Road Surface Mapping

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Initial Project Document and Group Identification

Divide and Conquer

Group 3

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1 Project Description

1.1 Project Background

While driving, car owners are annoyed at the uneven road surfaces and unavoidable potholes. Their hope is their vehicles don’t sustain any damage or need an alignment after a journey down a bumpy path. The department of transportation is usually informed of obstructions or irregularities in the road’s surface by travelers; however many backroads or country roads are not reported as the number of people driving these roads are significantly smaller than city roads or highways. Our surface mapping device can be attached to any car and will indicate the location of obstructions and holes found on any road that the car drives down.

Image processing is the act of modifying or analyzing a digital image to extract information or to alter the image in desired ways. Once in digital form operations can be applied and useful data can be extracted. Some of these operations include enhancement, restoration, compression, and pixel composition. Through analyzing the pixels of an image, it is possible to find changes in the location of a particular object in the image. Using this ability, it is possible to find shifts of a line due to depth changes of an object. In this project, our group explored the use of this subset of image processing to improve the effectiveness of road repair crews.

Our group is composed of two photonic engineers, two computer engineers, and one electrical engineer. The optical engineers will focus on the laser and camera setup, emitting a laser light and capturing images with a high speed camera, while the electrical engineer will focus on the power supply for the two designations in the project. Our device will have two components, one of which will consist of a laser diode and the second will include the web camera attachment to record the data in which the car is driving past, this is along the line provided by the diode. The role of the computer engineers is to make the data accessible. Accessibility will be implemented in two ways: organizing the data and presenting the data. Organizing involves establishing a database, synthesizing an algorithm that is capable of detecting road damage based on changes in laser line relative to the camera field of view, and refining data points into rasterization objects. Presenting involves designing a website to give the end user a visual of the damage to all scanned roads.

The goal of this project is to safely and efficiently map the surface of the road to locate road damage for repair. Therefore, the product needs to be securely mounted to a vehicle and protected from the elements, while operating at safe road speeds. The device will include a laser line system which will help indicate if there is a change in the depth of the road and a camera to capture these changes. The location of these changes or road damage will be tagged for repair using GPS. The data collected from the camera will be stored in a removable memory source such as a SD card or USB drives. The data will then be uploaded to a computer and run through a processing program to create a map of the road and identify damaged areas. A list of locations will also be generated that can be accessed through an application.

This project focuses on identifying road damage and where this damage is located. The Department of Transportation would benefit from this project as it presents a way of identifying and alert workers where they would need to go to repair the road. Companies like Google may also benefit as drivers could be altered to potential road damage on Google Maps. The government may be able to provide states with lower quality roads more funding through the federal-aid highway program. This project has the potential to provide many useful applications that would benefit companies, the government, and drivers.

1.2 Goals and Objectives

As stated above, the goal of this project is to safely and effectively map the road's surface and tag road work such as potholes with GPS tracking using a camera and laser system to detect changes in the surface of the road. After information is gathered from the optical system, this data will then be processed and users will be able to locate any road damage. Below are the core, advanced, and stretch goals for this project broken down by area and the objectives to reach these goals.

1.2.1 Optical Goals

The optical system goals of this project are pretty straightforward. Table 1 summarizes the optical goals of this project and the objectives needed to reach these goals. The optical system must be built in a way that provides a mapping resolution of 4 in X 4 in while scanned at a minimum speed of 10 mph. Our goal is also to map approximately the width of a car, around 6 feet. There are several objectives to meeting these goals. The camera frame rate will affect the resolution of our system along with the maximum speed the vehicle can travel. However, when choosing a camera the pixel size must be considered as it will affect resolution. The camera's field of view must be sufficiently wide enough to capture the average width of a car which is 6 feet. Also, the laser diode must have enough power to project a line of at least 6 feet and the powell lens that forms the line must have an angle of at least 90 degrees. Lastly, we want to be able to map damage that is at a minimum of 6 inches deep.

Table #1: Basic Optical Goals

Goals	Objective
Resolution of 4in X 4in	Camera frame rate needs to be a minimum of 40 Hz Camera pixels
Vehicle speed of 10 mph	Camera frame rate needs to be a minimum of 40 Hz
Map the road the width of a car	Camera field of view needs to image 6 feet wide Laser diode must have enough power to project a line of at least 6 ft. Powell Lens with an angle of at least 90 degrees
Damage Depth of at least 6 in	Laser line needs to be sharp enough for it to move in the frame

After reaching the basic goals of our optical design, there are a few advanced and stretch goals that will be worked towards. The advanced goals include a scanning system resolution of 2 in X 2 in while moving 20 mph. We would also like to map one full lane or approximately 11 feet and map any damage at least 4 inches deep. Finally, the stretch goals include a scanning system resolution of 1 in X 1 in at a speed of 30 mph or faster while scanning three lanes or approximately 33 feet. Mapping damage that is at least 2 inches in depth would also fall under this goal.

1.2.2 Electrical Goals

Table #2: Basic Electrical Goals

Goals	Objective
Power the laser diode	Provide enough power for laser diode to function
Power the web camera	Split power sources to provide the 5V current to the camera as well as what is needed for the diode
Function time 5 min	Start up time for device and active use time for demo

In the electrical perspective, there are several basic goals that would need to be met for the device to function properly. In the case of our device we have 2 main sections that need to be powered, including the laser diode and the web camera which will be capturing the recorded data to be sent to the server to be computed into where the road obstruction occurred and the measurements of it. With the objective/goals of these two parts being powered we also have to ensure that the device can turn on and maintain its function throughout the basic goal demo time of 5 minutes. During this demo time the device must start up efficiently and be able to transfer the data fully to the SD card to then convert into our database.

Once these basic electrical goals are met for this project, we can work on extending our basis to meet advanced and stretch goals to perform for the final demo. An advanced goal can include providing proof of an extended period of time that power is supplied for the road scanning around campus. Our current demo time for the scanner is 5 minutes of being able to scan and process data to our server, so an advanced goal that can be proved on demo day and still lie within the amount of storage we are able to hold in the SD card is to extend this time to 10 minutes. An example of a stretch goal would be to provide a port to the device, or allow for an extra use of the supplied power in the case that another feature would need to be added to assist with a further function of the device. If it is decided that our range of view needs to be lengthened or the capabilities of the software portion has to be increased then there should be variability in the supplied power to the device for such alterations.

1.2.3 Programing Goals

Table #3: Basic Programming Goals

Goals	Objective
Server	Ubuntu Server 22.04 LTS on a Raspberry Pi 4 Model B
Database	MongoDB Community Edition 6.0
Website Structure/Behavior	React
Website Look/Feel	Style the website's components using CSS
Data Processing	Use Computer Vision principles to find differences in elevation

Some basic programming goals of this project will be having a server, a database and a web application all working together to store and transmit data to the user. The database should be configured to store all of the data we will be working with which includes GPS locational data to the data from road scans. The website should not distort the information pulled from the database. The web application should also be professional in the way it presents information.

The advanced programming goals for this project is to store only essential data in the database such an example would be to not include all GPS data just time and position as long as the signal is good. Categorization of road damage is also an advanced goal which will help the user see which areas are more damaged. Providing user feedback upon startup of the device is an advanced goal because it is important to let the user know when the device is functioning properly and ready to record. Damage representation is important to allow users to see the exact damage in a particular area. Marking a map with road damage is important by giving the user a better understanding of where road damage actually is. A stretch goal for this project would be to include an interface where the user has a map of the scanned roads and the date they were scanned to keep track of which roads are due for scanning. This is a stretch goal because it is nice to have a feature where we can see what roadways were scanned most recently and it uses mostly the same method as marking a map with road damage.

Table #4: Advanced Programming Goals

Goal category	Objective
Database	Store only essential data
Website	Provide road damage categorization
Device	Provide user feedback on startup
Website	Display damaged road and location
Website	Mark map with road damage
Website	Map to display all scanned roads

1.3 List of Requirements and Specifications

When designing a prototype, engineers must take into account specifications that must be incorporated. Table 5 describes the requirements for the road surface mapping device. Numerical specifications and a description are included along with the level of priority. The three highlighted requirements are specifications that must be met for our prototype to be successful.

Table 5: Requirements and Specifications

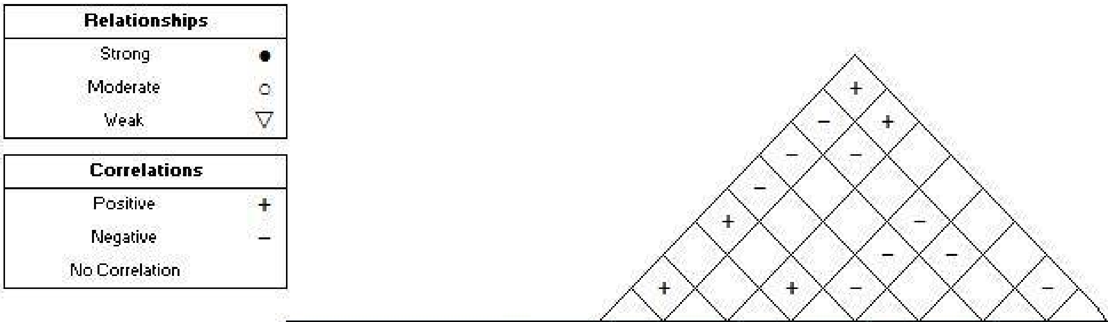
No	Requirement	Specification	Description	Priority
1	Horizontal Field of view	6 foot width	Camera needs to view at least the average width of a vehicle.	High
2	Speed of Car	10 mph minimum	Car will travel at min speed to be safe to use on most roads	Medium
3	Damage Evaluation	Damage is considered any hole that is at a minimum of 2 inch deep or 8 inch diameter.	Potholes that meet the standard requirement for repair need to be flagged by the device.	High
4	Camera Frame Rate	40 frames per second	Camera must image at the specified speed per	High

			speed of the car and resolution specifications.	
5	GPS tagging of road damage	Less than 2 meter	GPS tag locations of scans so the road damage can be located	High
6	Laser Diode	400 nm to 700 nm	The wavelength must be in the visible spectrum	High
7	On Board Data Storage	Specification TBD	Downloadable data storage to record the data while in operation. Data will be downloaded and processed.	High

1.4 House of Quality

The house of quality is a diagram that shows the relationship between marketing requirements and engineering requirements. It helps determine a product's ability to satisfy customer needs by examining the product's characteristics and features. The marketing requirements are standards that are important for the customer such as low cost, user experience, safety, and performance. Since this project is not sponsored by a company, our group members are considered the customers in this scenario. We chose specifications that would be important to a consumer interested in purchasing a road mapping device. Engineering requirements describe the design goals of the product that the group as the engineers on the project should adhere to. These requirements include criteria such as image quality, output power, operational lifetime, and cost.

Figure 1 shows the house of quality diagram with marketing requirements on the left and engineering requirements along the top. Target values for the engineering requirements are located at the bottom of the diagram. Each engineering and marketing requirement was then noted as having a strong, moderate, or weak correlation. To form the "roof" of the diagram a negative or positive correlation between engineering requirements was considered. One factor that stood out was the effect on cost. To improve any aspect of the product aside from wavelength, there will be a negative impact on cost.



Column #	1	2	3	4	5	6	7	8
Engineering Requirements / Customer Requirements (Explicit and Implicit)	IMAGE QUALITY	OUTPUT POWER	DIMENSIONS OF DAMAGE	FRAME RATE OF CAMERA	STORAGE	CAR SPEED	COST	LASER WAVELENGTH
USER EXPERIENCE	●	▽	●	●	○	○	▽	▽
SAFETY	▽	●	▽	▽	▽	○	▽	●
AFFORDABILITY	●	○	▽	●	●	●	●	○
PORTABILITY	▽	▽	▽	▽	▽	▽	○	▽
PERFORMANCE	●	●	●	●	○	○	○	●
EFFICIENCY	▽	●	●	●	▽	○	○	●
RELIABILITY	●	○	○	○	▽	●	▽	▽
DURABILITY	▽	▽	▽	▽	▽	▽	○	▽
Target	4in X 4in resolution	TBD	2 IN DEPTH OR 8 IN DIAMETER	≥ 40 FPS	TBD	10 MPH	≤ $600	400 - 700 nm

Figure 1: House of Quality Diagram

1.5 Project Block Diagram

1.5.1 Project Overview

Figure 2 shows a basic overview of the surface mapping project. Each block is color coded to show which engineer is responsible. Currently each stage of progression of the project is in the research stage. Color assignments can be found to the left of the figure.

