A Multi-purposed Lamp

A Technical Report submitted to the Department of Electrical and Computer Engineering

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In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Peach

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Capstone Design ECE 4440 / ECE4991

Signatures

Isaac Li

Tiger Wang

Andrew Ding

Jiahe Tan

Statement of work:

Isaac Li

I am mainly responsible for the software design of this project, the actual assembly of circuits, testing of the circuit, lamp body design and building, and the final video. I also designed the boards with Tiger and Andrew and chose most of the parts we used in this project. Specifically, I worked together with Jiahe to come up with the first version of the embedded code and I mainly tested and revised the code to make it work together with other boards. I also assembled the circuit of each board together with Tiger, tested each board and the project as a whole. Finally, I designed and built the lamp body and made the final demo video.

Jiahe Tan

I am mainly responsible for the software development and the design of the lamp body. My primary responsibility in this project is the general firmware of the desk lamp. I designed the controlling algorithm with Isaac and finished writing the embedded code. In addition, I helped Andrew to figure out and design the schematic of the LDR circuit and the power supply circuit. However, since I'm not on ground, I cannot help with the actual testing of the code. I also designed the 3D printing version of the desk lamp body using Fusion 360.

Sihan Ding

I am mainly responsible for the schematic design and the PCB board design of this project. Specifically, I designed and simulated the LDR circuit and the power supply circuit together with Jiahe. I worked together with Isaac and Tiger and came up with all the parts in this project. I drew the part dimensions and imported them into the user library and adjusted the simulation files so that they can be forward annotated to Ultiboard. I also designed all the PCB boards together with Isaac and Tiger and verified with FreeDFM. Since I was not on ground, I could not help with the soldering and testing of the circuit.

Qiyue Wang

I am mainly responsible for the LED driver circuit design, actual assembly of the circuit board and lamp body, and the testing of the circuit board. Specifically, I designed the LED driver circuit by choosing the transistor as a switch and the value of each load resistor by simulating in Multisim and testing on the actual circuit board. During the assembly of the circuit board, I, together with Isaac, chose the specific component of each part that can fit into our design. After finishing assembling the circuit board, I worked with Isaac to test each part of the circuit board.

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Abstract

Peach's final capstone project is a multi-purpose lamp that is ideal for both daytime and nighttime illumination. It is embedded with a lithium battery that can be recharged with the built in type-c port. The desk lamp supports both daytime mode and nighttime mode so that it can be used as a desk lamp in daytime and as a bedside table lamp or as a portable nighttime lamp at night. The light sensors embedded in the lamp allows it to adjust brightness automatically according to the brightness of the surrounding environment to provide appropriate illumination level. The brightness of the light can also be adjusted manually as the user prefered. The overall project design can be separated into three major parts: software design and programming, hardware design and PCB board layout design, exterior material selection and design.

Background

With the rapid development of modern technology, people's demands on household appliances become more environmentally friendly. In addition to simple and convenient to use. reducing energy consumption, saving electricity, protecting the environment, simplicity and convenience become the main theme of today's people's main demands for household appliances. Therefore, the demand for lighting is also evolving. People consciously adopt various methods to improve it to meet the various needs of our daily lives. One of the most common examples is the use of light-controlled switches as street light switches and switches in the corridors of residential buildings. The light will automatically turn on when there is insufficient light, and will not turn on when there is sufficient light during the day to achieve the purpose of energy saving.

Our idea is to implement the automatic light on desk lamp. Currently, the desk lamps that we use are basically equipped with two buttons; one is used to turn on and turn off the lamps and the other one is used to change between the "bright" mode and the "brighter" mode. The function of this kind of lamp is relatively single. It can only be used to realize a single light circuit and cannot be adjusted. Right now, due to the rapid increase of study pressure and work pressure, people reading and studying at desks are prone to myopia because the light is not compatible with the environment, so the old-style desk lamp with single function is not suitable for people's current needs. Our project adds a light dependent resistor (LDR) on the basis of the original common desk lamp to achieve automatic brightness control function. Therefore, the light produced by the desk lamp is able to compensate with ambient light. When the ambient light is strong, the light produced by the desk lamp will reduce. Conversely, when the ambient light is weak, the light produced by the desk lamp will become strong. In this way, the overall brightness will maintain at a constant level that is suitable for people's eyes to protect people's eyes from overly weak brightness or excessively bright light. This automatic feature can also save a great amount of electricity compared to old-style desk lamps which might cause the waste of energy due to excessive lightning. Our project also adds to the convenience of desk lamps. The dimming or touchable table lamps sold in the current market need to be adjusted continuously by themselves. With the implementation of the automatic light dependent function, the brightness can be adjusted accordingly; users do not need to switch the table lamps frequently by hand.

To make our project more user friendly, we add the feature of night lights. A common night light is a small, low-power electric light kept on at night for comfort and safety. It can provide people with enough light to see the room, but they are also dim so that the light will not disturb sleep. However, common night lights are usually plugged into the wall, which makes them not portable. Moreover, most night lights only have a single function. In addition to daytime mode, our project also adds support to night mode so that people can also use it at night. The shape of the desk lamp makes it easy to carry for people to carry it when they wake up at night. It will bring safety to users by preventing them from tripping in the dark. It will also provide convenience since there will be no need to always turn on room lights when waking up at night.

Similar night lights exist commercially. The MAX-TEK Store has produced a plug in motion sensor dimmable LED night light with manual brightness adjustment and automatic illumination for indoor places like stairs, garage, kitchen, hallway.[5] It has three brightness levels. The mentioned sensor night light comes with three different levels of brightness control settings. It also supports three lightning modes. “ON” mode will turn on the night light. “OFF” mode will turn off the light. “AUTO” mode will turn on the night light automatically when motion is detected within the sensing range and turn off after 25 seconds of inactivity. Our project serves a similar function as the existing product but different from the existing product in the way installed. The existing product is not portable, it must be placed at a fixed position. If people want to go to different places at night, the night light needs to be plugged into all places. However, our lamp is able to be carried around which will save users’ budgets. Additionally, our lamp is embedded with a lithium battery inside to provide power to the lamp to make it portable. In contrast, the existing product must be plugged in to the wall.

Similar desk lamps for day time are also available in the market. The TaoTronics Store has manufactured a touch sensor table lamp which allows adjustment of brightness through a touch sensor. [6] It provides a USB charging port and 4 lightning modes with 5 brightness levels for brightness for work, study, reading or relaxing. And it operates and responds with straight-forward touch control. The desk lamp we designed wins over the existing product by providing automatic brightness adjustment feature.

The project contains knowledge from many previous coursework: embedded system design and software design. We use MSP430 to realize the most of the functionalities of our project. Therefore, embedded system design is strongly related to our design and plays an important role.

Constraints

In the actual implementation of the project and the final manufacturing and mass production of the lamp, the following constraints were imposed.

Design Constraints

CPU Limitation

For the microcontroller, MSP430G2553 produced by Texas's Instruments was chosen to be the CPU. It has 16 GPIO ports and 16KB memory.

Software Availability

For software, National Instruments' Multisim was required for circuit design and simulation, and National Instruments' Ultiboard was required for PCB layouts. UVA has active licenses provided for both of the two tools. In addition, for software development, Texas' Instruments' Code Composer was required for the embedded code. It is an IDE to develop applications for Texas Instruments embedded processors, which is MSP430G2553 in our case. It is provided for free. For the design of the exterior lamp body, Fusion 360 of AUTODESK is a requirement for design on MacOS. Also, SolidWorks is a requirement for design on Microsoft Windows. Free educational license was provided by AutoDesk to use Fusion 360 for free. However, SolidWorks only provides student editions, so it needs to be purchased.

Manufacturing Limitations

Manufacturing constraints were mainly imposed by 3D printing. The Robertson Media Center (RMC) in Clemons Library has a 3D printing space to provide 3D printing to all members of the UVA community for free. However, all of the 3D printers are not available until after winter break. Therefore, we turned to use wasted paper boxes to build the exterior lamp body.

Economic and Cost Constraints

The budget for the project is 500 dollars per team. The budget constraint is enough for most of the components that the project required except for the expense of 3D printing. Since the Clemons Library does not provide free 3D printing service until after winter break, 3D printing provided by other service providers is too expensive regarding the budget.

External Standards

The following external standards apply to the project.

1. *Illumination Engineering Society for North America (IESNA)* - IESNA is a nonprofit organization that develops and publishes standards regarding lighting.
    a. **Energy Star Solid State Lighting Luminaires Specification**: The ENERGY STAR criteria cover the requirements for SSL products used for general illumination.
    b. General requirements:

        i. Warranty: A warranty must be provided for luminaires, which covers repair or replacement of parts of the luminaire housing, device.
        ii. Thermal Management: There should be test procedures for thermal management.
        iii. Drivers:
            1. Power Factor >= .90
            2. Minimum Operating Temperature below -20 degree Celcius.
            3. Maximum operating temperature should not exceed the driver manufacturer temperature during in-situ operation.
            4. A class A sound rating for noise management.
    c. Requirements for portable desk task lights:
        i. Minimum Light Output: Luminaire shall deliver a minimum of 200 lumens.
        ii. Zonal Lumen Density Requirement: Luminaire shall deliver a minimum of 85% of total lumens within 0-60 degree zone.
        iii. Minimum Luminaire Efficiency: 29lm/W.
        iv. Minimum CRI: 80.
2. *International Electrotechnical Commision (IEC) TC34* - TC34 mao and maintain the standardization structure and to prepare, review and maintain international standards regarding safety, performance and compatibility specification for electric lamps and electric light sources, luminaires and lighting systems.
    a. **34/781/CD:** IEC 62386-304/AMD1 ED1: Amendment 1 - Digital addressable lighting interface - Part 304: Particular requirements - Input devices - Light sensor: Published on 2020-11-6 to provide regulations on light sensors.
    b. **34/765/RR:** Review report on IEC 62386-102 Ed.2: Digital addressable lighting interface - Part 102: General requirements - Control gear.
    c. **34/757/CD:** IEC TS 63116 ED1: Lighting systems - General requirements
3. *Illumination Engineering Society of North America (IESNA)* - A nonprofit organization that develops and publishes standards regarding lighting.
    a. **ANSI/IES RP-7-17**: Recommended Practice for Lighting Facilities. The primary purpose of this standard is to serve as a guide and education tool for the design of lighting facilities.
    b. **IESNA RP-16**: Nomenclature and Definitions for Illuminating Engineering Addendum.
    c. **IESNA TM-16-05**: IESNA Techical Memorandum on Light Emitting Diode (LED) Sources and Systems.
    d. **IESNA LM-79**: IESNA-Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.

e. **IESNA LM-80**: IESNA Approved Method for Measurement Lumen Depreciation of LED Light Sources.

