Modular Autonomous Light

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1. Introduction

1.1 Objective

Problem:

Some modern buildings have motion detectors installed which are connected to a room's circuitry and can shut off the lights and power in a room when no one is occupying it. People can sometimes forget to turn off lights when they leave a room and this wastes a lot of power. However, currently, there is no modular solution that can be used with older buildings without having to open up the walls and rewire the internal circuitry. To make the action autonomous, we want to design a Modular Autonomous Light. It monitors the number of people/crowdedness in an area, usually classrooms/shop malls and it applies IoT without changing circuitry in the building to turn off lights/change brightness.

Solution:

We use WiFi MAC Address Tracking by counting the number of devices connected to the Internet. We will write a sniffer program on ESP 8266 Wi-Fi module to fetch information of devices (MAC address and connected AP) and APs (SSID and MAC address). 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. The number of people in a room is approximately equal to the number of devices tracked. A person is recognized as a unique MAC address of his or her phone.

1.2 Background

We are unable to find any product in the market that is similar to our design. There is an approach to install a wireless occupancy sensing system in large rooms[1] but it costs about $400/room for installation. Other solutions may rely on motions in the room and it may be inaccurate when people are staying still in a room.

In the original solution, they used two PIR sensors at the entrance to detect whether people are entering or exiting the room and count the number of people depending on the number of times the sensor gets triggered. Then they will send the data to the control unit through bluetooth communication to activate the motor to switch the light. In addition, the data will also be sent to their phone app via bluetooth communication and the users are able to see the usage of lights in a room and command the switch module to turn lights on or off on the app[2].

The major difference between our design and the original solution is that our design is targeting rooms with a capacity of around 40 people and larger classrooms, and we are not using any PIR sensors in our project. As a reference[3], conference rooms in the ECE Building at UIUC have a capacity of 12 - 24 people, lab rooms have a capacity of more than 40 people and classrooms have a capacity of more than 70 people. Compared to the original solution where it's hard to synchronize the counting of the number of people entering/exiting at different entrances, our solution wouldn't have such concern because we determine the occupancy of the room by counting the number of devices connected to the internet with WiFi MAC Address Tracking. However, our device may not be very accurate in small study rooms or conference rooms. Therefore we may consider adding features to enhance this functionality of our design to fit better in smaller rooms. Our design would be more accurate in counting people in the scenario when many people are entering or exiting the room at the same time especially when multiple people are gathered at the entrance of the classroom. Furthermore, a photoresistor will determine the general brightness of the room to decide whether lights are needed in the first place so it conserves energy by keeping lights off when occupants are detected if ambient light provided through other sources is sufficient.

1.3 Physical Design

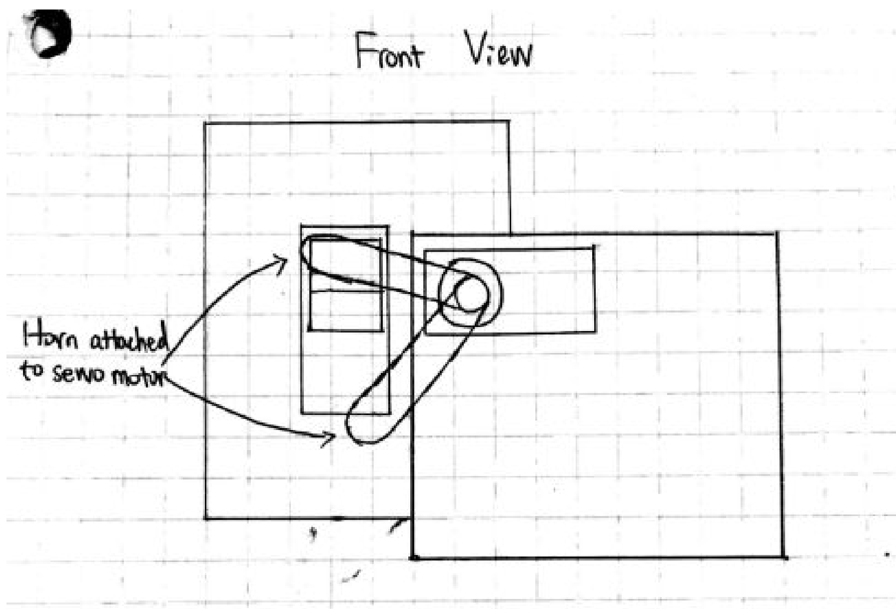

Figure 1. Physical Design(Front view of device)

