ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Automatic Bike Light System

Team #21

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1 Introduction

1.1 Problem and solution overview

A bicycle light is one of the most effective ways to improve bicyclist safety while riding at night. Unfortunately, it can be difficult to remember to turn a conventional light on until the rider is in motion, at which point the rider has to either blindly reach for the button on the front and rear light, or take their eyes off the road and look for it in the dark, neither of which is safe. Additionally, it is easy to forget to turn the lights back off, especially if the bike is parked in a well lit area. This results in draining the battery faster than necessary.

Our project addresses these issues by using a series of sensors and a microcontroller to activate and deactivate the lights on the bike. When the system is not in motion, it will turn the lights off, preserving battery life, and then turn them back on when the bike is in motion and it is dark enough to warrant turning the lights on. If the cyclist wants to manually turn the system off or turn the headlight on to provide better illumination of the road ahead, a toggle switch on the handlebars allows the rider to do so without having to take their eyes off the road or their hands off the handlebars.

1.2 Visual aids

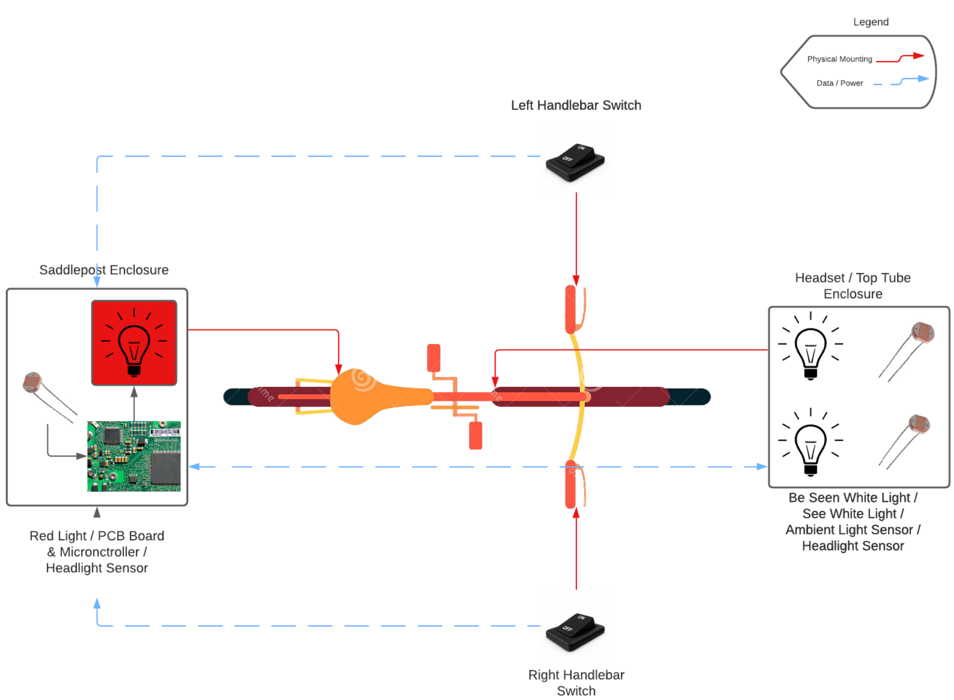

Figure 1: Automatic Bike Light System Visual Aid

1.3 High-level requirements list

To adequately address the problems described above and be considered a success, our project must meet several high level requirements.

- The system must transition from its deep-sleep mode into full operation within 15 seconds of the bicycle being in motion, and transition back to deep-sleep after being stationary for 5 minutes.
- The system must turn on the flashing indicators when the ambient light levels reach that of dusk for more than 10 seconds. The light level at dusk is being defined as 500 lux [1].
- The system should raise the brightness of the indicators in a vehicle is detected within 30 meters.
- The system should activate or deactivate in accordance with the user input from the first handlebar toggle switch. The system should also turn the headlight on or off, depending on the user input from the second handlebar switch.