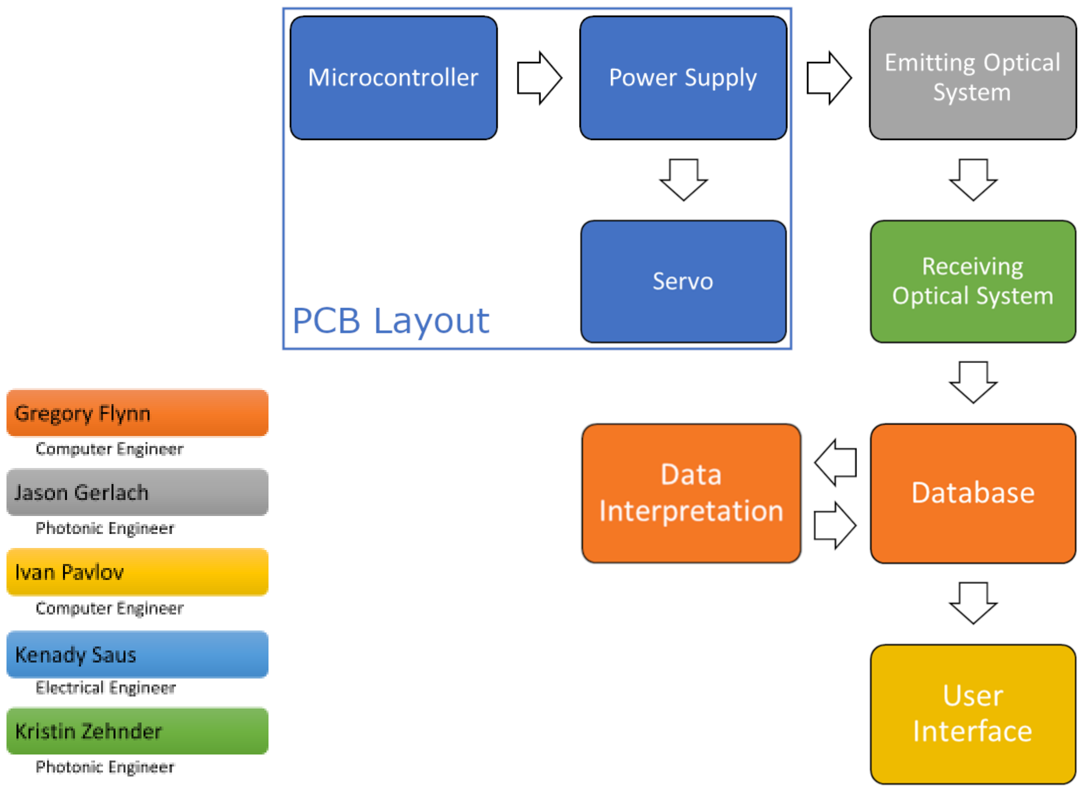


Figure 2: General Block Diagram

1.5.2 Optical Block Diagram

The optical block diagram, figure 3, includes the emitting optical system which is composed of a laser and powell lens system The lens system will generate a line on the road and images will be captured by the receiving optical system which includes a wide lens system and a camera. Figure 3A shows the optical setup from a side view while figure 3B shows a top down view.

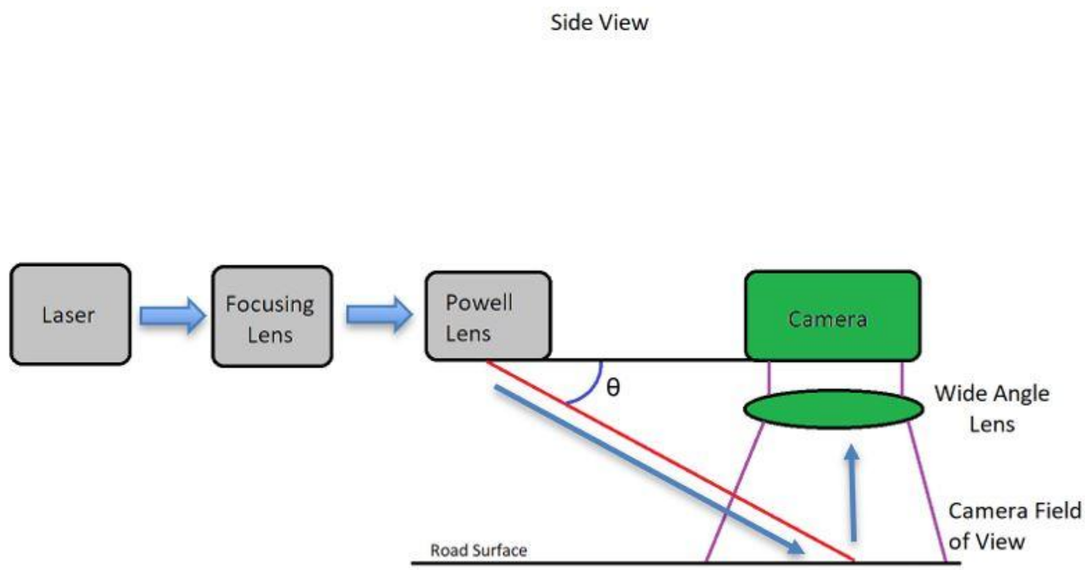


Figure 3A: Side view of optical system

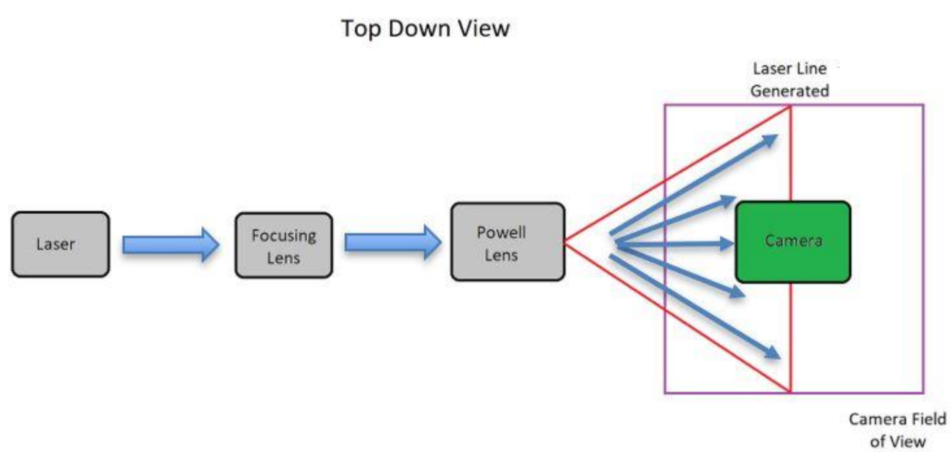


Figure 3B: Top down view of optical system

1.5.3 Software Block Diagram

Figure 4 goes into more detail about how data will be interpreted and presented. The data obtained from the photodetector will be stored locally on the device on removable storage. We will then organize this data into the separate pot holes, and store the pothole data in our database which is connected to the website for user presentation. Once the data is in the database we can use that to categorize each pothole, represent each pothole and map each pothole on a real world map. The figure also explores the procedure for developing a mobile application, although this is a stretch goal.

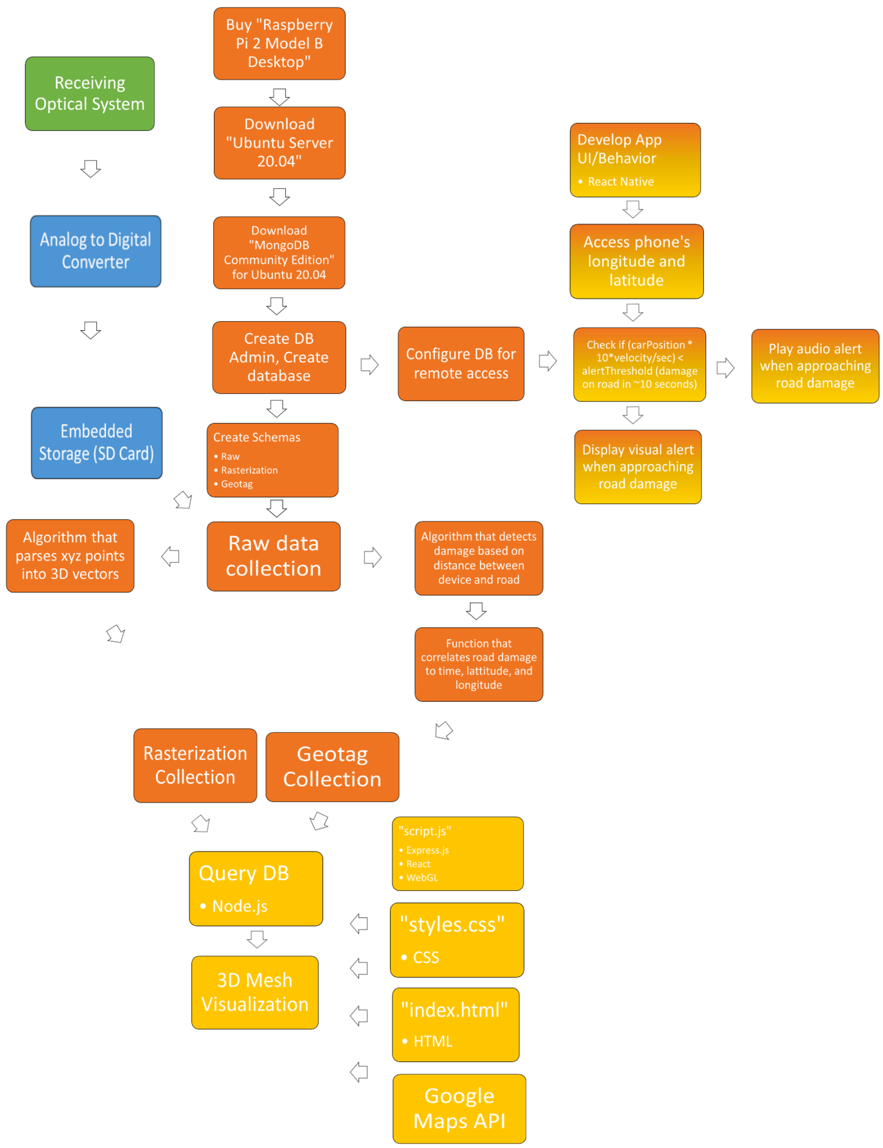


Figure 4: Software Block Diagram

1.6 Budget and Funding

The table below lists our current estimates for what would be required to build a working prototype of the road mapping system. As of now, there is no sponsor for the project and all costs will be covered by the members of the group. Adjustments to prices and required parts are possible while methods of scanning are in discussion.

Table 6: Prototype Budget

Item Description	Quantity	Total Estimated Cost
Red Laser Diode	1	$40.00
Focusing Lens	1	$40.00
Camera	1	$100.00
Powell Lens	1	$40.00
Wide Angle Lens	1	$60.00
Microcontroller	1	$30.00
Wiring	1	$20.00
Battery (9 volt)	1	$4.00
PCB	1	$40.00
Website Domain	1	$15.00
SD Card (2 GB)	1	$23.00
Mounting Bracket	1	$30.00
System Casing	1	$30.00
GPS Module	1	$20.00
Analog to Digital Converter	1	$40.00
Raspberry Pi 4 Model B Desktop	1	$197.90
Bluetooth/Wifi	1	$30.00
	Total	$759.90

1.7 Project Milestones

Table 7: Project Milestones

Task	Duration	Status
Senior Design 1 - Spring 2023		
Brainstorm Project Ideas	01/09/23 - 01/16/23	Complete
Project Selection	01/16/23 - 01/23/23	Complete
Divide and Conquer 10 Page Document	01/23/23 - 02/03/23	Complete
Research Component List	01/23/23 - 03/06/23	Researching
Schematic	01/23/23 - 03/20/23	Researching
Bill of Materials	01/23/23 - 03/20/23	Researching
75 Page Document	01/23/23 - 03/24/23	In Progress
Final Document	01/23/23 - 04/25/23	In Progress
Order Parts	02/27/23 - 05/01/23	Researching
Senior Design 2 - Summer 2023		
Assembly of Optical System	TBD	TBD
Testing of Optical System	TBD	TBD
Entire System Assembly	TBD	TBD
Assembly Testing (Stationary)	TBD	TBD
Redesign 1	TBD	TBD
Assembly Test 2 (Stationary)	TBD	TBD
Assembly Testing 3 (Mounted on car)	TBD	TBD
Redesign 2	TBD	TBD
Finalize Assembly	TBD	TBD
Final Presentation	TBD	TBD

2 Technology Investigation

2.1 Existing Technologies

While investigating ways that we could produce a product that would map the roads surface, different technologies were investigated. LiDAR (Light Detection and Ranging) is an emerging technology that can be used for many applications. The most commonly known is for navigation of autonomous vehicles in which LiDAR is used to gather information about the surrounding environment and obstacles. Light is emitted from a source and reflected back to a detector. The time-of-flight is recorded by the detector allowing the system to calculate the distance to the objects in the environment. In the next sections scanning and flash LiDAR are discussed in more detail with a third technology, camera vision.

2.1.1 Scanning LiDAR

Scanning LiDAR uses a laser and photodetector to generate a point map of distances from the emitter. The laser and photodetector are usually placed on a rotation servo that allows the LiDAR device to scan the entire environment it is placed in. The laser emitted a beam that creates a point on a wall or object and the scattered light is then detected by the photodetector. The time between the laser emission and the scattered light detection, called ‘time of flight’, is used to calculate the distance to the object.

The emitting system consists of a laser and lens system. For safety reasons, the laser is usually in the infrared range, 780 - 2500 nm, and normally 905 nm. The laser is required to have enough power to generate an appropriate amount of scattered light from the object being scanned. This power level needs to be balanced with keeping the laser in an eye safe range of power. The laser needs to be pulsed to create a unique emission event. The time of the pulse needs to be recorded for use in the time of flight calculations. The lens system is used to focus the laser to a small spot and then collimated to maintain intensity of the laser for the length of the beam. The laser pulse rate is determined by the detector's rise time. The shorter the detector rise time, the faster the laser is able to be pulsed.

The detection system consists of a lens system, filter, and detector. Once the collimated light leaves the emitting system, it will collide with an object for scanning. Scattered light reflects off the object and is collected by a lens system that will focus onto a detector. The lens system must be optimized to collect as much light as possible as scattered light has a low intensity reading. The detector needs to have a fast enough rise time to capture the incoming light and must have a signal to noise ratio that will enable the detector to overcome background noise from the environment. To help with the noise level, as light is focused onto a detector it will pass through a bandpass filter that will filter all light except for the wavelength of interest.

The emitter and detector systems are mounted onto a rotating servo to allow the system to scan the entire environment. In a typical scanning LiDAR system the emitter and detector would tilt to scan the environment in an up-down direction while the rotation would allow a 360 degree scan of the environment. The combination of tilt and rotation enable the system to cover most possible directions, resulting in a complete point map of the surrounding environment. To convert the recorded data into the point map requires the system to know the angle of tilt and the angle of rotation of the servo at the time of emission. The tilt of the system is controlled and recorded by a microprocessor. To find the angle of rotation, time must be recorded as the servo spins and speed of rotation must be known. With this information a map can be generated. Figure 5 shows a general scanning LiDAR system.