Tools Employed

During the implementation process of the project, the following tools were used to achieve the final result presented in this document. The tools listed below can be sorted into three major categories: hardware tools, software tools, and the lamp body exterior design tools:

Hardware tools:

For the PCB design and layouts, the project mainly relies on National Instruments' simulation and design tools Multisim and Ultiboard. These two electronic schematic design and simulation tools are essential for the hardware design of the project. We are familiar with the tool design tools from previous coursework, but we still had to improve our skills with Multisim and Ultiboard to accomplish the project hardware design.

Software tools:

For software design and coding, C programming language was primarily used. We use Texas Instruments' Code Composer Studio as an aid to programming. Code Composer Studio is an integrated development environment to develop applications for Texas Instruments embedded processor. Since we choose to use MSP430 as our microcontroller, Code Composer is a necessary tool for us to develop the software to be loaded into the MSP430 microcontroller. We are already familiar with Code Composer from the previous embedded class, but we still spent time exploring and improving our skills to finish the software development.

Design tools:

To design the lamp body of the project, SOLIDWORKS, which is a solid modeling software, was also used to help build the lamp body exterior for 3D printing. SOLIDWORKS is the major tool the project used for exterior design. However, It is a computer program that runs primarily on Microsoft Windows, and MacOS is not supported by SOLIDWORKS. Therefore, Autodesk's Fusion 360, a software for 3D CAD, modeling and 3D printing was utilized as a complement. MacOS is supported by Fusion 360, so Fusion 360 primarily served as a presenting purpose. Even though we have been exposed to these two softwares and have done 3D printing works with these two softwares in ENGR 1460 before, we are still not skillful enough to manage the design of a complicated lamp body. Therefore, a great amount of time and effort was spent on learning these tools.

Ethical, Social, and Economic Concerns

Environmental Impact

Electronic products will bring varying degrees of metal pollution. The pollution brought to the environment is very difficult to deal with. Most of the electrical components that we used in the desk lamp project do not have any significant negative impact on the environment, except for the LED strip and the lithium battery.

As a lighting source, the LED strip is composed of certain amounts of material that might cause metal pollution. Generally these materials contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers and other toxic and harmful substances or elements. However, the degree of pollution that can be caused depends on the materials used in the lighting products. The lead content of common lamps in the lamp tube, circuit board and lamp cap components exceeds the limit requirement, and the mercury content of the lamp tube also exceeds the limit requirement. As for LED, only the lead content on the driver board of the lighting lamp exceeds the limit requirement, so the advantages of LED lighting lamps are reflected in the environmental pollution.

The production of Lithium batteries uses lithium cobalt oxide, copper, aluminum, nickel, etc., which may have a certain impact on the environment. In addition, the main components of the electrolyte used in lithium batteries are dimethyl sulfate (DMC), diethyl carbonate (DEC), and ethylene carbonate (EC). This will lead to some organic waste gas volatilizing during the production process. In general, lithium batteries have a certain but limited impact on the environment.

Sustainability

The life cycle of the desk lamp is primarily limited by the lithium battery, which is the power source for the lamp. The service life of lithium batteries is only two to three years, and lithium batteries can generally be charged and discharged 300-500 times. However, the lifespan of a lithium battery is "500 times", which does not refer to the number of recharges, but a cycle of charge and discharge. Therefore, it may usually take several times charges to complete a cycle. Every time a charging cycle is completed, the battery capacity will decrease a certain amount. In general, even though the service life of lithium batteries is limited, this time is actually sufficient for a desk lamp.

The lifetime of the desk lamp is also affected by the LED strip. The theoretical life of leds is 100,000 hours, but this is only the highest value under ideal conditions. In fact, the lifespan of LEDs has a lot to do with current, brightness, materials, etc. When the led lamp is used for more than 1000 hours, it will appear light decay, which means that its brightness is not as bright as the original.

Health and Safety

Most of the components the project employed does not have risk on human health and safety, except for the lithium battery and the LED strip.

For lithium batteries, the most harmful component is the electrolyte solution. The electrolyte is an organic and volatile liquid, and it is corrosive. Inhalation of volatile gas for a long time will damage the respiratory tract and may cause respiratory diseases. Also, lithium-ion batteries have a certain amount of radiation because they contain cadmium, which can cause osteoporosis. As a result, if the lithium battery leaks accidentally or is thrown away randomly, it may have negative effects on the human body. In addition, when the lithium battery is short-circuited, needle punctured or squeezed, it will cause the internal diaphragm to rupture and cause a sudden temperature rise, and eventually an explosion. Usually, a regular lithium battery will explode in about 5 seconds when it is damaged.

As for LED strips, all light is harmful to the eyes, the only difference is the degree affected. For example, the natural light of the sun can be regarded as the least harmful. Since LED lights are driven by direct current, there is no flicker. Therefore, LED is the light source that is closest to natural light. Consequently, in principle, led lights have the smallest damage to the human eyes.

Manufacturability

The desk lamp presented by the project will be relatively easy to reproduce and manufacture. Almost all the components of the desk lamp are standardized parts except for the lamp body and the PCB board.

For the PCB board, if the circuit boards are produced wholesale, the production will be very efficient and cheap. Also, there are many mature assembly line methods for mass production of PCB boards in the market to choose. In addition, all parts needed are standard components that can be purchased in large amounts from manufacturers, and they are all inexpensive.

The original plan for the lamp body is 3D printing. However, since the free 3D printing option of Clemons Library was not available until after winter break, we made an alternative choice by making it using discarded boxes instead. If we continue with our original plan for mass production, the expense will be relatively high. The mainstream 3D printing technology is roughly divided into three types, FDM (Fused Deposition Rapid Prototyping), SLA (Light Curing Molding), SLS (Selective Laser Sintering). The prices of the three are from low to high. At present, almost all 3D printer technologies that we can see or buy in non-industrial grades use FDM, because both the raw materials and the printer cost are very low. The disadvantage is that the printing accuracy is low and the printing speed is slow. However, if we want mass production or commercial use, we may want to use SLA to print. SLA technology prints faster and has high accuracy, but it is very expensive. Therefore, we need to come up with other alternatives for the lamp body for manufacturing.

Ethical Issues

The project does not have any significant ethical issues related in this stage. However, for future work, an agenda is to make our lamp memorize the preference of brightness level and upload their daily illumination level routine to the cloud for analysis and calculation so that it will provide the user customized brightness level at different time slots. This new feature will turn the desk lamp into something similar to a smart home device.

Privacy issues is a point worth discussing for all smart home devices. People can control the lights and switches around themselves with a single voice. But while it is very convenient, risks are also surrounding. While people are using smart home devices, their daily routines and other information are uploaded to the cloud for analysis and calculation. If there are criminals intercepting it midway, people's privacy will be exposed. Also, the home should be a trusted area, therefore we should try solving the security problems of smart home products so that their consumers can enjoy the service without considering security issues. However, since we are not able to build a cloud computing system ourselves, the best choice for us is to use a third-party cloud computing service. Then the question becomes, do these big companies really want to protect people's security? What if their privacy information can help them make profits? The companies feel that it is enough to do their best on the product, but user information protection is a cost that can be saved, and even sometimes, user information is used to increase additional income. Therefore, privacy issues will be the biggest concern to overcome.

Intellectual Property Issues

The following three patent contains similar features with the project:

[1] presents a lamp with an automatic dimmer. It is a lamp that includes a light source in the top of a housing. The light source includes a driver, a light emitting member that is connected to the driver and a dimming controller which is also connected to the driver electrically. The dimming controller will compare the intensity of the sensed light with the intensity of the light emitted by the light emitting member, and the driver will either decrease the intensity of the light output or increase the intensity of the light source based on the comparison. This patent's main independent claim specifies that the patent is "a lighting device comprising an electro-optical sensor" and "the sensor member sends the sensed light to the dimming controller so that the dimming controller compares intensity of the sensed light with intensity of the light emitted by the light emitting member" and the sensor will instructs the driver to either increase or reduce the intensity of the light source. And one of the dependent claims says that "The lighting device of claim 1, wherein the housing is a table lamp." In general, the patent is a desk lamp that has a light sensor and will automatically change the light intensity based on the sensed light. However, this patent is limited to a desk lamp or a table lamp for daytime working. The project presents a desk lamp with light sensor, which is similar to the patent claims, but the project not restricted to

a desk lamp, but it can switch between daytime mode and nighttime mode and can be used as a portable light source at night. In light of these claims, the project is different from this patent and is still patentable.

[2] presents an automatically adjusting task lamp which consists of a control logic that is electrically connected to a light intensity selector, an ambient light sensor, and "the plurality of LED's and wherein the control logic compares the intensity of ambient light in the area surrounding the work surface with the desired intensity of light to be provided at the work surface and adjusts the supply of electrical power to the LED's so that the total of the variable intensity of emitted light and the intensity of ambient light in the area surrounding the work surface is approximately equal to the desired intensity of light to be provided at the work surface." The main independent claim of this patent states that the patent is "an LED task light comprising a power supply, adapted to provide a supply of electrical power". The patent does not contain a lithium battery for the power supply and therefore is not rechargeable. The main independent claim also states that the lamp is comprising of "a light intensity selector, adapted to allow a user to input a desired intensity of light to be provided at the work surface;" and "an ambient light sensor, adapted to determine an intensity of ambient light in the area surrounding the work surface;" Moreover, the independent claim does not mention that the light intensity of the task lamp can be adjusted manually by user. Also, similar to the previous patent, the patent does not support nighttime illumination. In general, based on the claims by the patent, the project is still patentable.

Finally, [3] presents a lighting device with an ambient light sensor. It is demonstrated to be a lighting device that includes a light source and a sensor that is able to provide illumination measurements based on ambient light detected by the sensor and will thus adjust "the projected light based on the provided illumination measurements to transition the projected light through a plurality of projected light levels until at least a new illumination measurement provided by the sensor is within the range of illumination levels." Moreover, the patent states that the device is able to be carried by a user or attached to a wearable accessory of users, such as a helmet or a headband. Therefore, the device presented by this patent is portable and can be carried at night by users. However, the lamp presented by the project is able to stand on desks or tables to be used as a desk lamp. The main independent claim of the patent states that the patent is "a lighting device comprising a light source, a sensor adapted to provide illumination measurements based on ambient light detected by the sensor including at least a reflected portion of the projected light;" Moreover, the main claim also states that there is a controller adapted to the device that will support the lighting device to "select a range of illumination levels and adjust the projected light based on the processed illumination measurements to transition the projected light through a plurality of projected light levels." This means that the patent is able to adjust brightness based on ambient light automatically and manually by the user. In the detailed description, the patent is described to be a lighting device that "One or more power sources may be provided in the body of the lighting device to provide power to various components of the lighting device. In various embodiments, power sources may be implemented, for example, by one or more batteries, solar cells, external power outlets, and/or other appropriate sources." However, lithium batteries with rechargeable functions are not mentioned in the patent.

