Bicycle Lighting System
ECE 445 Fall 2024

Project #5

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1. Introduction

1.1 Problem and Solution:

The problem we are looking to solve is that cycling in the dark (be it early morning or night) can be extremely dangerous, as cyclists simply cannot be seen by other users of the road, pedestrians, other cyclists, or most importantly, motor vehicles. Even if they are visible, the cyclist's movements and intentions can still be very hard for other roadway users to discern, causing the cyclist's movements to be unpredictable, which creates danger to themselves and others. This is an enormous problem, because countless people the world over rely on bicycles for their transportation to and from work, to the grocery store, and for any travel at all.

In many parts of the world, including here in Champaign, IL, for significant portions of the year this travel would all be done outside of daylight hours; both the morning commute to work and the evening commute home would require riding in the dark. Because the consequences of a collision have a very real potential to result in serious injury or death, a solution to this problem is critical.

If one currently wants to be able to to be seen from the front and rear, indicate turning, or indicate braking, a person would have to buy individual lights for each of these purposes, each with their own power supplies, and each with their own controls. This makes it very easy to accidentally leave one of these lights off before setting out (which can be dangerous), or leave something on after arriving (which would wastefully drain battery).

Our solution is to create a robust unified bicycle lighting system that allows the cyclist to be seen by other roadway users in the dark, as well as communicate their movements and intentions in the dark. We will do this by implementing a front headlight for visibility and illumination, a rear tail light for visibility, rear brake lights for communication, and turning indicators for communication. All of these lights will be under the same control system, allowing the rider to simply turn the entire system on or off as wanted with one switch.

We will use sensing on the brake levers to automatically turn on the brake lights when the brakes are engaged. The lights will automatically turn off when the brakes are released. The turning indicators will be controlled by the rider via buttons on the handlebars on their respectives sides (left indicator control on left end of handlebars, right on right). The turning indicators will automatically turn off after the completion of the turn by the bike (in the same manner as a car's turn signals automatically turn off after making a turn). The implementation of these lights and indicators, all under one easily controlled user interface, will make cycling in the dark much safer for cyclists and other roadway users.