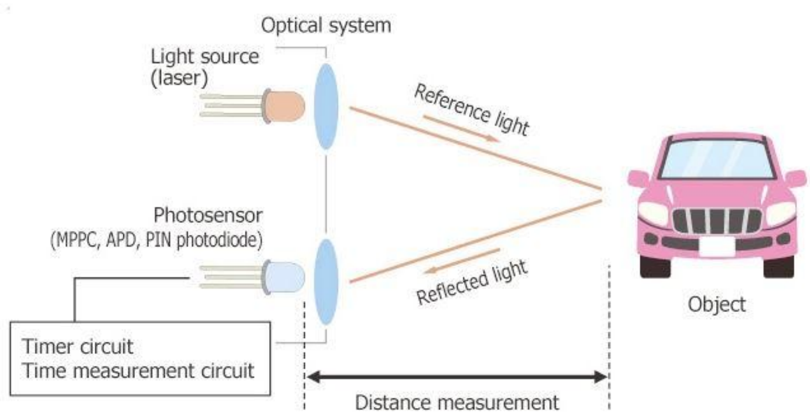


Figure 5: Scanning LiDAR System. This system includes a light source passing through an optical system. The reference light is then reflected to another optical system onto a photosensor. [1]

2.1.2 Flash LiDAR

Flash LiDAR is similar in concept to scanning LiDAR. However, with flash LiDAR the entire field of view is illuminated by a single pulse of a laser and an image sensor is used to detect and analyze the received photons. Depending on the application, the optical system may be on a rotation device such as a servo or may be stationary.

The emitting system of flash LiDAR uses a laser and a lens system. The laser is in the infrared range, 780 - 2500 nm, to remain eye safe for use around people. The nominal wavelength is typically 905 nm or 940 nm as a result of dips in the background radiation due to the fact that these wavelengths are easily absorbed by water in the atmosphere.

Figure 6 shows the spectral photon flux or irradiance at different wavelengths. A clear dip at 905 nm and 940 nm can be seen. The lens system will be used to create a large spot in the object field. This spot will illuminate a large area that is then imaged through an array of photodetectors. This allows flash LiDAR to generate many points for the point map at once.The laser is pulsed at a rate depending on the detector's rise time and time of flight is still used to determine the distance of an object. The emitting system also uses beam shaping optics to create the area of illumination. Collimating lenses are used to guide light through a diffractive element, such as a cylindrical lens.

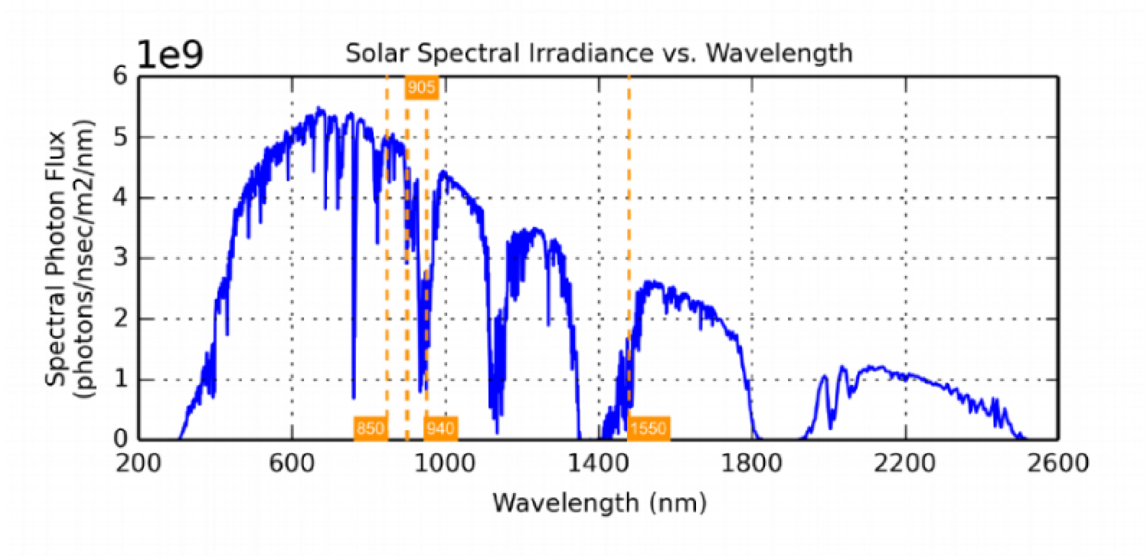


Figure 6: Wavelength versus Spectral Photon Flux. [5]

The laser is pulsed at a rate depending on the detector's rise time and time of flight is still used to determine the distance of an object. The emitting system also uses beam shaping optics to create the area of illumination. Collimating lenses are used to guide light through a diffractive element, such as a cylindrical lens.

The detector system in flash LiDAR is an array of photodetectors, similar to the way a camera works. Each photodetector in the array will be used to record the distance to one point in the large spot illuminated by the emitter system. The detector system uses a lens system to both collect the scattered light from the object and to limit light coming from outside the target area. The collection lens works much like an aperture focusing only the light from the target area onto the photodetector array. This aperture behavior is what allows the system to know that the light hitting the array in the upper left photodetector is coming from the upper left of the target area. The photodetector array's rise time must be proportional to the speed of the laser pulses, and signal to noise ratio must be taken into account. However, like scanning LiDAR, a bandpass filter is used to reduce the noise from the light gathered from the target area. The bandpass filter allows the system to remove light not in the same wavelength as that of the emitting system. This is crucial since the photodetectors in the array are sensitive to all wavelengths of light. Figure 7 shows a general flash LiDAR system.

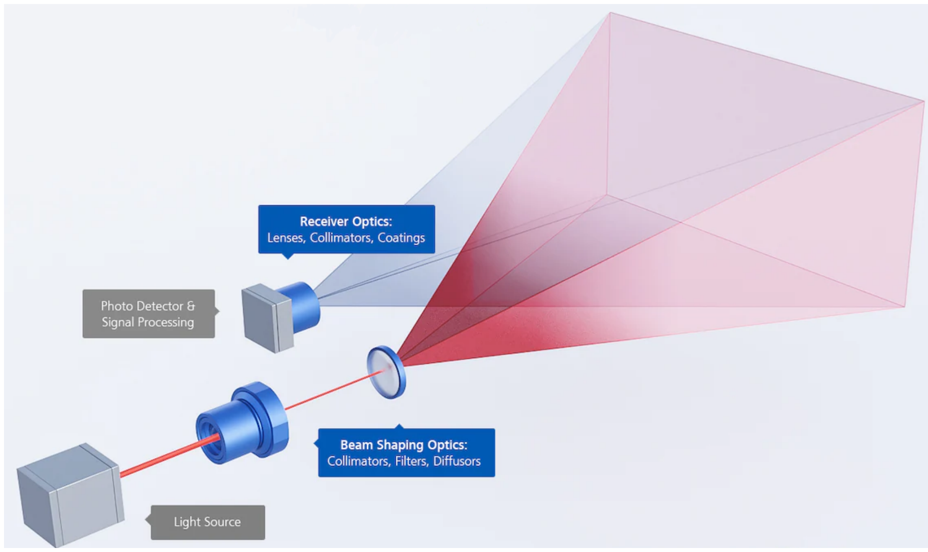


Figure 7: Flash LiDAR System. This system includes a light source passing through beam shaping optics and illuminating an area. Scattered light from the area is captured by the receiving optics and projected onto a photodetector where the signal is processed. [6]

2.1.3 Machine Vision

Machine vision, or camera vision, uses the images collected by one or many cameras to extract information about a targeted area. This can be a multiple of properties such as the location, orientation, condition, or identity of an object. After an object is illuminated, an image is sent to a camera's sensor where the analog data is converted to digital data. Signal processing is used to send the resulting data to a receiver such as a computer. The computer uses automated processes to extract the information from the images.

The illumination system lights the objects of interest to ensure the camera can capture a usable image. The lighting system used can have many different sources such as an LED, halogen light, or fluorescent light. Depending on the conditions, light may emitted from an angle, from behind the object, or straight on. Qualities such as brightness, distance from the light source, and color of the light must be taken into account to optimize the system.

After an object is illuminated a lens will capture the image. The lens chosen for the system will be determined depending on characteristics such as the field of view, aperture, depth of field, and depth of focus. For example, if the field of view of the camera does not capture the entire object, a wide angle lens may be used to lengthen this constraint. After the lens has captured the image it will send it to a camera's sensor. The sensor will capture the light, and convert the analog data into digital data. The camera is usually in the form of a charged coupled device (CCD) or a complementary metal oxide semiconductor (CMOS). It is chosen based on many qualities, but an important aspect is whether the camera is area scanning or line scanning. An area scanning camera captures a two dimensional image made up of a rectangular area of pixels that includes the area of interest. A line scanning camera captures a one dimensional image made of a line of pixels very quickly as the camera is moved over an object. These one dimensional images are then stitched together to form a two dimensional area. Other features that should be considered when selecting a camera for machine vision are resolution, the number of pixels that make up an image, and sensor size, the physical area exposed to light. Frame rate, number of frames per second, and exposure time, the length of time it takes the camera to capture the light from the object of interest, should also be considered.

The use of 3D imaging is a growing sector of machine vision with the most common being scanning based triangulation. Scanning based triangulation utilizes motion of the target object or of the imaging system during the imaging process. This process uses a laser projected onto the surface of the target object at an angle different from the angle that the camera is viewing the object at. The camera records the changes in the laser line profile as the object passes through the laser. Changes in the surface of the object cause deviation in the laser line profile which the computer can process into changes in the elevation of the surface to create a depth map of the object's surface. This allows the computer to create a 3D image of the object, which can be further processed by the computer to gather the data desired by the system. Figure 8 shows an example of camera vision being used in a production line.

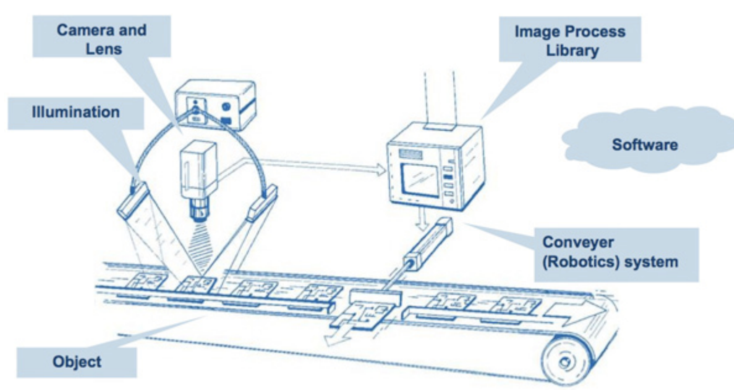


Figure 8: Camera Vision. As an object is moved along a conveyor belt, the object is illuminated and an image captured by a lens and camera. The digital signal is then processed and information about the object can be extracted. [7]

2.1.4 Technology Comparisons

This section will compare the previous three technologies, scanning LiDAR, flash LiDAR, and machine vision. Pro's and con's on each are weighed and a decision on a technology to pursue for the project. Table 8 tabulates specifications that apply to the surface mapping system prototype and gives a synopsis on how that specification would be met.

Table 8: Specifications Based on Technologies

Specification	Scanning LiDAR	Flash LiDAR	Machine Vision
Resolution (4in X 4in)	Based on rotation devices and car speed Detector must have a fast rise time	Based on rotation devices and car speed Requires detector array with fast rise time	Based on camera fps and speed of car
Vehicle Speed (10 mph)	High rpm and laser pulse frequency	High rpm and laser pulse frequency	Resolution decreases as speed increases
Laser (Wavelength)	Near infrared Light	Near infrared Light	Visible Spectrum
Cost	High	High	Medium
Horizontal Field of View (6 feet)	Determine when to record the data based on angle of rotation	Determine when to record the data based on angle of rotation	Wide angle lens on camera

While researching these technologies, there were many similarities found between scanning and flash LiDAR, as previously stated. The emitting systems both use near infrared light around 905 nm or 940 nm. The LiDAR systems are mounted on a spinning platform and many qualities of the system, such as resolution and vehicle speed are based on this rotation. To achieve an usable level of resolution would require the servo to spin very fast. Because the rotation will be very fast, a detector with a fast rise time must be used which is very expensive. As the speed of the car increases, the pulse frequency of the laser must also increase to capture enough time of flight information and again the detector's rise time must be even faster. It was also found that capturing the entire horizontal field of view would require a lot of calculations, specifically the angle of rotation of each pulse as the system spins on the servo.

Although there are many similarities in scanning and flash LiDAR there are also many differences. For example, since flash LiDAR illuminates an area the pulse frequency would not be as fast as scanning LiDAR. This is because flash LiDAR collects multiple points with each pulse whereas scanning LiDAR records only one point with each pulse. To obtain the same level of resolution scanning LiDAR must make multiple passes over the area that flash LiDAR can image in one pulse. This is demonstrated in figure 9.

