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Active Bike Light System Proposal

1. Introduction

a. Problem: While bike lights are one of the easiest ways to increase bicyclist visibility and thus improve bicyclist safety, it is very easy to forget to turn them on and off when riding at night. This is exacerbated by the varying requirements of the lighting system. When the sun is out, there is no need for the lighting system to turn on, but when the sun goes down, there are several modes of operation that can be demanded of the lights. The rear is the simplest, as it should always be blinking when it is dark out. The front lights should blink to alert oncoming drivers of the bicyclist's presence, but the bicyclist may also want to turn on a brighter, steady light to illuminate the road ahead. Current systems allow the rider to select these different modes of operation, but the switch is normally on the light itself, which necessitates reaching down and trying to locate the switch while riding. This poses a safety hazard, as the bicyclist is no longer concentrating on riding and their surroundings.

b. Solution: We are proposing an automatic lighting system that detects both ambient light and oncoming traffic and adjusts the behavior of the lighting system accordingly. When the ambient light level drops below a predefined value and an onboard real time clock deems it to be appropriate, the lighting system will turn on, and the front and rear lights will start blinking. This same system will be responsible for turning the lights off when the light level remains above the threshold for a certain amount of time. When it is sufficiently dark out, the system will use a series of sensors to check for oncoming traffic both in front of and behind the rider. If a vehicle is detected, the system will increase the brightness of the lights to alert vehicles of the bicyclist's presence. To address the need for the rider to be able to see the road in front of them, we will have a switch on the handlebars that allows for the rider to activate a constant light source with their thumb, eliminating the need to blindly reach for a switch they cannot see; they can turn it on without removing their hands from the handle bar.

c. Visual Aid

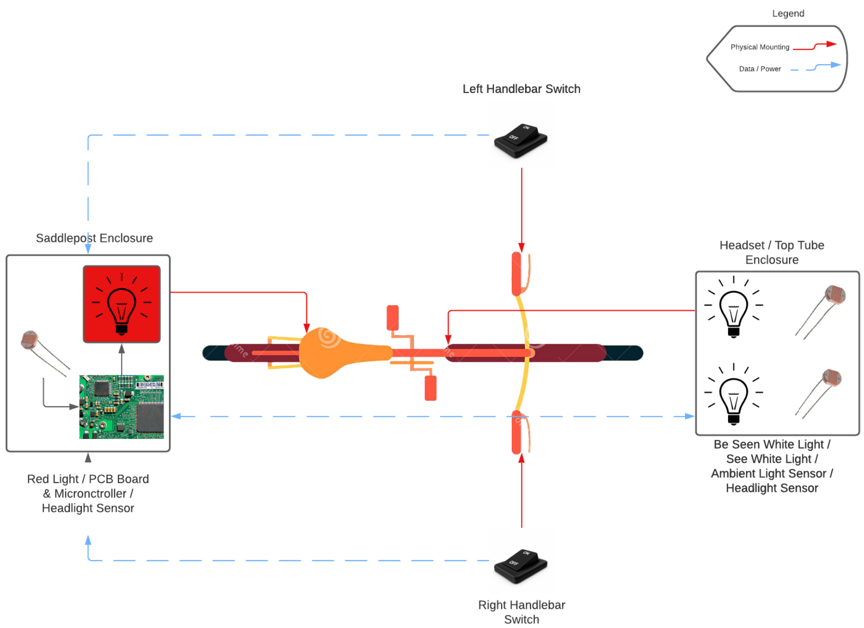

Figure 1: Visual Representation of Design

d. High Level Requirements: Our project has several components that can all be tested independently of one another. The first is the ability of an ambient light sensor to detect the local light level, and send a signal to a microcontroller letting it know that it is either above or below a defined threshold of ambient light. The second system is going to be the main lighting system. These lights will need drivers to power them, and the drivers will take a signal from the microcontroller to turn the lights on or off when appropriate, or modulate the brightness of the lights. Next, there will be a set of sensors that will detect the headlights of nearby vehicles, and if one is detected, then it will send a signal back to the microcontroller. The microcontroller itself will have several responsibilities, interpreting input from the various sensor systems, directing the outputs and maintaining time to verify the validity of any light sensor readings by checking it against the time of day. The switch on the handlebars will act as an additional input to direct the microcontroller to turn on the constant light at the front of the bike. Finally, the whole system will need to be powered, which will require a main battery to power the main systems and a small battery backup to maintain power to the microcontroller when the main battery is not available.

