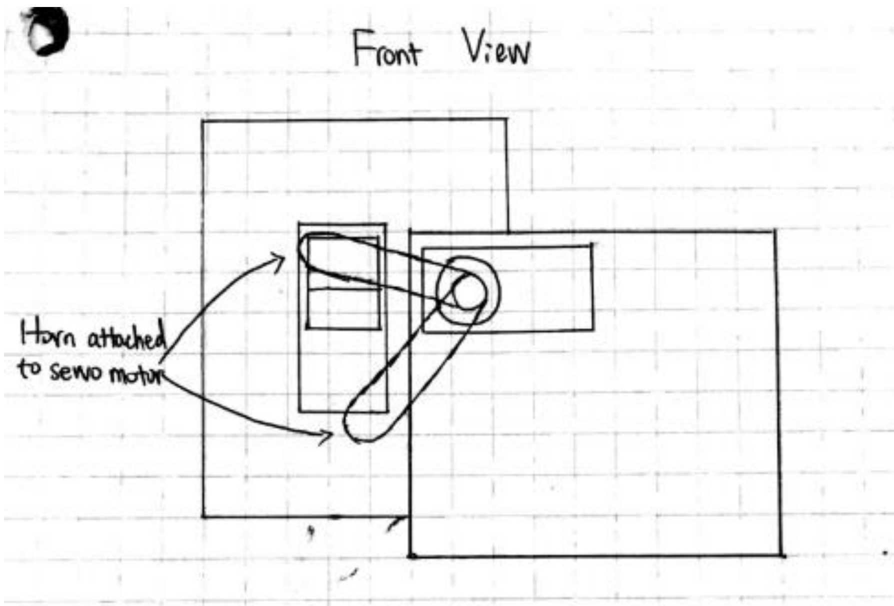

Figure 2. Physical Design(Front view of device)

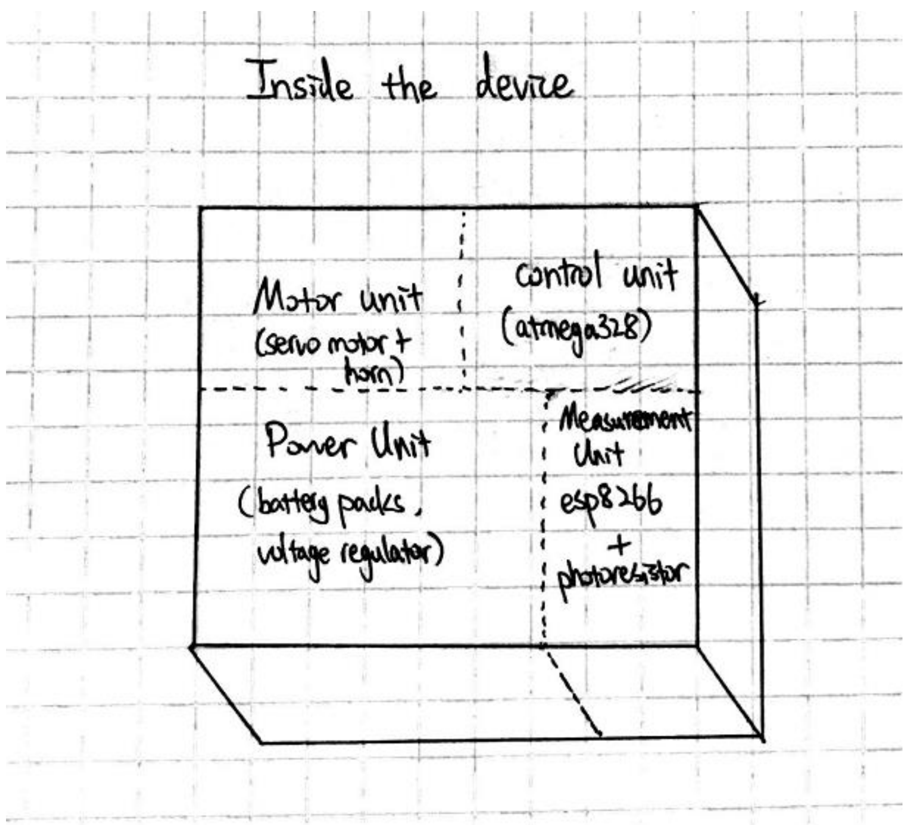

Figure 3. Physical Design(structure inside the device)

1.5 Block Diagram

Below is the block diagram of our design. As shown in Figure 4, there are four major units in our device. In the power unit, we use a 6 V D battery pack to provide power to the servo motor and phototransistor. We also implement a switch regulator to regulate 3.3 V from the batteries and supply power to the microcontroller chip ATmega328P and the Wi-Fi module ESP8266. The ATmega328P communicates data via UART with ESP8266, sends control signals to the servo motor via wire connection, and reads current and voltage values of the phototransistor via wire connection.

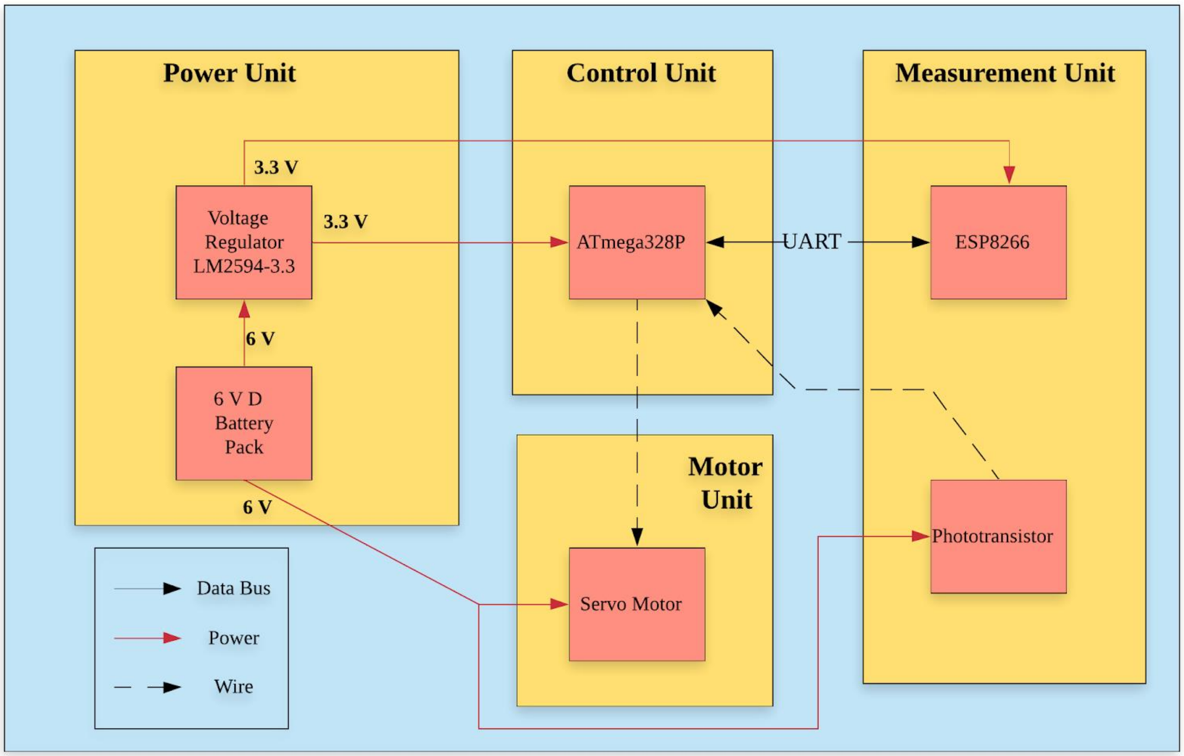

Figure 4. Block Diagram

2. Implementation Details and Analysis

2.1. Localization Algorithm - Andre He

Of our blocks, the piece that will pose the greatest problem will be the algorithm locating clients scanned by the Wi-Fi sniffer. This block will be used to improve sniffer's accuracy in scenarios in which devices are close to but not in the room. However, the correlation between signal strength and distance is affected by a large number of factors: non-uniform radiation pattern of the antenna, multi-path propagation (highly significant due to the short wavelength), scattering and path loss due to obstacles[1], etc. Finding and estimating the weight of each factor in our calculation is quite difficult and challenging. Accuracy estimation can really go wrong if the scenario has a unique setup we have not counted since scratch (edge cases).

To estimate the location of a client, we need first to measure RSS- or the Received Signal Strength. Our sniffer can read the RSSI of devices which we use to locate each client (x, y) based on its respective signal strength[2], as shown by an example in Figure 10 of the appendix.