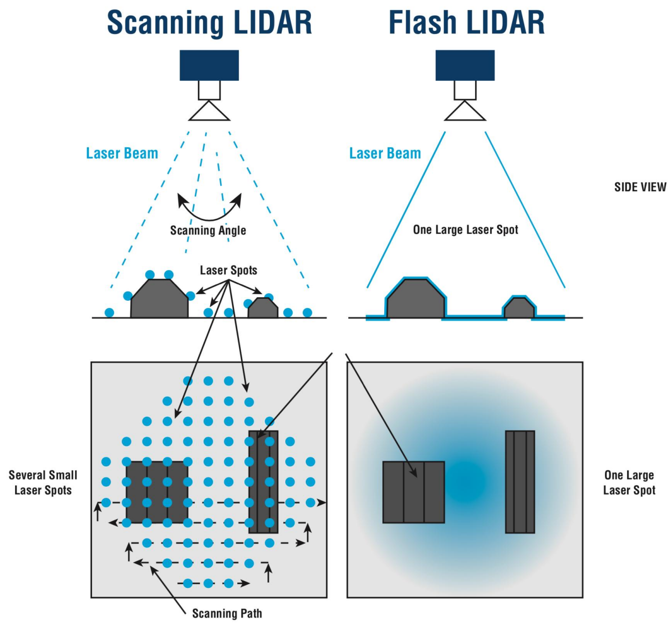


Figure 9: Scanning Versus Flash LiDAR. Differences in scanning techniques between scanning and flash LiDAR. Multiple spots will need to be scanned in scanning LiDAR to cover the same area as flash LiDAR.

Another difference is the detector type. Scanning LiDAR only requires the use of a photodetector with one sensor, while flash LiDAR requires an array detector which is a lot more costly. Flash LiDAR uses a lens system to spread the laser beam out to create a large spot in the object field. This dispersion of energy means that flash LiDAR requires a more powerful laser than scanning LiDAR and can be the reason for a short effective length on the imaging system. Flash also requires a lens system on the detector side that is used to gather the scattered light. This lens system must gather as much scatter light as possible while also ensuring that the light gathered is restricted to the target area. Scanning LiDAR uses a lens system to focus the laser to a fine point which is then collimated to maintain the spot size. This allows the beam to maintain most of its intensity till it hits the target. Lastly, if imaging an area, resolution would be based on the amount of points within the area scanned if pursuing scanning LiDAR as opposed to flash LiDAR where the resolution would be based on the detector array.

2.2 Electrical Technologies Available

In the sense of the electrical aspect of what option we have available to power our device, there are several options. These options include the decision between a DC-DC converter opposed to an AC-DC converter. Our next options are a voltage converter or using a battery as our form of supplied power. Each has very common uses in everyday technical applications, such as the medical, automotive industry or the phones that we carry with us everyday. The sections below will explore how each form of power supply performs in further detail. These options are also seen as a technology selection as well as the basis of part selection.

2.2.1 AC-DC Converter

The AC-DC Converter is a power supply option and is also known as a rectifier. This option is an electrical circuit that converts the alternating current into direct current. This process is completed by rectifying the AC waveform to produce a directional flow of current. This form of conversion is commonly used in electronic devices that require DC power such as computers, televisions and mobile devices.

The step by step process of the converter involves a circuit that uses one or more diodes to allow current to flow in only a single direction. The inputted message signal (AC) will have its voltage reduced to be suitable for the rest of the circuit to process. The diodes then in place of the circuit will rectify the AC waveform to allow the current to move in only one direction. This can be done by using a full-wave or half-wave rectifier. This will produce a DC waveform, however, this still needs to be filtered to ensure there are no fluctuations in the current. A capacitor can be a component used to filter the remaining DC current. Finally, if needed the voltage will have to be regulated to ensure it remains constant if the input voltage or load changes. Most applications that use an AC-DC converter option are devices that are supplied their current through an outlet. Such as a computer or a television, the device is plugged into the wall so the available current is much higher than what is needed from the device to operate. The converter is needed to ensure that the voltage is transformed or stepped down to only supply what is needed to the device as well as filtration.

2.2.2 DC-DC Converter

The DC-DC converter, also known as a voltage converter, is an electronic circuit that converts a DC input voltage into a different DC output voltage. This output is constructed by either increasing or decreasing the voltage level. This type of converter is used in applications that need stable and regulated power provided to different components. Examples of where this converter can be used are, solar power systems, automotive applications and electronic devices.

This process conducted by the DC-DC Converter is the input voltage supplied which can come from any other power source. The circuit then uses components such as diodes, capacitors, transistor or inductors to regulate the input voltage and provide a stable output voltage. Depending on what the end goal is of the converter, it can either step up or step down the voltage. The output voltage is then monitored to ensure that it remains stable and within a desired range for performance. Once regulated this can then be used to power the component or system. Benefits of this system is it provided features such as overcurrent, overvoltage and thermal protection. DC-DC converters can be used to provide different voltage levels to components in your phone such as the camera and the display. This converter is also used to disperse various voltage levels to systems in automotive applications such as the audio system, navigation and lighting.

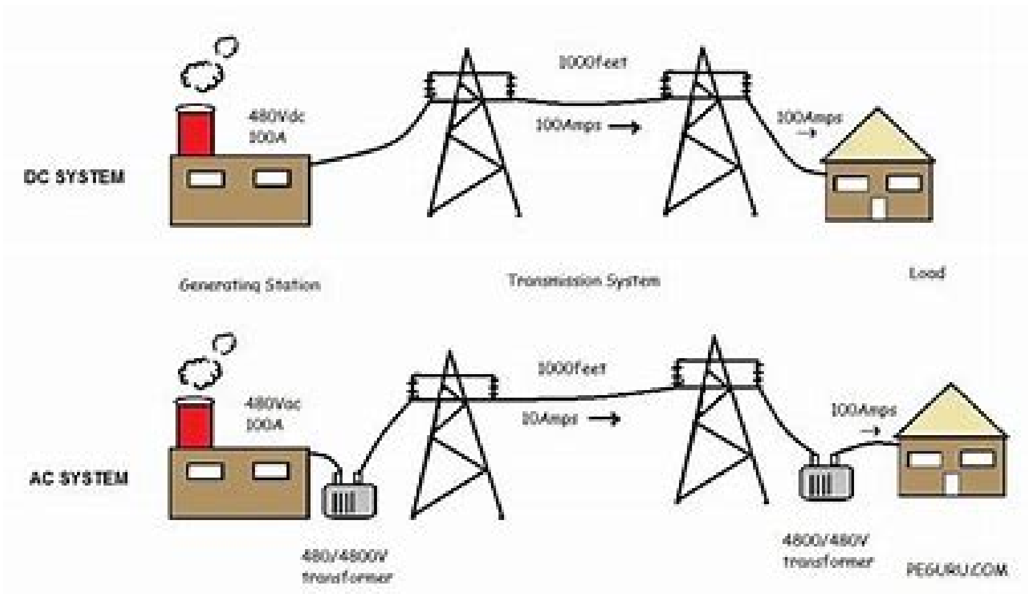


Figure 10: AC-DC Conversion Versus DC-DC Conversion

2.2.3 Voltage Regulator

A voltage regulator is an electronic device used to maintain a constant output voltage level regardless of input variations. This system can adjust the input voltage or output current to maintain a steady voltage level. These are commonly used in electronic devices and power supplies to ensure a stable consistent voltage to different components is provided. This is important to prevent damage from voltage fluctuations.

Several options of voltage regulators are line, switching and programmable regulators. Line regulators are the simplest version as they work by using a series pass transistor to drop the excess voltage from the input to the output. This allows the constant output voltage to be provided, but it is not always efficient because this system generates heat. Switching regulators are a much more efficient option. They use switching transistors to quickly turn the input voltage on and off. This allows the transistors to regulate the output voltage without wasting excess energy or heat. Lastly, programmable regulators allow the user to adjust the output voltage using an external feedback resistor. More flexibility is created allowing this to be used as a single regulator in multiple applications. Some voltage regulators can also provide the benefits of overvoltage, overheating and overcurrent protection.

This electronic technology option can be used in a wide variety of devices, such as mobile devices using the same concept as a DC-DC converter with the current being dispersed properly to multiple components including the display and camera. The regulator can also be used on industrial equipment to ensure that the different components receive the correct voltage at a stable and consistent rate.

2.2.4 Battery

A battery is a chemically storing device that converts the chemical energy into electrical energy. The electromechanical cells are connected and produce a desired voltage and capacity. This cell is made up of a cathode and an anode, and an electrolyte that separates the two electrodes. When a battery is charged, a chemical reaction occurs in the ions to then be transferred between the electrodes and electrolyte. This process stored the energy in a battery. When the battery is used the reverse reaction takes place. The stored energy is converted into electrical energy to be used as power. The amount of energy available is determined by its capacity, this is labeled by its voltage and ampere-hours. Batteries are beneficial for many applications, especially portable devices such as phones, and backup power supplies. Another benefit is that many batteries have the capability of being rechargeable. This means they can be charged and discharged multiple times using a different form of chemical reaction.

With a battery's portability and convenience they are used in many common applications. Devices such as phones, laptops or portable speakers require a small and lightweight powersource that can be easily recharged. Batteries are an ideal solution in this case. This ideal solution is also used in vehicles because they can be designed to withstand the high currents required to start the engine, or they can be used to supply power to the lights in your vehicle. Another very popular use is the inclusion of batteries in toys and games, such as video game controllers and electronic toys. The ideal-ness of a lightweight power source that can be replaced easily is very desirable.

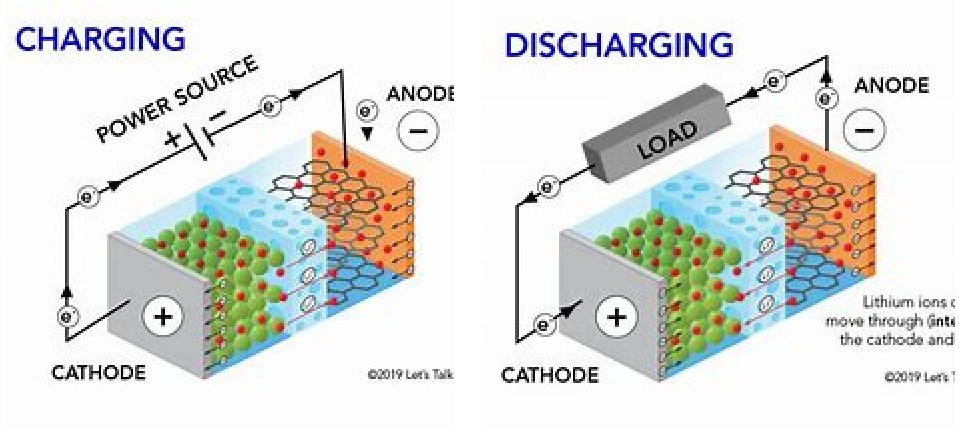


Figure 11: Process of Batteries

2.2.5 Electronic Technology Comparison

The electrical applications to technology as described above have many different benefits when used in specific circumstances. Using conditions specified to the needs of our project we can conclude that the battery option would have a better outcome for us. This conclusion will then be explored again in the part selection portion to compare the efficiency, cost, performance and noise. The application of these forms of power are considered both technical options as well as part selection options.

2.3 Programming Technologies Available

There are many programming technologies available for us to use for this project. These programming technologies range from programming languages to libraries we will use to simplify the work. Such technologies that will be discussed in more detail include WebGL, OpenGL and threejs. These technologies all focus on include built in functions that will help with the rendering of 2D and 3D graphics. As there is a time constraint on this project utilizing such technologies is beneficial in both reducing time necessary to create our own 3D graphical pipeline as well as reducing the number of lines of code we will need in the final product. It is assumed that we will be able to decompose the image data gathered from the camera sensor into a simple 3D object model which will then be displayed on our website when the user wants to observe the road damage virtually. In the next sections these three application programming interfaces will be discussed in more detail.

2.3.1 WebGL

WebGL or Web Graphics Library is a javascript API used for rendering and interacting with high-performance 2D or 3D graphics in compatible web browsers. WebGL provides certain functions such as rendering contexts, multiple types of buffers, textures and much more all of which will simplify programming and reduce the necessary code size.

WebGL is based on OpenGL ES 2.0 being a subset of OpenGL means it may not include all the features that OpenGL has, such features include tesselation shaders and compute shaders. WebGL is designed to be used on a website, and includes support for hardware graphics acceleration from the user's device. WebGL does not require native driver support. One benefit of WebGL is that it is easy to learn in comparison to OpenGL.

2.3.2 OpenGL

OpenGL or Open Graphics Library was released in 1992 by Silicon Graphics Inc and is an application programming language that is cross platform and cross language. This means that multiple languages can run this library such as python, java and javascript. Supporting multiple different languages is useful by allowing the developer to choose which language they want to use for their 2D and 3D graphical needs. OpenGL is desktop-centric, typically used to interact with the graphics processing unit. OpenGL has less overhead when compared to the overhead from WebGL. Some features OpenGL includes are accumulation buffers, tessellation shaders and compute shaders. Accumulation buffers are useful for creating effects such as anti-aliasing, and motion blur, both of which are features you would expect in a game. Tessellation shaders are useful for creating smoother surfaces than the original mesh allows, in other words tessellation allows the addition and subtraction of detail to a 3D mesh. The compute shader allows for high-speed computing utilizing the parallel capabilities of the GPU.