2 Design

2.1 Block Diagram

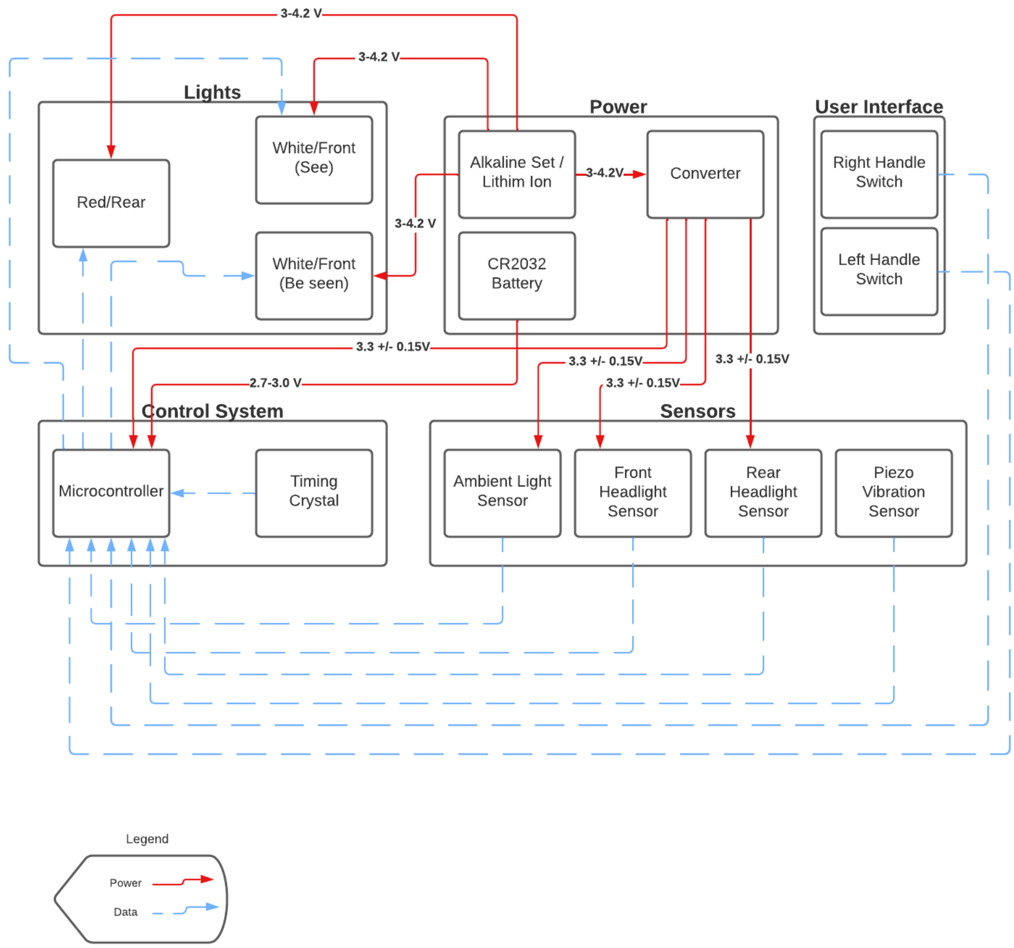

Figure 2: Automatic Bike Light System Block Diagram

The block diagram above shows the interactions between the main systems of our project. The power system provides power for all of the other systems, and due to the way our real time clock is implemented, it must have redundant energy stores. The primary battery is a large lithium ion battery pack, but when it is depleted, the microcontroller can be powered by a separate smaller battery in order to provide power while the main battery is being recharged. The lighting system is responsible for alerting nearby pedestrians and motorists of the bicyclist's presence. This is accomplished by a flashing white light on the front of the bike, and a flashing red light on the rear of the bike. The lighting system also has to be able to illuminate the road ahead, so there is a higher power LED array up front to provide a steady light source. The lights are controlled by the microcontroller, which is responsible for interpreting data from the sensor system, maintaining a real time clock, and responding appropriately according to the inputs received from the sensor systems.

Finally, the sensor system as a whole is responsible for monitoring relevant conditions such as light levels, vibration, or user input, and sending that data to the microcontroller when appropriate.