Now knowing this data we can predict its location by localization algorithms (Equation 1.1) with centroid/weighted centroid (Equation 1.2, 1.3). To locate the client at the averaged location, multiply locations (x, y) with centroid/weighted centroid[14].

$$\text{Average location: } \left(\sum_{i=1}^{N} w_i x_i, \sum_{i=1}^{N} w_i y_i\right) \qquad \text{(Equation 1.1)}$$

$$\text{Centroid: } w_i = \frac{1}{\mathrm{N}} \qquad \text{(Equation 1.2)}$$

$$\text{Weighted centroid: } w_i = \frac{SNR_i}{\sum_{j=1}^{N} SNR_j} \qquad \text{(Equation 1.3)}$$

Despite its simplicity, this algorithm has a relatively high accuracy. We also need to select an estimated area representing the room where we install our device. The estimated area is required to know if a device should be registered to count room occupancy based on its location compared to the room space. We decided to implement a signal strength-based location estimation method using all the APs in one service area. The method is implemented in a known experiment from "*An effective signal strength-based wireless location estimation system for tracking indoor mobile users"*[3]. While assuming its assumptions, setup, data, calculations and conclusions are correct, we use its derived results to verify our first high level requirement. The experiment is as the following:

Assume a scenario in Figure 5, where a group of users carry their mobile devices which communicate with the APs in each service area, we set up a 4-point AP method to estimate the error of client localization using actual distances from AP to the sniffer (in this case it is the AP calibrator).

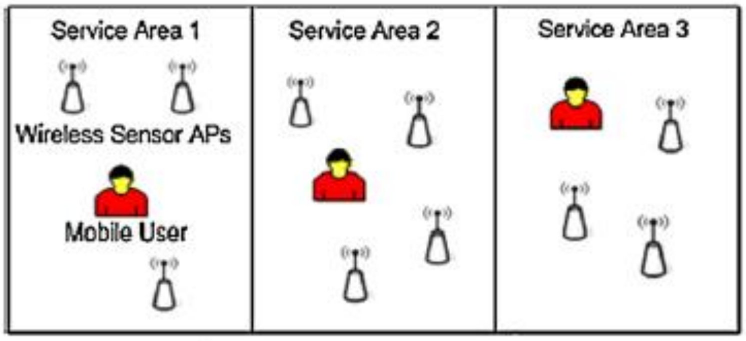

Figure 5. System architecture of the wireless location estimation system [3]

In one service area, to capture signal strengths at different distances, we assume that the device is in the position of the Calibrator at the height of desk level in Figure 6 and there are 4 APs at corners of the ceiling: AP1, AP2, AP3, AP4. The x ,y coordinates of each AP in units of meters are labeled next to each AP. The distances D1 to D4 were 4.3267 m, 2.6832 m, 7.2993 m and 8.0498 m respectively.

In a 5-hour session, with a scenario estimating with the constant set to be a value that gives the least average error, it is able to collect a dataset consisting of signal strength of each AP and render a plot (see Figure 11 in appendix) after calculating the results with Equation 1.1. The error can be as low as to be within 1 m (0.914m) considering a signal strength-squared euclidean distance relationship. Thus, high level requirement 1 (error within 1 m) is justified with the experiment.

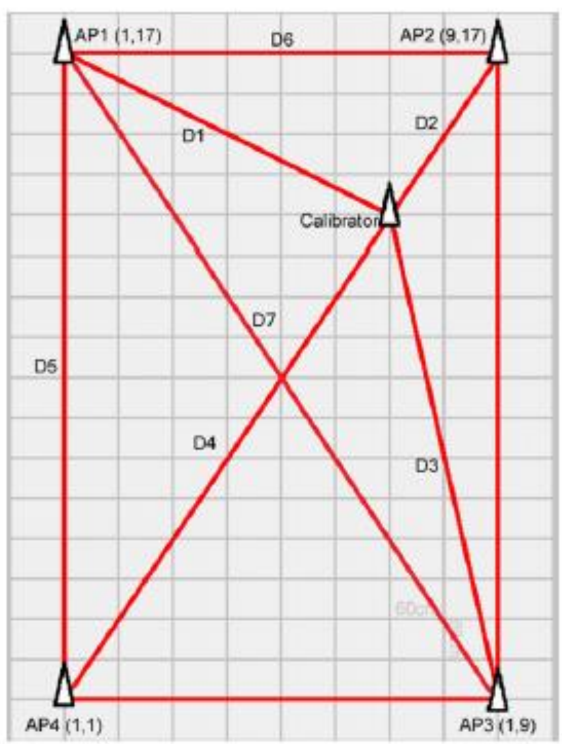

Figure 6. Experiment Setup

2.2. Wi-Fi Sniffer on ESP-8266 [4] - Andre He

A sniffer program is used in our design to track devices and their connections to APs. The Wi-Fi sniffer scans a list of devices and AP MAC addresses. The occupancy in a room is thus able to be determined by the number of known clients connected to a specific access point. Since people may carry more than one device, we do not count the actual number of people in a room.

```
void setup() {
  Serial.begin(57600);
  '''Set to promiscuous mode'''
  wifi_set_opmode(STATION_MODE);
  wifi_set_channel(channel);
  wifi_promiscuous_enable(disable);
  '''Set up promiscuous callback'''
  wifi_set_promiscuous_rx_cb(promisc_cb);
  wifi_promiscuous_enable(enable);
}

void loop() {
  channel = 1;
  wifi_set_channel(channel);
  while (true) {
    '''increment if no new device registered'''
    nothing_new++;
    if (nothing_new > 200) {
      nothing_new = 0;
      '''switch channel to read more devices'''
      channel++;
      '''scan channel 1-14'''
      if (channel == 15) break;
      wifi_set_channel(channel);
    }
    '''delay for readings'''
    delay(1);
    '''printout'''
    if ((Serial.available() > 0) && (Serial.read() == '\n')) {
      for (int u = 0; u < clients_known_count; u++) print_client(clients_known[u]);
      for (int u = 0; u < aps_known_count; u++) print_beacon(aps_known[u]);
    }
  }
}
```

Figure 7. Sniffer.ino

First we need to set ESP-8266 on operation mode to connect to a Wi-Fi network. Then select a WiFi channel (initial value at 1) to improve WiFi coverage. Disable promiscuous mode to set promiscuous callback (which is setup in another header file) and re-enable promiscuous mode.

After finishing setup we can check if any device scanned is new to our list. If it is registered then we increment its channel (reset to 1 at 14) and count the number of clients known connected to an AP. If the device is new then we register the client and increment the number of clients known. In addition to the number of clients known, we use the centroid method to estimate their respective locations and only count those in the room where our device is installed.

```
int register_beacon(beaconinfo beacon)
{
  ''' reset flag '''
  int known = 0;
  for (int u = 0; u < aps_known_count; u++)
  {
    '''set flag if AP known'''
    if (! memcmp(aps_known[u].bssid, beacon.bssid, ETH_MAC_LEN)) {
      known = 1;
      break;
    }
  }
  '''if AP new, increment AP count'''
  if (! known)
  {
    memcpy(&aps_known[aps_known_count], &beacon, sizeof(beacon));
    aps_known_count++;

    if ((unsigned int) aps_known_count >=
        sizeof (aps_known) / sizeof (aps_known[0]) ) {
      Serial.printf("exceeded max aps_known\n");
      aps_known_count = 0;
    }
  }
  return known;
}
```

```
int register_client(clientinfo ci)
{
  '''reset flag'''
  int known = 0;
  for (int u = 0; u < clients_known_count; u++)
  {
    if (! memcmp(clients_known[u].station, ci.station, ETH_MAC_LEN)) {
      known = 1;
      break;
    }
  }
  if (! known)
  {
    memcpy(&clients_known[clients_known_count], &ci, sizeof(ci));
    clients_known_count++;

    if ((unsigned int) clients_known_count >=
        sizeof (clients_known) / sizeof (clients_known[0]) ) {
      Serial.printf("exceeded max clients_known\n");
      clients_known_count = 0;
    }
  }
  return known;
}
```

Figure 8. Functions

Register_client and register_beacon record the detected clients and APs respectively. They count the number of known clients and APs, which determines if occupancy of the room changes.

```c
void promisc_cb(uint8_t *buf, uint16_t len)
{
  int i = 0;
  uint16_t seq_n_new = 0;
  if (len == 12) {
    struct RxControl *sniffer = (struct RxControl*) buf;
  } else if (len == 128) {
    struct sniffer_buf2 *sniffer = (struct sniffer_buf2*) buf;
    struct beaconinfo beacon = parse_beacon(sniffer->buf, 112, sniffer->rx_ctrl.rssi);
    if (register_beacon(beacon) == 0) {
      print_beacon(beacon);
      nothing_new = 0;
    }
  } else {
    struct sniffer_buf *sniffer = (struct sniffer_buf*) buf;
    //Is data or QOS?
    if ((sniffer->buf[0] == 0x08) || (sniffer->buf[0] == 0x88)) {
      struct clientinfo ci = parse_data(sniffer->buf, 36, sniffer->rx_ctrl.rssi, sniffer->rx_ctrl.channel);
      if (memcmp(ci.bssid, ci.station, ETH_MAC_LEN)) {
        if (register_client(ci) == 0) {
          print_client(ci);
          nothing_new = 0;
        }
      }
    }
  }
}
```

Figure 9. Promiscuous callback

Promiscuous callback in Setup() function (Figure 1). It receives the signals from both beacons and clients and parses data for main functions' implementation.

