Environment Adaptive Automotive Headlight

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***Abstract* — Driving at night is far more dangerous than daytime driving. This is due to decreased reaction time caused visual impairments such as lack of illumination and flash blindness. A lack of illumination limits the sight distance as well as depth perception of drivers leading to decreased reaction times. Flash blindness can leave an afterimage seen as a dark spot in our vision causing us to not see clearly and can even disorient drivers. Our project can be incorporated into vehicles to increase the safety of the driver, oncoming drivers, and pedestrians associated with our roadways. This project combines weather and lighting condition sensors to appropriately adjust the headlight for optimal benefit of all drivers. As well as modified optical systems for improved lighting.**

***Index Terms* — Optoelectronic Devices, Current Drivers, Geometrical Optics, Object Detection, Microcontrollers**

I. Introduction

When driving at night, our field of vision is reliant on the illumination of ambient light (i.e. Street lights), and the headlights on the vehicle. In rural areas illumination can be even poorer due to a lack of ambient light. The risk of being in a fatal crash is three times greater at night versus the day. One of the factors increasing the danger of night driving is compromised night vision. Our depth perception, color recognition, and peripheral vision can be compromised in the dark. Even the glare from oncoming vehicles can temporarily blind drivers. As humans age our reflexes slow down and it takes us longer to recover from being dazed by bright oncoming lights increasing the hazards for nearby drivers. The goal of this project was to help increase nighttime vision to make nighttime driving safer by creating an adaptive headlight that provides more light output in the necessary places while decreasing it in places to aid oncoming drivers.

II. Overview

The project is an Adaptive Headlight. The Adaptive Headlight enhances the safety of nighttime driving by sensing environmental changes and adapting to them by maximizing the illumination of surroundings. For the advancement in safety of ourselves and those around us while commuting. This headlight enables better visibility for the driver by adapting to the best option of lighting through optimizing the field of view, brightness and position of the projected light. Factors considered is the weather conditions and ambient factors such as ambient lighting. As for the safety of oncoming traffic we aimed to reduce visual impairments of bright headlights by adjusting the light path to keep the light in essential areas like the road and off the driver's windshield.

For the electrical side we researched car batteries to learn the amount of power the battery could output when the car is on verse when it is off. Our selected LEDs are running off of current drivers rather than constant voltage to provide us with optimal illumination control and stability.

For the optical portion of this project we used free space optics and light emitting diodes for light sources. Due to the nature of the project basic optical components such as reflector buckets to steer the LED source light. Along with basic single lens systems to adjust the divergence and beam power density. The choice for LEDs was to modernize the headlight system to a brighter more efficient system as LEDs have a lifespan of 50,000 hours compared to the standard halogen bulbs at 500 to 1,000 hours. The second reason for LEDs is that we are able to address each LED within a matrix in order to be able to change full beam pattern on the whole system. Another downfall of a halogen bulb is that they do not immediately dim or turn off whereas LEDs response times are well beyond our needs. To properly analyze the environment to assess the proper LED states we needed a variety of sensors such as a camera in which we will look for oncoming cars as well as backscatter conditions from fog, smoke and rain. We addressed that the lights need to initially come on during sunset to meet state laws. To decide just when to turn the headlights on in the evening we used a photodiode to detect ambient lighting and a microcontroller processes the return signal such that when a defined threshold is met the headlights will turn on to meet safety goals and conform with legal standards.

To verify the condition between rain, fog and smoke when the camera states there is large back scatter, we needed to have a sensor to decide when it is raining compared to the other conditions. This is due to fog and smoke conditions needing the fog lights on whereas rain we do not wish for fog lights as they just produce more glare to oncoming drivers than they benefit the actual sight conditions of the operator. To accomplish this, we could have solved this issue with an electrical based water sensor, but to add to the optical aspect of the project we used a laser diode coupled into an acrylic medium at an angle to obtain total internal reflection. Using Snells law we can see how a change in boundary conditions such as the change from an acrylic- air interface to an acrylic-water interface can cause the laser diode energy to leak and scatter through the interface losing a portion of the transmitted power. We can measure this difference using a phototransistor and be able to distinguish water from rain or fog compared to dry air in the case of smoke.

