Environment Aware Bike Light

Design Document

Team 31
Hosang Chun, Siddharth Sharma, Guan Qin
TA: Anthony Caton
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ECE 445

1 Introduction

1.1 Objective

To be safe riding at night, bikers use bike lights to illuminate dark streets.

The number of cyclists has been steadily increasing in major US cities such as New York, Chicago, Portland and San Francisco [1]. This means there is a greater requirement for safe, secure and well functioning bike lights in the market. The problem with bike lights in the market is that they do not offer enough environment awareness in order to influence their brightness. Adverse weather conditions, such as fog, pose problems in terms of visibility for the biker and can play a part in a lot of dangerous situations.

Our project aims to give an environment aware bike light to the biker, so that the biker does not need to keep adjusting his or her light while riding the bike. We would add LIDAR functionality to detect fog and turn on the bike light as well as a floodlight in order to allow others to clearly see the biker in the fog. This would provide a lot of flexibility in brightness for the bike riders while also ensuring their safety without loss of convenience.

To detect fog, we'll implement Differential Absorption Lidar, DIAL. Lidar stands for Light Detection and Ranging. Light is transmitted and reflected back in lidar systems and by measuring the difference of power or delay between the original signal and reflected signal, one can figure out desired information such as distance. In DIAL, there are two lasers at two differing wavelengths: one at absorption wavelength and one slightly off the absorption wavelength. The difference in amplitude is correlated with the concentration of aerosol, which in our case is water vapor and high enough difference would signify existence of fog.

1.2 Background

While there has been an increase in the number of bicycles sold and ridden across the US, there has also been a rise in accidents related to cyclists [2]. We believe that our idea can benefit the cyclist by increasing their safety as well as reducing the amount of power being used by the bike light. With more and more people switching to bikes as a viable mode of transportation, an environmentally aware bike light would become crucial for their use. We also believe our idea is unique and novel, as the only other self adjusting bike light we saw for sale in the market, was one which was dependant upon the velocity of the bike itself.[3] Therefore, we can see a great potential for such a product in the cycling market.

1.3 High Level Requirements

- The bike light should be detect fog via an empirically determined threshold based on our differential absorption lidar system
- The battery should power all modules in a sustainable manner
- The bike light should be safe for the humans in the vicinity of the bike light and the laser used should be safe for human eyes operating under the maximum permissible exposure for 840nm and 850nm.