1.2 Visual Aid

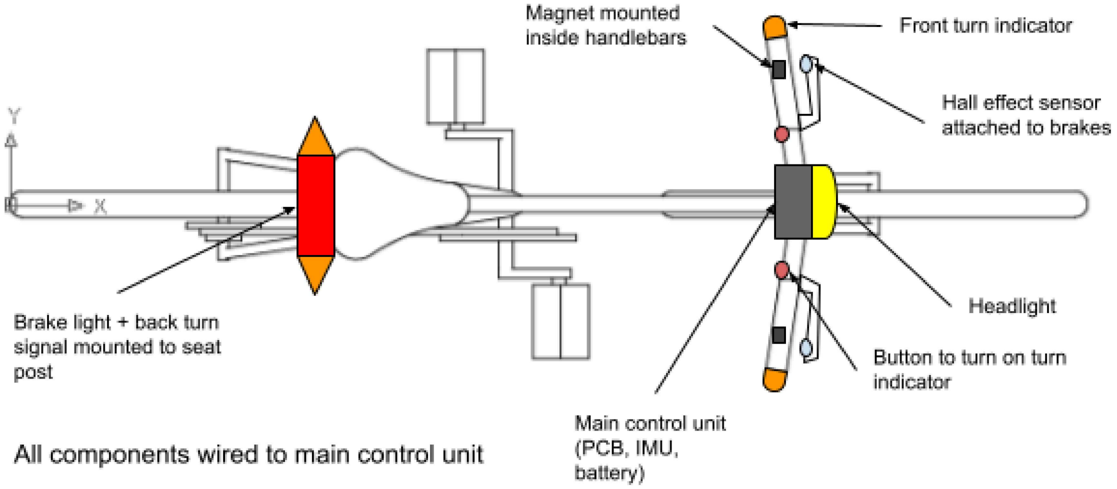


Figure 1: Diagram of all components overlaid on a graphic of a bicycle

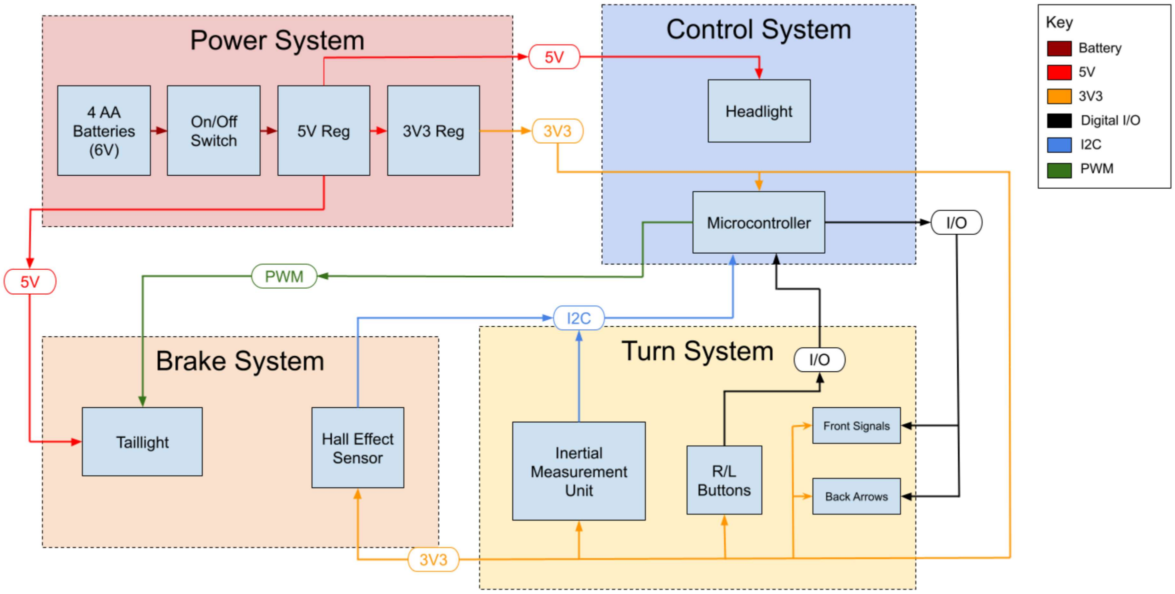
1.3 High-level requirements list:

In order for our project to be considered a success we must fulfill these requirements:

- The brake lights turn on when the brake levers are depressed by 0.5 cm or more. The brake lights must get 2 times brighter (as measured in lumens) than the taillight state. The brake lights turn off when the brake levers are released.
- The turn indicators are able to be activated by the rider without them taking their hands off of the handlebars. The turn indicators are automatically turned off by the microcontroller when the bike has made a turn of 90 degrees or sharper.
- Alleviate the need for multiple individual lights, each with their own respective power systems and controls, by unifying all lights, power, and controls under one singular system.

2. Design

2.1 Block Diagram



2.2 Subsystems:

2.2.1 Power System:

The power system will consist of 4 AA batteries in series adding up to 6V, a 5V voltage regulator and a 3.3V voltage regulator. The battery will feed directly into the 5V voltage regulator, which will go to both the lights as well as be fed into the 3.3V voltage regulator. The 3.3V output from that will go to the Control System components. This system overlaps with all three of the other subsystems, as they all need to be powered.

Requirement	Verification
The voltage rails must not have more than a 5% ripple.	We will verify this by using an oscilloscope, and make sure that the power rails are within this limit.
Must keep heat under 125°C, in order to ensure that the microcontroller is operating under its maximum operating temperature.	We will measure the heat given off by each of the regulators using an infrared temperature gun.

Must provide enough power to last for at least 1 hour.	We will measure how much current is being drawn with all of the lights on using an oscilloscope and then extrapolate that out to an hour. This should be less than the capacity rating of our 4 AA’s.
Provides both 5V as well as 3.3V	We can verify this using an oscilloscope, to make sure that the voltages being provided are still 5V and 3.3V even under load.