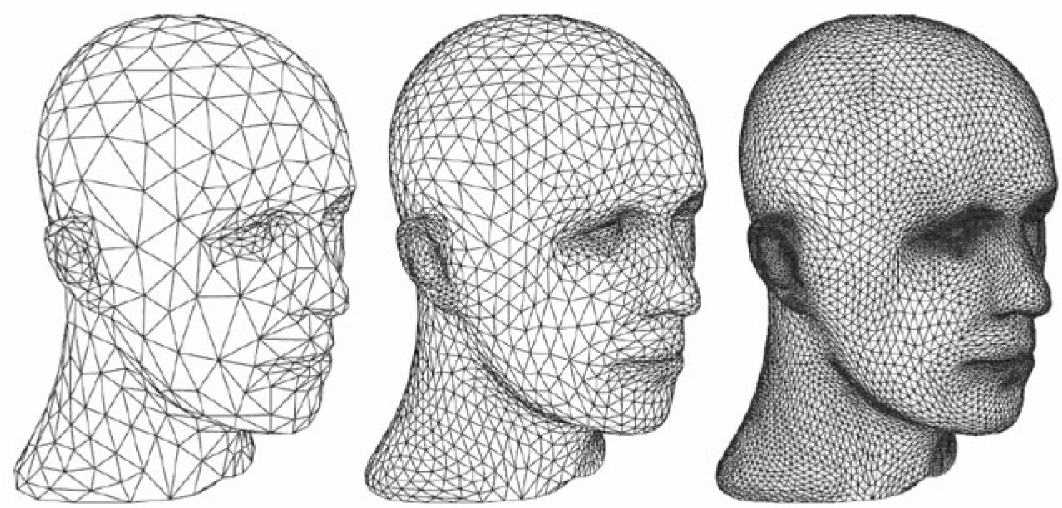


Figure 12: Tessellation example

2.3.3 Threejs

One such software is a library called three.js, which is a programming interface designed to create and display 3D graphics and animations in a web browser using WebGL. Threejs was first released in 2010 using the javascript language. Threejs offers support for scenes, data loaders and animations. Scenes offer support for adding and removing objects at runtime such as fog. Data loaders are important for loading 3D objects for rendering, including this means there is no need to import an individual library for loading objects. Animation support allows us to move 3D objects the way we want, such as making a player character jump correctly.

2.3.4 Programming Technology Comparison

The three different technologies above each provide their own benefits. In terms of this project some features included by the technologies are more valuable than others. Features that are not quite valuable to this project are tessellation shaders and compute shaders. These two shaders are provided by the OpenGL library but are excessive for our needs. Useful features to this project include object loaders as well as basic 3D rendering features offered by all technologies like scaling and rotation. Another criteria of these 3D modeling technologies is experience, which one of our group members took a computer graphics course which focused on utilizing the WebGL platform. WebGL being a subset of OpenGL and therefore being the software which we have the most experience in is a main driving force in choosing WebGL over Threejs or OpenGL.

Table 9: Comparison of Programming Technologies

Category	WebGL	OpenGL	Threejs
Experience	One semester		Zero experience
Features	• Simple • Vertex shader • Fragment shader	• Vertex shader • Fragment shader • Tessellation shader • Compute shader • Accumulation buffer • multi-language support	• Vertex shader • Fragment shader • Object loader

3 Part Selection

3.1 Illumination Source

There are two illumination sources that were considered for the road surface mapping prototype. These sources include Light Emitting Diodes (LEDs), and a LASER. These two sources work by converting electrical energy into light energy. They differ in irradiance, emission spectrum and beam profile. Each light source has its pros and cons in regards to their appropriateness to this project.

LED or Light Emitting Diodes, are made from semiconducting materials such as gallium arsenide and gallium phosphide. The use of these materials allows LEDs to emit light in the form of a photon. The three layers of an LED include a n-type semiconductor containing negatively charged electrons, a p-type semiconductor containing positively charged holes and a depletion region which acts as a barrier between the two types of semiconductors. When a forward bias is applied, a positive voltage terminal is connected to the cathode and current flows through the p type semiconductor to the n-type out through the anode to the negative voltage terminal. The depletion region narrows while holes and electrons move towards each other. Eventually the free electrons are able to combine with the holes and energy is released in the form of a photon.

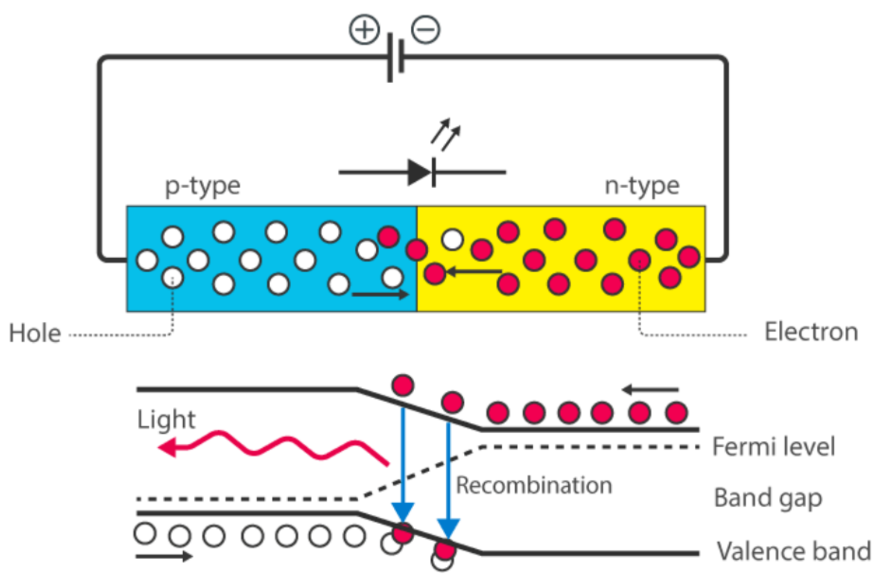


Figure 13: LED Schematic. This figure shows p-type material with holes and n-type material with electrons, crossing over the depletion zone to recombine. Electrons are

present in the conduction band before recombination, while the holes lie in the valence band. Electrons will relax, releasing energy in the form of a photon to drop to the valence band and combine with a hole. [16]

An LED produces a wide spectrum light with an omnidirectional emission. The light is not focused and has a wide spectral width. LEDs are a low cost, low energy solution to illumination. They produce little heat with most of the energy used in their operation going to light emission. Multiple LEDs can be used in tandem to create a single high power light source. This prototype requires a single coherent light source for illumination; therefore, the optical engineers determined that LEDs would not work well as an illumination source.

Laser is an acronym for "Light Amplification by Stimulated Emission of Radiation." A laser is composed of a laser cavity where the medium is composed of a solid, like a crystal, liquid, or gas and 2 mirrors, one with 100% reflectivity and the other between 30% to almost 100% reflectivity. Atoms are then excited by either optical or electrical energy. Once population inversion occurs, where more atoms are two or three levels above ground state than are at ground state, the excited atoms will release energy in the form of photons. As one atom is excited and produces a photon through spontaneous emission, it will initiate a second atom to release a second photon as they interact with each other, and so on. These photons have the same properties such as wavelength, polarization, and phase. The goal is to create optical gain within the system which will increase optical power of the system. To create this gain, photons will travel through the laser cavity, bouncing back and forth from mirror to mirror through the lasing medium. As the light gains intensity or is amplified, some of the light escapes from the cavity through the output coupler and the laser will emit a beam of light that is monochromatic, directional, and coherent.

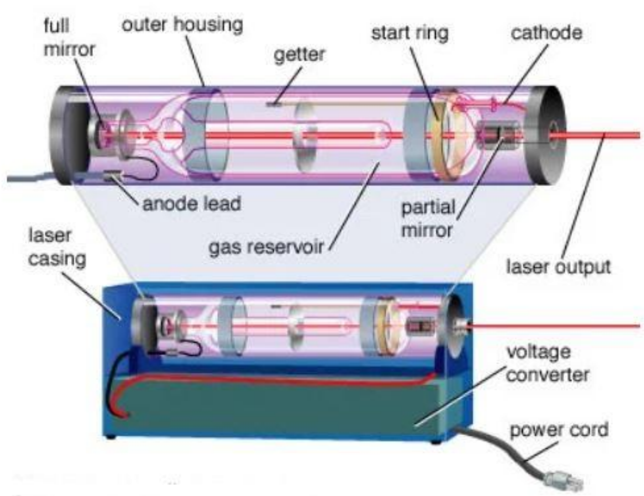


Figure 14: General Laser Schematic. This schematic shows two mirrors that form the laser cavity, along with the housing needed, and finally the laser output.

There are properties of a laser that are beneficial to this project including monochromatic, coherence, and collimation. Light that is monochromatic is made up of only one wavelength. In reality, the light is composed of a small bandwidth of light. The light emitted is also coherent, meaning all the waves of light are in the same phase spatially and temporally. Coherence allows the light to be focused to a very fine spot which is needed when using a powell lens in the illumination system. Lastly, light emitted from the laser will be collimated which will ensure the waves will travel parallel to each other and will not diverge even over long distances.

The surface road mapping prototype will require an optical system that generates a line across the road using lasers and a powell lens system. This section will investigate the type of laser needed. The camera chosen dictated that the light must be in the visible spectrum so the camera can see it. The most readily available laser colors are red, green, and blue and the colors are dictated by their wavelength. Table 10.a shows the Decision Matrix used to help determine which color (wavelength range) the laser should be for this project, while Table 10.b defines the criteria used.

Table 10.a: Laser Decision Matrix

Decision Factors		Red Light (630 - 670 nm)	GreenLight (520 -532 nm)	Blue Light (360-480 nm)
Criteria	Weight			
Cost	2.0	4.25	3.5	0.5
Safety	2.0	3.0	1.0	2.0
Wavelength	1.0	1.0	2.0	1.0
Weighted Total		15.5	11	6

Table 10.b: Criteria Definition for Table 10.a

Criteria	Definition
Cost	The price of a single laser diode of less than 5mW
Safety	safety elements that pertain to blue, green and red laser light
Wavelength	Wavelength that the laser will emit

Supported by the decision matrix, a laser with a wavelength in the red spectrum, 630 - 670 nm is best for this project's prototype. Below is an explanation behind the thought process of choosing red and why different criteria are weighted differently.

Cost was a criteria that was taken under consideration when choosing a laser for our product. Blue lasers are the most expensive, around 7 times more than green, while green is around 20% - 25% more expensive than red. Some of this is due to blue lasers using the newest technology of the three. Beam generation also adds to the cost for blue lasers. Green and blue lasers have similar beam generation processes. A pump laser diode emits a light at 808 nm wavelength. This beam enters a neodymium doped crystal which emits light in the 1064 nm range. The 1064 nm light passes through another crystal that doubles the frequency of the light causing the beam to become a 532 nm laser. This process of generating 1064 nm light then using another crystal to double the frequency to 532 nm light for green is much more efficient that generating 946 nm light then using another crystal to double the frequency to 473nm light for blue. A blue laser's frequency doubling crystals are more rare and the laser itself requires a larger pump diode which also increases cost.

Safety was also explored which incorporated which wavelength to use. There are four main classifications for lasers that describe hazard levels. For example, a class 1 laser is considered eye safe but may be hazardous if viewed with an optical component. The output power has a maximum of 0.4uW and is usually found in an enclosure such as a CD or DVD player. A class 2 laser has a max output power of 1mW and emits only visible light. They are considered to be safe for any unintentional eye exposure due to the aversion response. The aversion response is the time it takes of someone to blink or turn their head away from unintentional exposure which is 0.25 seconds. Class 3R lasers have an output power between 1 and 5 mW and are considered safe from unintentional eye exposure. However Class 3B are hazardous to the eyes as they can burn the retinas. It is suggested or recommended to wear protective eyewear when operating these lasers. Class 3B lasers are not considered burn hazards, but they will heat up the skin and other materials. Output powers between 5mW to 500mW fall into this category. Lastly, class 4 lasers have an output power over 500mW. They are hazardous when exposed to the eyes and can be burn hazards to the skin and other materials. Protective eyewear is always recommended when operating a class 4 laser.

Aside from taking into account the class of a laser for safety reasons, there are also aspects of the visible light spectrum that should be considered. For example, researchers from the National Institute of Standards and Technology have found that green lasers may emit levels of infrared radiation that can be harmful to the human eye. This is due to the way that the green light is generated in the green lasers. Inexpensive green lasers may lack the infrared filter that keeps this energy confined. The human eye is also sensitive to green light which may actually be a deterrent. The brightness of the laser has been known to leave an "after-image" on the retina. Researchers are also studying the negative photobiological effects of blue light and the resistance of the aversion response. Since the eye is less sensitive to wavelengths in the blue and violet range, the blinking or head turning response may be slower and could cause injury to the eye.

3.2 Camera

As light travels to an object, some rays are absorbed while others are reflected. The human eye perceives color by using cone cells to gather the reflected light and sends a signal through optic nerves to the brain telling it what wavelength and in turn what color is seen. The human eye is most sensitive to green which is why it appears the sharpest. However, in this project we are not looking at light with the visible eye, but instead we are using a camera to capture the required laser color.

A camera sensor can not see color and filters must be used to tell the amount of a certain color of light. There have been many versions of filters on a camera, one being a three-CCD camera. A three-CCD camera uses 3 separate sensors each with a different color filter of either blue, red, or green. The information from each sensor is combined through processing methods and a color image can be produced. This method of color imaging is inefficient and costly. Currently, the most popular method of imaging in color is the use of a Bayer filter which is an array filter. A simple pattern of blue, red, and green filters cover different pixels. Each pixel can only report one color depending on the filter. The Bayer filter consists of 25% blue filters, 25% red filters, and 50% green filters. Figure 12 shows a typical Bayer array filter pattern. There are more green filters because the human eye is more sensitive to green light and it helps mimic the human eye. Since each pixel is filtered by only one of the three colors, each pixel can not specify what color it is on its own. An algorithm is applied which will essentially guess what color should be present based on the neighboring pixels. This process results in a camera with more pixels dedicated to green light rather than blue or red.