2. Design

2.1 Block Diagram

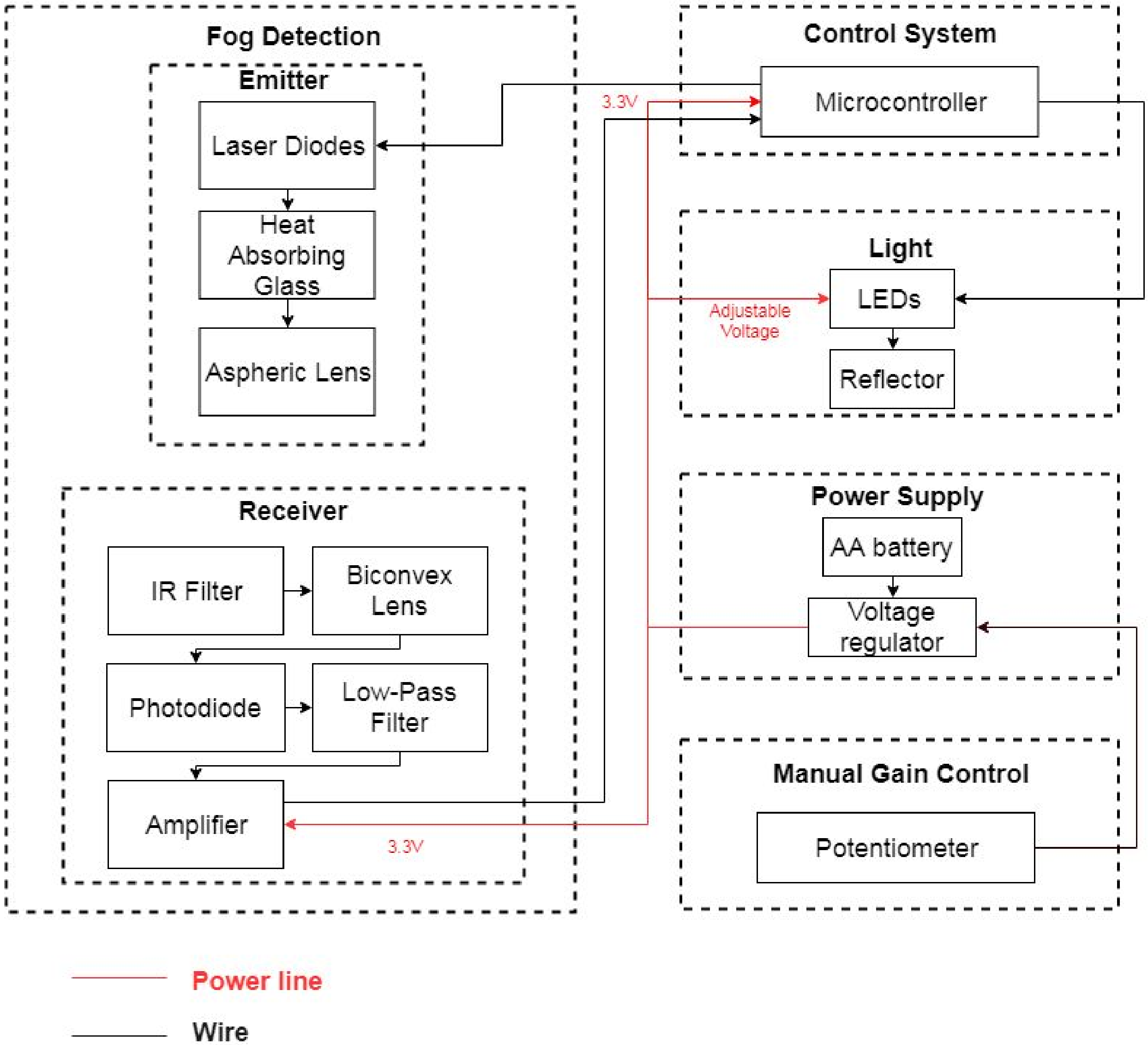

Figure 1. Block diagram of the whole system

Physical Design

The enclosure of our design is a plastic box (Length:150mm x Width:70mm x Height:30mm). This plastic box consists of 2 layers. The bottom layer is for the PCB and potentiometer. The top layer is divided into 4 blocks for battery holder, laser emitters, receiver, and LED lights. The direction of LED lights and the direction of laser emitters should be orthogonal to each other to avoid interference. The laser emitters and receiver should be placed in the same direction for less noises. The length of the laser emitters block should be greater than the focal length of aspheric lens which is 10mm. The length of the receiver block should be greater than the focal length of Biconvex lens which is 25.4mm.

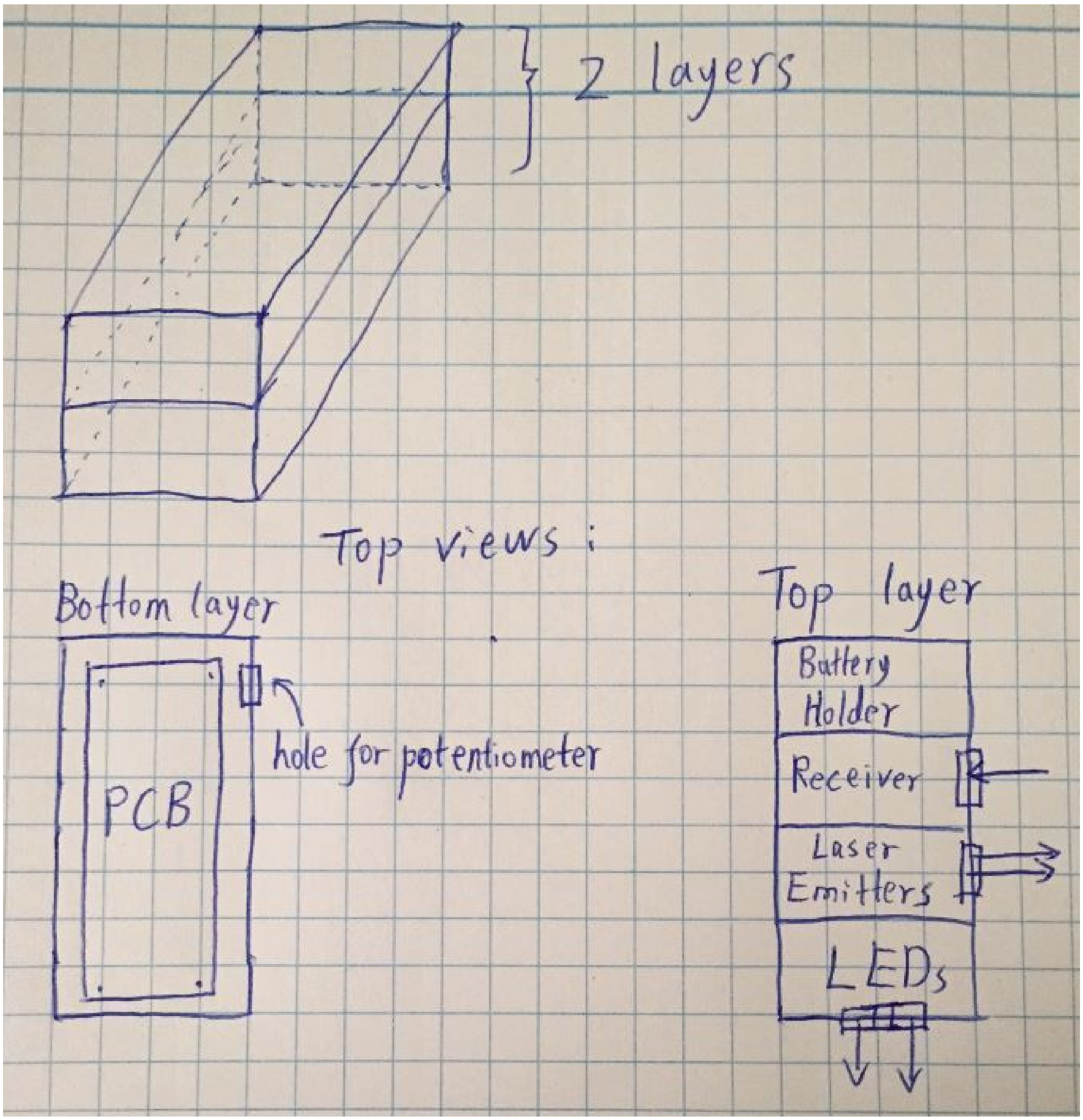

Figure 2. Physical Design of Product

2.2 Component Analysis

2.2.1 Power Supply

Power supply module consists of two parts. First part is a power source which consists of multiple AA batteries. Second part is voltage regulator. Voltage regulator is a DC-DC converting circuit. It will maintain the voltage level of power source (batteries) and convert it into different voltage levels for other modules.

2.2.1.1 AA Batteries

The input voltage is 4.5V. Thus, we need three 1.5V AA batteries in series for input voltage. We are going to use Energizer L91 Lithium batteries with 3500mAh capacity. In regular mode, only one LED is on. The default current through the LED is 700mA. Thus, the estimated battery life is 5 hours which is greater than our requirement (2 hours).

Requirements	Verification
1. 4.5V input voltage. (Tolerance: ± 0.5V) 2. Batteries can power the bike light in regular mode for 2 hours.	1. Connect the 3 AA batteries in series and use a multimeter to measure the voltage drop. Confirm that it’s 4.5V. (Tolerance: ± 0.5V) 2. Turn on the bike light in regular mode and confirm that the light is on after 2 hours.