2.2.2 Turn System:

The turn system will be comprised of the rear turning indicators, the front turning indicators, and an Inertial Measurement Unit (IMU) sensor, two user interface buttons, and all the wiring connecting these to the microcontroller. The turning indicators will be turned on by the buttons by the rider. This will turn on both the front and rear turning indicators on the respective side. The turning indicators will be automatically turned off by the microcontroller once the IMU has sensed that the turn has been completed. This will overlap with the power system and control system.

Requirement	Verification
Turn indicators, either back or front, are visible to traffic in all directions from at least 500 feet away.	Verify by visual inspection from multiple locations at least 500 feet away from the bike that the turn indicators are visible.
Turn indicator turns on when the user clicks a button on the handlebars, and is disabled when either the rider clicks the button again or when the rider has turned 90 degrees or fewer.	Read I2C communication from IMU using an oscilloscope to verify correct reporting of turn angles. Visually inspect that turn indicators are shut off by microcontroller when microcontroller receives information that a turn of 90 degrees or sharper has occurred.
The front turn indicators should be visible to the rider from a normal riding position, so that the rider knows the status of their indicators.	Verify by having at least 3 different riders try riding with our light system installed and report if they could readily and comfortably see the turn indicators.

One control button on each side of the handlebars, accessible without having to re-position hands from normal riding position.	Verify by having at least 3 different riders try riding with our light system installed and report if they could operate the turn indicator buttons without having to re-position their hands.

2.2.3 Brake System:

The brake system will be composed of the brake lights, the Hall effect sensors, the taillight, and the wiring connecting both of the aforementioned to our microcontroller. We will be mounting magnets inside of the handlebars, with hall effect sensors attached to the back of the brake levers. As the brake levers are depressed by the rider, the sensors will sense this, and report it to the microcontroller. The microcontroller will then turn the brake lights on. When the Hall sensors sense that the brakes have been released, the microcontroller will turn the brake lights off. The brake lights will be turned on when the left, right, or both brake levers are engaged. This will overlap with the power system, control system, and lighting system.

Requirement	Verification
When the brake levers are depressed by more than 0.5 cm, the brake lights are turned on	Verify by observing I2C communication from Hall Effect Sensor at different distances from our magnet. We will code our microcontroller so that the brake lights are turned on at the appropriate threshold of magnetic field.
The “taillight” is clearly different from the “brake light”. These two lights occupy the same physical place, but when the brake light is on, it is a significantly brighter light than the tailight. This is the same way taillight/brake lights work on cars and motorcycles.	Verify by a lumen meter that the brake lights are 2x or more the lumens of the taillights.
The brake light will turn off and the taillight will return to its normal state upon release of the brakes.	Verify that the microcontroller correctly turns the brake lights off once the data sent from the Hall Sensor indicates that the magnet is back past the threshold for brake

	engagement.
The taillight is always on and visible from at least 500 feet away.	Verify by visual inspection from at least 500 feet away from the rear of the bike that the turn indicators are visible.

2.2.4 Control System:

The control system is comprised of the logic inside of the microcontroller, the headlight, and a master switch which controls power to the entire set of lights and the microcontroller. The microcontroller logic is responsible for interfacing with the brake system and the turn system. This, the control system, also interfaces with the power system.

Requirement	Verification
The entire system must be activated and deactivated by the power on/off switch.	Once turning the system on, check each individual system by checking that the taillight is on, the turn signals work, the brake lights work, and the headlight is on.
Headlight is visible from a distance of 500 feet.	Verify by visual inspection at a distance of 500 feet away from the front of the bicycle.
The inputs to the control systems should be fast and able to send the digital signal or pulse width modulation signal within 10 ms.	Verify using an oscilloscope, probing the inputs (hall effect sensor, buttons, and inertial measurement unit) and also probing the outputs (headlight, taillight, turn signals) and measuring the delay between the inputs and the outputs.
The pulse width modulated signal sent to the taillight/brake light should be able to perform a duty ratio between 10% and 100%.	Verify using an oscilloscope and test with different frequencies and duty ratios that we are able send a gate signal between 10% and 100%.