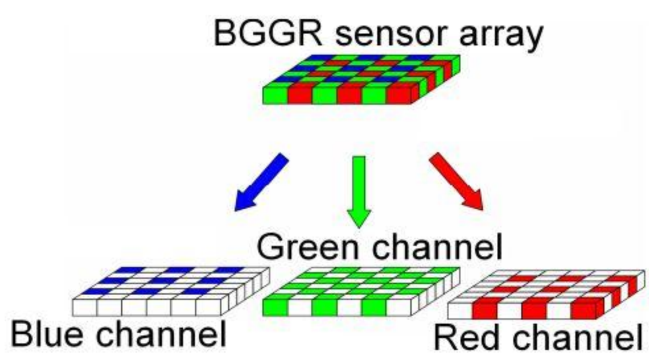


Figure 15: BGGR (Blue, Green, Green, Red) Bayer sensor array [2]

There are several properties that must be looked at when choosing a camera including resolution, frames per second, field of view, and cost. Resolution is the number of elements called pixels that make up the sensor of a camera. The more pixels the better the quality or crispness of an image. This is important to our project as we will be tracking a line as it shifts pixel position. However, frames per second (fps), the frequency in which a camera can capture an image within a second, must also be taken into consideration. Table 11 lists the mapping resolution and speed specifications for our basic, advances, and stretch goals and the corresponding frames per second needed for each combination using $fps = (63360 \ x \ speed)/(3600 \ x \ resolution)$.

Table 11: Resolution and Speed Specifications

Specification	Frames per Second
4 in Resolution at 10mph	44
4 in Resolution at 20mph	88
4 in Resolution at 30mph	132
2 in Resolution at 10mph	88
2 in Resolution at 20mph	176
2 in Resolution at 30mph	264
1 in Resolution at 10mph	176
1 in Resolution at 20mph	352
1 in Resolution at 40mph	528

The camera's field of view determines the maximum area that can be captured. To map the road's surface, we are tracking a horizontal line; therefore, the horizontal field of view is the focus of this project. Our basic goal is to capture the projection of the laser line of at least 6 feet. As the length of the line increases, the field of view must also increase. We will be able to compensate for a larger field of view by increasing the distance the camera will be from the ground. Another aspect of this project will be to increase the camera's field of view by creating a wide angle lens system in front of the camera. More about this is discussed in a subsequent section.

Table 12 shows a list of features that are important to the project and the corresponding specifications. Table 12 shows two cameras that were researched and features compared.

Table 12: Features of ELP-USBFHD085-MFV and ELP-USBFHD03AF-A100

Feature	ELP-USBFHD085-MFV	ELP-USBFHD03AF-A100
Pixel Size	2.0 um X 2.0 um	3.0 um x 3.0 um
Image Area	5440 um X 3072 um	5856 um X 3276 um
Frames per Second	260	100
Resolution	640 X 360	640 X480
FOV	100 degrees	100 degrees
Price	$77.00	$50.99

Even though the ELP-USBFHD085 is more expensive, the features outweigh the cost. The increase in frames per second is the biggest advantage in selecting this camera. This increase will allow us to achieve a much faster mapping speed which in turn will make this device safer and more convenient to use. The higher frame rate is key to achieving some of our advance and stretch goals. There are other cameras with even higher frames per second, some have even greater resolution, but they cost substantially more money and are out of reach with our current budget. These more advanced cameras are also bulkier and would be more cumbersome to attach to the back of a car. They would also represent a significant theft risk to the end user. The pixel size is smaller which for our purposes is an advantage. The smaller the pixel size the greater the spatial resolution the sensor has while the larger the pixel size the greater the dynamic range the sensor has. Therefore the smaller pixel sizes will allow us to measure smaller increments of change in the laser line's profile. While the dynamic range is usually important for clear images, we are not concerned in maintaining the image quality. For this project, we need to know how the laser line shifts in the camera's image space as a means to track the ground elevation changes. This may result in an image that is unclear to the human eye but perfect for digital analysis. The image resolutions are very similar. Both have 640 pixels in the horizontal, which means that we will have a possible 640 points of measurement for our transversal resolution. This is about the standard for cameras that meet our frame rate and budget constraints. The vertical resolution is related to the height resolution of the system. A greater vertical resolution means that we can measure greater changes in the elevation of the road. In this regard the ELP-USBFHD03AF-A100 would be more advantageous. This advantage however is not significant enough to make it the more suitable camera. In fact this advantage comes with its own disadvantage in the memory cost of each frame. The greater number of rows of pixel, the larger the file size of the recorded video.

3.3 Line Generator Lens

This section will discuss what type of lens to use to generate the line that will be tracked to make the road's surface. There are two lenses that were considered, a cylindrical lens and a powell lens. Cost, uniformity and possible length generated were examined.

A cylindrical lens is composed of at least one optical surface having different radii in the x and y direction, or in the shape of a cylinder. The shape of the lens causes the incoming light to defocus or focus light in only one direction. A single or multiple cylindrical lens can be used to shape a beam of light to the needed dimensions. For example, two cylindrical lenses can be used to circularize the beam, one lens to collimate light horizontally and the other lens to collimate the light vertically. Another common application of a cylindrical lens is for line generation. A plano concave lens will shape a beam of light into a line. Figure 16 shows how a plano-concave cylindrical lens can be used to create a line.

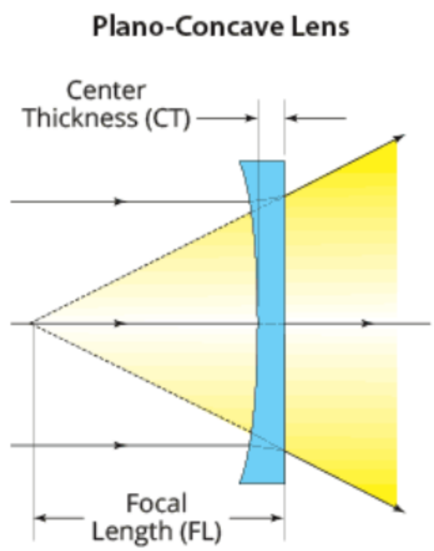


Figure 16: Plano-Concave Cylindrical Lens [19]

Cylindrical lenses are lenses that have different radii in the x and y axes of the lens. These lenses typically have one curved axis and one flat axis. These asymmetrical properties give a cylindrical lens its unique properties. Cylindrical lenses are used to focus or expand light in one axis only. This differs from the typical spherical lenses that affect both the vertical axis and the horizontal axis. This single axis effect allows cylindrical lenses to focus a laser into a line instead of a point. The line is the circular spot of the laser elongated perpendicular to the cylindrical axis of the lens.

Cylindrical lenses suffer from chromatic aberration the same as spherical lenses do. Chromatic aberration is a color distortion that stems from the refractive index of the lens varying with wavelength of different colors of light. The varying refractive indices result in the different wavelengths being focused to different spots. The asymmetrical properties of cylindrical lenses can result in some manufacturing errors in the lens. Due to this lack of symmetry, the cost of a cylindrical lens can be expensive as the manufacturing process requires precision when shaping the lens. Three such errors are wedge, centration and axis twist. Wedge is an angular deviation between the planar side and the cylindrical axis of the lens. Ideally the planar side of the lens and the cylindrical axis of the lens should be parallel. If the two sides of the lens are not parallel it will result in an image shift along the non-power direction. Another manufacturing error is called centration. Centration is an angular deviation of the optical axis in respect to the edges of the lens. This will result in beam deviation and make alignment of the lens in the system difficult. Axis twist is the third possible manufacturing error. Axis twist is a rotation in the cylindrical axis that results in it not being parallel to the sides of the lens. This will cause a rotation in the light passing through the lens which would have to be corrected by rotating the lens. These errors all stem from the manufacturing errors such as misalignment during the polishing process. This means that manufactures need to closely monitor the manufacturing processes which also results in a higher cost for cylindrical lenses.

A powell lens is another type of lens that will shape incoming light to project a line. It is in the shape of a prism that has a rounded “roof” and converts a beam of light into a uniform line. The fan angle is determined by the refractive index of the lens and the angle of the roof. An increase in the steepness of the roof or the refractive index will increase the fan angle which in turn increases the length of the generated line. The width of the generated line is dependent on the incident beam. A narrow incident beam that is parallel to the roof of the powell lens will yield a thinner line width than a wide incident beam perpendicular to the roof of the powell lens. However, many powell lenses are optimized for a 0.8 mm diameter incident beam. Figure 17 displays a beam incident on the roof of the powell lens, the light traveling through creating a fan angle.

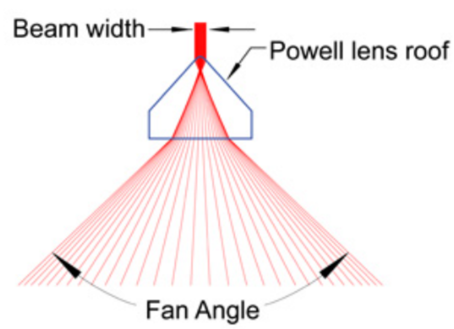


Figure 17: Powell Lens Fan Angle Generation [17]

It’s important to note that due to powell lens properties, the system is able to take an incoming Guasian beam and convert it to a flat beam of light. When light passes through the lens, it produces large amounts of spherical aberrations which reposition the light along the line. The line generated by the powell lens is uniform in intensity by redistributing the bright center to the ends of the line. The uniformity created by a powell lens is not absolute as there will be some variations throughout the line. These variations are dependent on characteristics of the lens's aspheric surface and even the fan angle. Another property to consider is contained power. Eighty percent of the line generated from a powell lens contains 80% of the power. If less than 80% power is contained, the ends of the line will increase in brightness. Figure 18 shows a Guassian input distribution that is incident on a powell lens and the new output distribution that is relatively flat. The output distribution has good levels of contained power as the peaks are minimized.

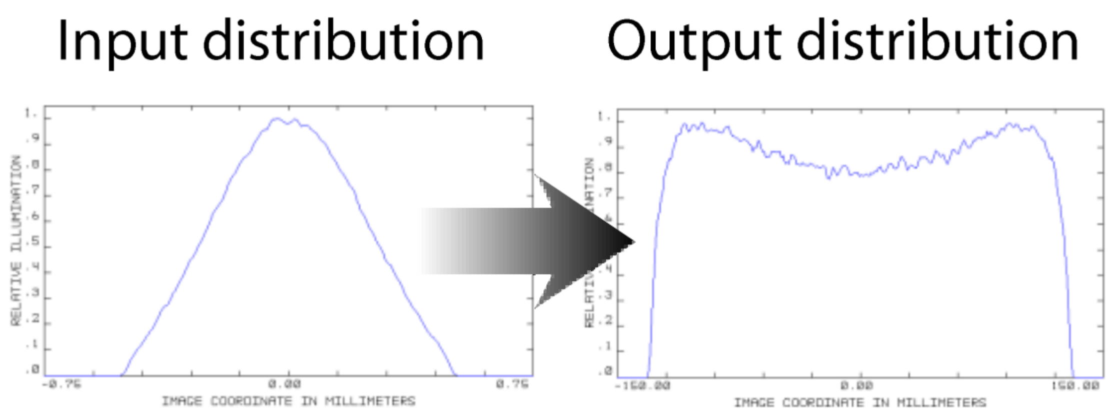


Figure 18: Input Distristribution Versus Output Distribution. When a Gaussian beam is incident on a powell lens, properties of the powell lens convert a Gaussian illumination profile to a flat profile. [18]

A cylindrical lens can generate the same line as a powell lens; however they differ in line intensity. A cylindrical lens produces a nonuniform Guassian beam while a powell lens will produce a uniform beam. Figure 19 shows the difference between the line formed using a cylindrical lens versus a powell lens.

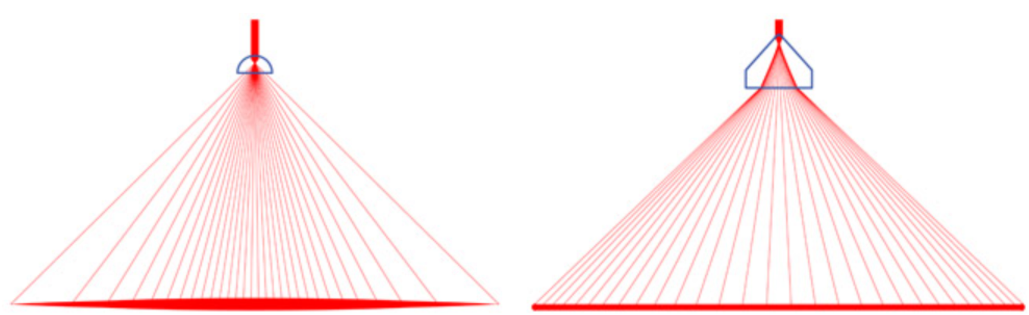


Figure 19: Cylindrical Versus Powell Lens Line Generation. The figure on the left shows a beam of light incident on a cylindrical lens. The cylindrical lens will create a beam in the shape of a line. However notice the intensity is strongest in the middle and weakest on

the edges. The figure on the right shows the same system but a powell lens is used. Notice the powell lens distributed the intensity equally throughout the beam line. [17]

Table 13.a is a decision matrix that helps determine which lens to use and table 13.b defines the criteria. In this instance the criteria that was chosen was cost and line uniformity were used to determine whether to use a cylindrical lens or powell lens for line generation. A powell lens will be used for the project prototype.

Table 13.a: Line Generator Lens Decision Matrix

Decision Factors		Cylindrical Lens	Powell Lens
Criteria	Weight		
Cost	3.0	1.0	2.0
Uniform intensity	3.0	1.0	2.0
Weighted Total		6.0	12.0

Table 13.b: Criteria Definition for Table 13.a

Criteria	Definition
Cost	The cost of the line generating lens
Uniformity	The uniform intensity of the generated line

After determining that the line generating lens used for the prototype is a powell lens, we looked for one that would meet the requirements of the project. One of our basic goals is the ability to map the width of 6 feet of road with an advance goal of mapping an entire lane (11 feet horizontally). With these goals in mind, a powell lens with a fan angle of 110 degrees was found. However, there are cons when using a fan angle greater than 20 degrees. As the angle increases the uniformity of the line decreases. It was decided that any distortion that occurs will not affect the end result of the project. The powell lens selected is a BK-7 Powell lens with a 110 degree fan angle sold by sunshine electronics.