In light of the above reasons, the lamp presented by the project is patentable.

Detailed Technical Description of Project

The goal of our project is to build a multi-purpose lamp that can save energy during the day and serve as a night lamp during the night. The overall project consists of three boards in total and a msp430 launchpad. We start by introducing the three boards: light dependent resistor and led driver board, power board and switchboard.

Block Diagram

The Block diagram of our project is shown in Figure 1. There are 7 parts in the project: the switch circuit, the LDR circuit, the LED driver circuit, the 3.3V power circuit, the 12V boost converter, the lithium battery charger module and the MSP430 connector. In the end, we make three boards to include these some of the functionalities, and the booster converter and the lithium battery charger module come with existing boards. The switch board consists of the switch circuit. The LDR and LED driver circuit consists of the LDR circuit and the LED circuit. The power board consists of the power circuit and the MSP430 connector.

The battery charger module outputs a 4.2V voltage and provides power to the entire lamp. The 4.2V output passes through the mains switch S3 and goes into the boost converter and 3.3V power unit to produce a steady 12V and 3.3V Vcc.

The switch unit is powered by a 3.3V Vcc and is used to adjust manual/auto, daytime/night time, light brightness. The output of the switch board is connected to Port 1.0 - 1.3 of the MSP chip.

The LDR unit is also powered by a 3.3V Vcc and outputs a signal varying from 0.6V - 3V into Port 1.4 of the MSP chip to monitor the brightness.

The LED driver unit is powered by the 12V Vcc. Port 2.3 of the MSP chip outputs a brightness control signal to the LED driver unit.

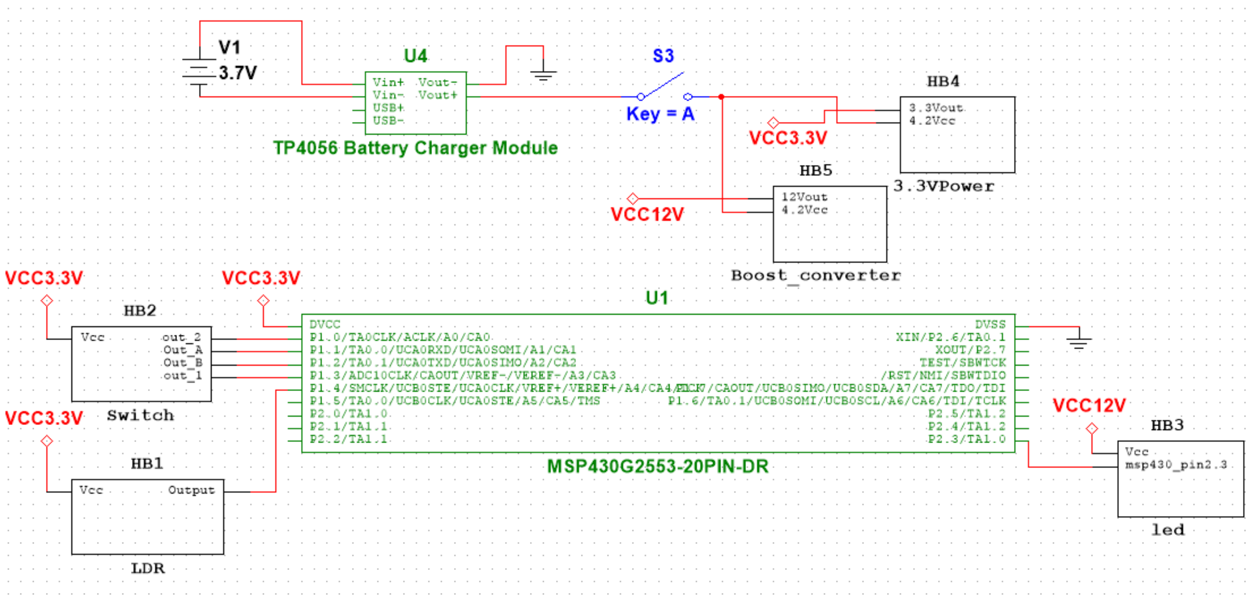

Figure 1 Block Diagram

LDR and LED Circuit

LDR circuit

The function of the LDR circuit is to produce a variable DC signal that changes according to the surrounding light intensity. The output voltage range fits in the 0-3V ADC voltage range. We use a light dependent resistor, which changes its resistance according to the light intensity, to control the output voltage.

For the light dependent resistor, we choose GL5528 which has a light resistance (10 Lux) of 10-20kΩ and a dark resistance of 1MΩ. The reason for choosing GL5528 is its light resistance matches our controlling resistor's values.

The circuit schematic is shown in Figure 2. We have R1=4.7kΩ and R2=1kΩ act as a voltage divider to produce a constant 0.6V voltage to fit in the voltage range of the ADC unit. U1A separates the circuit and avoids interference. R3 and the LDR in parallel and R6 with U1B together form a non-inverting amplifier. As the LDR varies its resistance, the overall resistance of R3 and LDR varies. This change in resistance changes the overall gain of the amplifier and thus changes the output voltage. The value of R3 is set to 27kΩ to pull down the total resistance of the parallel resistors to prevent large gain when LDR resistance is at 1MΩ. The value of R6 = 5.2kΩ was chosen from simulations. The output, Msp_connector1, is connected to Port 1.4 of MSP430 to supply ADC input.

LED Driver circuit

The LED Driver Circuit is to provide power to LEDs and realize the dimming function of LEDs. In the whole design, we used one 3.7V lithium ion battery and a boost converter unit to produce a 12V voltage to power the LEDs.

The LEDs we use in the design is a narrow rigid LED light bar which has a forward voltage of 0.21A at a working voltage of 12V. The maximum luminous flux of a single LED light bar, which contains thirty LEDs, is 255 lm at 12V working voltage. The color of the LED light bar is natural white, which has a temperature of 4000K. According to the recommended light level for various indoor activities, a minimum illuminance level of 100 lx is required for a workplace with occasional visual work and a illuminance level of 250 lx is recommended for office work. Thus, a single LED light bar is able to provide enough luminous flux for most occasions.

In this circuit, we use a NPN transistor (2N3904) to act as a switch to control the on and off of the LEDs. As shown in the schematic diagram below, when the msp430 gives out a signal, the transistor works in the saturation region and it will turn on the LEDs. When the msp430 sends no signal to the circuit, the transistor will be in the cutoff region and the LEDs will be off. Switching between saturation and cutoff region can effectively control the on and off of the LEDs and used to control the duty cycles of the LEDs in order to dim the LEDs.

When the transistor is in the cutoff region, the V_{BE} is equal to 0.7V. The current in the collector Ic is equal to 0.021*3=0.063A, so the current in base I_b is equal to 0.063/100=0.00063A. The output voltage from msp430 is equal to 3V, and now we can calculate the resistance connected to base R9 equal to (3-0.7)/0.00063=3650Ω. Next we will find a value for R10, which are connected to the LEDs. The power supply is equal to 12V and each LED has a forward voltage of 3.2V and a forward current of 21mA. Thus, the resistor value should be (12-3.2*3)/0.021=114Ω. From the calculation we have a maximum theoretical value for the resistors in order to enable the LEDs. Then we use multisim to do a simulation in order to find the specific working range for the resistance values. With the simulation results, we choose a R9 of 820Ω and a R10 of 22Ω.

The PCB layout is shown in Figure 3. The power supply and ground line are set with a width of 30 mi to allow sufficient current. All the test points are placed close to the output to reduce interference. The connectors are put at sides and face outside to make sure the wires can be connected nicely without interfering with each other.