These are the most important functions in implementation. After running loop() function (Figure 1), the program generates a list of devices and APs with their respective MAC, channel, SSID(AP) and RSSI. Here is an example printout:

```
Type:        /-----------MAC----------/----------AP SSID---------/  /----MAC---/  Chnl  RSSI
 BEACON: <================ [                    TardisTime]  1afe34a08bc9    8     -76
 BEACON: <================ [                    xfinitywifi]  56571a0730c0  11   -90
 BEACON: <================ [                               ]  52571a0730c0  11   -91
 BEACON: <================ [                  ATTGH6Gs22]  1005b1d6ff90  11    -95
 BEACON: <================ [                  ATT4P3G9f8]  1c1448777420  11   -92
 BEACON: <================ [                  HOME-30C2]  5c571a0730c0  11    -91
 BEACON: <================ [                  ATT8Q4z656]  b077acc4dfd0   11   -92
 BEACON: <================ [                  HOME-B1C2]  94877c55b1c0  11   -94
 BEACON: <================ [                    HUXU2012]  0c54a5d6e480  6     -94
 BEACON: <================ [                     xfinitywifi]  0c54a5d6e482   6    -97
 BEACON: <================ [                     xfinitywifi]  0c54a5d6e481   6    -96
```

DEVICE: 18fe34fdc2b8 ======>[	TardisTime]	1afe34a08bc9	8	-79
DEVICE: 18fe34f977a0 ======>[	TardisTime]	1afe34a08bc9	8	-94
DEVICE: 6002b4484f2d =====> [	ATTGH6Gs22]	0180c2000000	11	-98
BEACON: <=============== [	HOME-01FC-2.4]	84002da251d8	6	-100
DEVICE: 503955d34834 =====>[	ATT8Q4z656]	01005e7ffffa	11	-87

2.3. Phototransistor Specifications and Setup - Brandon Noble

By exposing the KDT00030TR phototransistor to light through the front of the switch box, the room's lux can be measured through the current output by the phototransistor. Phototransistors are able to produce a higher current than other photodetectors, and are inexpensive both in cost and power usage. Using a phototransistor does pose the problem of differing output currents at the same lux for light sources with different peak frequencies. This would pose a problem if we expected a light source other than natural sunlight, which has a peak frequency near equal to fluorescent lighting, allowing us to use its data for the KDT00030TR as an expected current at the desired illuminance.

For the expected purpose of the modular autonomous light, the desired illuminance will be 200+ lux, in accordance to NOAO's recommended light level for office settings[5]. If connected to a 10k Ohm resistor, as shown in Figure 13, and using Figure 12's expected output current for 200 Lux of a fluorescent light, the expected voltage output will be ~0.3V, and an output current of 0.02mA. Since the circuit of the phototransistor is fairly simple, it is included in Figure 16 of the appendix that the input of the phototransistor is from digital output pin PD6 of ATmega328P and the output is connected to analog input pin PC5 of ATmega328P.

2.4. Power Unit - Ricardo Zeng

2.4.1 Battery

We are using 5 1.2V D batteries with a max capacity of 10000 mAh connected in series to provide 6 V to power up our motor unit and photoresistor. We choose D batteries because of its high max capacity and it can provide enough power for our design to last for at least 24 hours to satisfy our high level requirement.

2.4.2 Voltage Regulator

We are using LM2594 switch regulator to regulate 3.3 V from the batteries and provide power supply for the Atmega328p microcontroller chip and esp8266 wifi module. We chose LM2594 as our voltage regulator because it provides enough current output to our units. It also has a low dropout voltage since we are only using 6 V as our power supply. It also has a much better performance compared to a linear low dropout voltage regulator that it has approximately 77% efficiency rate at the providing 6 V input voltage. The switch regulator will share a PCB with the ATmega328P microcontroller since it regulates 3.3 V power to the microcontroller. The circuit schematics of the switch regulator is shown in Figure 14 in appendix.

2.5. Servo Motor - Ricardo Zeng

We chose to use a servo motor because it fits the best in the scenario of our design. Compared to dc motor, servo motor has less noise and it's easier to implement [6] because we don't need extra regulators to control the motor which would add more complexity to our circuit. Since we only need to turn the light switch on and off, we don't require a very precise rotation that we only need two angles to achieve our goal so we are not using step motors. In addition, a light-weight servo motor provides enough torque to flip the switch. In the current market, the weight of a toggle light switch is about 10 oz which is 0.2kg. Our device would be placed at a distance within 5cm so it requires 9.8 [m/s^2] * 0.2 [kg] * 0.05 [m] = 0.098 [Nm] = 1 [kg-cm] torque from the motor to flip the light switch. In addition, we want to flip the switch on and off so we will program the motor to turn to two desired angles. To control the angular position of the motor, we would need to vary pulses width between 1ms to 2 ms as shown in Figure 15 in appendix. Since the circuit of the phototransistor is fairly simple, it is included in Figure 13 of the appendix. The PWM pin of the servo motor is connected to PB0 of ATmega328P to control the pulse width of the motor and the servo motor is directly powered by the 6 V battery pack.

2.6 Control Unit ATmega328p

ATmega328 is used to build a standalone Arduino on PCB[7][8]. It is used for the purpose of turning on the servo-motor to flip the switch based on data collected from esp8266 and voltage value from the photoresistor. We also need a breakout board (SparkFun USB to Serial Breakout - FT232RL) to program ATmega328. The microcontroller chip is powered by 3.3 V regulated from the switch regulator mentioned in section 2.4.2. The circuit schematics of ATmega328P is shown in Figure 16 in appendix. In the circuit schematics, the motor and the phototransistor are connected to the I/O pins of ATmega328P and the servo motor is powered by the 6 V battery pack.

3. Conclusion

3.1 Implementation Summary

Hardware Components

The PCB shown in Figure 17 in appendix contains the microcontroller ATmega328P-PU, servo motor, phototransistor, and the voltage regulator. The connection of the pins are described in section 2.3, 2.4.2, and 2.5. The ATmega328P will set the pulse width of the servo motor to control the rotate angles of the horns attached to the motor to turn the lights on/off depending on data collected by the ESP8266. In addition, the ATmega328P will read the output current and voltage values of the phototransistor and determine if the surrounding luminance is enough.

Software Programming

We use Wi-Fi MAC Address Tracking by counting the number of devices connected to the Internet. A sniffer program (section 2.2) on ESP-8266 Wi-Fi module fetches information of devices and APs (type(client/beacon), MAC, SSID(only AP), channel, and RSSI). Then this information will be sent to the microcontroller chip. If there's more than zero devices connected to the AP, the microcontroller chip will send a signal to activate a motor to switch on the light. If the number of devices drop to zero as people may leave the classroom and the connection to the AP is lost, the microcontroller chip will send another signal to activate the motor to switch off the light. Please refer to section 2.2 for implementation of the Wi-Fi sniffer and its example output(printout).

3.2 Unknowns and Uncertainties

Due to the Covid-19 pandemic and the lockdown of campus, we are not able to test most of the hardware parts in our design because we do not have access to the labs. However, we still design the PCB for future testing if we can continue the project after the lockdown is over. Without access to the lab, we are not able to test the circuit of the voltage regulator because we don't have an oscilloscope to measure the voltage at home. In addition, we are not able to test the functionality of the servo motor and the usage of the battery pack because of limited time.

3.3 Ethics and Safety

Our design follows the IEEE code of ethics Rule 1: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment”[9]. A number of ethical issues arise from Wi-Fi tracking. Privacy, property and accuracy are three ethical issues we try to solve in the design of our project. The biggest concern of our design is definitely privacy issues. You can know someone’s location based on his/her device(s) as MAC addresses are scanned and picked up by the mini sniffer. This collection of individuals’ information can be used illegally, such as predicting his/her behavior to track individual daily movements. To follow the ACM Code of Ethics principle 1.6[10], we must respect the privacy of these data and reduce vulnerability risk. Therefore, we will use an SHA-256 hashing function from the SHA-2 family[11] to pseudonymised MAC addresses of personal devices and delete part of the digits of the hashed MAC address[12]. To avoid storing and holding user’s information, the sniffer deletes data entry (MAC address, channel, etc.) once a device disconnects from the AP. In addition, we will try to get consent from school/organization to access device information. This device will not provide data to any third parties to violate ownership of personal information in its testing, demoing, and completed product.