2.2 Physical Design

2.3 Power System

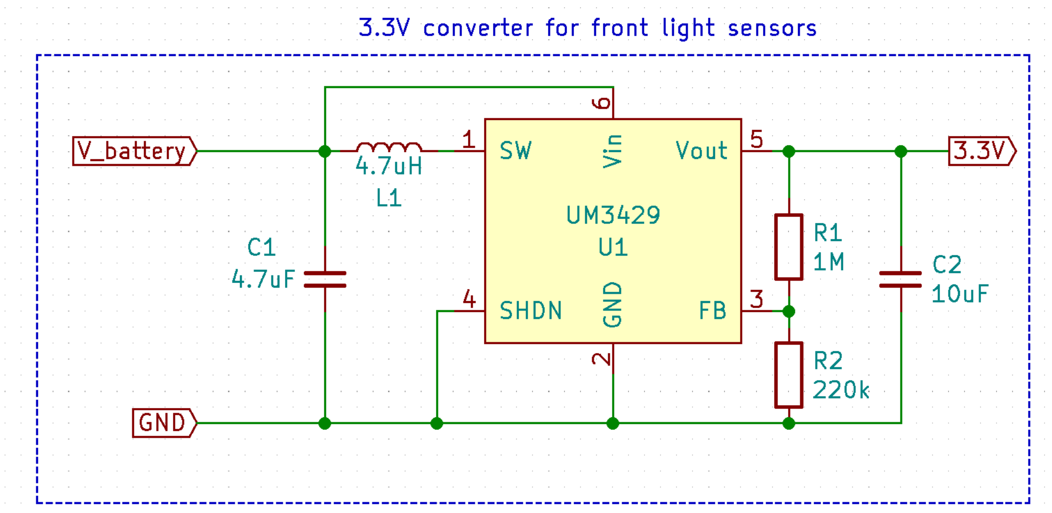

Figure 3: Front 3.3V converter

The power system is responsible for making sure that all components receive the voltage and current that they need. The basis of our power system is a pair of 18650 lithium ion batteries connected in series. The decision to use rechargeable rather than primary cells was driven by the desire to reduce waste, and was supported by the ability of lithium ion cells to store enough energy to allow for more than 5 hours of continuous use between charges. Since the output voltage of the batteries varies based on the state of charge [2], provisions were necessary to avoid damaging sensitive electronic components. One option was to implement a master voltage regulator that would maintain a constant voltage out of the battery module, but this would have to be able to deliver upwards of one amp of current. This is not impossible, but it would be large and potentially expensive.

Instead, we specified as many components as possible with acceptable voltage inputs that include the direct output voltage of the batteries. The only systems that require voltage regulators are the photodetection systems because they use a voltage divider to set the reference voltage. Figure 3 shows the circuit schematic for the 3.3V converter contained within the front lighting and detection module. Because the converter is only powering the comparator and providing a stable voltage for the voltage divider, we only need one of them in the front module.

We also decided to regulate the voltage going into the microcontroller because the voltage on an input pin cannot exceed V_{dd}+0.3V. The output of the Li-Ion battery module will never drop below 3.0V when in use, and the photodetection circuits output up to 3.3V, so the voltage regulator is not completely necessary, but to avoid problems in the future, we decided to add the voltage regulator going into the microcontroller.

The second part of the power system is the backup CR2032 battery. This battery is responsible for powering the microcontroller when the main battery module is either fully depleted or removed for charging. Maintaining a constant power supply for the microcontroller is necessary for the implementation of a real time clock. If the power supply to the microcontroller is interrupted for an extended period of time, then the real time clock will begin to fall behind. To address this, we added a small backup battery connected to only the microcontroller, which allows the real time clock to maintain time even when the main battery is removed.

Requirements	Verification
The converter has to maintain a constant voltage within the range of 3.3 +/- 0.15V.	Using the battery input into the 3.3V converter, and an oscilloscope connected to the 3.3V output, ensure that over several minutes of operation the converter does not exceed its specified operational bounds.
Converter must remain under safe temperature conditions, under 100°C	During aforementioned voltage regulation test, use IR thermometer to monitor and chart component temperature. Ensure it does not exceed 100°C.