2.2.1.2 Voltage Regulator

TL1963A-33DCYR is a low-dropout regulator with fixed 3.3V output. The device can supply 1.5A output current with a dropout voltage of 340mV. TL1963A-33DCYR will supply voltage for fog detection and control system. We are going to use another voltage regulator to generate forward voltage for LEDs which is TL1963ADCQT. This device can generate adjustable output voltage from 1.21V to 20V with 1.5A current. The output voltage depends on the following equation:

$$V_{OUT} = 1.21V\left(1 + \frac{R2}{R1}\right) + I_{ADJ} \times R2$$

The ADJ current is 3uA at 25 Celsius.

Requirements	Verification
1. TL1963A-33DCYR generates 3.3V output voltage with 4.5V input voltage. (Tolerance: ±0.2V) 2. TL1963A-33DCYR maintains 3.3V output voltage when the input voltage goes down. (Tolerance: ±0.2V) 3. TL1963ADCQT generates 2.85V output voltage with 4.5V input voltage. (Tolerance: ±0.2V) 4. TL1963ADCQT generates 2.85V output voltage when the input voltage goes down. (Tolerance: ±0.2V)	1. Use a DC voltage supply to generate 4.5V DC voltage as input. Use a multimeter to confirm that the output voltage is 3.3V. (Tolerance: ±0.2V) 2. Use a DC voltage supply to generate 4.0V DC voltage as input. Use a multimeter to confirm that the output voltage is still 3.3V. (Tolerance: ±0.2V) 3. Use a DC voltage supply to generate 4.5V DC voltage as input. R1 is a 4k resistor and R2 is a 5300 ohms resistor. From the equation above, output should be 2.85V. Use a multimeter to confirm that the output voltage is 2.85V. (Tolerance: ±0.2V) 4. Use a DC voltage supply to generate 4.0V DC voltage as input. R1 is a 4k resistor and R2 is a 5300 ohms resistor. Use a multimeter to confirm that the output voltage is 2.85V. (Tolerance: ±0.2V)

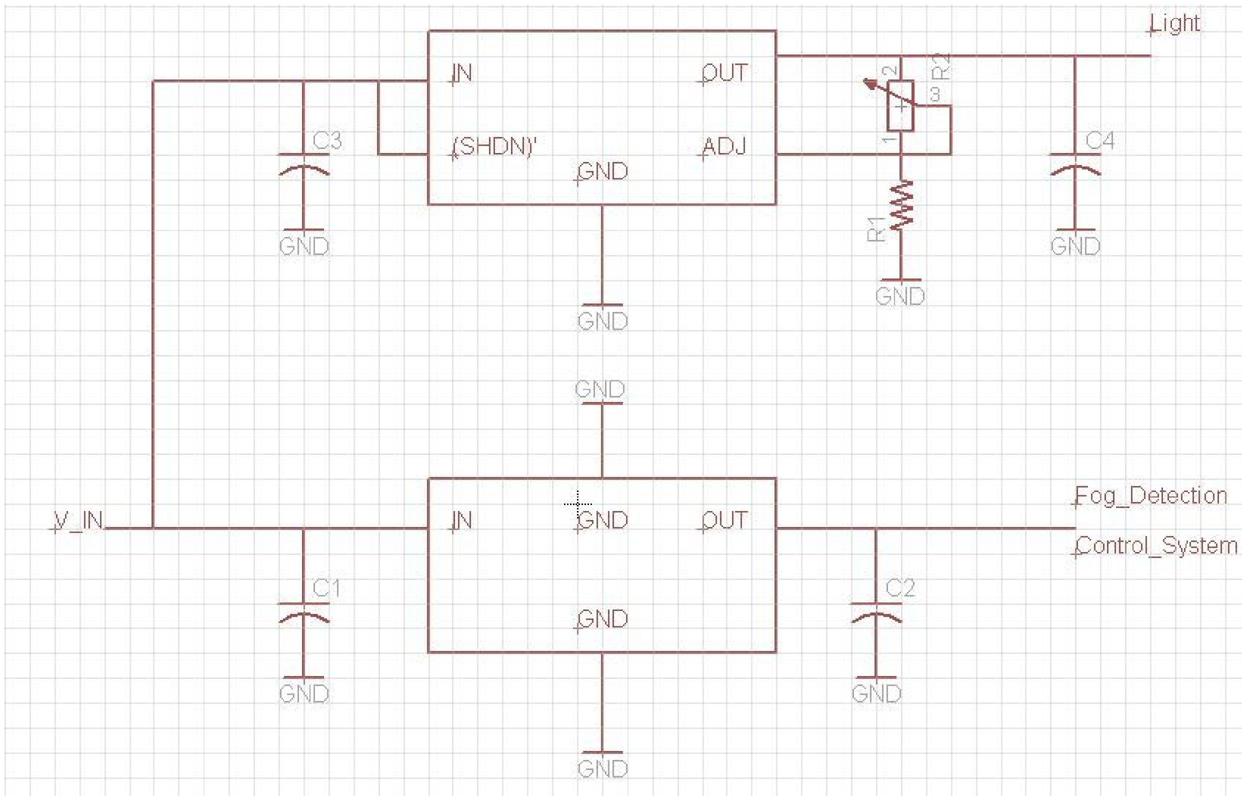

Figure 3. Circuit Schematic for Voltage Regulator

2.2.2 Light

The light system consists of two high-power LEDs in the center. Only one LED is going to be used during regular operation. When the fog is detected, both LEDs would light up to provide additional brightness. GW CSSRM2.PM-N3N5-XX53-1 is a high-power LED with 2.8V forward voltage and 160lm/W luminous efficacy. The luminous flux for a single LED should be 314lm with 700mA forward current. We will use C12469_LISA2-R-PIN as reflector for LEDs. This reflector fits our LEDs and provide a 80 degree viewing angle. The second LED is in series with a NMOS(IRLB8721PBF) with 2.35V maximum threshold voltage. This NMOS is controlled by microcontroller.