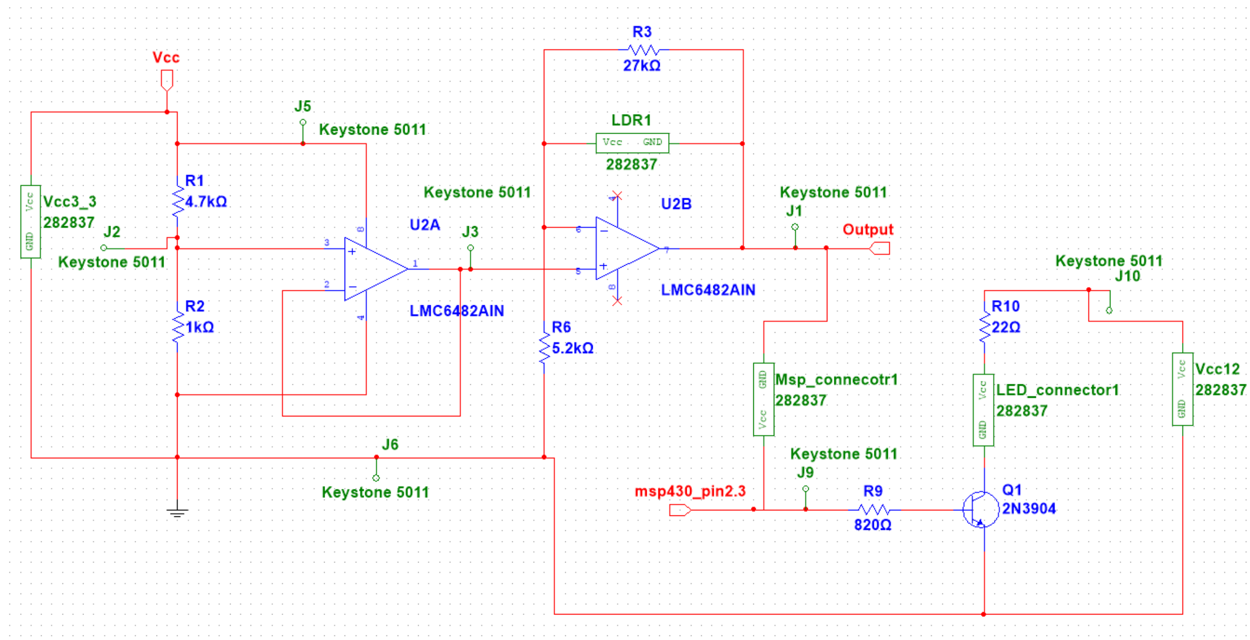

Figure 2 LDR and LED driver board schematic

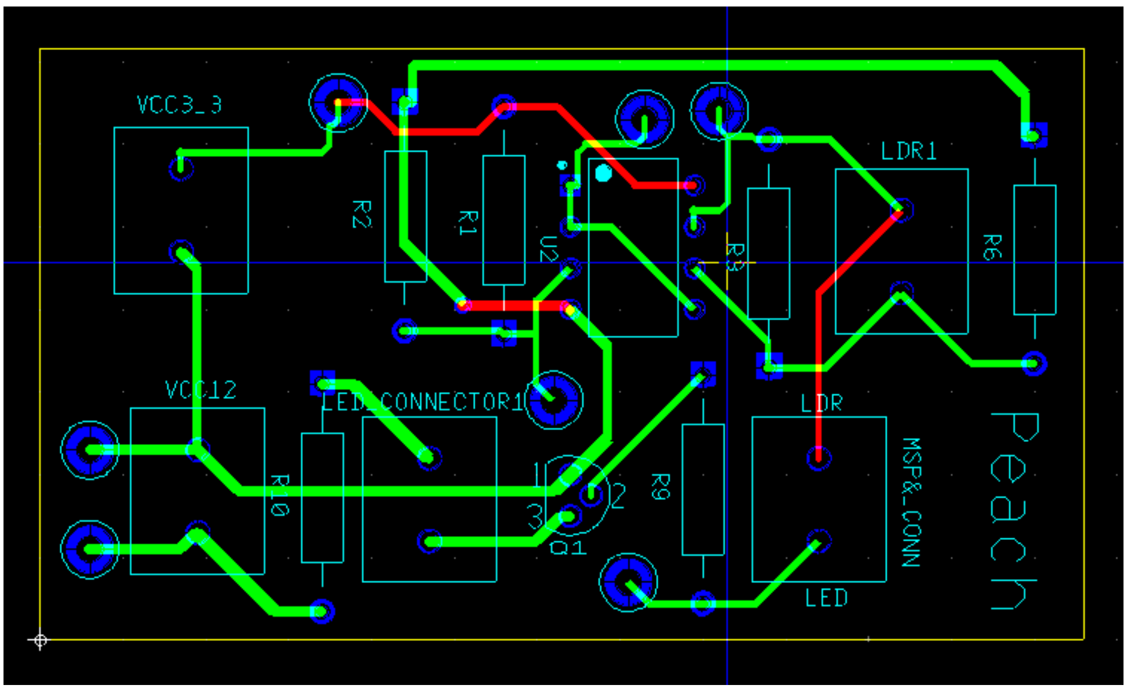

Figure 3 LDR and LED driver board layout

Switch Board

The switch board has two switches and one incremental encoder. For the incremental encoder, we choose PEC12R-4220F-N0024 which outputs a standard 2-bit quadrature code. For the normal switch, we choose EG1218, which is a simple slide switch.

As shown in Figure 4. The overall board design is pretty straightforward, we simply connect each switch with a pull-up resistor and connect it with the microcontroller. We connect every output to Port 1 to do the debouncing, and since we do it in software, we don't connect a capacitor in parallel with the switch.

For the pull-up resistors of the tact switch, we choose 35kΩ because it's the typical pullup resistor value in the datasheet. For the rotary encoder's resistors, we simply choose a large enough resistor to limit the current, therefore selecting 4.7kΩ resistors.

The PCB layout is shown in Figure 5. The switches and the encoder are placed in a line to make the user interface more friendly. The connectors are put at sides and face outside to make sure the wires can be connected nicely without interfering with each other.

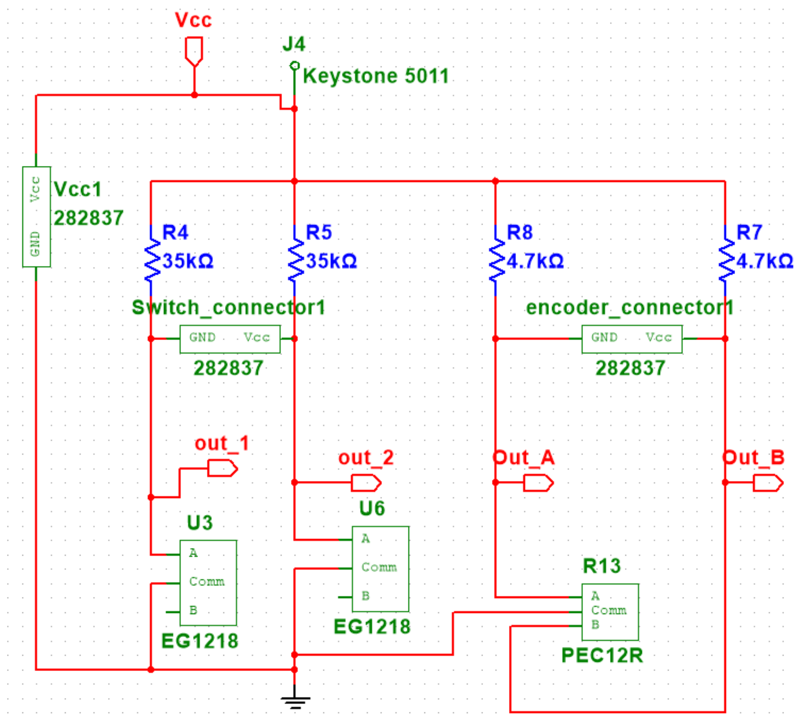

Figure 4 Switch board schematic

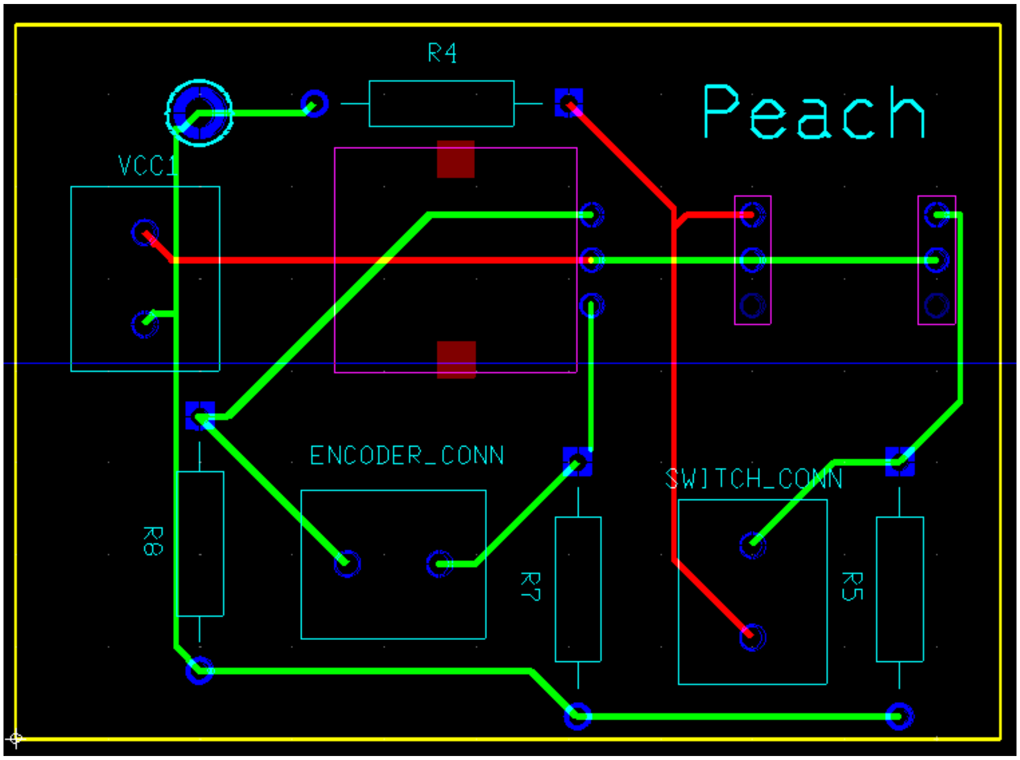

Figure 5 Switch board PCB Layout

Power Board

The power board has one voltage regulator to supply 3.3V to the LDR and switch circuits. For the voltage regulator, we choose AP7381, which has a wide input voltage range up to 40V.

As shown in Figure 6, the power board has two connectors supplying LDR circuit and LED circuit. Another wire directly supplies the 3.3V output from the voltage regulator to the MSP connector. Two 2.2μF capacitors are placed at the input and output of the voltage regulator to reduce vibration in voltage.

The PCB layout is shown in Figure 7. The power supply and ground line are set with a width of 30 mi to allow sufficient current. The voltage regulator is put closely with the capacitor. The connectors are put in one line to make sure the wires can be connected nicely without interfering with each other. The MSP connector is placed at the lower part of the board to balance the center of gravity.