Figure 9: Requirements and Verification Table for 3.3V Converter

2.4 Sensor System

2.4.1 Ambient Light sensor

The ambient light sensor is responsible for detecting how bright the surrounding environment is, and if it gets darker than a set value, it notifies the microcontroller that it may be appropriate to turn on the lighting system. The sensor utilizes a photodiode to directly detect the light levels, and the current produced by the photodiode is run through a resistor to produce a voltage. This voltage is then compared to a reference voltage from a voltage divider, and if the voltage from the voltage divider is greater than the voltage from the photodiode, the comparator outputs a logical high, which the microcontroller detects. By using a potentiometer rather than a pair of fixed resistors in our voltage divider, we have the ability to tune the cut-off brightness by adjusting the potentiometer, rather than replacing individual resistors.

2.4.2 Headlight Detectors

The headlight detectors are identical to the ambient light sensor from an electronic hardware perspective. The only differences are the specific tuning of the potentiometer and

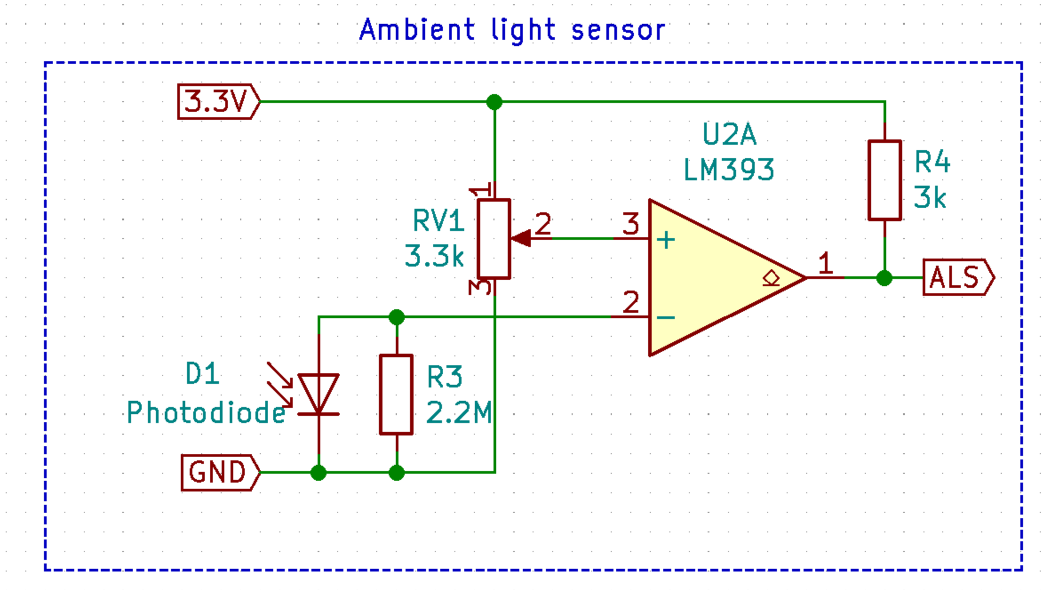

Figure 4: Ambient light sensor circuit

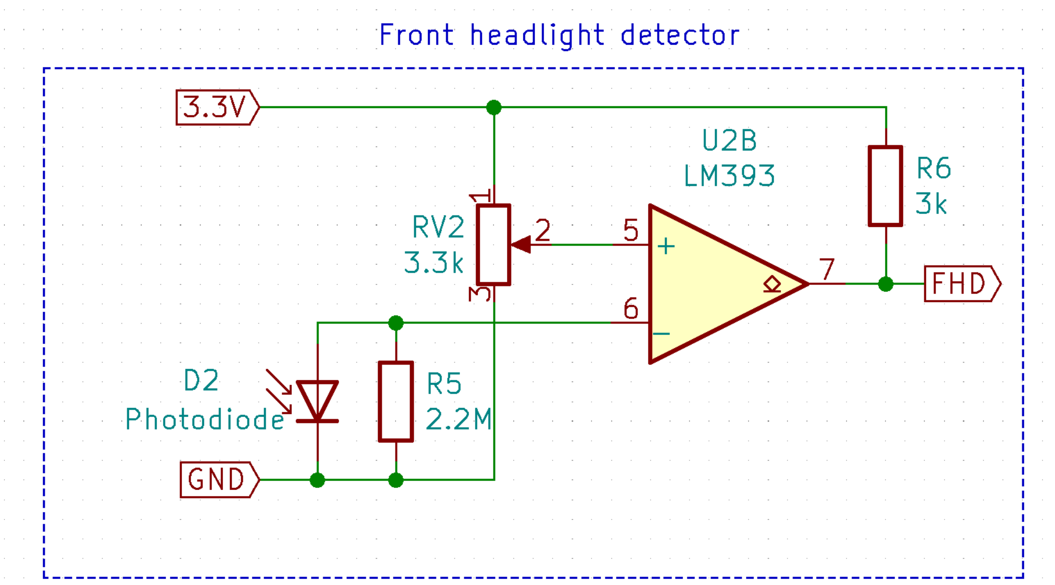

Figure 5: Front headlight detector

the physical placement of the photodiode in the sensor housing. Where the ambient light sensor is located at the surface of the housing to give it as much light as possible, the headlight detectors are set into the housing to restrict the light that can reach the photodiode. By setting the photodiode at the back of a small tube, only rays of light that originated from nearly straight ahead can reach the photodiode. Light coming from sources overhead (like street lights) or wide angles (like porch lights) will not be able to reach the sensor. This allows the sensor to only detect light that comes from sources similar to a headlight.

2.4.3 Motion Detection Sensor

The motion detection sensor is just a piezoelectric film that is connected to an IO port on the microcontroller. When the bicycle is moved, or in motion, the vibrations will cause the film to bend a small amount, which induces a voltage. This signal is sent to the microcontroller, and serves as an interrupt signal to wake the microcontroller out of its deep sleep mode.