2.3 Tolerance Analysis:

2.3.1 Voltage Regulator Analysis:

We are making sure that our voltage regulators will not be giving off too much heat and break down. We are using two separate step downs, one from 9V to 5V and another from 5V to 3.3V. We are ensuring that these two step downs are feasible and better than stepping directly from 9V to 3.3V.

We do not want our regulators to exceed 50°C ambient. We got this number by finding the maximum recorded temperature in Urbana (42.7°C) [1] and knowing that the chip on the inside will be hotter than the outside temperature. This seems like a reasonable limit to set for ourselves.

The chip's maximum operating temperature is 125°C. This means that for the worst case scenario, we will have a 75°C temperature rise. According to the data sheet for the LM1117 [2] using the SOT-223 package, the junction to ambient thermal resistance is 61.6°C/W.

Using the 75°C rise in temperature we divide by the junction to ambient thermal resistance. This gets us 1.218W, which is the absolute worst case power that can draw.

Using this maximum and the equation for power, and our system if we went straight from 9V to 3.3V we would have a 5.7 volt drop, which when plugged into $P=I*V$ gives us a maximum current draw of 213.68mA. When we compare this with our step down from 5V to 3.3V we get a voltage drop of 1.7V and a maximum current draw of 716.47mA. Our control system will be nowhere near this upper limit, so we will not need a heatsink for the heat given off by the 3.3V regulator if we have 5V as the input.

For the 9V to 5V drop, we have a voltage drop of 4V which gives us a maximum current that we can draw being 304.5mA. This means that our project will need LEDs that don't require as much current, but still is well within the range of what we'll need.

2.3.2 Hall Effect Sensor Analysis:

We want to make sure we don't have to adjust the position/sensitivity of the hall effect sensor and the magnet too much. So we should do some analysis on different types of magnets with our hall effect sensor, ALS31313 [4]. According to the datasheet we could have a +-500, +-1000, or +-2000 Gauss sensitivity based on how we program it.

Let's also say that we don't want the magnet on our handlebars to be too thick and only use magnets that are 0.125" and smaller. Every magnet will come with a gauss level reading, most likely from the surface. We can measure the magnetic field from the center point of the magnet to the given magnetic field at the surface. Because our magnet height is 0.125”, the gauss level reading at the surface is 0.0625” from the center of the magnet.

We know that a given magnetic field will drop off in strength at the distance from the centered cubed. Gauss Strength is related to 1/d^3. We can measure the average distance on most bikes from the handlebars to where the brakes sit to be roughly 5cm. According to our Brake System specification we want the lights to trigger after 0.5cm of movement. This leaves us with 4.5 cm from the center of the magnet to where the brakes sit.

Converting 0.0625” into centimeters, we get a value of 0.15875cm. The distance between the brakes and the center of the magnet, 4.5cm, to the distance of the surface level to the center of the magnet, 0.15875cm, gives us a ratio of 4.5/0.15875 = 28.346. This means that whatever our gauss level is, we need to divide that number by 28.346^3 or 22776.99. So if we have a 4000 Gauss magnet at the surface. We would have a 4000/22776.99 = 0.175 Gauss at 4.5cm away.

If we use our sensor at the +-500 sensitivity, and our sensor has 12 bits. We can get a resolution of 500/4096, which gives us 0.122G. This should be enough to detect the magnet which is 4.5 cm away. And we will only get more sure it will detect when you pull the brakes harder and the distance between the brakes and the handlebars decreases.

3. Cost and Schedule

3.1 Cost Analysis:

The total cost of our design’s non-standard parts are $58.47, we will assume that the rest of the standard parts (resistors, capacitors, wires, etc.) will cost us another $20. We are not using any outside labor to machine parts for us, so all of the labor for this project will be done by the three of us. If we assume that we are each making $40/hour, and work on this project for 10 hours a week for 15 weeks. The total cost of labor for our project will be $40/hr * 10 hrs/week * 15 weeks = $6000 per person. For the three of us the total cost of labor will be $18,000. If we are to combine all these costs, we get a total of $18,078.74 for the project.