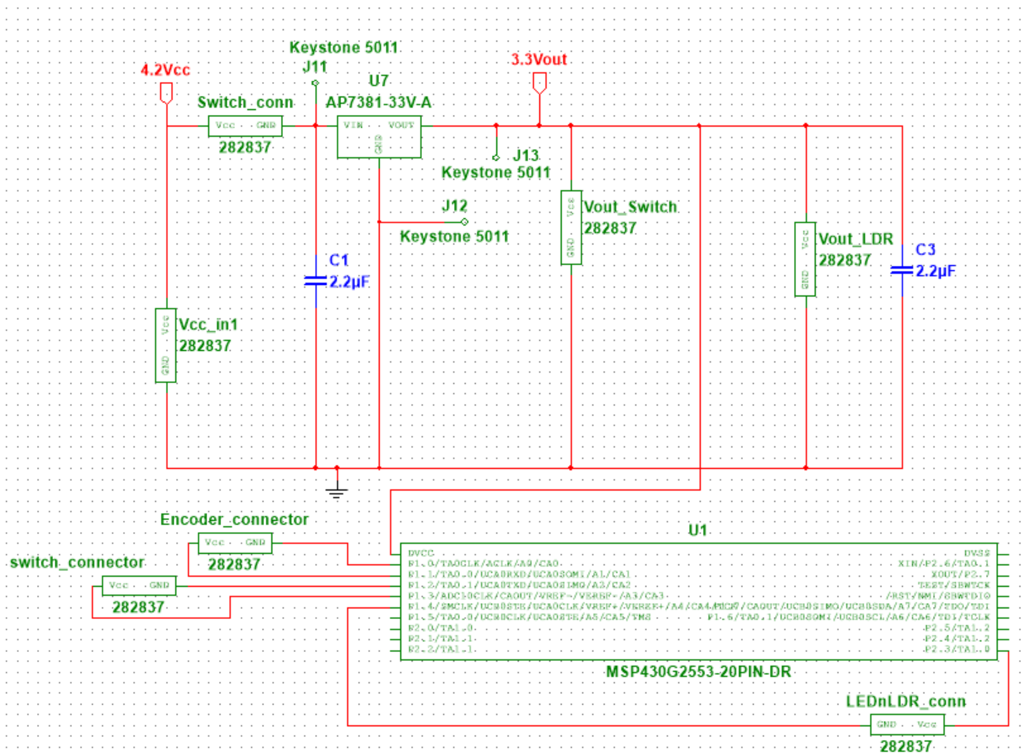

Figure 6 Power board schematic

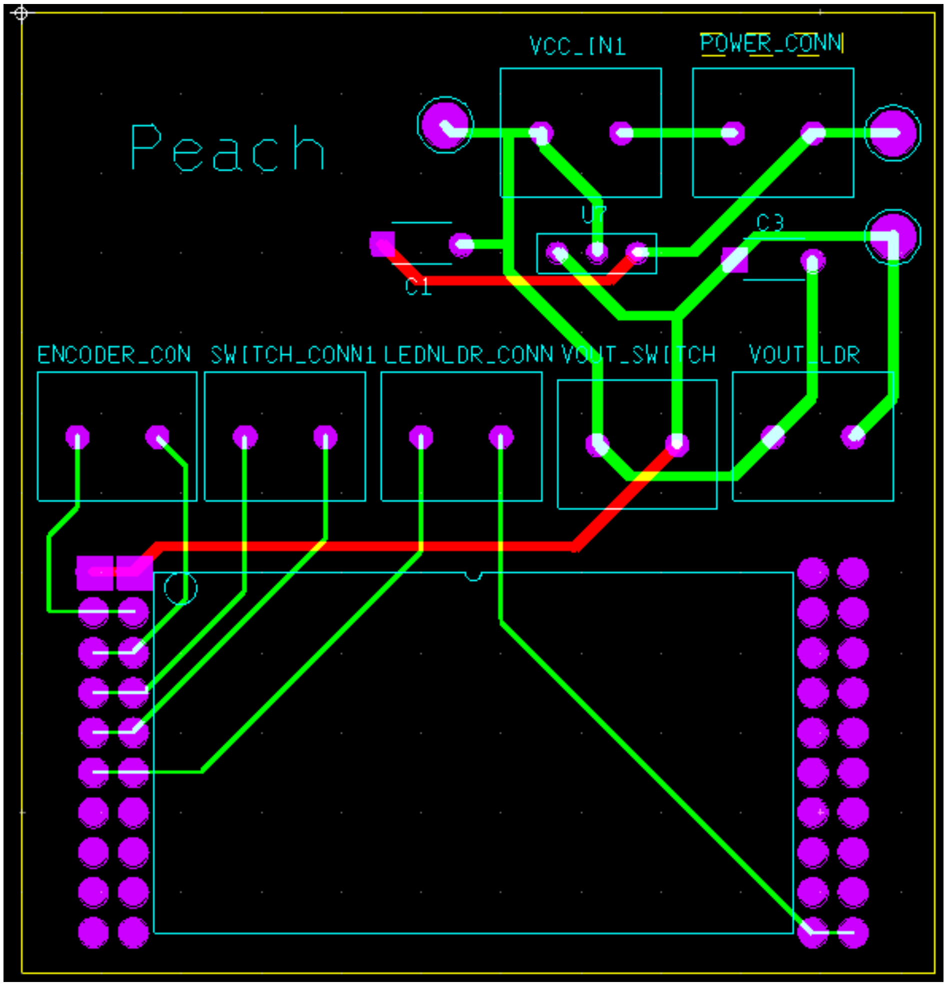

Figure 7 Power board PCB Layout

Boost Converter Unit

We used MT3608 Step-Up Adjustable DC-DC Switching Boost Converter Module for Arduino (shown in Figure 8) and set the output to 12V to supply the LEDs.

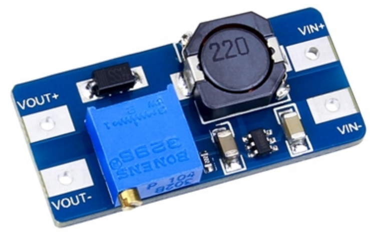

Figure 8 MT3608 Boost Converter Unit

Lithium Battery Driver

We used PowerBoost 1000C (1528-1349-ND in Digikey) to charge and output a 5.2V supply power to the entire lamp. The unit is shown in Figure 9.

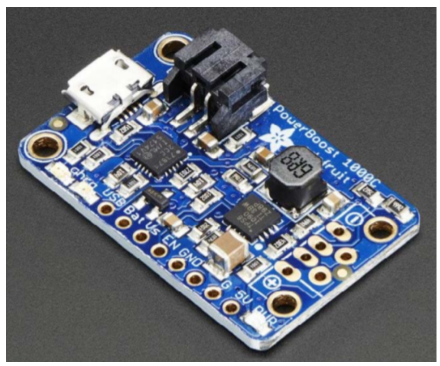

Figure 9 PowerBoost 1000C

MSP430 and Code

The software design of our project consists of three main parts: Reading input from switches and the encoder, setting up the timer to output PWM signals, and reading ADC input and adjusting PWM duty cycle accordingly.

Read Switch Status

To read switch status, we simply configure the ports to initialize them as inputs, and read the switch status using the ReadSwitchStatus function.

Read Incremental Encoder Status

To read incremental encoder status, we first read the switch status of its two outputs, then we created a finite state machine (shown in Figure 10) based on the two inputs read, A and B. Rotating the encoder clockwise will go clockwise in this FSM, therefore increasing the count to 4. Once it reaches 4, it will reset the count to 0 and increase the PWM duty cycle by the current step. Similarly, rotating the encoder counterclockwise decreases the count to -4. Once it reaches -4, it will reset the count to 0 and decrease the PWM duty cycle by the current step. The PWM duty cycle is checked with the minimum and maximum level when it is changed.

In the infinite loop of the main function, it reads the switch status of both outputs of the encoder at each cycle if it is not in the auto mode.

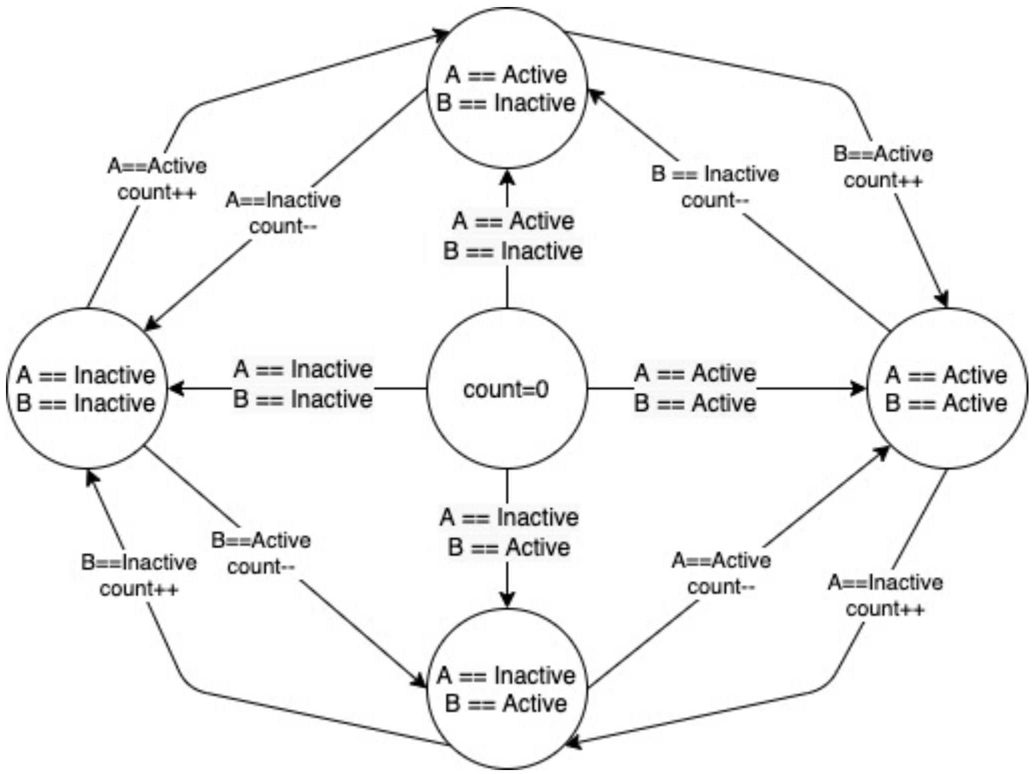

Figure 10 Encoder Finite State Machine

Configure Timer A to Output PWM Signal

We configure timer A in the function ConfigureTimerA in timerA.c. First, we stop and clear the timer. Then, we assign a value to TA0CCR0 and an initial value to TA0CCR1 and change the mode to Reset/set mode. After that, we configure GPIO 1.2 so that the timer output is connected to the port pin. Finally, we enable TACCR0 compare/capture interrupt flag and start the timer in up mode using the SMCLK. In the main function, we also configure the Digitally Controlled Oscillator to 16Mhz. After everything is configured, whenever we want to set the PWM duty cycle, we simply set TACCR1 = TACCR0 * (pwm_level / MAX_LED_VALUE), where MAX_LED_VALUE is 100.

Read ADC Input

To read ADC input, we simply configure GPIO 1.3 to read ADC input, enable and start conversion first and save the data in ADC10MEM as current ADC input. Since we use ADC10, it ranges from 0 to 1024. However, since the gain of the non-inverting circuit in the LDR circuit doesn't change too much when the illumination level is high and the resistance of LDR is low, we design a custom function that scales the ADC input to amplify the change in ADC input when it's low, and reduce the change in ADC input when it's high. As it is shown in Figure 11, it drops to 0 when ADC is less than 0, has a slope of 1/4 when 200 < ADC < 500, and has a slope of 1/20 when ADC > 1000. Since our PWM level has a maximum value of 100 and a minimum value of 20, this function converts ADC to LED PWM duty cycles within the range. When PWM duty cycle is below 20 or above 100, it will automatically be set to the minimum or maximum value.