The decision to use a piezoelectric film to detect motion rather than an accelerometer or other motion sensor came down to power consumption. Since this sensor has to always be on, minimizing its power consumption is critical to extending battery life. Since a piezoelectric element produces its own voltage, it does not need to consume any power to be monitoring for vibrations. All peripheral systems can be shut down, and the film will still send a signal to the microcontroller if it bends from a vibration. An accelerometer on the other hand would require a constant power supply, which would accelerate the discharge of the battery.

2.4.4 Handlebar Toggle Switches

The handlebar toggle switches are responsible for taking user input and sending it to the microcontroller. One switch is a main power switch. It will force the system into its deep sleep mode, regardless of what the sensors are saying is appropriate. The other state for that switch puts the sensors back in control of the system state. The second switch is used to toggle the headlight on and off. On well lit streets and bike paths, it may not be necessary to have the headlight on, so the user can turn it off to preserve the battery.

2.5 Lighting System

2.5.1 Front Indicator

The front flashing indicator is a set of 3 flashing white LED's placed on the front of the bike. They are necessary to alert cars and pedestrians in front of the bike that the bike is present. The LED's are controlled by a current regulator, which is necessary to control the brightness of the LED's. If the headlight detectors determine there is a car in front of the bike, the microcontroller can increase the brightness of the front indicator to get the attention of the driver. This control is also used to implement the flashing. Rather than having an RC circuit to produce the flash, the microcontroller varies the duty ratio of the control signal it sends to the current regulator. A duty ratio of zero will turn the light off, and a duty ratio that is not zero will turn it on. By adjusting the non-zero duty ratio, the brightness can be modulated in software.