Requirements	Verification
1. 314lm luminous flux with 700mA forward current for a single LED. (Tolerance: ±50lm, ±70mA)	1. Use a DC voltage supply to generate 2.85V DC voltage and use a multimeter to check if the current is 700mA. After that, use a lightmeter to confirm that the luminous flux is 314lm. (Tolerance: ±50lm, ±70mA)

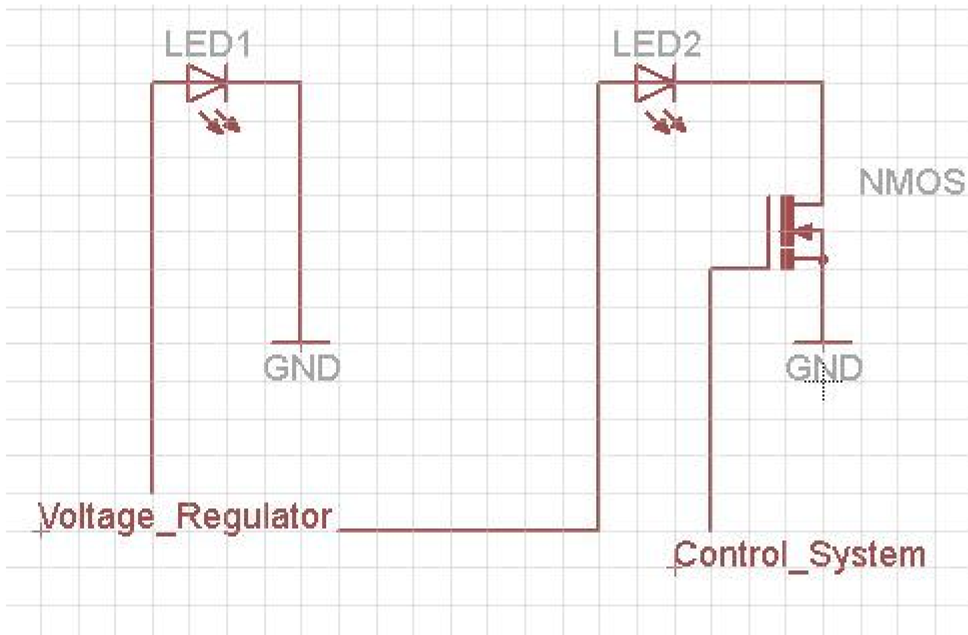

Figure 4. Circuit Schematic for Light System

2.2.3 Control System

The control system consists of a ATMega328p microcontroller. This microcontroller would be receiving a photodiode input and depending on the values received by the photodiode this would either turn on the fog LEDs or not.

The value to turn the foglight on would be determined by how much backscattering difference we get from the two photodiodes, which is determined by the lidar equation [4] as follows

$$N_S(\lambda, z) = \left(\frac{P_L(\lambda)\Delta t}{hc/\lambda}\right)\left(\beta(\lambda, z)\Delta z\right)\left(\frac{A}{z^2}\right)\left(\eta(\lambda)T^2(\lambda, z)G(z)\right) + N_B\Delta t.$$

Equation 1. Generalized lidar equation

where

- $N_S(\lambda, z)$ = expected photon counts at detected wavelength λ in the range interval (z - Δz/2, z + Δz/2)
- λ = detected photon wavelength (m)
- $P_L\lambda_L$ = laser output power at laser wavelength λ_L(W)
- λ_L = Laser radiation wavelength (m)
- Δt = integration time (s)
- h = Planck's Constant (6.626 x 10^{-34} J/s)

- c = speed of light (2.999 x 10^8 m/s)
- $\beta(\lambda, \lambda_L, z)$ = volume backscatter coefficient at range z under laser radiation at wavelength λ_L for the scattered photons falling into the wavelength λ ($m^{-1}sr^{-1}$)
- Δz = thickness of the bin range or interval (m)
- A = receiving telescope aperture area (m^2)
- z = range from the scatter to the lidar receiver
- $T(\lambda_L, z)$ = one-way transmittance of the atmosphere for the wavelength λ_L from the lidar transmitter to the range z
- $T(\lambda, z)$ = one-way transmittance of the atmosphere for the wavelength λ from the lidar transmitter to the range z
- $\eta(\lambda, \lambda_L)$ = lidar optical efficiency for the transmitted wavelength at λ_L λ and received wavelength at λ
- $G(z)$ = geometrical probability of radiation at range z reaching the detector, based on the geometrical considerations
- N_B = expected photon counts per range bin due to unit time due to background noise and detector dark counts.

The microcontroller would be attached to multiple LEDS in order to make a flood light effect and allow for better light to shine through in fog. It would also be connected to the potentiometer block in order to allow voltage control and gain for manual handling of the lights.

The code will be programmed based on empirical data received and all calculations done will be verified to get best possible results.

The microcontroller would be used with a USB to Serial Bridge chipset, in our case the FT232R which would directly interface with the AVR’s UART. The clock for the microcontroller will run through a 16MHz crystal.

Requirements	Verification
1. Microcontrollers should work at a given input voltage of 3.3 V. 2. Microcontroller should be able to control multiple LEDS. 3. Microcontroller should be able to successfully read data from photodiodes. 4. Based on backscatter, microcontroller should be able to turn on required LEDs as fog has been detected.	1. We will use an oscilloscope to measure input voltage and current to make sure that the microcontroller is being turned on at that range. 2. Write program to switch LEDS on and off based on voltage input provided. 3. Test using different wavelength objects, to result in different values of the voltage for the photodiode which should be reflected by the microcontroller.