Accuracy is another concern that arises from Wi-Fi tracking. To ensure authenticity, fidelity and accuracy of data collected and processed, we will test our programs to minimize errors before releasing the product through the use of our Localization Algorithm[13], which will estimate the distance from the sensor that an individual’s device is. By using this algorithm, we’ll be able to determine if a detected cellular device is within the room or simply within the detection radius of the sensor.

Our testing and debugging techniques follow the IEEE code of ethics Rule 9, “to avoid injuring others, their property, reputation, or employment by false or malicious action”[14]. Working in an electronic lab is very challenging and dangerous, so we will always work in pairs and take care of each other in the lab to avoid possible false actions. We also finish lab safety training and understand the lab manual before we attend the labs and use the equipment. Before we test the motor to switch the light, we would use self adhesive bandage wrap to wrap the horn attached to the motor to avoid hurting someones’ finger while the horn is rotating. In addition, during our testing, we will use a thermometer to ensure different electronic parts in our device stay below safe temperature to prevent possible overheating. We will also connect resistors in parallel with certain ICs or voltage regulators when we do unit testing to avoid shorting the circuits and burning the ICs.

Furthermore, adequate ventilation during soldering and operating in, at minimum, groups of two when assembling any of the hardware/circuitry will be required to allow for one partner to be a responder in any accident that may occur due to an unforeseen incident while testing. Prohibiting one person from working on the device alone not only keeps the group as a whole safer, but ensures that the finished product is understood by each group member.

For better collaboration during the testing phase, our team will follow the IEEE code of ethics Rule 7[15], we adhere to "seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others". We will improve our project and fix possible errors with TAs' and professor's feedback and suggestions.

The primary goal of our project aligns with ACM Code of Ethics principle 1.1[16], which is "contribute to society and to human well-being". We save power in commercial buildings or teaching buildings by keeping the lights off when people forget to turn the lights off when they leave the rooms or when the luminance in the room is enough without lights on. Thus, proper testing will be carried out to ensure accuracy in the usage of a room, to keep a room from needlessly being lit, wasting more power than is being saved from the device being automatic. Furthermore, it must be shown that the passive power use of the sensors are insignificant against the power saved from the automatic light switch, so as to justify its use.

3.4 Future Project Improvements

In our design document, the estimated area is required to know if a device should be registered to count room occupancy based on its location compared to the room space. We decided to use a signal strength-based location estimation method using all the APs in one service area. The method is implemented in a known experiment from "*An effective signal strength-based wireless location estimation system for tracking indoor mobile users"*[3]. For future project development, we expect to set up our own experiment in school facilities to map out all APs in the building and draw zones for each restricted area to locate devices. We need to use an AP calibrator to measure its distances from each AP in the room then use the two-point signal strength model to determine AP's locations. This can improve the overall accuracy measuring occupancy. We will have a file containing all AP locations and a printout stored in a png file.

4. First Project Progress

ATmega328p board:

Circuit schematic (Figure 18 of appendix), PCB (Figure 19 of appendix). Designed to allow for maximum flexibility in design, with all input and output pins separated by different connector branches. The power connectors are separated from both, though one unused connector remains, as noticed in the schematic. The PCB design barely remains below the length and width restrictions, and retains all available pins, having been designed to have the ATmega328p mount soldered on in place of the ATmega328p. By making as little of the necessary circuit soldered directly to the board, the design becomes more adaptive to later changes.

XBee board:

Circuit schematic (Figure 20 of appendix), PCB (Figure 21 of appendix). The XBee board is, more specifically, the XBee mount board. Similarly to the ATmega328p, the object being soldered to the board is the XBee's mount, rather than the XBee itself, though this is less for adapting the board to changes, and instead for testing and debugging, as this was the expected problematic segment of our design.

LM1117 Voltage Regulator board:

Circuit schematic (Figure 22 of appendix), PCB (Figure 23 of appendix). Converts 4.5V to 3.3V, with unused connector. Designed for the handheld monitor.

TC1262 Voltage Regulator board:

Circuit schematic (Figure 24 of appendix), PCB (Figure 25 of appendix). Converts 6V to 3.3V, with unused connector. Designed for the patient's blood pressure sensor.

NE555 60s repeater board:

Circuit schematic (Figure 26 of appendix), PCB (Figure 27 of appendix). Uses an NE555 repeater board to generate a positive-edge trigger approximately once a minute. For use in activating the blood pressure sensor on the patient. The math behind what parts are used was described in the design doc, and thus for the sake of brevity will be left out as assumed.