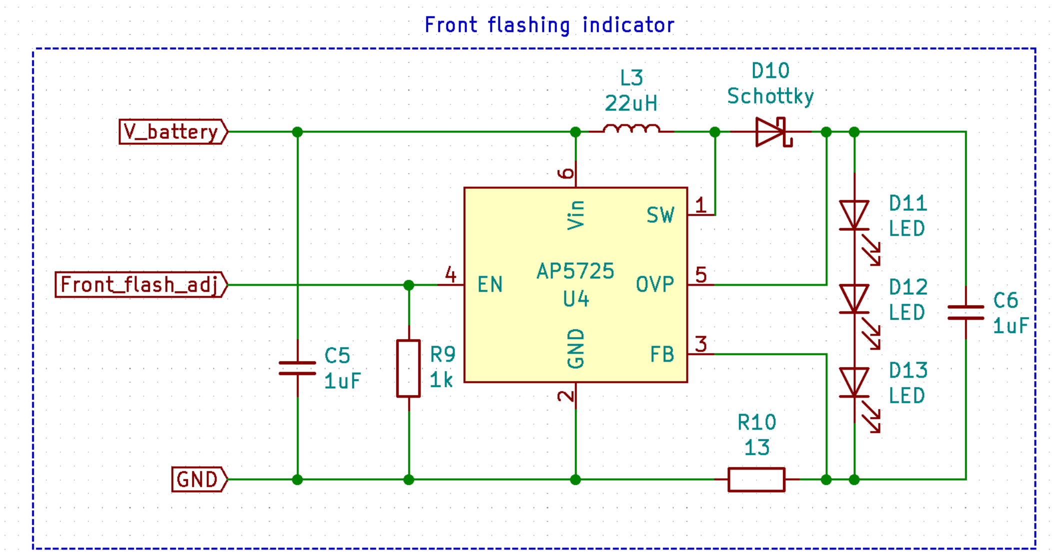

Figure 6: Front indicator light circuit

2.5.2 Rear Indicator

The rear indicator is identical to the front indicator, except the lights are red and it goes on the back of the bike. The only difference from an electrical standpoint is the current limiting resistor value. Because the red LED's we are using require more current than the white indicator LED's, the resistor has to be smaller.

2.5.3 Front Headlight

The front headlight is a set of 6 white LED's that have to be capable of illuminating the road ahead enough to see potential hazards. To determine a target light output, we first found the light output of comparable bike lights to be 100-200 lumens [3]. We decided to aim for the brighter end of that range, with a target output of 200 lumens. The LED's are driven by another current regulator, with the same ability to control brightness in software, rather than hardware.

2.6 Microcontroller

2.7 Tolerance Analysis

Due to changes in our design since the project proposal, there is now a critical tolerance in our system. The output of our photodetection circuit is limited to the output voltage of the 3.3V converter. That signal is then sent to the microcontroller, which can only accept