2. Design

a. Block Diagram

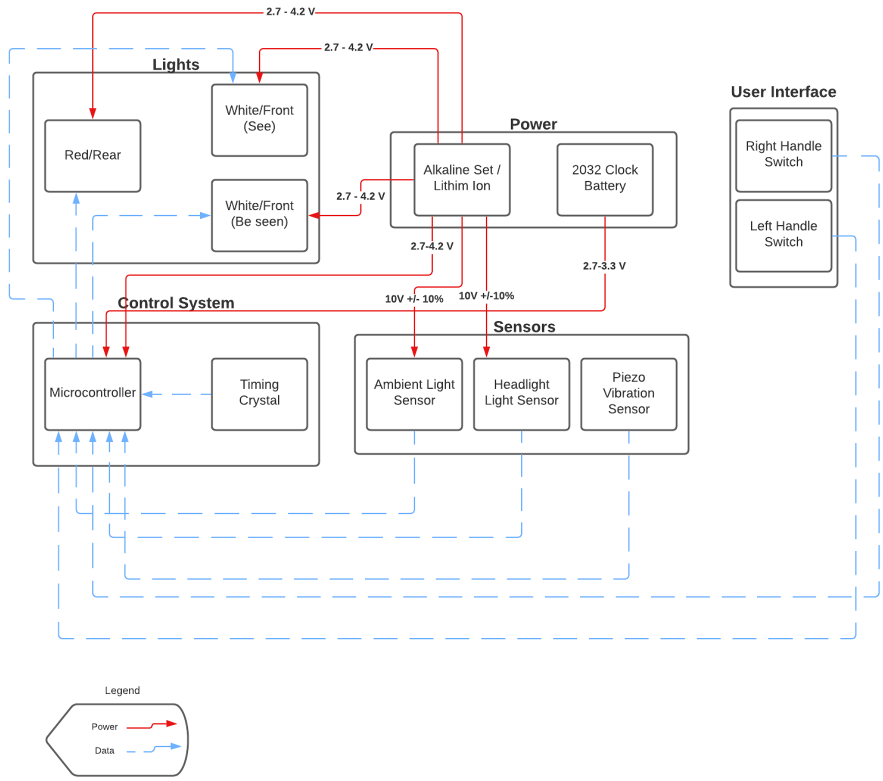

Figure 2: Block Diagram of Components and their Connections

b. Subsystem Overview

i. Power system

➢ Overview

The power system will be divided into two parts. The first is a primary battery module that consists of a pair of large cells. These cells are intended to be rechargeable, but depending on the power consumption of the system, we may end up switching to non-rechargeable (primary) cells. When this module is capable of meeting the power requirements of the system, it will do so. However, in the event of this module not being able to meet the demands of the whole system, the second part of the system will activate. The secondary battery is going to be a much smaller CR2032 button cell, and it will only be connected to the microcontroller. This cell will not be connected to the sensors or the lights, meaning it is only present to maintain the power to the microcontroller, and thus, keep the real time clock accurate.

- ➢ System responsibilities
  - Provide power to sensor system, microcontroller, and lighting system
  - Supply power to the microcontroller at all times
  - Smoothly transition between main battery and backup battery
- ➢ System components
  - Main battery module (DK# 3145-L37A52-2-1-3WA3-ND)
  - Reserve CR2032 battery (Already have some)
  - Miscellaneous diodes, resistors, capacitors, and inductors as necessary

ii. Lighting system

- ➢ Overview

  The lighting system is fairly straightforward, with a front and rear set of flashing lights to alert nearby vehicles and pedestrians, and an additional front light that does not flash, which lights up the road in front of the bike. To allow for maximum flexibility of this system, we are using a current regulator to control each set of lights. This allows the microcontroller to control the brightness of each LED module by changing the signal it sends to the regulator. This setup also allows for brighter lights than if we drove the LEDs directly from the microcontroller, as the current regulator can deliver more current than the microcontroller can. The light that is not flashing needs to be bright enough to allow the rider to see the road ahead, so we are targeting an output of approximately 200 lumens. The flashing lights do not need to be as bright, so we are targeting roughly 50 lumens. These numbers may change once we have a prototype and can see how visible these lights are.
- ➢ System responsibilities
  - Alert nearby vehicles and pedestrians of the bicyclists presence.
  - Illuminate the road in front of the bike allowing the bicyclist to see hazards
- ➢ System components
  - 3 front flashing LEDs (DK# 897-1069-1-ND)
  - 6 front headlight LEDs (MSR# 710-158563460)