5. References

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Appendix

Figures

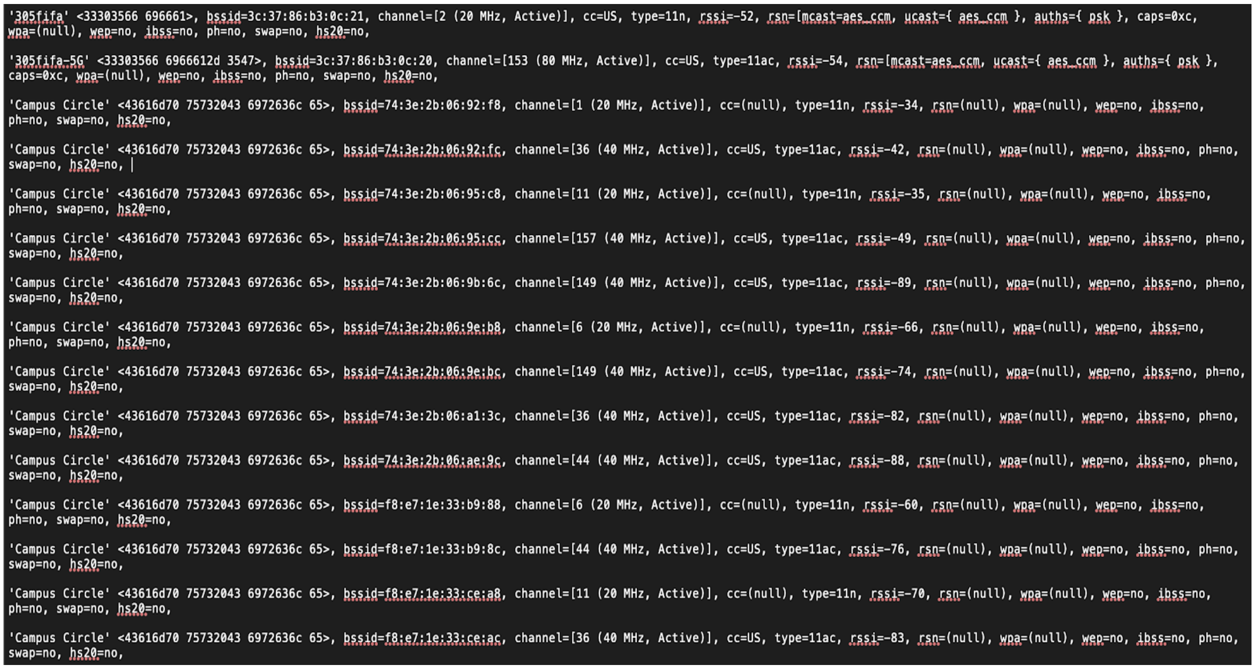

Figure 10. RSSI scan on MAC OS X

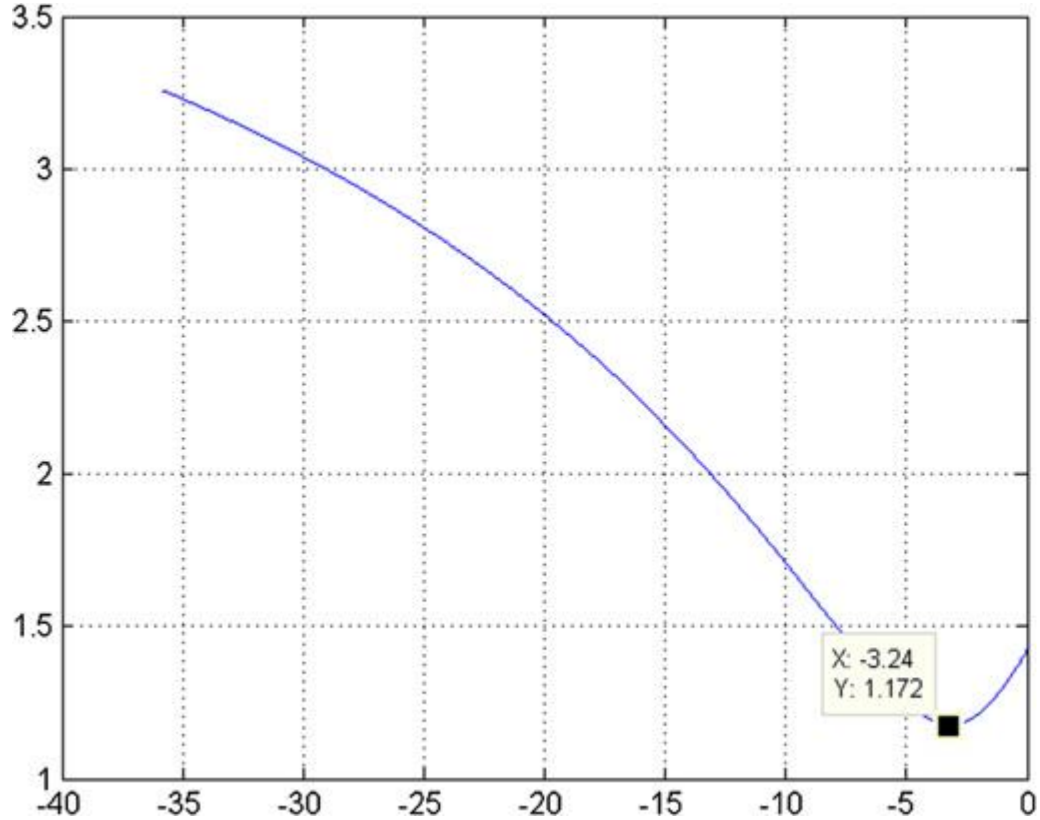

Figure 11. RSSI vs distance

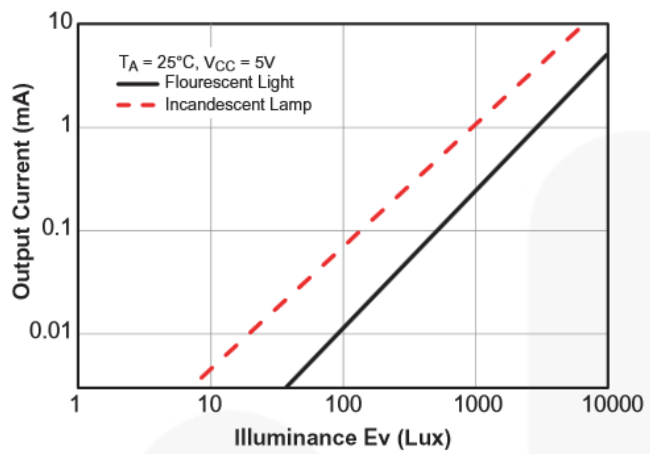

Figure 12. Output Current v. Lux for KDT00030TR

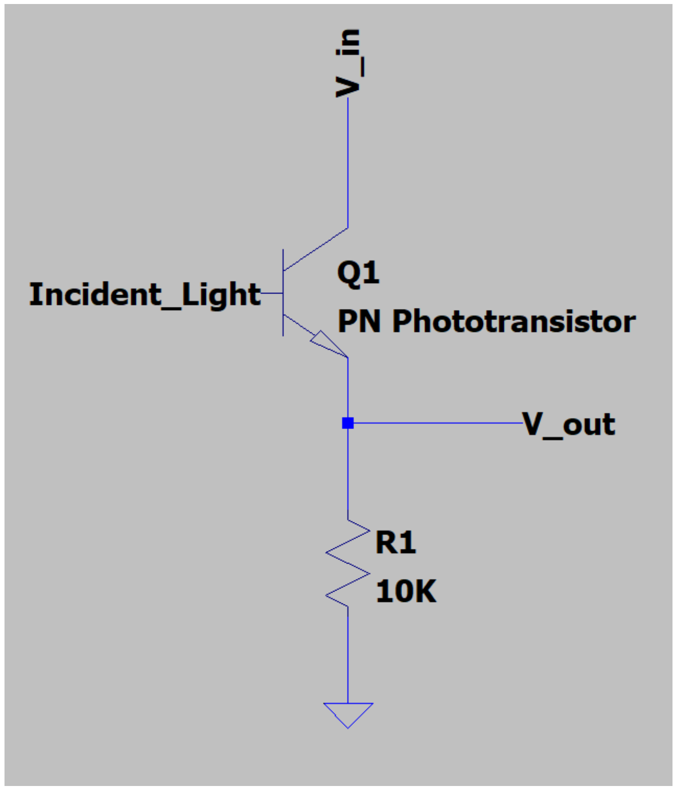

Figure 13. Photoresistor Circuit

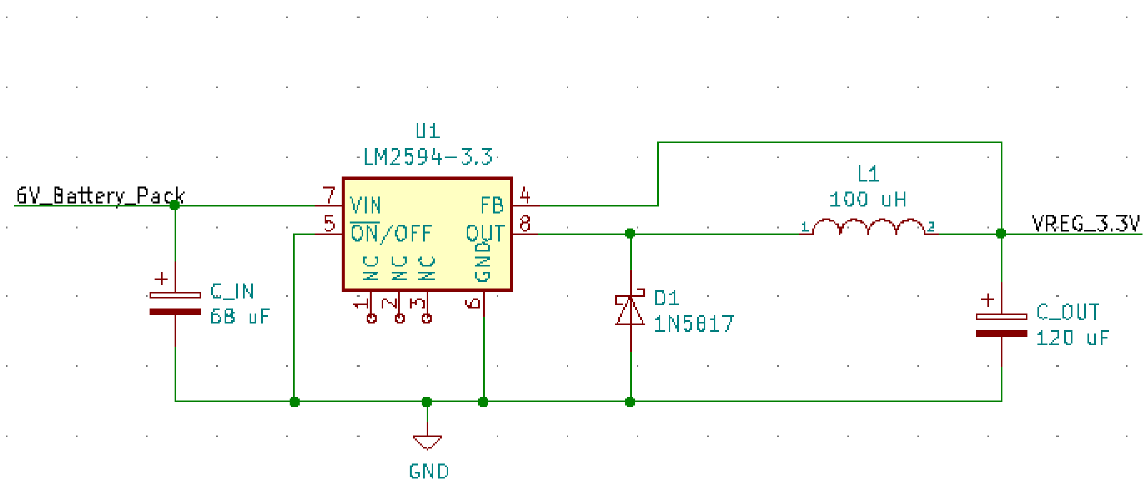