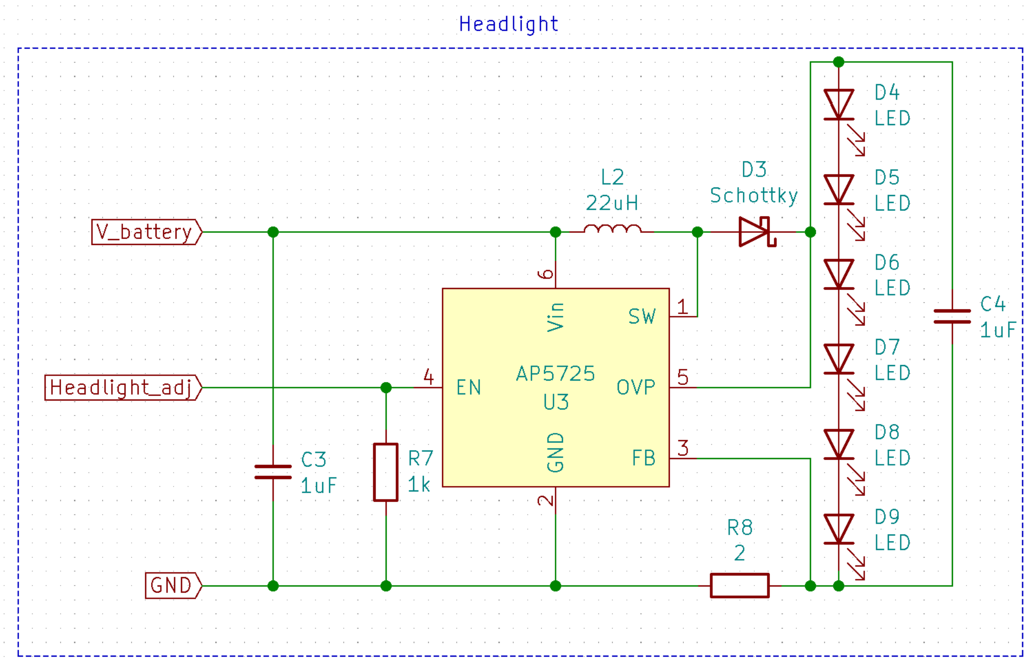

Figure 7: Headlight circuit schematic

voltages up to 0.3V greater than its own input voltage. Since its supply voltage is 3.3V from an identical 3.3V converter, the tolerances on the outputs of both converters will be the same. Therefore, the tolerance on both converter outputs is $\pm 0.15V$. If the output of the photodetection circuit converter is at the top of this tolerance (3.45V) and the output of the microcontroller converter is at the bottom of this range (3.15V), then the difference between them is exactly 0.3V, and the controller can still accept the input without being damaged.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

We are going to assume a wage of $40 per hour for each team member and assume we spend 15 hours a week working for 9 weeks.

$40 per hour x 15 hours x 9 weeks x 3 people = $16,200

We estimate the total cost of labor for the project to be $16,200.

3.1.2 Parts

We do not expect to use the machine shop for our project and as a result have excluded that information from the parts table. Tools such as soldering equipment and oscilloscopes that may be needed throughout the project are either already on hand or can be found in the senior design lab.

Description	Manufacturer	Supplier	Supplier Part #	Quantity	Cost
CR2032 Backup Battery	—	—	—	1	$0
354 Main Battery Pack	Adafruit Industries LLC	Digikey	1528-1834-ND	1	$19.95
USB LiIon/LiPoly Battery Charger	Adafruit Industries LLC	Adafruit	259	1	$12.50
PIC18F27Q43-I/SP Microcontroller	Microchip Technology	Digikey	150-PIC18F27Q43-I/SP-ND	2	$4.94
ED281DT DIP Socket	On Shore Technology Inc.	Digikey	ED3050-5-ND	3	$1.11
R38-32.768-12.5-EXT-5PPM Tuning Fork Crystal	Raltron Electronics	Digikey	2151-R38-32.768-12.5-EXT-5PPM-ND	2	$0.32
885012008038 15 pF Capacitor	Würth Elektronik	Digikey	732-7882-2-ND	4	$0.44
VTP9812FH Radial Photodiode	Excelitas Technologies	Digikey	VTP9812FH-ND	2	$1.34
AP3012KTR-G1 Step-Up DC-DC Converter	Diodes Incorporated	Digikey	AP3012KTR-G1DITR-ND	1	$0.49
CFR-25JB-52-2M4 2.4 MOhm Resistor	YAGEO	Digikey	2.4MQBK-ND	1	$0.10
PV36W105C01B00 1 MOhm Potentiometer	Bourns Inc.	Digikey	490-2877-ND	1	$1.47
LM393PE3 CMOS Differential Comparator	Texas Instruments	Digikey	296-49723-ND	4	$1.68
ICS-308-T IC Socket	Adam Tech	Digikey	2057-ICS-308-T-ND	10	$1.41
MSP1006-ND Piezoelectric Vibration Sensor	TE Connectivity Measurement Specialties	Digikey	MSP1006-ND	1	$6.77
LW514 White LED	Seoul Semiconductor Inc.	Digikey	897-1069-1-ND	5	$3.45
VLCS5130 Red LED	Vishay Semiconductor Opto Division	Digikey	VLCS5130-ND	5	$2.90
AP5725WG-7 LED Step-Up Driver	Diodes Incorporated	Digikey	AP5725WG-7DITR-ND	5	$3.15
					Total Parts Price: $62.02