III. Optics

The optical system of our headlight is comprised of a high-power LED, an acrylic lens, and a reflector. For each sub-section of the headlight (i.e. fog light, high beam, low beam, etc.) a different optical system has been designed to appropriately accommodate the purpose and needs of the subsystem. Below each subsystem will be discussed in further detail of the optical system and specifications of the system.

A. Low Beam

The optical system for the Low beams is comprised of an aluminum housing for the LED and a single singlet lens system. Since each LED being used is a high-power LED, they need to be properly heatsinked for long term use and for overall safety of the semiconductor device. The singlet lens being used in the system is made of acrylic and has a specified focal length (f) of 20 mm and a diameter (d) of 16.5 mm. In order to calculate the $F^{\#}$ of the Low beam system equation 1 shown below was used, where f is the focal length and d is the diameter of the lens. Using equation 1 shown below gives us an $F^{\#}$ of 0.825. For automotive headlights the light must be projected around 300 ft for the low beams. Using a single lens gives us an optical power of 50 D which was calculated by using equation 2 as seen below.

(1) $F^{\#} = f/d$
(2) $\Phi = 1/f$

In order to achieve a larger brightness and control over the field of view of the headlight the Low beam system is comprised of an array of 5 LED's with an identical housing and optical systems. Each LED will be individually driven by a current driver to maintain control of each LED and allow for control over the headlights overall field of view. The headlight will be able to toggle on and off the Low beams depending on the detection of oncoming cars headlights. This meets our goal of being able to avoid blinding oncoming drivers and preventing after images. In order to detect oncoming cars a camera will be used and will have a sampling rate of 2- 5 Hz. Each LED will be assigned a field of view and a number 1 to 5. When a bright light is detected in that section of the field of view then that LED will be turned off. The overall field of view can be seen below in Fig. 1. As seen below in Figure 1 the low beam is divided into 5 different fields of view with each being assigned to a corresponding LED, in field 2 an oncoming car is present. Since we have an oncoming car in field 2 that LED would be toggled off to avoid blinding the oncoming driver and creating an afterimage on their retinas. The program for toggling on and off each LED will be discussed in more detail below.

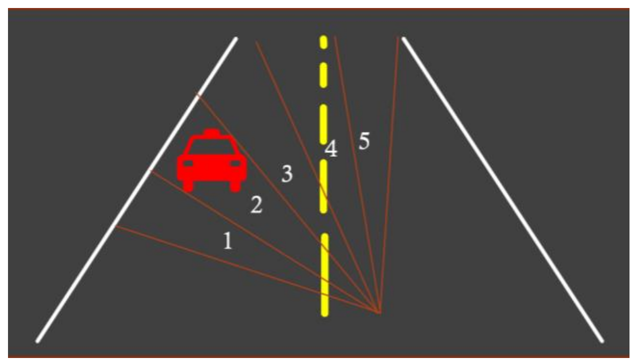

Fig. 1. Overview of field of view assigned to each LED

Each LED is comprised of a 2x2 matrix, in order to avoid imaging the pattern of the LED chip the lenses are placed just before the focal point. This allows for a smooth square pattern to be imaged at infinity. A smooth beam pattern is specified in legal standards for automotive headlights and placing the LED just before the focal point allows this to be achieved.

B. Fog Lights

The next subsystem of the headlight is the fog lights. These lights are situational and will only be turned on during smoky or foggy conditions. The placement of the fog lights will be low to the ground to avoid the back scatter from the dense water droplet content of the fog. Due to the nature of reflection of light on an interface with a difference in refractive index when normal low beams are used in tandem with fog lights the amount of reflected light is minimized, and the illumination of the road and surrounding areas is maximized. The design of our fog light system is a parabolic reflector. A circular beam shape was our specification for the fog lights. Designing a parabolic reflector achieved this goal. The design for the reflector can be seen below in Fig. 2.

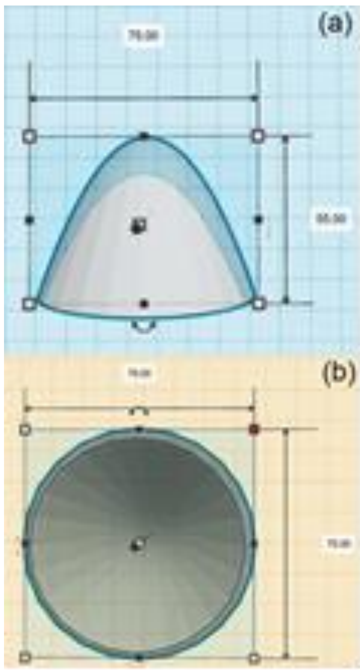

Fig. 2. (a) X – Z plane (b) X – Y plane

The optical power of the reflector is calculated using equation 3 as seen below. The reflector has a radius (r) of 55 mm.