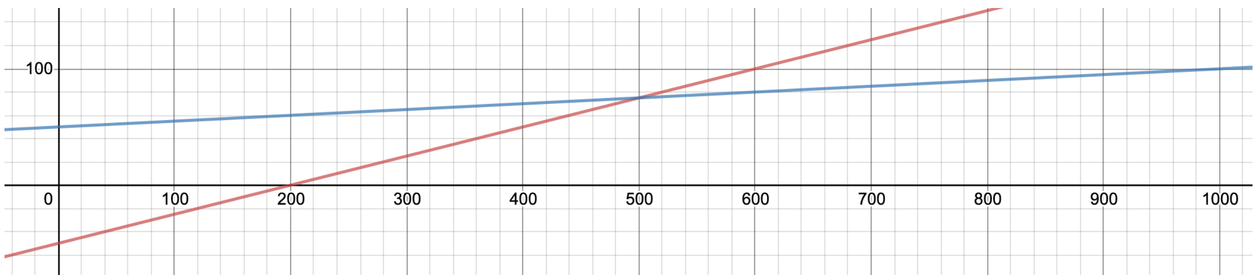

Figure 11 ADC Function

TimeDelay Function

This function uses Timer A1 to delay the process by a certain amount of time. The basic idea is to wait for the timer to overflow.

Auto Mode

The auto mode is determined by the auto mode switch. When auto mode is true and night mode is false, the PWM duty cycle is determined by the ADC input according to the previous section. To add more tolerance, we only adjust the pwm value if it changes more than 3. To make the change of lighting level smoother, we use the TimerDelay function described above to delay the while loop for a short amount of time, and change the pwm value in small steps to the new value.

Night Mode

The night mode is determined by the night mode switch. When turned on, it will adjust the PWM duty cycle to the minimum value and decrease the pwm manual change step from 2 to 1.

Main Function

The main function has a while loop that runs forever. It checks the switch status of the night mode and auto mode button at the start of each cycle, then determines to set the PWM duty cycle using the auto mode logic or the manual mode logic based on the mode it's currently in. When both auto mode and night mode is off, it's manual mode. When night mode is on, it's night mode, and when auto mode is on and night mode is off, it's auto mode.

Project Timeline

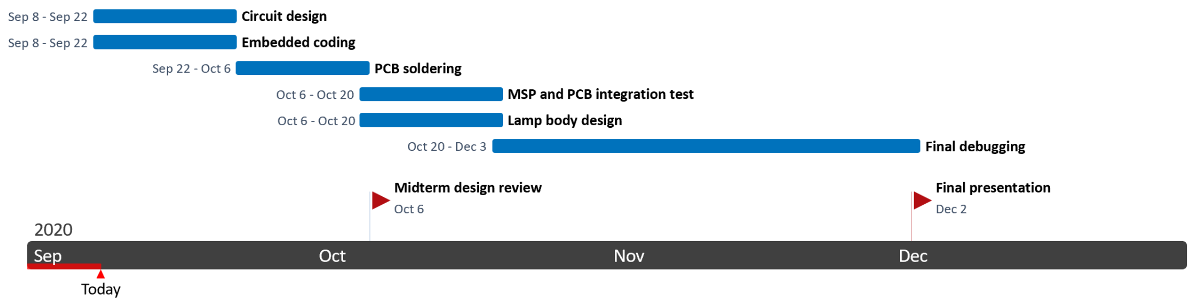

Figure 12 Project Timeline Picture 1

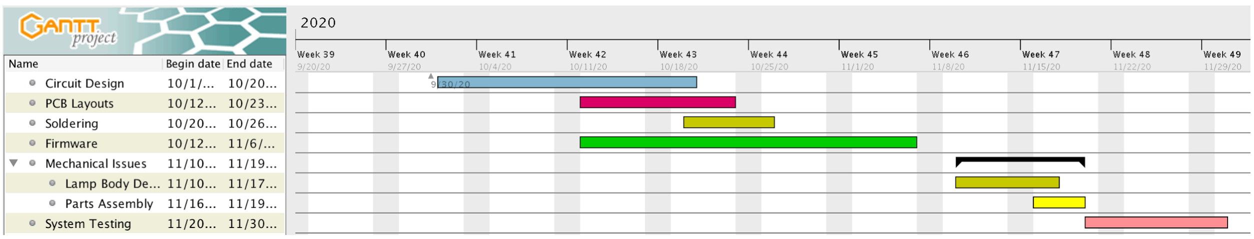

Figure 13 Project Timeline Picture 2

Figure 12 is the initial Gantt chart created in the beginning of the capstone project. The final Gantt chart is shown in Figure 13. As shown in both figures, there are significant differences between the original planned timeline and the final timeline. At first, we plan to work on the circuit design and writing the code in parallel. However, We didn't get all our schematics done before the midterm design review on Oct. 1st and we thought that we needed the actual PCB board for the testing of the code, and the deadline of PCB board sendout on Oct. 23rd is more urgent. Therefore, all four of us work on the circuit design and PCB layouts in the beginning part of the capstone project. After the board sendout, we started working on the programming of embedded code and soldering the parts in parallel. Since two of our group members are not on ground and the other two are on ground. Tiger and Isaac were working on the soldering of parts. Andrew, Jiahe and Isaac were working on the firmware design. Finally, when we got both the embedded program and PCB tested integrated, Jiahe began the design of the lamp body and after that the actual assembly was done by Isaac and Tiger before December.

Test Plan

The test plans we proposed in our mid-term summary consists of three boards: light dependent resistor board, led driver board, and switch board. The test plans are shown in Figure 14, Figure 15, and Figure 16.

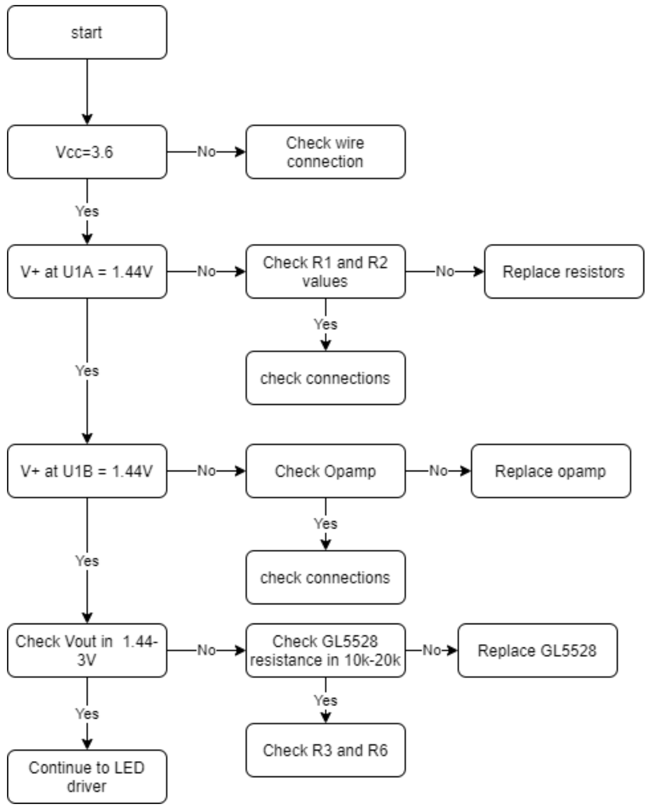

Figure 14 LDR Board Test Plan

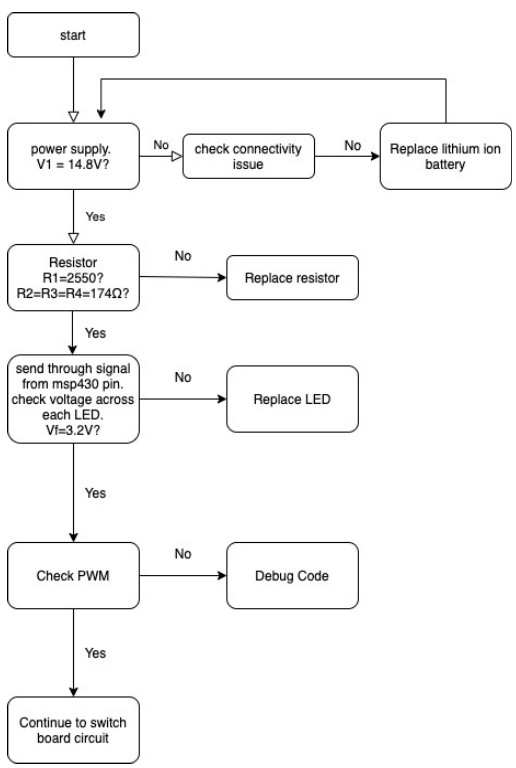

Figure 15 LED Driver Board Test Plan

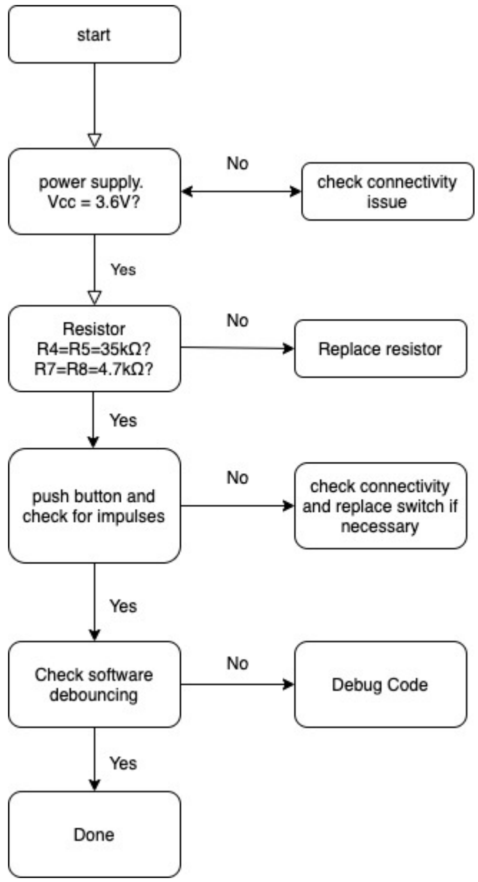

Figure 16 Switch board Test Plan

However, since we merged the LDR board and LED driver board together and added a new power board, we didn't stick to the original test plan. We will discuss how we tested each board in the following sections.

LDR and LED Driver Board

We first check the resistor values to see if they match our schematic. Then we start by checking the LDR sub circuit. We supply 3.3V voltage as input to the circuit and check the voltage at pin1 of the op-amp to see if the voltage divider circuit works as expected. The calculated value should be 0.579V, and we measured the voltage to be 0.583V, therefore meeting our requirements.

We then measured the output at pin 7 of the LDR circuit to observe its range. To observe its maximum value, we cover the LDR completely so that it reaches its maximum resistance which is around 1000kΩ. Since it's in parallel with a 27kΩ resistor, their resistance in parallel is around 27kΩ, so the overall gain of the circuit should be around 6 and the output voltage should be around 3.5V. We measured the output voltage to be 3.3V, which is close to our expected value. To observe its minimum value, we shine torch light on the LDR, and its resistance will drop to a value that is lower than 10Ω. This will result in a gain of around 1, therefore the minimum output voltage should be around 0.583V. We measured the output voltage to be 0.584V, which matches with our expected value.