3.4 Communication

To accommodate our advanced goal of providing user feedback we will need some sort of communication between the vehicle operator and the device. For this goal we need a system which tells the user whether the device is ready to record or not. The feedback system should have no effect on the function of the rest of the device.

This can be done in two forms, the first form is the device having a cellular connection where it can communicate with the server and store the device's status. The second way this goal can be achieved is through a Bluetooth connection with the users phone that displays status on an application. There are a few differences between these two methods.

Bluetooth is a technology that allows wireless communication between devices in a short range area, the original purpose of Bluetooth was to connect devices together without the need of a wire. Bluetooth range is usually only up to the 10 meter range or about 33 feet. This technology operates on the electromagnetic spectrum at 2.402 GHz to 2.48 GHz in the ultra high frequency radio waves area. The international telecommunication union set aside this frequency range for Bluetooth, WI-FI and ISM bands, which are bands set aside for Industrial, Scientific and Medical purposes, this frequency is globally unlicensed meaning you do not need a license to use bluetooth technology.

Bluetooth operates by using a method called frequency-hopping spread spectrum. This method is one where the communication signal frequently changes to different frequencies that both devices, the transmitter and receiver are aware of. This technology is also used to avoid interference and to prevent people from listening in, as you would have to be aware of all the frequencies being used to get all of the information from the broadcast. Bluetooth technology is packet-based with leader/follower architecture, the leader shares a clock signal with the followers which establishes an order of communication. The leader only transmits on even clock slots and receives on odd ones, while followers transmit on odd slots and receive on even ones. Packets being transmitted through Bluetooth may be multiple slots long.

Cellular technology is what mobile phone networks are based on. Cellular technology has multiple parts to make it work. The underlying technology that connects cellular users is the network of cell towers scattered around the globe. The cell towers as well as our mobile devices include a transceiver that is capable of both sending and receiving data. These cell towers are also connected to the public switched telephone network in order to connect users to a wider telephony network. Mobile data is handled by a packet switched network while calls and texts are handled by a core circuit switched network. Cellular frequencies operate in the ranges of 806-947MHz and 1700-2000MHz. In terms of connecting to a cellular network one would need a subscriber to the network, subscribers are sometimes given a subscriber identification module or a SIM card in order to connect to the network. Subscribing to a cellular network is not free. In terms of this project we will mainly be interested in the data services provided by cellular networks to transfer information to and from our device if we choose this technology.

The first difference between the methods is the use of the server to store device status, with the cellular connection the status of the device is only seen when the device has a cellular connection. This is problematic for situations where cellular service may be spotty or non-existent. With a bluetooth connection the status of the device can be seen at all times without being affected by a lack of cellular signal. The feedback system will have no effect on the device's function, that is the device will still run properly whether or not the user can see how the device is doing.

The second difference between the two methods is cost. The cellular connection requires the user to pay for a subscription to the cell service as well as the parts necessary. Bluetooth operates a little differently in that it does not require you to subscribe to the network before you can access it, in this regard the only cost associated with implementing Bluetooth into our system is the cost of parts.

The third difference between the two methods is speed of the connections. The bluetooth module which we are looking at boasts a speed of 2 Mb/s whereas the cellular connection only has speeds of 158 Kb/s. Though both of these are more than adequate for giving the user simple feedback of how the device is doing.

The final difference between these two methods is difficulty/complexity. The criteria for this is what the user has to do to maintain and use either of these systems as well as what we have to do in order to implement them. For a cellular connection the user must remember to pay for the connection before the service expires, this is not the case for a bluetooth connection. To use the bluetooth connection the user must connect through bluetooth to the device, such as connecting to a pair of bluetooth headphones, this is not necessary for a cellular connection as it should automatically connect to cell towers. For implementation of either method we have to consult how other projects used these technologies. More projects implemented a bluetooth connection with their designs meaning we know it is possible, and there must be adequate documentation of how to use Bluetooth modules. Since less projects are using a cellular connection we might have a harder time finding documentation and getting this system to work. Table 14.a is a decision matrix that helps determine which communication device to use and table 14.b defines the criteria.

Table 14.a: Communication Decision Matrix

Decision Factors		Bluetooth ANNA-B112-70B	Cellular Connection BC660KGLAA-I03-SNASA
Criteria	**Weight**		
Cost	High	$9.96	$13.86
Speed	Low	2 Mb/s	158 KB/s
Difficulty to implement	Medium	Low	Medium
Difficulty to maintain	High	Low	High

Table 14.b: Criteria Definition for Table 14.a

Criteria	Definition
Cost	Cost of the module and its implementation
Speed	Amount of data transferred from device to user
Difficulty	Effort needed to implement and effort needed from end user to use

3.5 Data transfer

Data transference is important to this project because we need a way to populate the database with data gathered from each use of the device. There are a few methods for this which include cellular connection, bluetooth or saving data to a physical device and uploading it to a computer later. Transferring data through a cellular connection is not ideal because areas without service will not ever be uploaded to the database. Using bluetooth for data transference will allow for having parts serve multiple purposes. For the purpose of not having the device lose data we will not be considering having a cellular connection to transfer data to the database. For these two methods of transferring data between device and database there are a few differences that are important.

The first difference between local storage and a bluetooth connection is where the data is stored. With local storage there is a dedicated storage device for the data gathered about the road. With the Bluetooth connection the data would be stored on whatever device it is connected to whether it be a phone or a laptop, this is problematic because most times a phone or laptop is not used for only one purpose meaning other applications may use up storage space. If there is not adequate storage space for either of these methods the extra data would be lost. Losing data is something we want to avoid at all costs, and managing how much storage is used on a device with a single purpose such as an SD card in our device is much easier than storing data on the user's phone which can have variable storage space, as well as other applications that utilize that available space.

The second difference between these two methods is reliability. Reliability here is defined as the consistent and accurate transmission of data gathered from the device to wherever it will be stored. With a bluetooth connection data reliability is entirely dependent on the Bluetooth link between the two devices. Ways for data to be lost between the device and the database include but are not limited to: connection failure, interference, weak signal and loss of storage device. With a local storage device such as an SD card or USB drive we eliminate the loss of data due to connection failure, weak signal and reduce the chance interference corrupts the data. In a Bluetooth connection, connection can fail for some simple reasons such as the user's device turning off or malfunctioning. In our case weak signals may be ignored as a threat to reliability as a Bluetooth device will be able to communicate with the user's device from anywhere reasonable around a vehicle. Interference may threaten both systems but it would be far more common for Bluetooth interference as many of today's devices and vehicles have and utilize Bluetooth, drivers on the roads we will be scanning might be using Bluetooth to connect their phone to their cars infotainment systems meaning this increases the chances that other devices may be operating on the same frequency as our device. Having other devices operating on the same radio frequency closeby can introduce packet collisions, leading to a loss of packets. The last threat to storing data safely affects both storage methods and is not as big a threat as some others and is mainly due to human error.

The third and final difference between the two methods is the work required to use each method. Transferring data to a separate device using Bluetooth requires connecting our device to the users device, this step is already taken when we implement the user feedback system. Transferring data using a physical device such as an SD card requires remembering to physically insert the SD card into the device and removing it from the device after operation. Both methods are simple to execute but introducing human error may be missed.

The final difference between both of these methods of transferring data is cost. The cost of an SD card system is largely dependent on the size of the card. For 128GB SD card storage it will cost about $22, the bluetooth module we were looking at in the previous section costs about $10 but this expense is already accounted for within the user feedback system whereas the SD card's main use would be to store data gathered from our device. Table 15.a is a decision matrix that helps determine which data transferring method to use and table 15.b defines the criteria.

Table 15.a: Data Transfer Decision Matrix

Decision Factors		Local Storage	Bluetooth
Criteria	**Weight**		
Cost	Medium	$26.00	$9.96
Reliability	High	High	Medium
Work	Low	Simple	Simple
Storage location	Medium	On scanner device	On user device

Table 15.b: Criteria Definition for Table 15.a

Criteria	Definition
Cost	Cost of the storage method
Reliability	Consistent and accurate transmission of data gathered
Work	Effort required for user to use this method of storing data
Storage location	Location of which data from the road scanner will be temporarily stored

3.6 GPS module

GPS locational data is important to this project because it fulfills one of our goals which is to GPS tag road damage. The purpose of tagging the location of road damage is to accurately map where the damage is on a map for visualization. The two methods to determine this accurately is to either have a GPS module onboard our device or to gather GPS data from the user's phone once it is connected to Bluetooth. One issue that might arrive from both of these solutions is that when GPS connection is lost we will not have locational data to tag any road damage meaning we will have to come up with a method to maintain locational data even when GPS is not available. We have 2 GPS modules in mind to compare to our other method of using the user’s phone. There are a few differences between these methods including price, reliability and how long to start a GPS connection.

The first GPS module is about $9 and about half the price of the second GPS module at $22. Using the user’s device to provide GPS data is free since a Bluetooth module is already required for communicating with the user to provide feedback of the device's status as discussed in section 3.4 .

The second difference, accuracy, is more important to our project than the cost of the three different methods. Accuracy is defined as how close a GPS’s locational data is to the device's actual location. The first GPS has an accuracy of 2.5m CEP and the second GPS module has 2m CEP accuracy whereas using the user's phone depends on the device the user has. CEP stands for Circular Error Probable meaning that if you drew a circle with a radius of 2.5m around where the GPS said its location is there would be a 50% probability that the GPS is in fact in that area for the first GPS module. Between the two GPS modules and collecting GPS from the user's phone, the second GPS module is the most accurate to the GPS’s actual position.

The third difference between these methods is reliability. Reliability in this context refers to situations where locational data may be lost or corrupted. With the Bluetooth connection sending GPS data to the device we risk losing locational data if the user's phone dies, disconnects from Bluetooth or otherwise the Bluetooth data becomes corrupted for whatever reason. All three methods risk losing GPS locational data if the GPS link is lost, but they differ slightly at the strength of the connection they can support. Just like accuracy, reliability is completely dependent on the device the user has for the Bluetooth connection case. The first GPS module can support tracking and navigation down to -166dBm and the second GPS module supports only down to -147dBm. A lower dBm rating for this means the module can support a connection with a weaker signal. With this knowledge this shows us that the first GPS module supports a slightly weaker signal than the second module. Supporting a weaker signal is beneficial for us because it may reduce the number of instances where we have to rely on other methods of gathering locational data such as calculating the time between two individual Locations to estimate the speed at which the vehicle was traveling and the associated physical location of any road scans.

The last difference between the three methods is the time it takes the module to get an initial GPS fix. This is important to this project because it determines when the device is ready to start recording road damage, in other words how long the user has to wait before they can start driving to collect data. The first GPS module has a cold start time of 26 seconds and the second device has a cold start time of 29 seconds. Collecting locational data from the user’s phone purely depends on how quickly the user can connect to the device, we believe connecting to the device through Bluetooth will take longer than the other two methods and therefore this difference is less important to us than others since regardless if we use the user's phone to collect GPS data we are still connecting to Bluetooth to provide the user with feedback from the device, in other words it is expected that the user will take more time to get started than it will take for the GPS modules to initially connect with a satellite.

One difference between the two GPS modules is the datasheet that is provided with both of them, the second GPS module has a more detailed data sheet and provides a schematic as well as a block diagram. These included materials will make using and understanding the module that much easier as the specifications and the pin assignments are given directly on the second module's datasheet, reducing research time and possible troubleshooting that may occur. This factor is very important as it gives us more confidence in implementing this module in a timely manner. Table 16.a is a decision matrix that helps determine which GPS module to use and table 16.b defines the criteria.

Table 16.a: GPS Module Decision Matrix

Decision Factors		GPS 1 LG77LICMD	GPS 2 377-MAX-M10S-00B	Users Phone
Criteria	Weight			
Cost	Low	$9.07	$22.21	$0.00
Accuracy	High	2.5m CEP	2m CEP	Unknown
Reliability	Medium	-166dbm	-147dbm	Unknown
Cold start	Low	26s	29s	Unknown

Note: in reliability lower dBm is better, this means this is the weakest signal that can provide a positional fix

Table 16.b: Criteria definition for Table 16.a

Criteria	Definition
Cost	Cost of the module and its implementation
Accuracy	How close the device's calculated position is from the truth
Reliability	Cases where locational data may be lost or corrupted
Cold start	Time for the device to start gathering locational data

3.7 Microcontroller

For this device to provide many of the features we will need a device capable of controlling it all, this is where microcontrollers come in. A microcontroller is a compact integrated circuit that is designed to control specific operations in an embedded system. Two microcontrollers are compared in this section, the msp430fr6989 and the raspberry pi zero w. The MSP board is familiar to many students at UCF, critical to some embedded systems classes in understanding some basic functions of computers and embedded systems. Some functions such as timers and serial communication were covered in these classes using this very same microcontroller. This means as students here at UCF we have a very good understanding of the features of this board and how to utilize them.

On the other hand the raspberry pi zero is a device with which we have no real life experience in programming and using its many features. The two boards are actually quite different from each other, the MSP board is a simple microcontroller while the raspberry pi is a full on computer. The MSP board is a 16MHz RISC architecture processor, and the raspberry pi is a 1 GHz 64 bit ARM processor. ARM (Advanced RISC Machine) is a part of the RISC architecture which means Reduced Instruction Set Computer. The MSP CPU is roughly 625 times slower than the raspberry pi board based on processor speed alone.