(3) $\Phi = 2/r$

Using equation 3 the calculated optical power of the reflector is 36.36 D.

C. High Beam

The final optical subsystem in our headlight is the high beams. For this system we designed a projector imaging system comprised of a single parabolic reflector with a rectangular aperture. The reason behind this beam shape is that the high beams need to be able to cover the same field of view as the low beams. As per specifications high beams must be able to be seen out past 500 ft of the vehicle, and be off when an oncoming car is within 500 ft. The high beam housing will be placed directly above the low beam module in order to increase the intensity of the beam and to be imaged at farther distances. To comply with the larger projecting distance of the high beams the reflector will be pointed along the optical axis of the unit, parallel with the road. The design of the reflector can be seen below in Fig. 3. The diameter of the reflector is 25 mm. Using equation 3 the calculated optical power of the high beam reflector is 80 D.

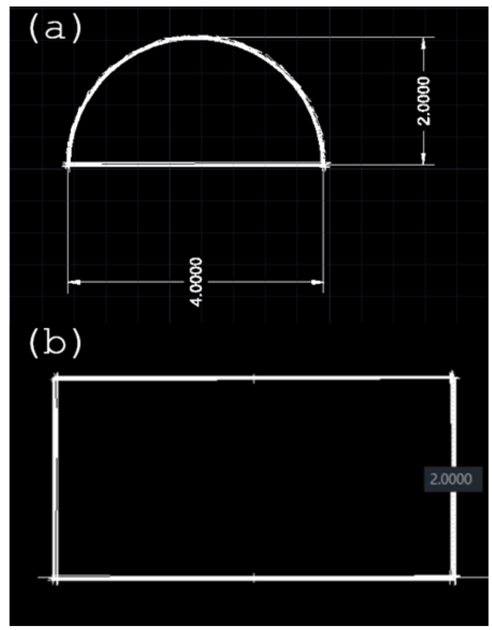

Fig. 3. (a) X – Z plane (b) X – Y plane (all units in inches)

IV. Power

For this project we are going to assume that we are always getting power form the car battery, which can deliver varying voltages depending on the age of the battery and whether it is being charged by the alternator. To power the headlight system the components used in this project should be able to handle varying input voltage from 10 V to 17 volts. However, for cost effectiveness, practicality and prototyping we will be using a 240-watt computer power supply that will output 12 Volts.

Figure 4 shows an overview of the electrical power subsystem. It shows how the MCU will control the LEDs through the voltage driver and read sensors data. It shows what component will be place on the board their quantity and interconnections.