Figure 14. Circuit Schematics of Switch Regulator

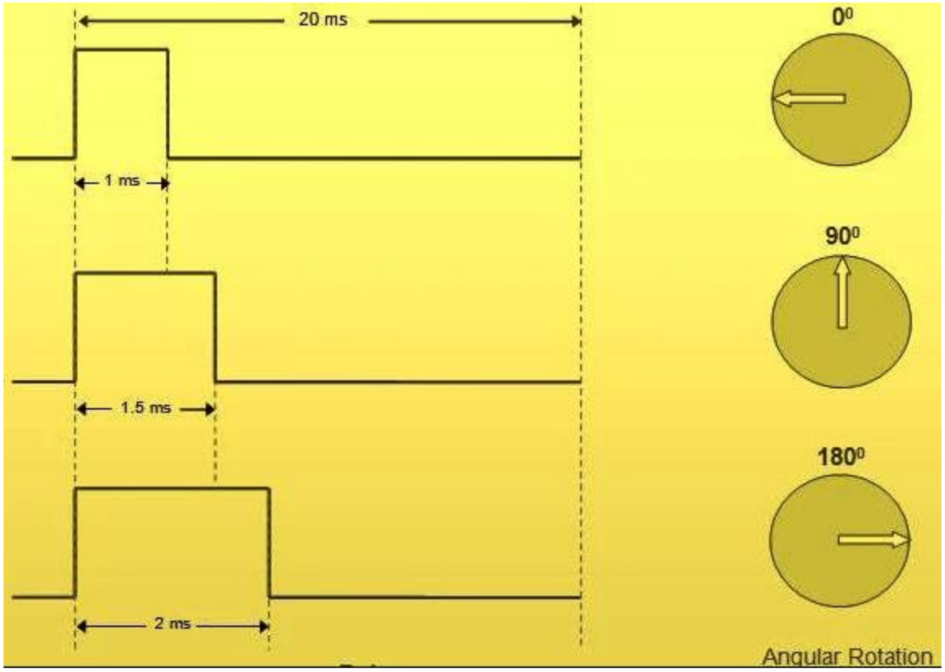

Figure 15. Pulse Width Timing Diagram

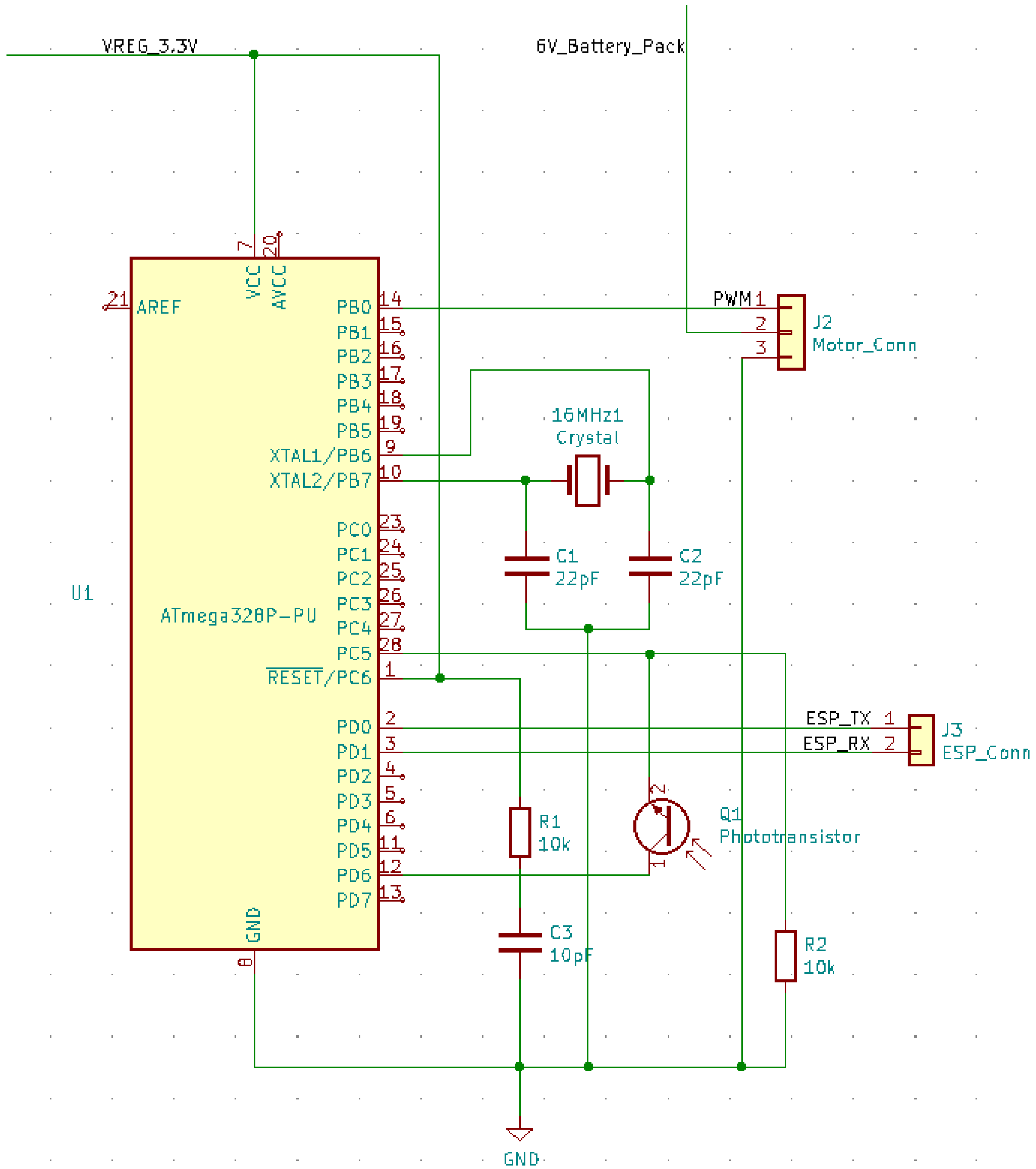

Figure 16. Circuit Schematics of ATmega328P, Servo Motor, and Phototransistor

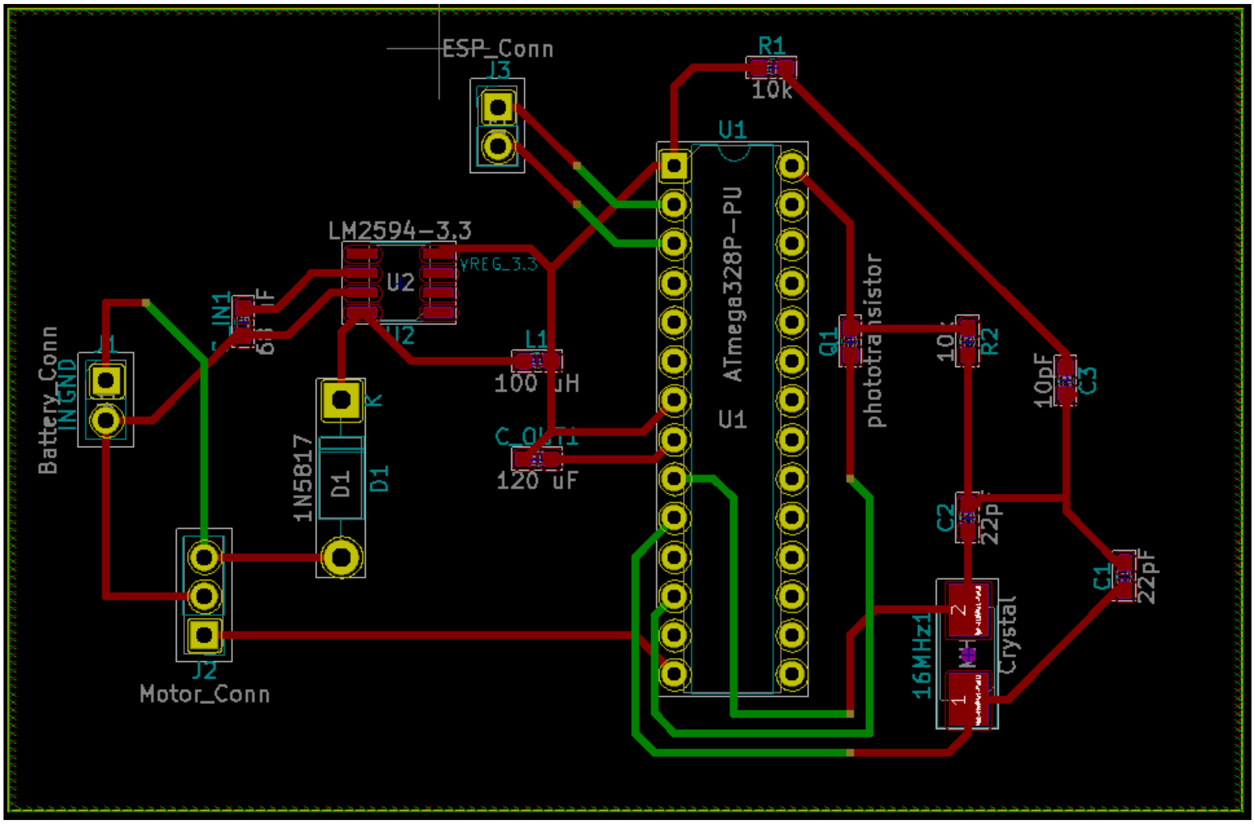

Figure 17. PCB design of the second project

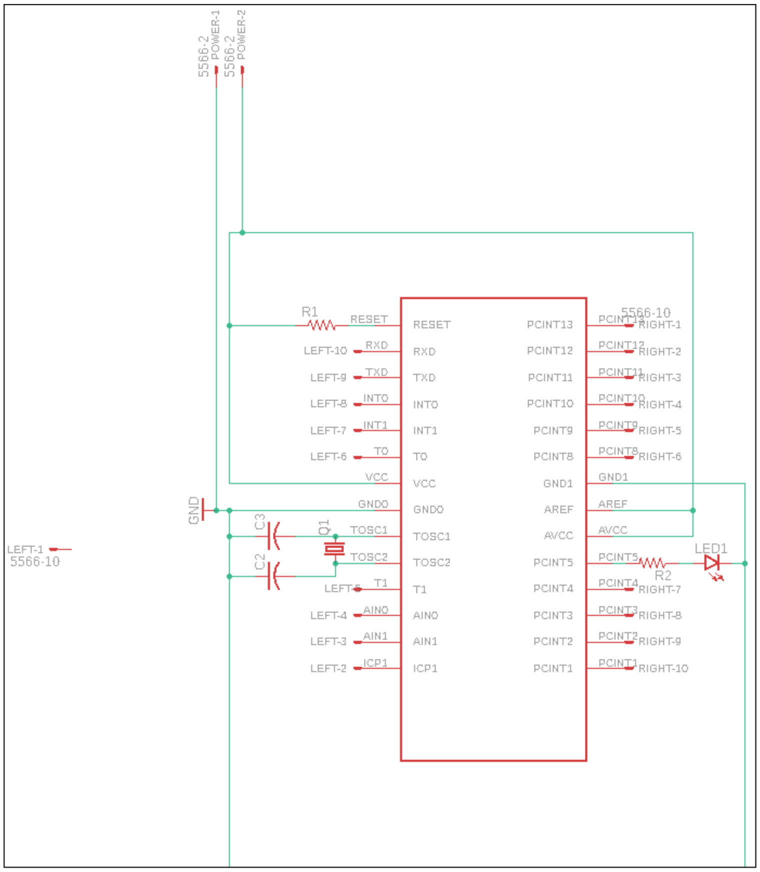

Figure 18. Circuit design of 1st project's ATmega328p