To check the LED driver circuit, we apply 3.3V to drive the transistor and 12V to supply the LED. We then measured the base current, which is 3mA, the collector current, which is 85mA, and the voltage across LED, which is 10.7V. The current values are within the range of the transistor, which has a maximum collector current of 200mA.

Power Board

The power board itself is pretty simple to test, since the main part is the voltage regulator. However, there are more tests associated with the msp430 since this board interfaces with the launchpad. Those tests will be covered in the msp430 section. In addition to testing the voltage regulator, we also test the lithium ion battery, the charger board, and the boost converter board. The lithium ion battery has a voltage of 3.82V, which is close to the 3.7V value we anticipated. The charger board outputs a constant voltage of around 5.2V, and we measured it to be 5.18V, therefore meeting our requirements. The boost converter board takes the output from the charger board and should output a voltage of 12V. We measured the output to be 12.1V, which also matches our requirements. Finally, we supplied the 5.18V output from the charger board to the power board and measured the output voltage of the voltage regulator to be 3.29V, which is close to our anticipated output of 3.3V. Finally, we tested the main switch connected to the power board simply by turning it on and off and observing if the LED turned on and off as expected, and it appeared to match our expectations.

Switch Board

We simply measured the resistance of the resistors and the other tests are associated with msp430.

MSP430 and Code

After all the boards were tested separately and proved to be working, we connected everything together and started testing MSP430. To test MSP430 and code, we simply have to test the two buttons and the incremental encoder and see if the LED lights behave as expected.

We first tested the incremental encoder to see if manually changing the PWM duty cycle of the LED works as expected. To do so, we simply rotated the encoder clockwise and counterclockwise to see if the LED lights intensity increased and decreased as expected. We also checked if the LED PWM duty cycle stayed at the minimum or maximum level as we kept rotating the encoder counterclockwise or clockwise, and it matched our expectation.

We then tested the auto mode button. It stayed off at the start, and we rotated the encoder to ensure the lamp was in manual mode. We then turned on the switch and observed that the light intensity changed to a different level, which meant it changed to a lighting level according to the illumination level measured by the LDR. We rotated the encoder to make sure the manual adjust function was disabled. Then we covered the LDR completely and observed that the light intensity increases smoothly to a very high level. Finally, we shined torch light on the LDR and observed that LED light intensity dropped smoothly to a lower level.

To verify that our auto mode algorithm works as expected, we measured the PWM duty cycle and the output voltage at the LDR circuit to see if they match. The maximum ADC input is 1000, and our algorithm divided it into three ranges: below 200, bigger than 200 and below than 500, and higher than 500. We first tested the case when the ADC input is below 500 and greater than 200, in which case the LDR should receive a illumination level of general room lighting. As we can see in Figure 17, with the LDR circuit output voltage to be 1.42V, the ADC input should be $\frac{1.42}{3.3} \cdot 1024 = 440$, which is less than 500. According to our algorithm, the lighting level should be $\frac{440}{4} - 50 = 60$. Since our maximum lighting level is 100, the duty cycle should be around 60%. The measured duty cycle is 59.7%, which is close enough to our expected result.

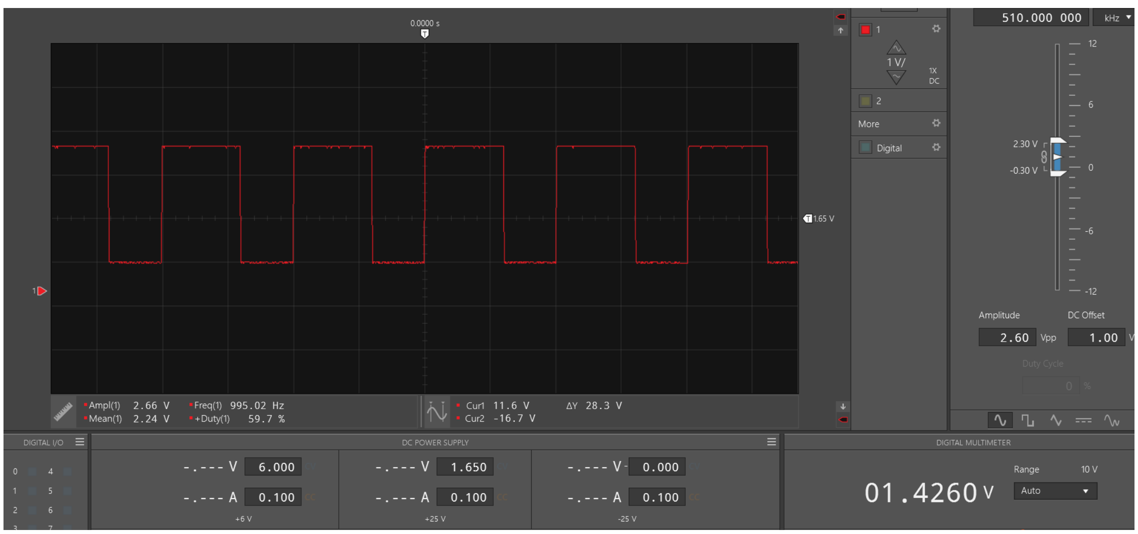

Figure 17 LED Duty Cycle General Lighting Level

We then tested the case when the ADC input is less than 200, in which case LDR receives high intensity lights. As we can see in Figure 18, with the LDR circuit output voltage to be 0.605V, the ADC input should be $\frac{0.605}{3.3} \cdot 1024 = 187$, which is less than 200. According to our algorithm, the lighting level should be 0, but since our minimum lighting level is 20, it will be set to 20 and thus has a duty cycle of 20%. The measured duty cycle is 19.9%, which is close enough to our expected result.

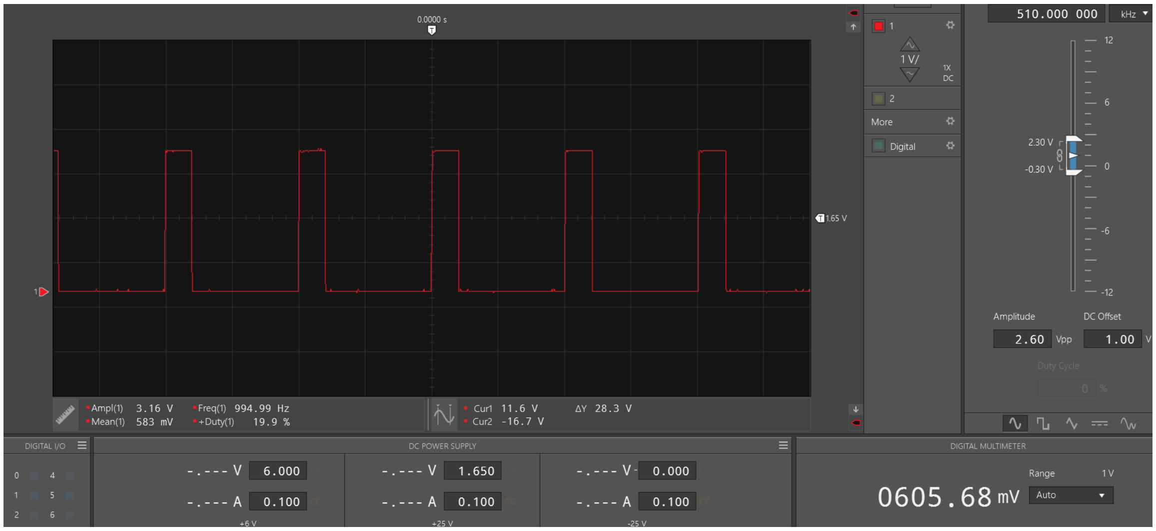

Figure 18 LED Duty Cycle Low Lighting Level

Finally, we measured the case when the ADC input is higher than 500, in which case LDR receives little light. As we can see in Figure 19, with the LDR circuit output voltage to be 2.09V, the ADC input should be $\frac{2.09}{3.3} \cdot 1024 = 649$, which is less than 500. According to our algorithm, the lighting level should be $\frac{649}{20} + 50 = 82.45$. Since our maximum lighting level is 100, the duty cycle should be around 82.45%. The measured duty cycle is 83.6%, which is close enough to our expected result.

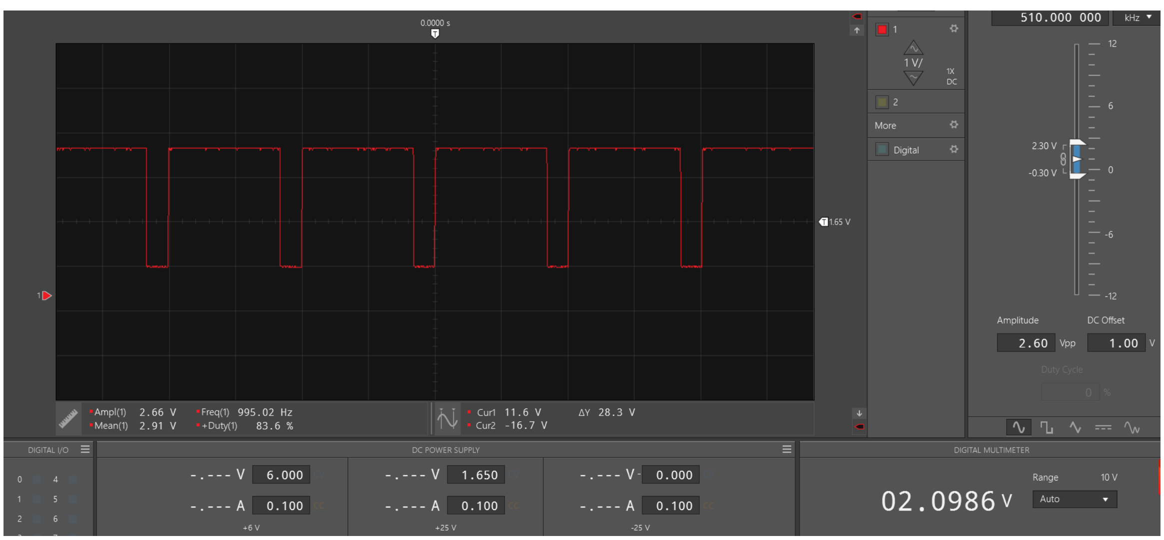

Figure 19 LED Duty Cycle High Lighting Level

Now we can conclude that our auto mode works as expected and we move on to testing the night mode button. After turning on the night mode, the light intensity should drop to the lowest level, the manual mode is enabled and the manual adjustments will have smoother steps compared to the normal manual mode, and even if the auto mode is turned on, it will not have any effect. We first put both buttons to the off state and then turned on the night mode switch. We observed that the light intensity dropped to the lowest level and as we rotated the encoder, the light intensity changed more smoothly, indicating that it was changing at a lower step compared to the normal manual mode. Then we turned on the auto mode and observed that the light intensity didn't change. We then shined torch light on LDR and covered the LDR to make sure the auto mode didn't have any effect when night mode was on. Finally, we turned off the night mode and tested the auto mode functionalities were working as expected.