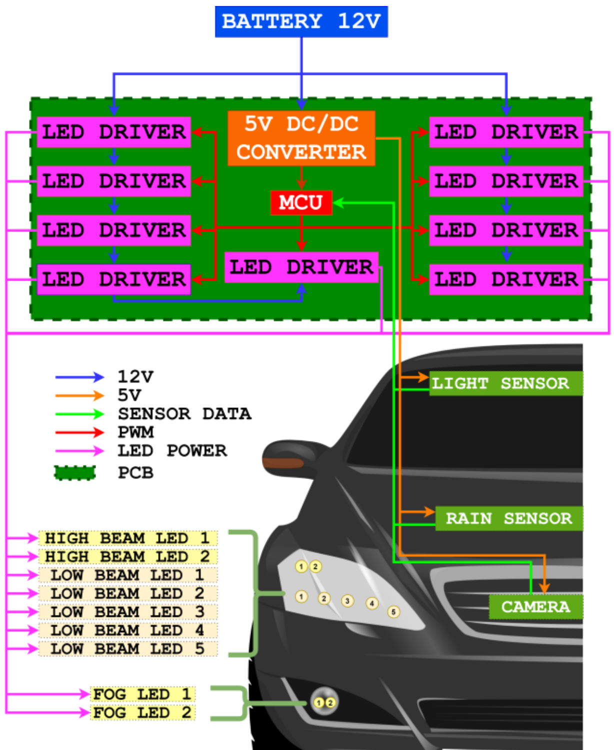

Fig. 4. Overview of the Electrical system

A. LED Current Driver

The LED drivers help power the LED by controlling forward voltage and current. The brightness of an LED is controlled by the current going through the semiconductor die, therefore we choose a current driver. The LEDs used in this project will run at a current of 1.5 amperes this is an ideal point where the LED is bright enough, our frame is able to dissipate the heat. Properly driving the current helps the longevity and life of the LED. Overcurrent can cause discoloration and failure and undercurrent leads to underperformance of the LED. The LEDs have two voltage configurations 12-volt and the 6-volt option we went with the 6-volt option. In total there are 9 LEDs that need to be powered. The LEDs used in the project have the same current and voltage characteristics so the same LED driver setup can be used to power them.

To power the LEDs in the headlight unit we researched and tested different voltage and current drivers. After rigorous testing we settled on a driver that was cost effective, reliable and well preforming. The A6211 IC is a dedicated LED constant current driver by Allegro MicroSystems. It come with a variety of circuit protections features to ensure the longevity of the device and protecting it from mishandling such as short circuits and overheating. The efficiency of the driver was measured to be around 86%. The A6211 driver can be adequality controlled by a microcontroller through PWM. We can adjust the output current going to the LED simply by changing the duty cycle of the PWM signal. Lastly this driver has a small 8-soic form factor and few external components greatly reducing the total size of the PCB.

From figure 5 we can see that the A6211 current driver is essentially a buck converter with a shut resistor for current feedback. There are some component values that we must determine in order to have the circuit work properly.

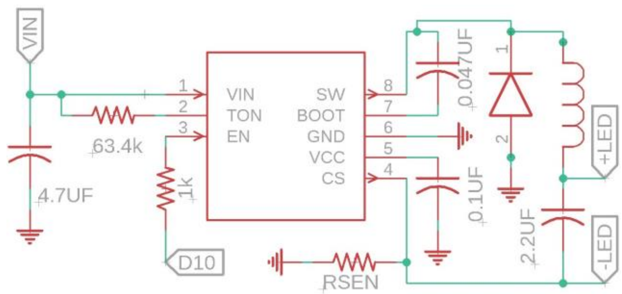

Fig. 5. A6211 LED current driver schematic

First, we must set the amount of current passing through the LED. This is done by picking the proper shunt resistor Rsen value. The way the IC knows the current passing through the LEDs is by measuring voltage through the Rsen resistor through the CS pin. This voltage is compared to an internal threshold voltage 'Vcsreg', which is typically 0.2 volts. The way we set the LED current is by diving Vcsreg by Rsen. We went with a Rsen resistor of 0.1 Ω. Using this resistor value will make the IC output approximately 2.0 amperes which can then be lowered down to 1.5 amperes using PWM. The approximate duty cycle needed to lower the current to 1.5 amperes was around 55 %.

The next value we need to select is the switching frequency since this is a buck regulator. This driver is most efficient when the switching frequency of 1 MHz. This value is set by the 63.4 kΩ resistor which is the recommended value from the manufacturer. The inductor size was chosen by looking at the manufacturers chart that compared switching frequency verses LED current, so we settled on a 10 µH inductor capable of handling the high current. The 2.2 µF capacitor attached to the output of the LED terminals is used in case there is some flickering, the capacitor will minimize this. All other component values such as the boot capacitor, Vin capacitor and Vcc filter capacitor no modification was needed so the recommended manufacture values were used. Lastly a Schottky diode capable of handling 1.5 amperes was selected.

B. Voltage Regulator

The sensors and microcontroller used in the headlight cannot use 12 volts, so a 5-volt rail is needed. The voltage regulator takes a variable input DC voltage and then outputs a fixed DC voltage level. There are two options for this problem using a linear or switching regulator. Linear dc to dc regulator bad because of high inefficacy due to the difference input and output voltage that will generate a lot of heat. So, we went with a switching regulator since they are vastly more efficient than linear regulators. The tradeoff is that we will need more components such as inductors and diodes smooth out the high current spikes from the off and on switching and a capacitor that smooths out the output voltage.