- 3 rear flashing LEDs (DK# VLCS5130-ND)
- 3 current regulators (DK# AP5725WG-7DICT-ND)
- Miscellaneous resistors and capacitors as required

iii. Microcontroller

➢ Microcontroller overview

The microcontroller is going to take in all of the data from the various sensors and inputs, and make sure the system reacts appropriately. All of the peripheral components and systems receive control signals from the microcontroller, so it is vital that the microcontroller is programmed correctly. Any issues with the programming can cause the whole project to fail. Running the microcontroller constantly would rapidly drain the battery and is not necessary, so it will be able to put itself into a low power consumption mode where nearly all processes are shut down. There will only be two interrupts that will wake it back up; an interrupt from the oscillator, or an interrupt from the vibration sensor. The oscillator interrupt will be periodically sent within the microcontroller to update a real time clock. To implement the real time clock, a 32.768kHz crystal will be connected to the microcontroller, and the controller will use the external crystal with the controller's own internal oscillator circuit. This method allows us to implement a real time clock to establish daylight hours. If the ambient light sensor detects low light levels, it will tell the microcontroller, and the microcontroller will then check the time to ultimately decide if it is appropriate to turn on the lights. If the time is during daylight hours, the microcontroller will disregard the light sensor reading, as it is probably just in the shade. However, if the time is outside of daylight hours, the microcontroller will accept the light sensor reading, and turn on the lights. The second interrupt that can bring the controller out of its sleep mode comes from the piezoelectric vibration sensor. The vibration sensor will induce a voltage that the microcontroller will see, and once the microcontroller reads this voltage, it will start to wake up. This system will allow the microcontroller to go to sleep and save power when the bicycle is stationary for an extended period of time, only waking up when it is detecting motion.

- ➢ System responsibilities
  - Interpret data from photo sensors
  - Modulate light brightness
  - Periodically wake up to update real time clock
  - Sleep when stationary
  - Wake up when vibration sensor interrupt arrives
- ➢ System components
  - PIC 18F27Q43 (DK# 150-PIC18F27Q43-I/SP-ND)
  - 32.768kHz crystal (DK# 3155-32.768K12.5P2/DT38-ND)
  - Miscellaneous resistors and capacitors as required

iv. Sensor system

- ➢ Overview

The first sensor that our project will use is a photodiode based ambient light sensor. This sensor will be placed facing upwards to allow it to detect the light coming from the sky. By feeding the output of the photodiode circuit into a comparator, we can compare the circuit's output voltage to a reference voltage, and the comparator output voltage will change when the difference between the input and reference voltage changes sign. Additionally, since the reference voltage will be set by the microcontroller, we can adjust the threshold we consider to be "darkness" in software, which simplifies the hardware design of the sensor system. The second set of sensors is the headlight detection system. The electronic hardware is identical to the ambient light sensor; a photodiode based light detection circuit being fed into a comparator. The difference is the placement of the photodiode. Where the ambient light sensor is placed close to the surface of its housing, giving it the maximum field of view to determine the ambient light, the headlight detectors will be set into their housing, which reduces the effective field of view. By placing the photodiode inside the housing rather than at the surface, only light coming in from certain angles can hit the detection surface. By changing the distance from the surface to the photodiode, and shape of the aperture, we can have the photodiodes only detect light on the road, rather than all around. This will keep the system from interpreting a streetlight as a headlight. The third sensor will be a piezoelectric film vibration sensor. This will be on the

PCB, and detects vibrations. Vibrations will cause the sensor to flex, inducing a voltage that the microcontroller will read. Depending on the magnitude of the induced voltage, an amplifier may be required, or additional mass will be attached to the sensor, which will cause more flex when disturbed by larger motions, resulting in a greater induced voltage. The last component that will send data to the microcontroller (and thus can be considered part of the sensing system) is the pair of switches on the handlebars. One of the switches will be used to turn on the main headlight and the other will allow the rider to turn the system on.

- ➢ System responsibilities
    - Detect ambient light levels
    - Detect nearby vehicle headlights
    - Detect vibrations that indicate the bike is in use
- ➢ System components
    - Three photodiodes (DK# VTP9812FH-ND)
    - One piezoelectric film sensor (DK# MSP1006-ND)
    - Two toggle switches (DK# 2449-ANT11SF1CQE-ND)
    - 10V regulator (DK# AP3012KTR-G1DICT-ND)
    - Two comparators (DK# 296-49723-ND)
    - Miscellaneous capacitors, resistors, and inductors as required

c. Subsystem Requirements

i. Power system

- ➢ The main battery voltage must remain between 4.2V and 2.7V
- ➢ The main battery should be able to provide sufficient current to power the microcontroller, the lights, and the sensors, at all times while the voltage is in the specified range
- ➢ The backup battery must remain between 3.3V and 2.7V
- ➢ In the event of the main battery voltage falling outside of specification, the backup battery must automatically take over, providing power to the microcontroller
- ➢ The voltage going into the photosensor circuit should be set to 10V, with a tolerance of +/- 10%

ii. Lighting system

- ➢ The front LED headlight should output enough light to allow the rider to see the road in front of them while riding at speed (20-25 km/hr)