5. Read voltage from potentiometer to allow for manual control of LEDs. 6. Microcontroller needs to turn on laser diodes in alternating fashion.	4. Based on the empirical backscattering data, decide on a threshold over which the fog lights would be turned on. Program the microcontroller for the above and test by shooting the laser through the humidifier. 5. Print out the readings from the potentiometer to make sure they are changing as desired. 6. Run the microcontroller's code for switching diodes. Connect to the oscilloscope and acquire the time versus voltage graph and check the duty cycle.

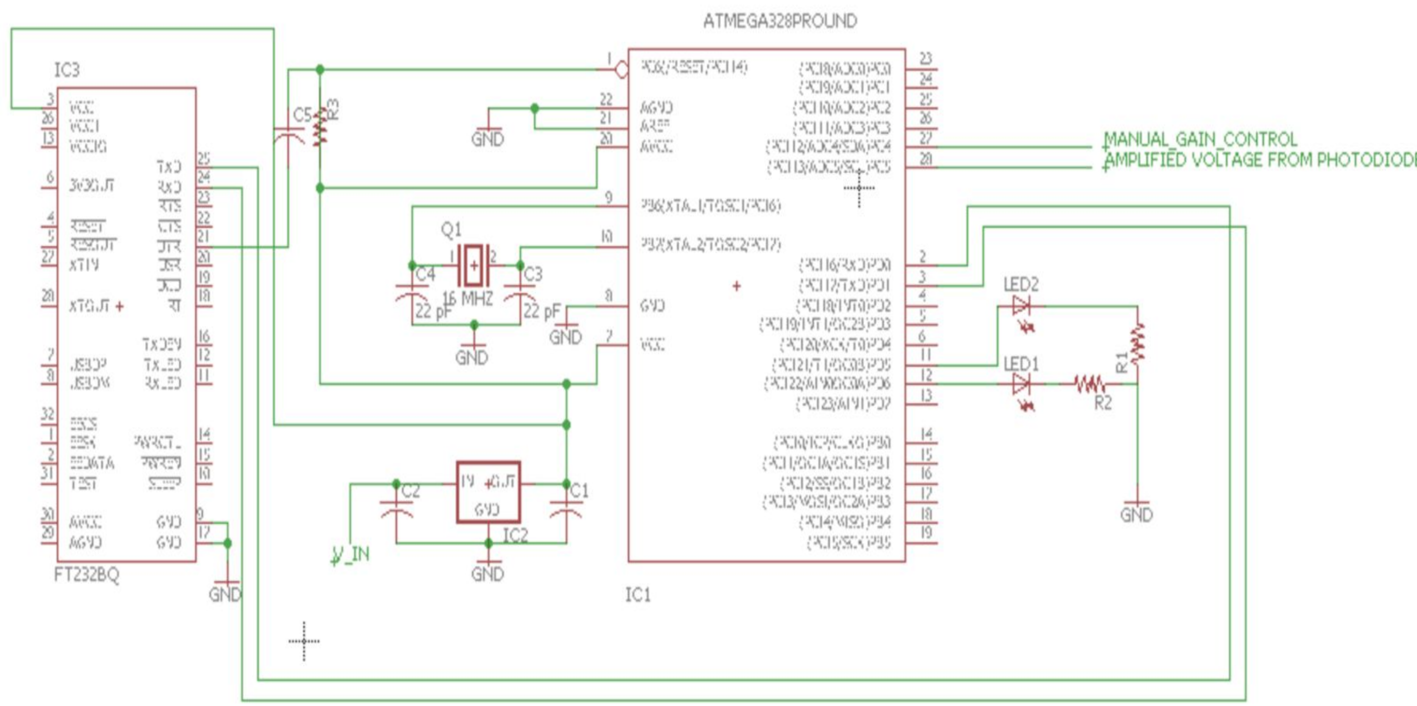

Figure 5. Circuit Schematic for Microcontoller

2.2.6 Fog Detection

To detect fog, we are thinking of implementing a small Differential Absorption Lidar. The Lidar would be comprised of two parts, the transmitter and the receiver.

2.2.6.a Transmitter

We have researched the absorption bands for water vapors. We have looked into High Resolution Transmission (HITRAN) data for the absorption band research.

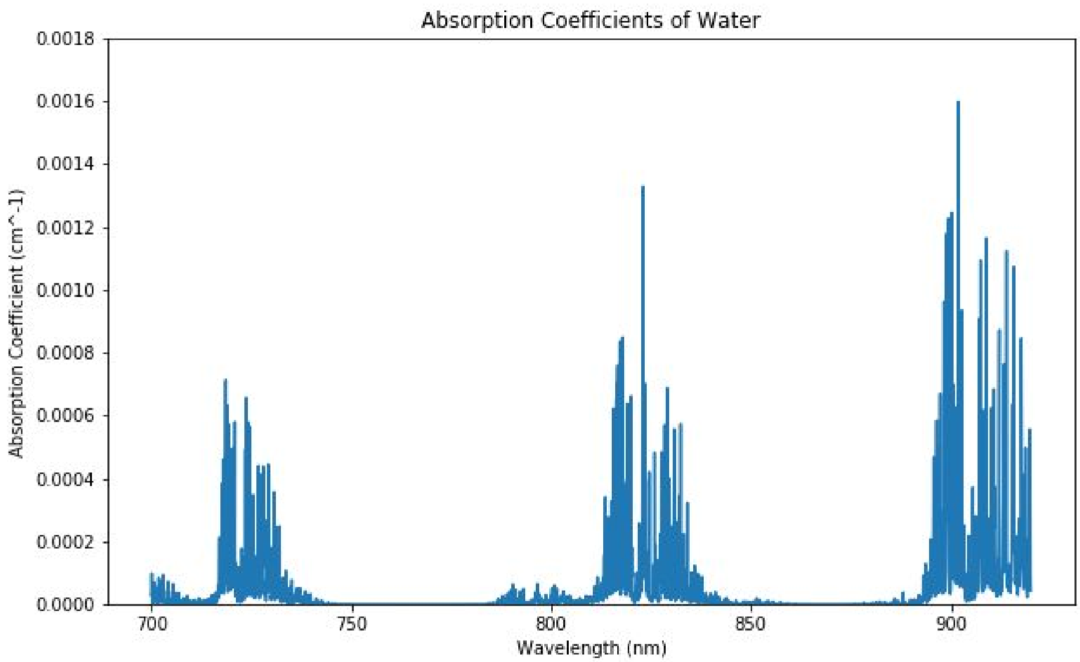

Figure 6. Absorption coefficients of water [9]

Potential absorption band to use were 820nm, 940nm, 1360nm. However, we weren't able to find laser diodes that were able to shoot at that wavelengths. Therefore, we have decided to use 808nm and 850nm laser diodes for our on-axis and off-axis diodes.