The switching regulator we are using is the TPS563240 step-down voltage regulator by Texas Instruments. It has a wide input range and it can supply up to 1 ampere which is more than what our microcontroller and sensors need, all while being inexpensive. This IC also has minimal ripple voltage which is necessary to protect our MCU and sensors.

Figure 6 shows the schematic for our voltage regulator. For the design of the TPS563240 regulator we used the WEBENCH Power designer tool by Texas instruments to aid us in the component selection process. We inputted our Vin range and Vout voltage and max current supply. We settle on this one because of its simplistic and effective design. The regulator use a buck converter topology and it uses a feedback pin (VFB) to read the voltage between the set of two resistors based on the resister value different output voltages and be achieved. This driver also features a high switching frequency which allows us to use a smaller inductor saving us space on the PCB. Lastly, we have a diode is used to prevent the back flow of current.

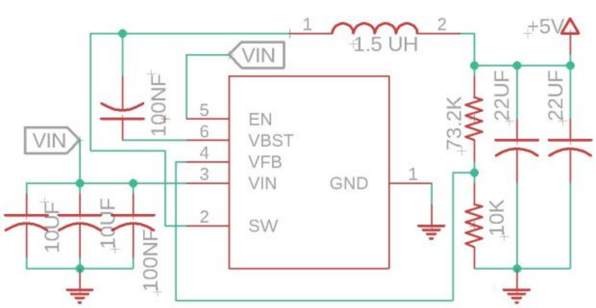

Fig. 6. TPS563240 voltage regulator schematic

V. Printed Circuit Board

From figure 4 we can see that our PCB houses most of our electronic components. Figure 7 shows the PCB design for this project, in this PCB we find 9 A6211 LED drivers with control signals from the MCU and some block terminals to easily connect the LED lights. The 5-volt regulator for the MCU and some sockets for the sensors. Lastly the MCU board with a 16 MHz crystal, reset button, sensor pins and programing pins. Prior to putting all the components, we checked to see if they were individually working to not waste time and components. Lastly, we included a power indicator and programing indicator to ensure all components were working properly.

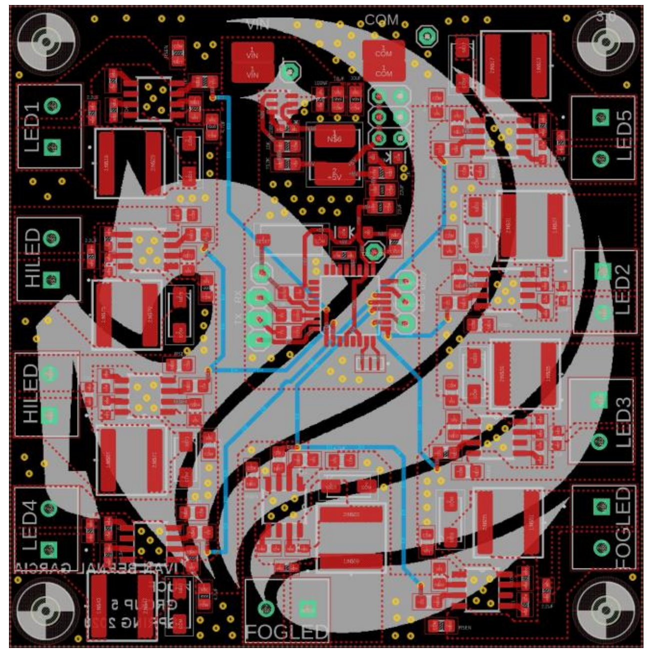

Fig. 7. PCB layout

For design this PCB we used Eagle since it offers a wide range of features, it is free to use, widely used and user friendly. The board is almost square measuring at 76 mm by 77 mm. The board itself has 2 layers and inexpensive at around 3 dollars per board. The methods for PCB design was to have neighboring components as close as possible. We did this to reduce the total board size. The LED driver where put on the outside of the board for connecting the power leads easier to the LEDS. The 5-volt regulator was place close to the MCU in the middle to further save space and to avoid having long traces. Lastly a power and programming SMD LED was used to show to the state of the device and for easier trouble shooting.

We added thicker traces were possible to ensure good conductivity current flow and heat dissipation, since thinner traces can be damaged easier. Polygon traces were used in places were multiple components were spread out the a having thick traces would help with current flow and reduce resistance. Having a thicker piece of copper is good for several reasons such as heat dissipation, less resistance and noise for the signals and a stronger build. Generally having a thicker piece cooper greatly increase the cost back for our purposes 1oz copper board was all we needed.