- ➢ The flashing lights should be visible to motorists from 100 meters away
- ➢ The brightness should be variable in software, and otherwise constant

iii. Microcontroller

- ➢ The microcontroller should be able to to interpret signals coming in from the various sensors, and respond in accordance with the description provided in the microcontroller system overview
- ➢ It should be able to enter a sleep mode when appropriate to conserve power
- ➢ It must be able to wake up again, resuming normal operation when the correct interrupts are received
- ➢ The real time clock should be able to keep accurate time over a 12 hour period, before resetting

iv. Sensor system

- ➢ The ambient light sensor should be able to differentiate between daylight hours and night
- ➢ The ambient light sensor should not be so sensitive that it turns the lights on and off while riding under street lights
- ➢ The headlight detection circuits should be able to detect oncoming vehicles from a reasonable distance
- ➢ The vibration sensor needs to be able to detect when the bike is being moved, and use the resulting vibrations to wake up the microcontroller
- ➢ The switches on the handlebars should be easy to activate, and changing their position should result in the operation of the system changing in the requested manner

d. Tolerance Analysis

i. By design, our components are all under-stressed, and if there was a potential issue with a component being near its design limits, we replaced the component in question with an uprated one that was safer. That has two results: our system should be very robust, leaving us lots of overhead for additional capability if we should want or need it, and the tolerances are not an issue with our design. If our battery happens to output only 2.5V instead of 2.7V, it does not matter because all components powered directly by the battery can tolerate input voltages between 1.8V and 5.5V.

ii. The only calculations we felt were really necessary was approximating the power consumption of our system, to allow us to size the battery module. To do this, we made a few assumptions to simplify the math:

- ➢ The power consumption of the system while in its deep sleep mode is negligible. According to the datasheet, the processor draws less than 800nA at an internal voltage of 1.8V when in its lowest power mode, and since all peripherals are shut down when in this mode, all other power consumption is zero. Based on this value, in conjunction with the intended battery capacity (19.24Wh), the main battery could power the controller in this mode for : $\frac{19.24Wh}{800nA*1.8V} * \frac{1\ day}{24h} * \frac{1\ year}{365.25\ days} = 1524\ years$
- ➢ Power consumption from the sensors is insignificant. The circuits are very small, only active when the controller is awake, and even when they are on, the only thing that draws current is a comparator (200uW per comparator), and there are only 3 comparators in the system. This is a negligible amount of current, and could be sustained by the main battery for many years.
- ➢ The only major consumer of power is the set of lights.
- ➢ To compensate for the assumptions we have made, we will assume worst case scenario power consumption for the lights (full brightness, and on all the time)

Doing this calculation, we get the following power consumption for the lighting system:
Flashing red lights: $3\ lights * 2.2V * 50mA = 330mW$
Flashing white lights: $3\ lights * 3.2V * 20mA = 192mW$
Headlight: $6\ lights * 3.2V * 150mA = 2880mW$
Total power consumption:
$330mW + 192mW + 2880mW = 3402mW$
Estimated battery life: $\frac{19.24\ Wh}{3402mW} = 5.66\ hours$

Since the lights can drain the main battery in 5.5 hours, but the system in standby would take over 1500 years, we can see that our assumption of the lights being the most significant consumer of power is reasonable. Based on these calculations, we know we have at least 5.5 hours of battery life, even if the lighting system was set to maximum brightness, which it will not be. The flashing lights will have a duty ratio of roughly 50%, and the headlight is expected to only be set to 60% of its maximum brightness. This means we can expect in excess of 8 hours of continuous use under anticipated operating conditions. We believe that this is an acceptable amount of battery life, and that the battery we initially specified will meet our requirements.

3. **Ethics and Safety**

a. 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. 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. This should help remind the user to charge the system when required and when it might be necessary to stop a ride.

b. As with the construction of any physical project, there are safety considerations that have to be taken into consideration during both design and production. If any element of the system becomes a risk to the designers or potential users, we intend to flag and report them to all necessary authorities. All necessary safety precautions will be used when assembling the system.

c. There are also safety concerns that must be addressed with any system that utilizes lithium-ion batteries. Our system will not be demanding power from the battery module at a level that could cause a risk of fire. As long the batteries are sourced from a reputable supplier, we do not anticipate any significant danger or risk inherent to this project.