The rays from the laser diodes are going to be collimated by aspheric lens. These diodes will be placed at the focal length of the lens.

We were able to find laser diodes that are 5mw in output. These without attenuation would be not eyesafe.

To make it eyesafe, we'll put bandpass filters to lower the power. We have looked into couple filters. We have settled with KG-5 heat absorbing glass. Using Neutral Density filter would've minimized the power difference equally throughout whole bandwidth, but since we are not using that, we would have to compensate for power attenuation from wavelength difference.

There are variants of the heat absorbing glass, but only one is able to provide enough attenuation without killing the laser output, the KG-5

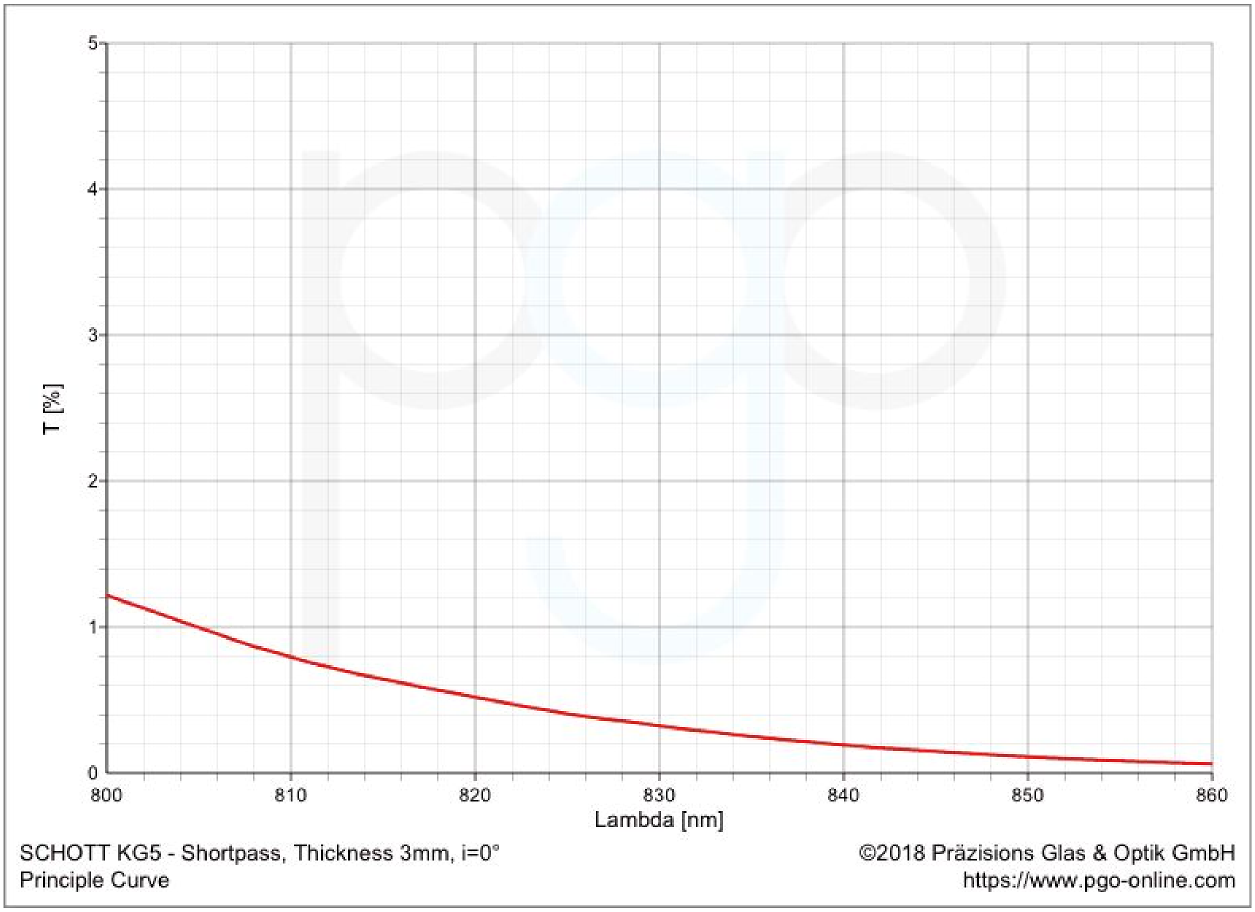

Figure 7. Transmission Curve of KG-5 [5]

We'll multiply the measurement values from the photodiodes with a constant to compensate for the power attenuation.

We'll not use a dedicated laser driver. We'll use the microcontroller, since the microcontroller runs at 16MHz. The clock rate is high enough to alternate laser diodes at the rate that we need.

Requirements	Verifications
1. Output power needs to be eyesafe. 2. Laser is outputting at right wavelengths.	1. Tools : Optical Power Meter After laser and heat absorbing glass is in series, check the power level. It needs to be less than 0.39mW but greater than 0.

	2. Tools: Wavelength Meter Measure the laser. See if it outputs right wavelength. Tolerance : ±1nm

2.2.6.b Receiver

We need to filter out visible light range. The visible light range would affect the values we would be measuring and we are only interested in intensity of light rays in 808mm and 850mm.