Description	Manufacturer	Quantity	Extended Price	Link
ATMega324 PB-AU	Microchip technology	1	$2.23	link
ICM-42670	TDK InvenSense	1	$3.43	link
SENSOR HALL EFFECT I2C	Allegro Microsystems	2	$2.60	link

LED J WARM WHT 3000K SMD	Cree LED	1	$0.10	link
LED RED CLEAR 0603 SMD	Würth Elektronik	20	$3.00	link
LED ORANGE DIFFUSED 0603 SMD	ams-OSRAM USA INC.	20	$2.28	link
MAGNET 0.250"D X 0.125"THICK CYL	Radial Magnets, Inc.	2	$1.04	link
BATT HOLDER AA 4 CELL 6.5" LEADS	Adafruit Industries LLC	1	$2.95	link
Secondary Optical Lenses for Vollong and ProLight LEDs - 30 Degree	SuperBrightLEDs	1	$1.99	link
Clear PLA filament	ELEGOO	1	$15	link
TAPE ELECTRICAL BLK 3/4"X6.7YDS	3M	1	$7.33	link
ELEGOO PLA Filament 1.75mm Black 1KG	ELEGOO	1	$13.99	link
SWITCH PUSH DPST-NO 16A 125V	E-Switch	1	$2.53	link

3.2 Schedule:

Week	Task	Person
October 6th - 12th	Design main board schematic	Sloan
	Design hall/front turn signal board	Quentin
	Design tail board	Jack
	Order Parts	All
October 13th - 19th	Order PCBs, **deadline 10/15**	All
	Program the ATMega	Quentin
	Model main control housing	Sloan
	Model hall/front turn housing	Jack
October 20th - 26th	Order PCBs, **deadline 10/22**	All
	Wiring/soldiering main control board	Quentin
	Wiring/soldiering turn/hall board	Jack
	Printing main control + hall/turn housing	Sloan
	Model tail housing	Sloan
October 27th - November 2nd	Test hall sensor I2C connection/communication	Quentin
	Test IMU I2C connection/communication	Sloan
	Print tail housing	Sloan
	Wire/soldier taillight	Jack
November 3rd - 9th	Testing control system	Jack
	Testing turn system	Sloan
	Testing break system	Quentin
	Testing power system	All
November 10th -	Assemble on bike	

16th	Group testing in field	All
	Testing with non-group members	
November 17th - 23rd	Mock Demo	All
	Make necessary changes/adjustments	All
November 24th - 30th	Thanksgiving break	All
December 1st - 7th	Final Demo	All

4. Discussion of Ethics and Safety

The ethical concern of our project is relevant to IEEE ethical code I.1. Our project is directly related to the health and safety of our users and the public at large. The goal of our project is to promote the safety of cyclists by increasing their visibility and declaring their intentions using a system of lights. This will decrease the likelihood of collisions and crashes that could result in injuries or even death, for the riders, or for others.

The relevant safety code that governs our project, is Illinois Law (625 ILCS 5/) Illinois Vehicle Code, which states that bikes riding at night must have a white lamp on the front visible from a distance of 500 feet, and must have a red rear lamp visible from at least 500 feet. We will obey this law, and ensure that any bike using our project's system is fully in compliance.

5. Citations

[1] "Averages and Records for Champaign-Urbana Illinois," Illinois.edu, 2024. https://www.isws.illinois.edu/statecli/cuweather/cu-averages.htm#:~:text=The%20record%20high%20is%20109 (accessed Sep. 18, 2024).

[2] "LM1117 800-mA, Low-Dropout Linear Regulator." Accessed: Sep. 18, 2024. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm1117.pdf?ts=1726643965724&ref_url=https%253A%252F%252Fwww.ti.com.cn%252Fproduct%252Fcn%252FLM1117

[3]"ALS31313," *https://www.allegromicro.com*, May 18, 2021. https://www.allegromicro.com/~/media/Files/Datasheets/ALS31313-Datasheet.ashx (accessed Oct. 03, 2024).

[4] "VEHICLES (625 ILCS 5/) Illinois Vehicle Code." 2024 https://ilga.gov/legislation/ilcs/ilcs4.asp?DocName=062500050HCh%2E+12+Art%2E+VI&ActID=1815&ChapterID=49&SeqStart=140200000&SeqEnd=142900000&Print=True