Therefore, we conclude that our lamp passed all our tests and matches our design.

Final Results

The following table demonstrates the requirements for a complete multi-purpose lamp capstone project that is fully functional. The requirements were decided in the initial project proposal. First, the lamp should be able to turn on and off through the on/off switch. Second, to determine if the daytime manual mode functions properly, the intensity of the lamp should be able to change through the rotary encoder. Third, the light intensity should increase when the environment is dark and should decrease when the environment is relatively bright to satisfy the requirements of daytime auto illumination mode. Fourth, the requirement for a fully functional nighttime mode lamp should be able to be turned on, and the intensity would return to the lowest level at the same time. Finally, when the night mode of the lamp is turned on, the light intensity should be able to adjust only manually through rotating the rotary encoder.

	Requirements	Satisfied	Not Satisfied
ON/OFF	Able to turn on and turn off the lamp by the on/off switch	X	
Daytime Manual	Can adjust the brightness of the lamp through the rotary encoder when auto mode is off.	X	
Daytime Auto	The light intensity will increase when the environment is dark and will decrease when the environment is bright automatically.	X	

Nighttime ON/OFF	When night mode is turned on, the intensity of the LEDs will become to their lowest. The intensity of the LEDs will not change automatically even if the auto button is turned on.	X	
Nighttime Manual	Can adjust the intensity of the LEDs manually through the rotary encoder.	X	

The right side of the table shows the final result of the multi-purpose desk lamp capstone project. From the testing result, the desk lamp can be said to satisfy all the requirements that is stated in the initial project proposal functionally. However, the exterior body of the desk lamp does not meet the production level that was initially expected due to the reason mentioned in the above constraints section.

The team was satisfied with the final result. However, the only thing that would have made it better is if the team would get the design of the lamp body earlier to be able to 3D print the lamp body. The final result taught us to plan ahead before things are passed.

Costs

The costs of building each unit of one completely functional multi-purposed desk lamp is listed in the table below. The table below also shows the expected costs of mass production of the desk lamp in quantity of 1000.

	Unit Costs if 1 desk lamp produced	Unit Costs if 1000 desk lamps produced
Switch Board + LDR Board + LED Driver Board + MSP430 Launch Pad	$56.13	$45
Power Boost Charger	$19.95	$15.95

MT3608 Step-Up Adjustable DC-DC Switching Boost Converter	$1.95	$1.50
LEDs	$7.95	$7.15
Lithium Battery	$6.59	$4.5

Future Work

To expand upon the current project, we suggest to implement three additional features in addition to the current version of desk lamp.

1. Automatic On and Off Control:

    With automatic on and off control features, the desk lamp will automatically light up when there are people around, and it will automatically turn off when people leave, without the need for people to manually press the switch. This feature can prevent people from leaving while the light is still on, which can save electricity and energy.

    To achieve this, a infrared IR sensor circuit will be used. The infrared sensor can not only measure the heat of the object, but also detect the movement of the object. The transmitter is an infrared light-emitting diode, and the detector is just an infrared photodiode, which is sensitive to the same wavelength of infrared light emitted by the infrared light-emitting diode. When infrared light is irradiated on the photodiode, the resistance and output voltage will change proportionally with the size of the received infrared light. The major difficulty of implementing this feature is to build the infrared IR sensor circuit which no one of our group has experience with.

2. Remote Control from Mobile Client:

    In addition to the automatic on and off control and automatic brightness control, an improvement in the current project would be to replace the manual control switches with an mobile application. Therefore, people will be able to use their mobile phone to control the on and off and the brightness of the lamp. As mentioned in the above ethical issues section, we also plan to collect the brightness preference of each user and upload to the cloud for computation so that the table lamp can achieve the dynamic lighting effect that is most suitable for the customer’s personal preference. The major difficulty in implementing this feature is that none of the group members have experience with mobile application development.

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Appendix

Appendix A: CAD drawings

Some of the CAD drawings are shown below. Figure 20 shows the overall lamp body design. Figure 21 shows the inside view of the lamp body, including the slots to hold boards. Figure 22 shows the place to place switches on top of the base and the hole at the back which are for the charger socket and the light dependent resistor.

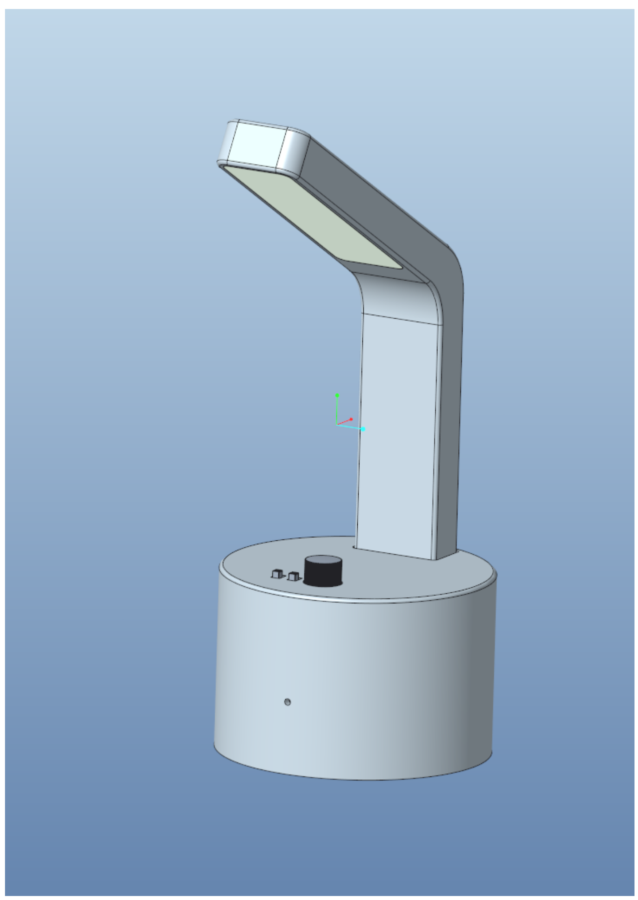

Figure 20 Lamp body overall

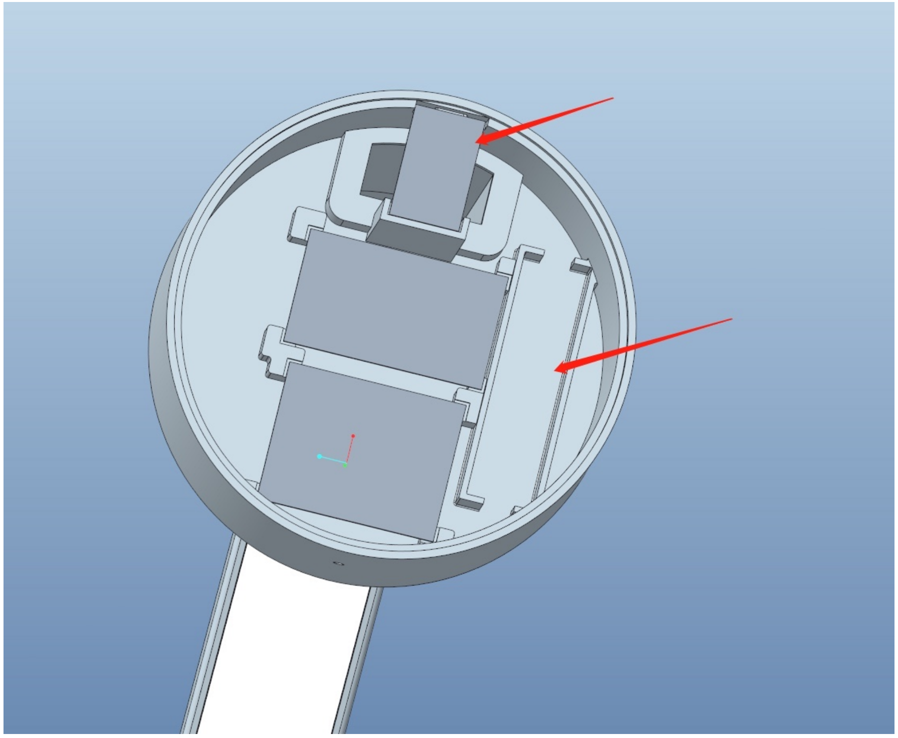

Figure 21 Lamp body inside view

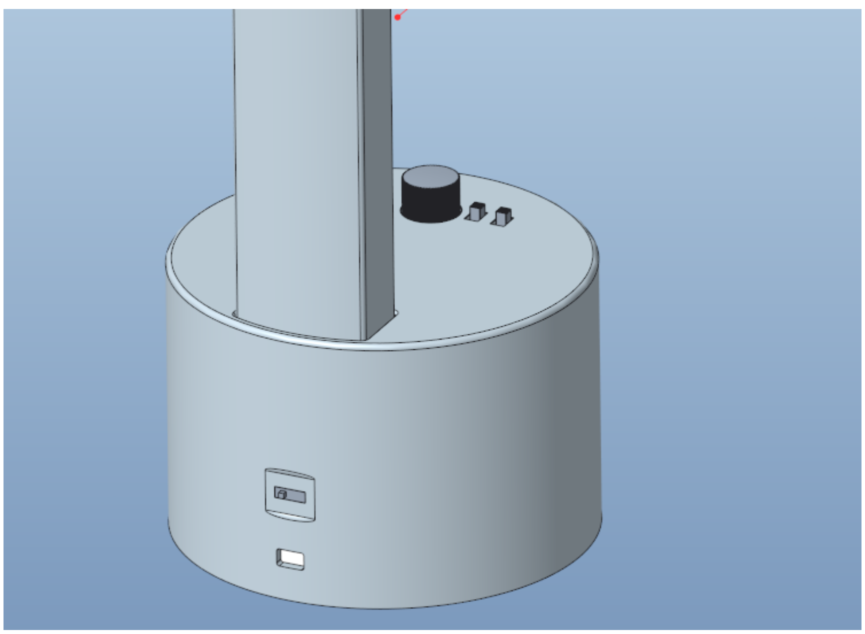

Figure 22 Lamp body back view