We need a lens to focus all the divergent rays to one narrow spot.
We'll place the photodiode at a point of convergence.

We'll be using a biconvex lens to focus.
The point of convergence can be calculated using the lensmaker's equation.

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right],$$

Equation 2. Lensmaker's equation

However, since our lens is only 9mm thick, we can use thin lens approximation, which drops the final term of the lensmaker's equation.

$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Equation 3. Thin lens approximation of lensmaker's equation.

Since the space is small on our device, we can't afford to have long focal length.
We'll use a biconvex lens with 25mm focal length to focus our rays.

Requirements	Verifications
1. Collimating lens needs to converge at the focal length.	1. Tools : Light source, Ruler Shine a divergent light towards our lens. Since it's a biconvex lens, it doesn't matter which side you shine at. Measure the point of convergence from the center of the lens. Tolerance : ±0.3cm

As for the photodiode, we will have to pick a diode that has high responsivity at the wavelengths that we'll be using.

VEMD5060X01 is the model that we'll be going to be using. This has light current at 26uA. Other photodiodes have light current averages at 5~10uA.

The signal is very low at this level. The amplification would be needed at this stage.

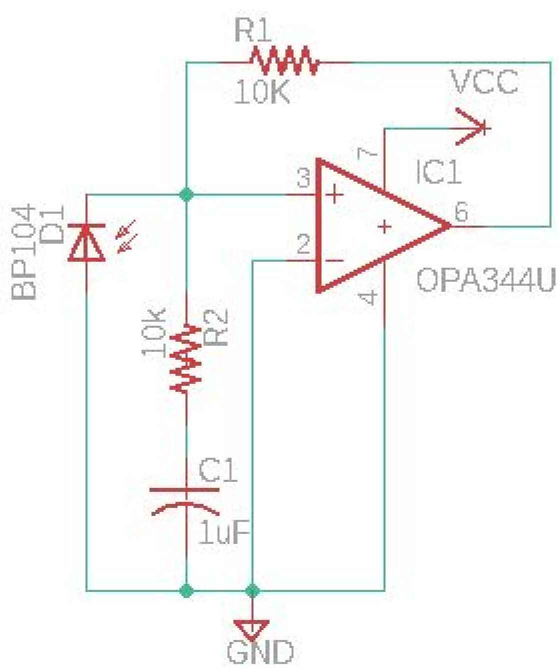

Figure 8. Circuit Schematic for Amplifier and Filter

The operational amplifier circuit would amplify to the point where the peak of the photodiode would provide approximately 3V.

Requirements	Verifications
1. Amplification is as expected	1. Tools : Oscilloscope - One of the channels, connect to where a photodiode is. - On the other, connect to the end of the feedbacking resistor. - Do a division of those two channels and see if it nears the gain factor we've set. Error range : 5%

2.2.7. Manual Gain Control

Manual gain control consists of R1 and R2 which are mentioned in the "Voltage Regulator" part. R1 is a constant 4k resistor and R2 is a 10k potentiometer. By changing the resistance of R2, we can change the output voltage from voltage regulator. The default value for R2 is set to 5300 ohms to provide 2.85V forward voltage.

Requirements	Verification
1. 10k ohms potentiometer (Tolerance: ±5%) 2. 4k ohms constant resistor (Tolerance: ±5%)	1. Use a multimeter to confirm that the maximum resistance of potentiometer is 10k ohms. (Tolerance: ±5%) 2. Use a multimeter to confirm that the resistance of constant resistor is 4k ohms. (Tolerance: ±5%)

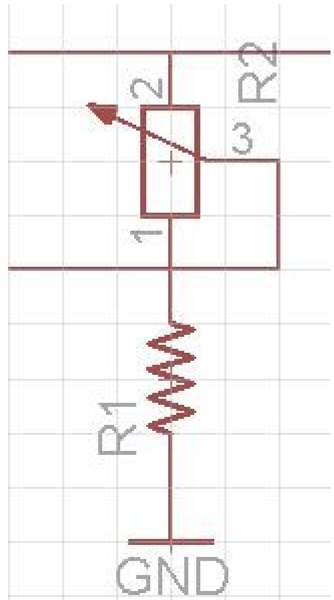

Figure 9. Circuit Schematic for Potentiometer

2.3 Tolerance Analysis

The bulk of the project is on lasers. The laser would be our focus for tolerance analysis.
The laser wouldn't have much.

Even after collimation, since the fog patches is random, the incident angle from the laser would be random.

Therefore only control that we have on this project is how much reflected rays we can catch.
Behavior of lens is governed by these formula.

$$Spot\ Diameter\ *\ Focus\ Angle\ =\ Lens\ Size\ *\ View\ Angle$$

According to the datasheet of the photodiode, 5 mm by 4 mm is our dimension. Let's approximate the dimension as 4mm square. Spot diameter is then close to 4mm.

Focus angle is $tan^{-1}(Lens\ Radius \div Focal\ Length)$. In our case it's 26.56 degrees.
Lens size is 25.4mm and therefore our view angle is 4 degrees. Since the rays are uniformly scattering, this narrow view shouldn't be impacting our project.