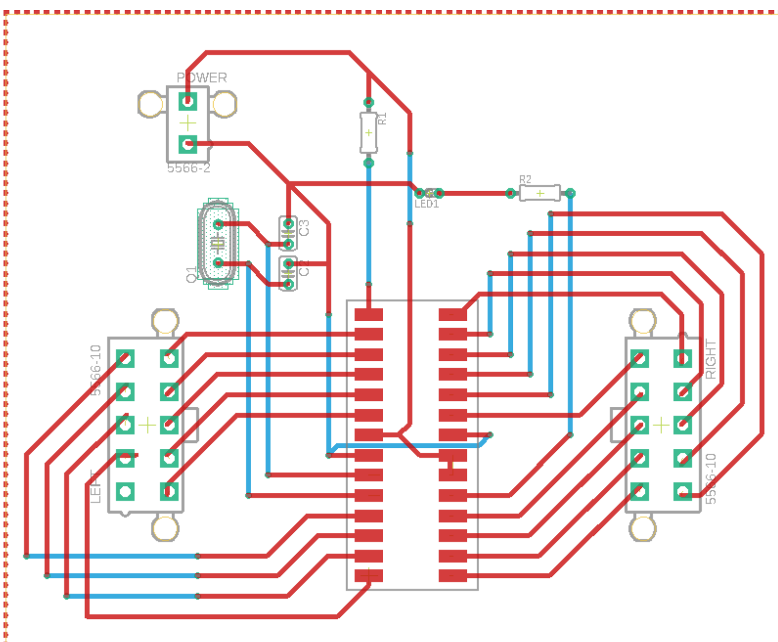

Figure 19. PCB design of 1st project's ATmega328p

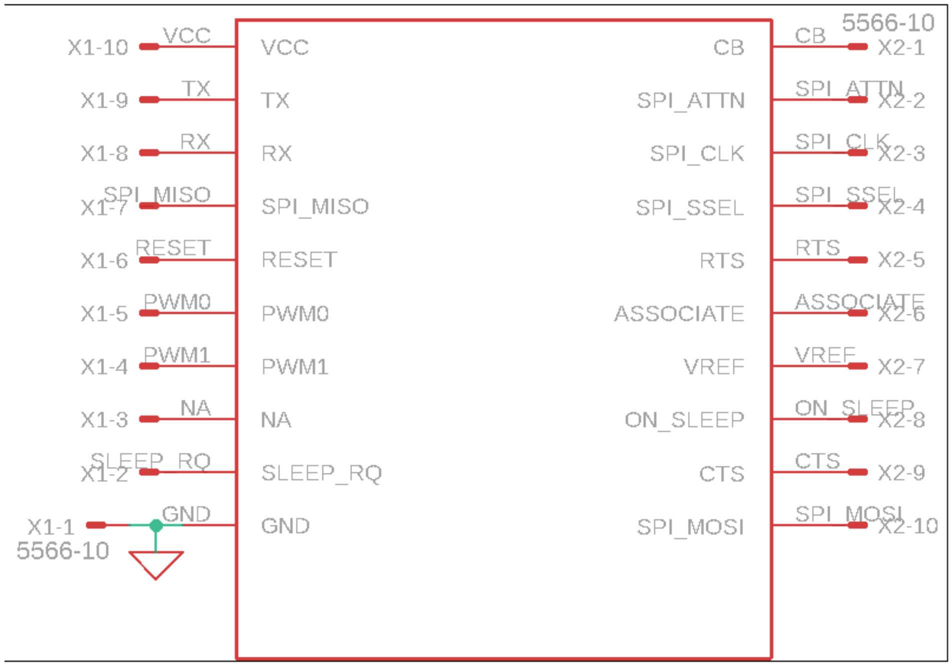

Figure 20. Circuit design of 1st project's XBee Mount

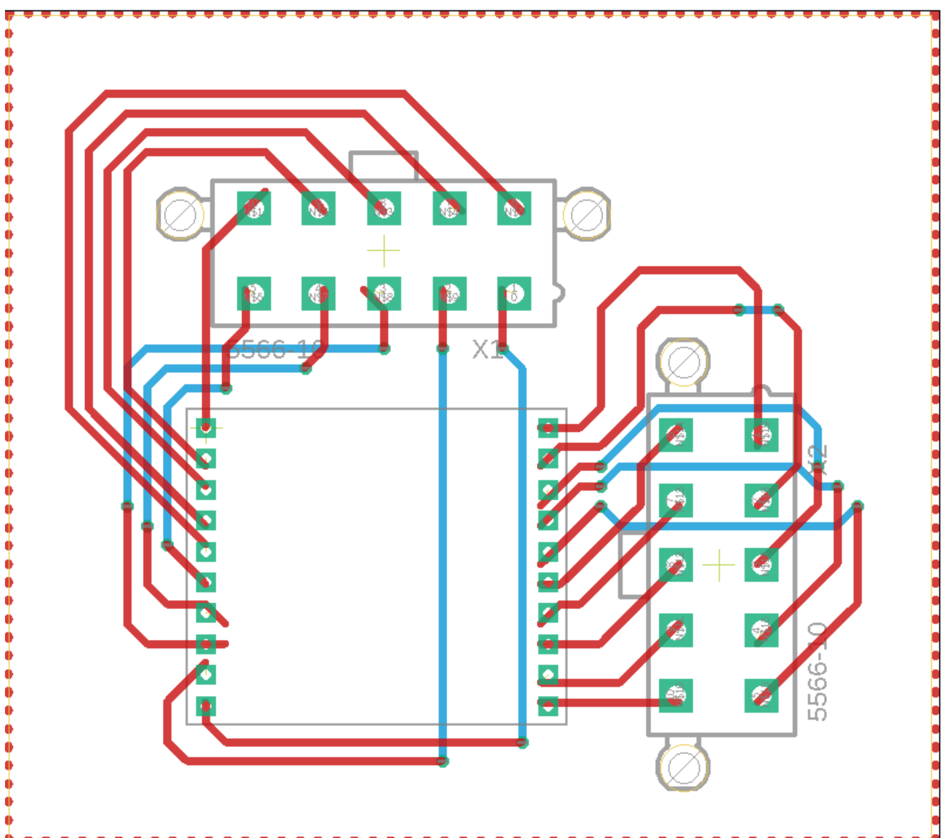

Figure 21. PCB design of 1st project's XBee Mount

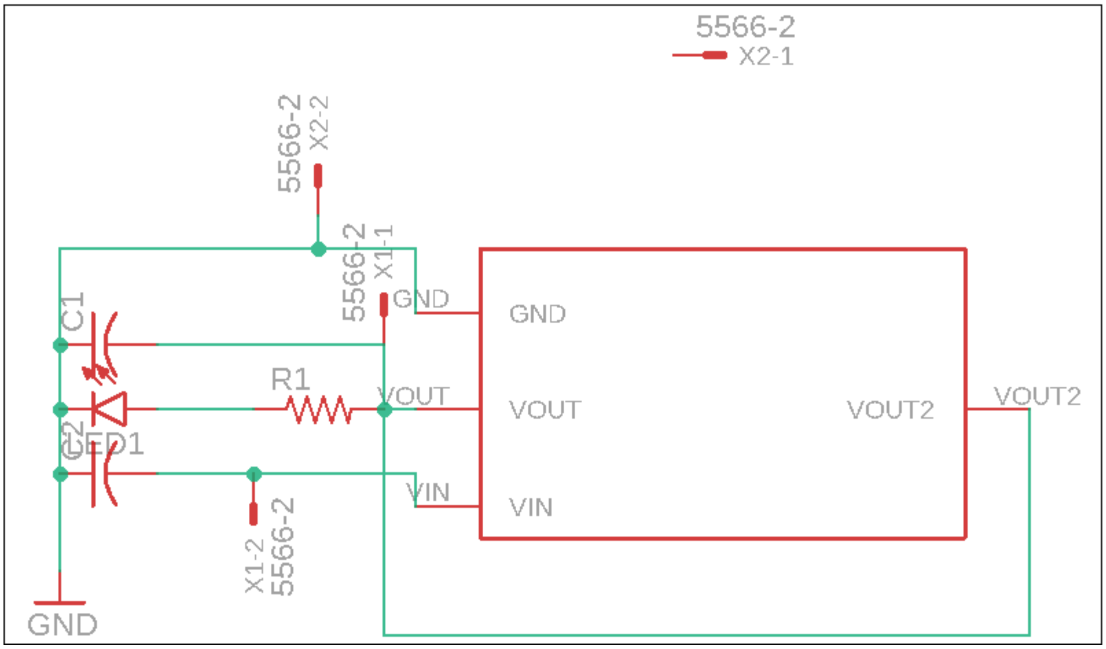

Figure 22. Circuit design of 1st project's LM1117 Voltage Regulator

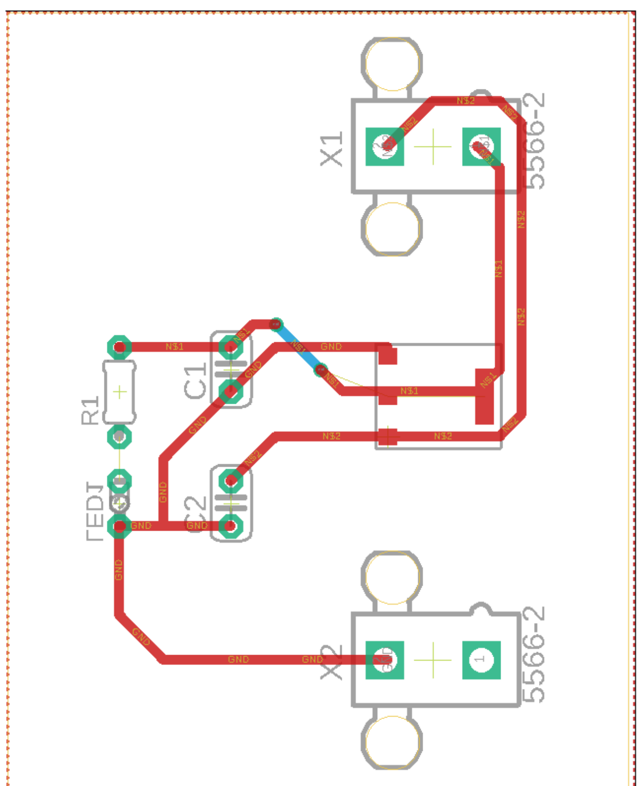