Figure 8: Parts Table

Grand Total: $16,200 (Labor Costs) + $62.02 (Total Parts Price) = $16,262.02

3.2 Schedule

Week	Neeraj	Jeremy	Brian
2/21	Order Parts	Finish Design Document	Finish Design Document
2/28	Prep for Design Review	Begin Programming Microcontroller	Finalize PCB Layout for Review
3/7	Validate Ordered Parts	Finish Programming Microcontoller	Order Final PCB
3/14	Spring Break	Spring Break	Spring Break
3/21	Assemble Lighting Subsystem	Design and Print Enclosures	Assemble Power Subsystem
3/28	Solder PCB	Assemble Sensor Subsystem	Assemble and Calibrate Clock System
4/4	Calibrate Sensor Subsystem	Debug Microcontroller	Assemble Handlebar Switches
4/11	Debug Faulty Subsystems	Combine Assembled Subsystems on Bicycle	Debug Faulty Subsystems
4/18	Start Final Paper	Start Final Presentation	Work on Final Demonstration
4/25	Finish Final Paper	Finish Final Paper	Finalize Presentation

Figure 9: Schedule Time-Table

4 Discussion of Ethics and Safety

4.1 Potential Ethical and Safety Issues

One of the biggest safety concerns that this project poses is a safety concern inherent to all bike lights; whether or not it will warn the user when the battery is low, potentially leaving the user with a non-functioning light without warning. This is especially dangerous in low-light conditions which could leave the rider in a dangerous situation where they can't see the path ahead of them, increasing the risk of injury and accident. To ensure the safety of the cyclist, we intend to implement a power indicator to warn the user when the system is in danger of shutting off the lights entirely. Putting the power indicator somewhere that is easy to see should ensure that the rider knows when it is time to charge the system and when it may be unsafe to take a longer ride.

There are also safety concerns that must be addressed with any system that utilizes lithium-ion batteries. Since our product requires a mobile power source, we have decided that rechargeable batteries offer a solution to this problem and have the added benefit of being cheaper to have over the long run compared to buying new replacement batteries once the ones in use lose charge. Although our system will not be demanding power from the battery module at a level that could cause a risk of fire, we need to still be careful and ensure that the batteries are enclosed in a waterproof container to mitigate the inherent risks associated with batteries[4]. In order to prioritize safety, we are going to use off-the-shelf solutions with the battery and charger where possible, given that these products are rigorously tested to meet safety standards.

As for ethical concerns concerning the project, there is nothing that is particularly outstanding given the nature of this project. Referring to both the IEEE and ACM codes of ethics, the only thing that is relevant to our project is a commitment to sustainability mentioned in the IEEE Code of Ethics[5]. We commit ourselves to sustainability by making the choice to use rechargeable batteries rather than non-rechargeable ones, which should reduce the environmental impact our product has. Lithium-Ion batteries must be recycled or disposed of separately from normal waste [6], so by eliminating the need for the users of our product to handle such responsibility we make a small yet important effort towards being ethical in our design and considering the environmental impact of our creation.

References

[1] Y. Kishida. “Changes in Light Intensity at Twilight and Estimation of the Biological Photoperiod.” (1989), [Online]. Available: https://www.jircas.go.jp/sites/default/files/publication/jarq/22-4-247-252_0.pdf (visited on 02/21/2022).

[2] SWE. “Lithium-Ion Information Guide.” (Unknown), [Online]. Available: https://www.swe.com/lithiumion/ (visited on 02/20/2022).

[3] R. Annis. “A Quick Guide to Lighting Up Your Bike.” (2013), [Online]. Available: https://www.popularmechanics.com/adventure/sports/a9469/a-quick-guide-to-lighting-up-your-bike-15997921/ (visited on 02/20/2022).

[4] U. E. 4. S. 2. C. Staff. “Safe Practice for Lead Acid and Lithium Batteries.” (2016), [Online]. Available: https://courses.engr.illinois.edu/ece445/documents/GeneralBatterySafety.pdf (visited on 02/20/2022).

[5] IEEE. “”IEEE Code of Ethics”.” (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/21/2022).

[6] U. S. E. P. Agency. “Used Lithium-Ion Batteries.” (2021), [Online]. Available: https://www.epa.gov/recycle/used-lithium-ion-batteries (visited on 02/20/2022).

Appendix A Example Appendix

An appendix can go here! Make sure you use the `\label{appendix:a}` above so that you can reference this section in your document.