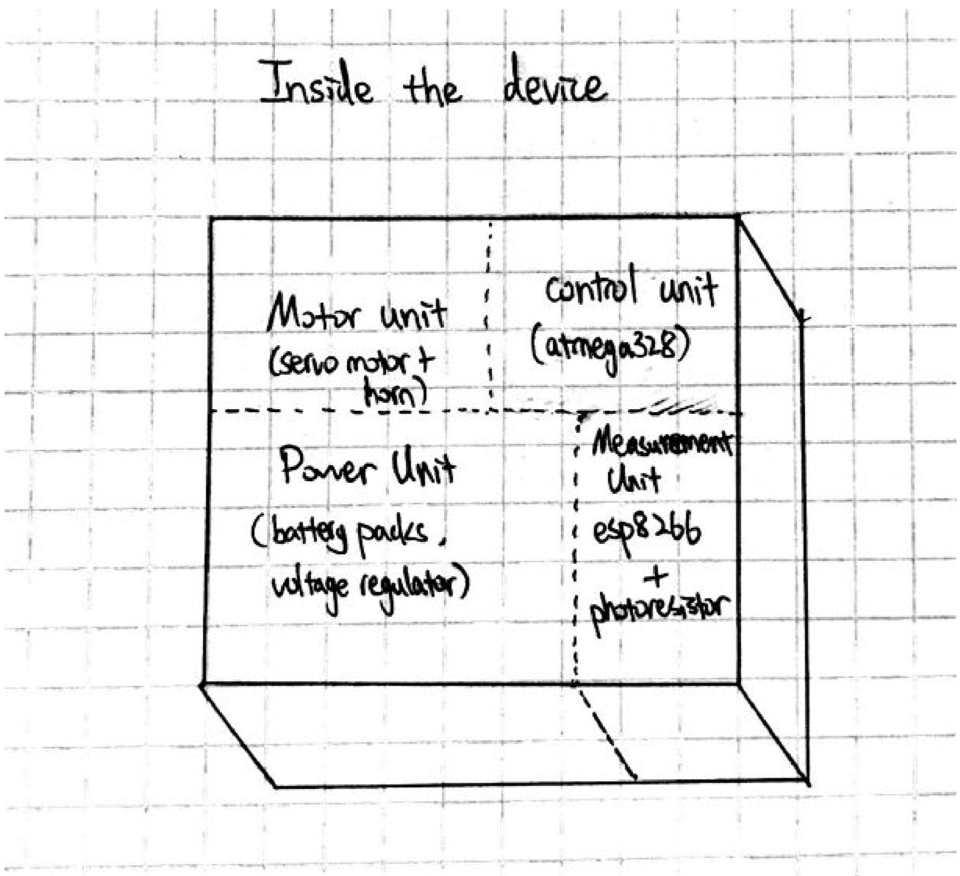

Figure 2. Physical Design(structure inside the device)

1.4 High-Level Requirements

- Has at least 80% successful rate of scanning devices (device showed up on printout)
- The light must be switched within 1 minute depending on occupancy of the room, and so long as detected illuminance is below 500 lux
- Has an overall accuracy of 80% to turn on/off light(s).