Figure 23. PCB design of 1st project's LM1117 Voltage Regulator

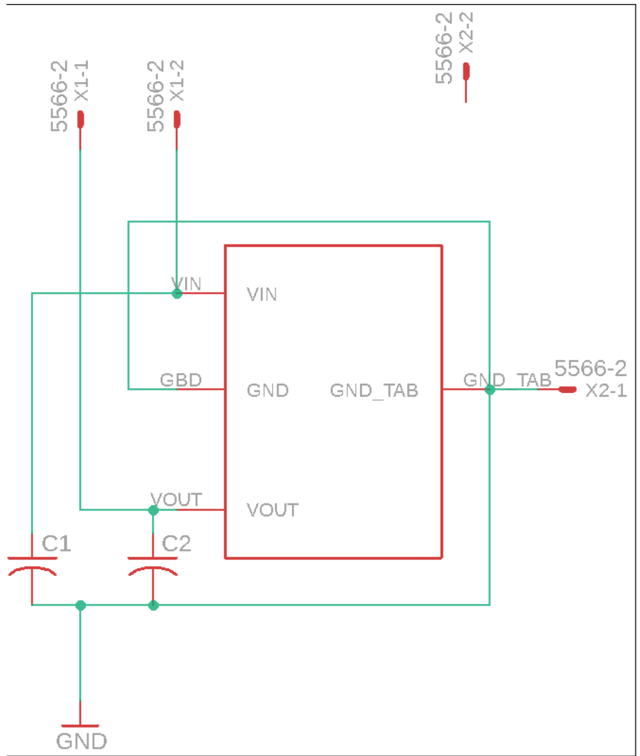

Figure 24. Circuit design of 1st project's TC1262 Voltage Regulator

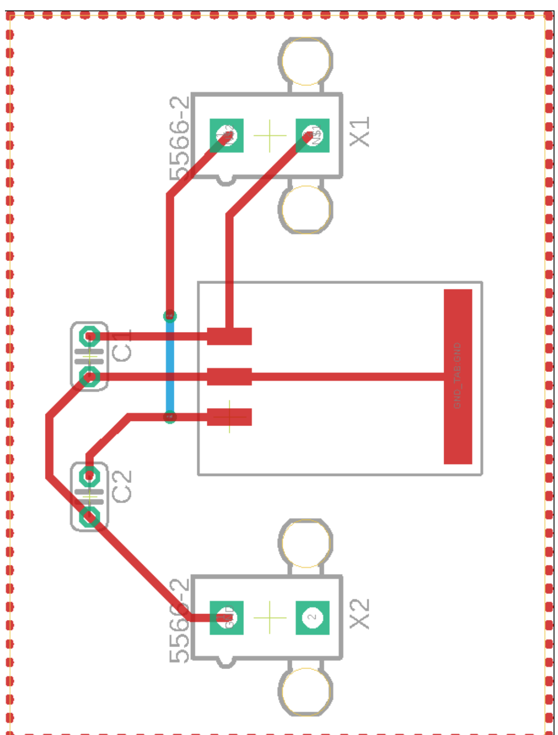

Figure 25. PCB design of 1st project's TC1262 Voltage Regulator

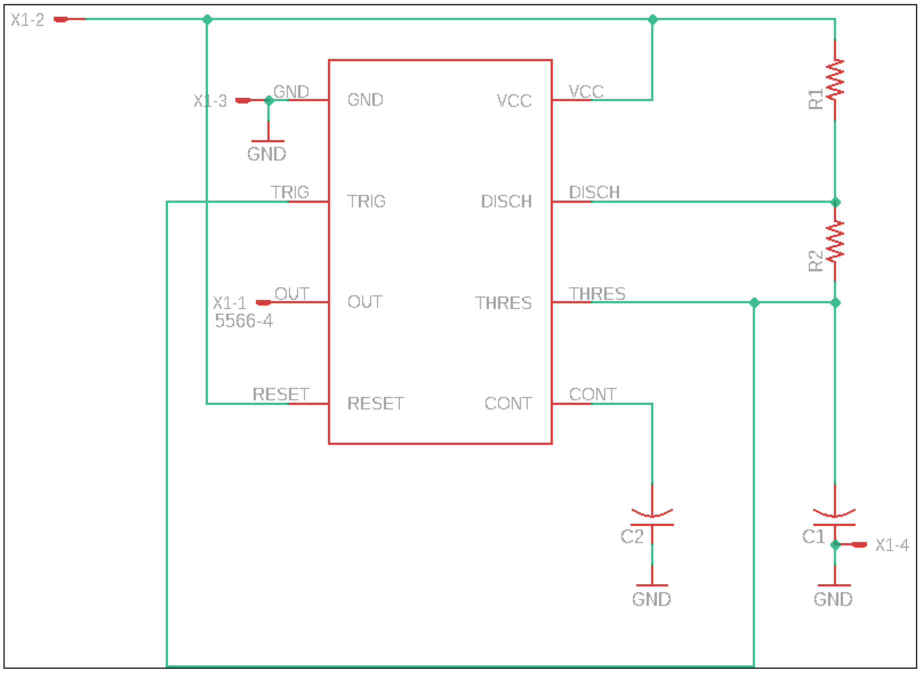

Figure 26. Circuit design of 1st project's NE555 repeater

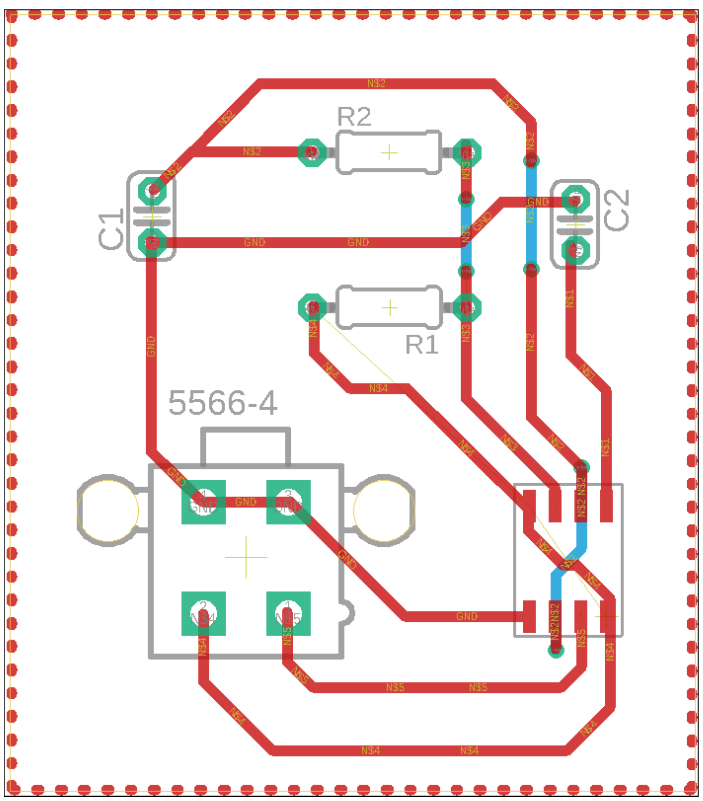

Figure 27. PCB design of 1st project's NE555 repeater