3. Cost and Schedule

Labor :
Assuming the labor cost is $35/ hour per person, we have calculated the total hours required to do the tasks:

Task	Hours of work needed
Design PCB and enclosure	15
Make revisions to circuit	20
Testing each part on breadboard	15
Code microcontroller to control LEDs and Laser Diodes	25
Soldering and making enclosure for circuit	12
Testing of laser at different wavelengths to gather empirical data	35
Presentation, final report and demo preparation	20
Miscellaneous	10
Total	**152**

Total hours = 152
Total labor cost = Total hours * $35 * 3 = $15960

3.1 Cost

Parts	Model	Quantity	Price	Total
Energizer Ultimate Lithium Batteries (6-pack)	-	1	7.99	7.99
3.3V voltage regulator	TL1963A-33DCYR	1	2.85	2.85
Adjustable voltage regulator	TL1963ADCQT	1	3.15	3.15
LEDs	GW CSSRM2.PM-N3N5-XX53-1	2	2.54	5.08
Reflector	C12469_LISA2-R-PIN	1	2.39	2.39
NMOS	IRLB8721PBF	1	0.85	0.85
Microcontroller	ATMega328p	1	2.14	2.14
SparkFun FTDI basic breakout 3.3 V	-	1	14.95	14.95
SparkFun 16MHz Crystal Oscillator	COM-00536	1	0.95	0.95
840nm Laser Diode	D840-5I	1	31.61	31.61
850nm Laser Diode	D850-5I	1	36.12	36.12
KG-3 Heat Absorbing Glass	49-087	1	22.50	22.50
Aspheric Lens	36-165	1	19.50	19.50
IR Filter	43-948	1	10.00	10.00
Biconvex Lens	LB1761	1	25.90	25.90
Photodiode	VEMD5060X01	1	1.87	1.87
Total	**-**	**-**	**-**	**187.85**

Total Cost = Labor Cost + Parts Cost = $15960 + 187.85 = $16,147.85

3.2 Schedule

Weeks	Hosang	Sid	Guan
Week 1 : 10/8 - 10/14 (Design Review)	Order laser diodes, photodiodes, optics Design PCB	Order microcontroller and UART	Order batteries, regulators, LEDs, reflector, NMOS
Week 2 : 10/15 - 10/21 (Teamwork Eval, Soldering)	Enclose the parts, Prototype circuit on breadboard	Prototype circuit on breadboard	Test each part on breadboard
Week 3 : 10/22 - 10/28 (1st round of PCBway)	Set Threshold in the prototype	Code and verify LED applications along with manual gain control	Contact with machine shop for the physical design
Week 4 : 10/29 - 11/4	Assemble our system using the enclosure	Write program to alternate laser diodes and calculate threshold for detecting fog	Revise the circuit Revise the physical design (if needed)
Week 5 : 11/5 - 11/11 (Progress Report, Final round of PCBway)	Set threshold in our final enclosure	Submit individual progress report, work on integration of different modules	PCB check and soldering
Week 6 : 11/12 - 11/18	Further testing and Begin integration	Work on improving laser functionality and getting finer data points	Circuit testing and integration
Week 7 : 11/19 - 11/25	Thanksgiving Break		
Week 8 : 11/26 - 12/2 (Mock Demo)	Mock Demo and Further Integration	Work on integration with other parts	Mock demo preparation and circuit integration
Week 9 : 12/3 - 12/9 (Demo, Mock Presentation)	Last minute realignment of optical system	Write final analysis and testing final procedures	Further circuit testing and debugging
Week 10 : 12/10 - 12/16 (Presentation, Final Paper)	Work on final paper and presentation requirements		

4. Ethics and Safety

The major safety concern in our project would be the use of a laser. The use of a moderate or high powered laser can permanently damage the retina of the eye. Therefore, proper use of the laser is definitely needed. The wavelength of the laser needs to be safely decided and the power of the light needs to be low enough that it causes negligible or no damage. We plan to stay within Class 1 range of laser.

According to ANSI Z136.1, For exposure duration from 10 to 30,000s, the maximum permissible exposure (MPE) is $10^{0.002*(\lambda-700)} * 10^{-3} \ \frac{W}{cm^{-2}}$ [7]

For 808nm, that value is 1.644 * $10^{-3} \ \frac{W}{cm^{-2}}$ and for 850nm, it is 1.995 * $10^{-3} \ \frac{W}{cm^{-2}}$

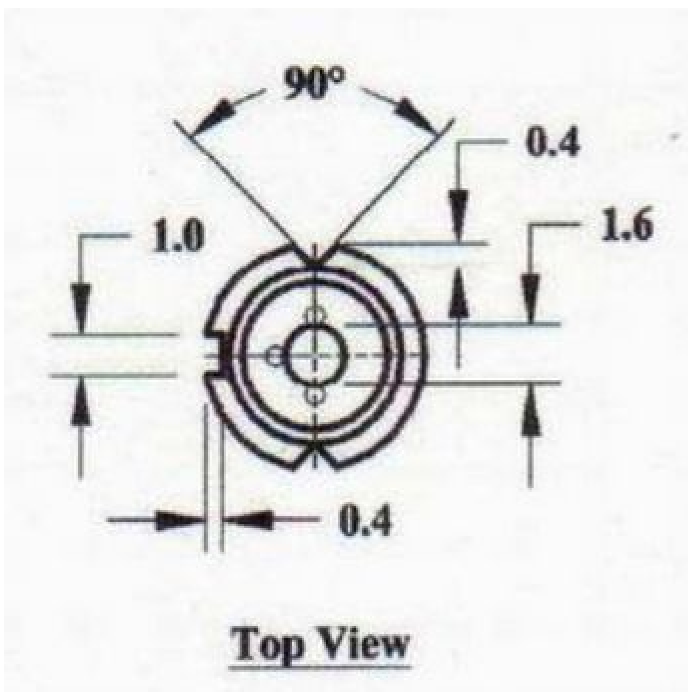

Figure 10. Technical drawing of the 5.6mm TO-Can package for laser diode [

Our laser diodes both have 0.8mm radius for the beams. With our heat absorbing glass, at 808nm, we'll have 0.2% power of original output at 840nm and 0.1% at 850nm. So, which means the highest output per area would be 4.974 * $10^{-4} \ \frac{W}{cm^{-2}}$, which is far below the requirement.

We’ll abide by the IEEE Code of Ethics and there are specific points from the Code that we would like to mention.

Since our design involves laser, we need to assure it will not cause any harm to people according to IEEE Code of Ethics #1 and #9 [8]. If we discover our design can cause damage to people, we will fix the issue and make it safe.

We also will make our judgements on safety as IEEE Code of Ethics #3 requires. We will be realistic to our safety claims and we will be honest about those concerns.

5. Citations

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