The soldering process was straightforward. Some of the components are small (603 and 805) so special care must be taken not to break the component by applying too much heat. However, using a Hot Air Rework Station and 63/37 No Clean Leaded Solder Paste made the job much easier.

When you first get the Atmega328p-AU chip it is not programmed to do anything. To program the MCU on the PCB various methods were tried. Eventually we found the Pocket AVR Programmer. The In-System Programming (ISP) pins were used to program the board using the Arduino IDE. Software.

VI. Environmental sensors

For Our environmental sensors we needed to detect ambient light, rain, fog, and smoke. To accomplish this, we incorporated two sensors that will work as inputs to the microcontroller and use feedback from the camera later described to determine the environmental conditions.

A. Ambient light sensor

The ambient light sensor will be among the cheaper and easier sensors we have. We were being very budget conscientious as we needed to keep cost as low as possible. We used a photocell in a voltage divider setup to be able to measure the ambient light of various conditions. Using this data, we set a threshold point in which we want the headlights to not only come on. This point would be the amount of light we commonly see in dawn and dusk hours. Such that the headlight will be on at all times within legal standards and for safety.

B. Rain sensor

The other main concern for the use of headlights in Florida is the need to have headlights on in the rain. To add novelty to our system we decided not to go with a moisture sensor off the shelf or even a rain collector that water from the rain would complete the circuit indicating it's raining. We decided to go with a demonstration of total internal reflection. Using a piece of acrylic, a laser diode, and photodiode we are able to normalize the first plane of incidence at the critical angle.

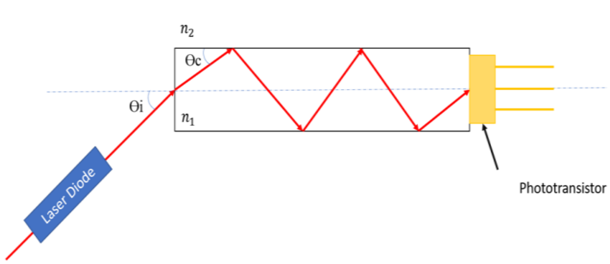

Fig. 8. Rain Sensor

By transmitting the laser output at the critical angle of the acrylic to air interface we can couple the laser output through to the far side of the acrylic where a photodiode is used to detect how much light is successfully transmitted through. This will be our "normal" condition, so when it rains the acrylic to air interface will now be acrylic to water interface in which the critical angle needed will be much greater than our angle of propagation that was set on the previous acrylic to air interface. This change makes us no longer at the necessary angle to keep the light in the acrylic but rather transmit through the interface decreasing the amount of light transmitted to the far side of the acrylic and incident upon the photodiode. Therefore, we can tell that if the light incident upon the photodiode is significantly less than the "normal" state then it is raining.

VII. Microcontroller

The job of the microcontroller in this project is to be the controller of each individual headlight, take input from the sensors, and analyze the picture that the camera takes. In order to do all of this, it needs enough pins for I/O as well as be fast enough to change the headlights in a timely manner. The microcontroller that we are using is the ATMEGA328P-AU.

We chose this microcontroller because it has plenty of I/O ports as well as a 32-bit processing speed. Usually in an image processing project you want a microcontroller or a computer that has a very fast processing speed. An example would be a 64-bit quad core processor. In our project, we do not need this processing power for two main reasons. The first is that our image is a very low resolution (160 x 120). This means that there are much less pixels that our processor needs to do analysis on. The second reason that we don't need a fast processor is that the analysis we are doing is very primitive. We are only looking to see if there is light in the pixels we are analyzing. To do this, we only need to check the value stored in data corresponding to that pixel. If the value is high enough, we know that there is light in the pixel.

VIII. Camera

Our camera's purpose is so that our microcontroller has a picture to analyze. A picture will be taken of the road in front of the car every so often so that the microcontroller has a new picture when it is analyzing. The camera we are using in this project is the TTL Serial Camera. There are several reasons why we are using this camera over other ones. First, this camera is produced by Adafruit and they have distributed an open source library for anybody to use alongside their products. Since they've done this, it makes the camera easy to use and test. The second reason that we are using this camera is because it serves two purposes in our project.