2. Design

2.1 Block Diagram

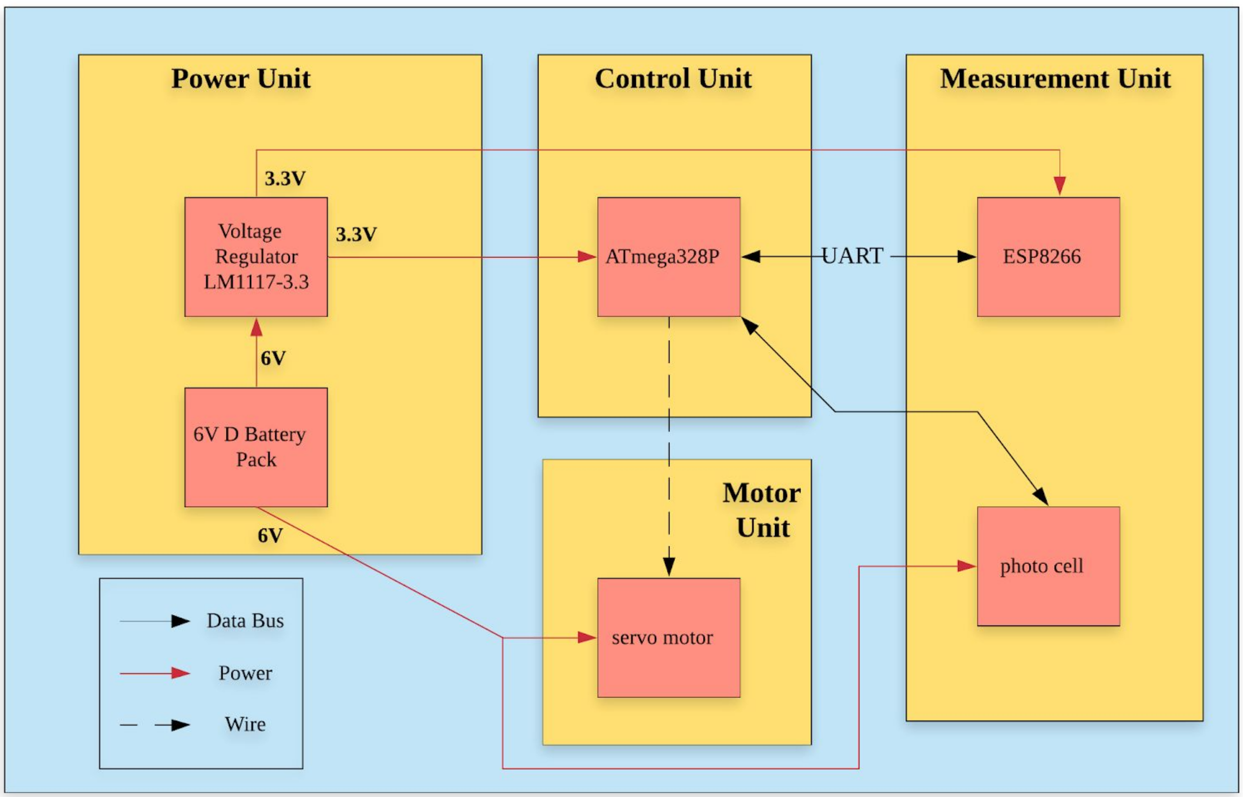

Figure 3. Block Diagram

2.2 Functional Overview and Block Requirements

2.2.1 Power Unit

Batteries

We are using 4 1.5V D batteries with a max capacity of 16500 mAh in series to provide 6V 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 several days.

Requirement 1: The batteries can provide enough power for the design to last for at least three days before we need to recharge.

Voltage Regulator

We are using LM1117 voltage regulator to regulate 3.3V from the batteries and provide power supply for the Atmega328p microcontroller chip and esp8266 wifi module. We chose LM1117 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 6V as our power supply. It's also less complicated for us to implement compared to a switch regulator.

Requirement 1: The voltage regulator should output a stable 3.3V +/- 5% and at least 500mA to other units.

Requirement 2: The voltage regulator should maintain thermal stability below 125 degree Celsius.

2.2.2 Motor Unit

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 [4] 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.

Requirement 1: Motor must be able to provide a torque of at least 0.05 Nm in order to flip the switch

Requirement 2: Motor must turn to two angles (90 degrees (+/- 15 degrees) and 180 degrees (+/- 15 degrees)) and stop precisely when it reaches the targeted angle.

2.2.3 Light Sensor

CdS Photoresistor

Photoresistor is very common and cheap. With a decent light sensitivity, we can determine if light is switched on or off. By using a CdS photoresistor mounted on the front of the frame, the approximate brightness of the room can be measured by connecting a pull-down resistor of 10k ohms in series to the CdS photoresistor, and measuring the voltage between the two resistors. If the voltage is near one-eleventh of the provided voltage (if the CdS photoresistor is around 1k ohms), the room will be considered bright enough for use.

Requirement 1: CdS Photoresistor, when connected to microcontroller's analog input pin, the voltage on the pin must have ~2.5V or higher when it is light out and near ground when it is dark.

2.2.4 Wi-Fi mini sniffer

ESP-8266 Wi-Fi Module

ESP-8266 can perform as a standalone system to interface with other systems to provide Wi-Fi through SPI/SDIO[5]. We picked a Wi-Fi module over bluetooth/XBee because it works well as a standalone system. It is efficient, easy to program and cheap. We will write a sniffer program on ESP-8266 to scan a list of devices and the respective AP one is connected to. ESP8266 is required to run in promiscuous mode which will display devices and Access Point MAC and SSID. ESP-8266 is required to run in promiscuous mode, which enables nodes (i.e. device->AP) to share with peers to maximize packet distribution.
Requirement 1: ESP-8266 must be able to communicate over IEEE 802.11b/g/n at 4.5Mbps with a 50Ω nominal RF connecton.
Requirement 2: It must be able to communicate over both SPI and UART.
Requirement 3: ESP-8266 must run in promiscuous mode.

Serial flash

The serial flash is connected to ESP-8266 by SPI, and it stores the program used by ESP-8266 WiFi module. The memory size is 1MB and is subject to change as program size varies.
Requirement 1: Operates consistently at 80 MHz (depends on real purchased product)
Requirement 2: Size must be >= 1MB to store program

2.2.5 Control Unit

ATmega328

ATmega328 is used to build a standalone Arduino on PCB[5][6]. 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.
Requirement 1: Operation voltage is 3.3V and input voltage is recommended to be 7-12V.
Requirement 2: Motor must be turned on after ATmega328 receives an on/off signal from ESP-8266.

2.3 Mini Sniffer Pseudocode

```
Setup() {Set opmode
        Set channel
        Promiscuous mode disable
        Promiscuous mode enable
        }

loop() {Set channel
        Check if any device is new to the list
        If not, increment channel
```

```
Count APs known
For each AP:
        Count scanned clients
}
```

2.4 Protocol

We use UDP protocol to transmit data. Since we have verification mechanisms within our design, it is suitable to use UDP as error checking and correction are not necessary. UDP effectively reduces the complexity of routing protocol.

3. Ethics and Safety

One major concern of our design is privacy issues. A number of ethical issues arise from Wi-Fi tracking. You can know someone's location based on his/her device(s) as MAC addresses are scanned and picked up by the mini sniffer. We will write a hash algorithm to anonymize MAC addresses of personal devices and delete part of the digits of the hashed MAC address [7]. In addition, we will try to get consent from school/organization to actually access device information. As a promise, we will not provide data to any third parties.

Our testing and debugging techniques follow the IEEE code of ethics, "to avoid injuring others, their property, reputation, or employment by false or malicious action"[8]. 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.

4. References

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