The first purpose is of course a camera but the second purpose it serves is a storage device. This camera takes the picture and holds the data for us. With other cameras, we would have to store the picture it takes in another device like an SD card. Doing this would make the headlight's speed suffer by a few milliseconds to maybe even a whole second. The third reason that this camera was chosen is because the resolution can be brought down all the way to 160x120. This is a horrible resolution for most projects that use a camera but a great resolution for us. It is great because it means less pixels for our processor to do analysis on, which means a faster project. Finally, the last major reason why this camera was chosen is because we already had one and wouldn't have to spend money on a camera.

IX. Logic

The microcontroller will take input from each sensor and camera. Analysis will be done on the picture taken by the camera. Once analysis is done, the microcontroller will determine which lights should be dim or bright by the sensor inputs as well as the data from the picture analysis. Here is a picture showing how the data from the picture analysis is stored in our memory so that you can better understand the chart that proceeds it. One bit is for the light sensor, another for the water sensor, and the last 6 are for the camera analysis. Each bit of the camera field corresponds to a different area or zone in the picture.

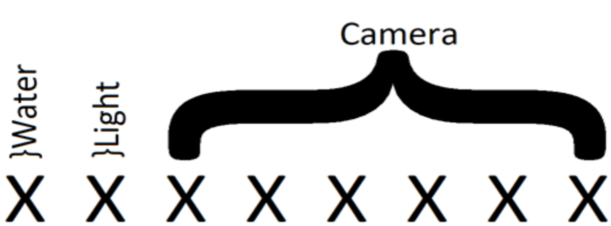

Fig. 9. Controller Variable Data

Here is a chart that shows the state of the headlights for each sensor and which areas the microcontroller has decided to be on or off. The output column shows which LED will be on and in the same row, the state the controller needs to be in for that LED to be turned on. 1 is triggered by light or water, 0 means no light or water, and x means it doesn't matter for that case.

Output	Camera	Light Sensor	Water Sensor
High Beam LEDs	111111	1	0
LED 0	XXXXX0	0	X
LED 1	XXXX0X	0	X
LED 2	XXX0XX	0	X
LED 3	XX0XXX	0	X
LED 4	X0XXXX	0	X
FOG LED	111111	1	1

Tbl. 1. Controller Logic

X. FRAME/HOUSING

The frame for this project is primarily constructed from metal materials such as aluminum to help with heat dissipation from the LED pods. Achieving a common layout to many vehicles the fog light is detached such that it can be mounted lower on a vehicle but is in its own enclosure such that it can be easily mounted and dissipate the heat generated by the light itself. The low beam is the base with the high beam structured on top to provide a higher and more direct path of propagation. The electronics are mounted behind the lights so that the height does not push our requirements. The camera and rain sensors will be mounted adjacent so that they are the forwardmost objects on the assembly to receive a clear FOV for the camera and a direct path for water to hit while driving down the road. Lastly the ambient light sensor is mounted directly above the whole assembly to ensure only the light directly above is captured to give a true reading of the ambient lighting condition.

XI. SAFETY

This Project has very minimal safety requirements as it is a stand-alone system meant to be a plug and play style. The safety requirements are that the system is to properly turn on lights in the ways necessary by law for the safety of all motorists and pedestrians. The headlights are turned on in all situations of darkness and rain. We also need to make sure the headlights turn on during foggy and smoky conditions. This was accomplished by the camera in which any large amount of backscatter detected the lights will come on in the appropriate fashion.

XII. Conclusion

In conclusion of this project, we have completed a prototype of what could be a more refined system if more time and facilities we're able to be accessed. The core functions of the system are functioning. We made a low beam with addressable pods so that we can shape the beam with five individual FOVs. The system takes into account the ambient light, rain and a direct image of what lays ahead to look for the desired conditions in which the headlight needs to be used. The camera not only helps assess the environmental conditions but the physical environment of where other cars are so that the appropriate beam (High/Low) is being used as well as allowing the low beam adapt to dim the region in which oncoming cars are to aid the vision of all other drivers at night. The headlight also meets all power requirements running off of a 12 V input and pulling less than 20 Amps at any given point. For the size we are within weight specification and within the maximum size.

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BIOGRAPHIES

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