Another difference between these two options is that the raspberry pi zero provides useful features that we will need for some of the goals of our project. One such feature that the raspberry pi zero has is Bluetooth, this reduces the complexity of connecting a Bluetooth module to a microprocessor as we would need to do if we choose the simple msp430 board. Another feature the raspberry pi zero includes is an integrated SD card slot in the device. As per the Data transference section (3.5) of this paper we prefer having local storage of the road data for increased reliability and simplicity therefore having a dedicated SD card slot already built in will also simplify the work we have to do. The last useful feature that the raspberry pi zero has is the two micro-usb ports on the device, this is useful to this project because the camera we are looking to get has a usb plug, and to connect the camera to the device we will simply need a male micro-usb to a female usb-a cable. This also reduces the need for us to design a way to connect the camera to our device. Some other features the raspberry pi zero include is a wifi module and an hdmi output but these might not be features we will necessarily use.

In comparison the MSP board is pretty basic compared to the raspberry pi zero, this is partially because the raspberry pi zero is meant to be a computer, it even has its own GPU. One drawback of the raspberry pi zero is that since it is a computer it needs an operating system in order to run and the Raspbian OS take about 8GB of the SD card's storage capacity, this might be a non issue because the official documentation from raspberrypi.com states "the boot partition on the SD card must be 256GB or less otherwise the device will not boot up", meaning even if the system takes takes 8GB we still have over 240GB to store our data which is more than we presume we will need.

One similarity between both of these devices is neither includes a GPS module so we will need to implement that individually in both cases to fulfill one of our project goals. With the MSP board this increases the complexity because we will need to design and support a total of 5 components. On the Raspberry pi zero w we need to design and implement only the GPS module and the power system.

To summarize the main benefit of the raspberry pi zero system is that it already includes many of the features we are looking to include within our design. Having these features included reduces our workload and reduces the cost of parts we will need. The raspberry pi zero w was originally marketed at only $15 to make it available to many users, us implementing a Bluetooth communication system alone would cost roughly $10 in parts and some effort in programming the system to work. In the raspberry pi zero system this is all taken care of making it a good deal at a price of $15. Unfortunately this device is sold out on many websites for this price and can only be found on other sites for close to $50 that said it is still a pretty good deal as it reduces our workload on just getting the system to work with all of its parts correctly, this can help us focus on getting the device to do its job earlier than with the MSP board. Table 17.a is a decision matrix that helps determine which microcontroller to use and table 17.b defines the criteria.

Table 17.a: Microcontroller Decision Matrix

Decision Factors		MCU 1	MCU 2
Criteria	**Weight**	MSP430F2418TZCA	Raspberry Pi Zero W
Cost	High	$17.28	$47.90
Features	High	• 2 timers	• usb-c port • SD card slot • Bluetooth
Familiarity	Low	Moderate experience	Zero experience

Table 17.b: Criteria definition for Table 17.a

Criteria	Definition
Cost	Cost of the device
Features	Features that are useful to our project.
Familiarity	Experience with the device, in terms of use and programming

3.8 Power Supply

In the electrical configuration sense of our device there are many different possibilities of how to build and maintain our goals with the most efficient parts. The first decision to be made is what kind of power configuration would provide the best operation. The goal of this device is to begin with a power supply that generates the laser configuration as well as the camera to detect and save images through the process of driving a vehicle on the obstructed road. This data then needs to convert to a digital system to be read by the software. The software portion will create a website with a visual representation of what the laser and camera collected. In order to decide which form of power supply will operate our device we need to understand how each option performs. These options were previously discussed in the technology comparison section. As researched these applications apply to both sections, but in this instance we will discuss further the decision factors such as cost and performance.

Our first option is an AC-DC converter which works by converting the incoming AC voltage into stable and regulated DC voltage that can be used to power electronic devices. The AC voltage is rectified using diodes converting the alternating voltage into a pulsating DC voltage. This DC voltage is filtered using a capacitor to create a stable DC voltage. Voltage regulators can then be used to maintain a constant output voltage by adjusting the current flow. AC-DC conversion is known as a good option for power supply because of the compatibility/flexibility in terms of voltage and current levels that can be supplied. The AC-DC converter is also highly efficient, with power efficiency of over 90%. With this power efficiency, very little power is wasted during the conversion process resulting in a lower energy need. With the result being a conversion to a DC voltage, this is highly reliable and safe because DC is safer at the low voltage levels and does not have the same potential for electric shock. However, this AC-DC converter is not always the best option in terms of power supply because of the complexity of a simple battery powered device or direct DC power. This can make design terms in the schematic and SD2 more difficult to troubleshoot. Electrical noise is also a large factor about AC-DC. This can affect the performance of sensitive electronics. Finally this method can be inefficient when powering a device that requires only a small amount of power. In our case for our model the converter could end up wasting more power than necessary making the product inefficient.

The next option is a DC-DC converter which works by converting one level of DC voltage to another level of DC voltage. This type of power supply is used to step up or step down the voltage level of a DC power source to match the load requirements. The input stage of the DC converter is passed through an inductor and followed by a switch, such as a transistor or MOSFET, to control the flow of current. The output stage passes through an inductor to step up or step down the voltage level. A diode converts an AC voltage back into a DC voltage to then be filtered to smooth out ant noise. In terms of power supply DC-DC is a very popular option. The efficiency level is higher than 95% meaning very little power is wasted in the conversion process. As of safety and reliability, there is not as high of a potential for electric shock and has been proven highly reliable. The most important advantage of DC-DC conversion is it provides good noise immunity which is important when the load is sensitive to voltage fluctuations and electrical noise. The weight and portability makes it a popular option for automation electronics. For the design of our project this can seem like a very good contender for the build of our power supply. Although the advantages seem promising there are several disadvantages that cause us to not adhere to specific electrical standards. DC-DC converters can generate electromagnetic interference which affects the performance of nearby electronic devices. Being that our device will be mounted on a vehicle we want to ensure the least amount of interference. The cost of the device can be on the more expensive side as well compared to other options and it can be seen as more complex to design rather than a simple battery.

Our third option is a voltage regulator. This is a device that is used to regulate the output voltage of a power supply, ensuring that it remains constant regardless of changes in the input voltage. There are linear and switching voltage regulators. A linear voltage regulator uses a variable transistor to regulate the output voltage. These are relatively simple and inexpensive but are less efficient than switching regulators and are used for lower power applications. A switching voltage regulator works by using a switching method, such as a MOSFET, to turn the input voltage on and off at a high frequency. This generates a high frequency AC which is then filtered into a constant DC voltage. Switching regulators can be more efficient but are more expensive and complex than other options. Voltage regulators have many advantages such as high efficiency and stability. These are designed to maintain a constant output voltage and provide a stable reliable power supply. Regulators also provide low-noise power supply which can be important for applications in which electrical noise would affect the performance. There is also the ease of use, this option requires little to no external components for design, causing them to be suitable for a wide range of applications. While voltage regulators can be a good option there are plenty of drawbacks including heat dissipation and limited voltage range. In many cases voltage regulators can also not be able to provide enough current for high power applications with the design of a limited current capacity. Another disadvantage would be the higher cost compared to other power supply solutions.

Finally our last option for the power supply is a battery approach. Using batteries is using a device that converts chemical energy into electrical energy through a chemical reaction. When a battery is connected to a load, the chemical reaction between the anode and cathode generates an electric current which flows through the load to provide power. As the process continues the materials are consumed and the battery's voltage decreases until the battery is dead. The amount of power available is dependent on the chemistry of the battery, the cells and the load. The capacitance of the battery is the amount of charge that the battery can store and deliver over time. These are a popular choice because of its rechargeable capability as well as it being portable. The portability factor ensures that these will operate without needing another source to cause a reaction such as a wall outlet or another device. Because these can provide consistent power as long as they are charged they can be a very reliable option for uninterrupted power. There is minimal risk associated and they are known for being highly efficient. The last top advantage is the sustainability of batteries because they can be reused many times, reducing the concept of waste. However, there can be some disadvantages to the use of batteries for power supply. Batteries do contain a limited capacity and can only provide a certain amount of power before the need of recharge or replacement. This is an issue if the device is on a continuous operation. The charging time can also impose an issue if the device needs to be used again immediately but the battery has not been fully charged. If the batteries also need to be replaced very often the cost of the type of battery and the amount of replacement can add up to be more expensive than other power supply options. Compared to the other options the drawbacks of the battery powered option is not as significant as the other. In the case of our device we will be moving forward in the design process with using the battery option.

For a more concise overview of the decision of how to power the laser driven device a table is provided below with the decision factors including criteria and weight.

Table 18.a: Power Supply Decision Matrix

Decision Factors		AC-DC Converter	DC-DC Converter	Voltage Regulator	Battery Power
Criteria	Weight				
Portability	low	medium	high	medium	high
Noise	medium	medium	medium	low	low
Cost	medium	$8	$8	$6	$4
Efficiency	high	low	high	medium	high

Table 18.b: Criteria Definitions for Table 18.a

Criteria	Definition
Portability	Can the size of the part travel well and compactly in our device
Noise	Electrical noise interference
Cost	Cost of the hardware
Efficiency	Ability to achieve end goal with little to no waste of power

All options are known for their reliability and efficiency but with the specific requirements and specifications of our design the main two applicable are the DC-DC converter and a battery. For the portability necessity on the road mapping system, it is in our best interest to choose the use of a battery. The device at this moment does not require a specific voltage that the battery cannot provide, and the DC-DC converter could introduce inefficiencies and add weight/complexity to the device. The rechargeable, portable and self-contained power source, the battery is the final choice into which we can now break down the options to secure a choice for which chemical reaction would suit our device best.

3.9 Battery

Using the above reasoning and further research to decide which option between the DC-DC converter and a battery is better, we have come to the final decision of a battery for the power supply configuration. Because of the portability, noise and rechargeable options we found that a battery is the best solution for a device that would be mounted on a vehicle without an outside power source such as a wall outlet providing current at a consistent rate. The next objective is to now decide which chemical reaction in a battery is preferred for the resulting lifespan and voltage. The options we will explore are lead-acid, lithium-ion, nickel-cadmium and nickel-metal hydride batteries.

Lead-acid batteries are a common choice for high-powered applications. These are inexpensive but have a lower energy density than other batteries so this makes them heavy and bulkier. Lead-acid batteries are also sensitive to temperature and require regular maintenance. The specifications can vary based on the size and capacity but some common values are, they typically have a nominal voltage of 2 volts per cell. A typical 12-volt lead-acid battery contains 6 cells. The capacity of a lead-acid battery is measured in ampere-hours (Ah) and can vary from a few Ah to several hundred Ah. For a common 12-volt battery these can weigh around 30-50 pounds because of the chemical compounds. Relative to the weight, the size can be generally large as well. There are small sealed batteries and large industrial options for heavy duty applications. The full charge time depends on the size and charging rate, but typically takes several hours. One of the benefits of the lead-acid battery is they can provide a high current discharge rate for short periods of time making them suitable for high power applications as well as a self-discharge rate of 1-3% per month. Lastly, the average lifespan is typically ranging from 3-5 years if it is well maintained. Overall, lead-acid batteries are reliable and cost-efficient for applications that require high current discharge but these have a lower energy density and shorter life span.

Lithium-ion batteries are another popular option due to their high energy density, low self-discharge rate and long lifespan. This rechargeable option has several specifications to differentiate it from other chemical reactive batteries. Lithium-ion batteries have a nominal voltage of around 3.7 volts per cell. The average cycle life is the limited number of charge/discharge cycles that the battery can compute before it degrades. For the lithium-ion option, it typically has around 300-500 cycles or a 2-3 year lifespan. This depends on the quality of maintenance and usage throughout its lifetime. The full capacity charging time is from 3-5 hours but has the option to reach 80% charging capacity in 1-2 hours making it a quick and efficient choice. The difference of lithium-ion compared to lead-acid is the discharge rate. Lithium-ion batteries have a self-discharge rate, which means they retain their charge for longer periods of time without the need for recharge. This self-discharge rate is around 1-2% per month. Another specification of this type of battery is the operating temperature. This can be seen as a disadvantage because the performance can be affected by high temperatures resulting in a reduction of their capacity and lifecycle. The optimal operating temperature would be around 68-77 degrees Fahrenheit.

Nickel-cadmium batteries are the third option being explored, as it can be used as a rechargeable and portable application. The specifications include the nominal voltage of 1.2 volts per cell and a capacity that ranges from 300 mili-amphere-hours (mAh) to 500 mAh depending on the size. The cycle life is normally 500-1000 charge/discharge cycles and an average lifespan of 2-5 years. The self-discharge rate is faster than the lithium-ion option but is still slower than the lead-acid, this is at a rate of 10-20% per month. The nickel-cadmium battery has temperature ranges for each transition and use including the operating temperature of -4 to 122 degrees Fahrenheit, the charging temperature range of 32 to 113 degrees Fahrenheit and the discharging range of -4 to 149 degrees Fahrenheit. This battery can be a better option compared to the lead-acid because of the size and weight options that range from very small in the weight of grams to large cells at the weight of several kilograms.

The last battery option we will discuss is nickel-metal hydride batteries. These are most commonly used in digital cameras and portable audio players. Some specifications of the nickel-metal hydride batteries are that they have the nominal voltage of 1.2 volts per cell which is slightly lower than alkaline batteries whose nominal voltage is 1.5 volts per cell. The capacity range is typically from 500 mAh to 5000 mAh and they should be operated at room temperature for optimal performance. NiMH batteries have a higher self-discharge rate compared to the lithium-ion and nickel-cadmium options. The rate of the nickel-metal hydride is up to 30% of loss of charge per month. An advantage to the use of these batteries is the charging capabilities. These can be charged using a variety of charges such as fast chargers and smart chargers. The charging rate depends on the battery’s capacity but averages around 1-5 hours. The cycle life of the NiMH is around 500-1000 charge/discharge cycles and it has a lifespan of 2-3 years. Another advantage is this battery is considered less harmful to the environment than other types because it does not contain toxic heavy metals such as lead or cadmium.

The table below will show a comparison between the available battery options to help demonstrate the final decision.

Table 19: Battery Specification Comparison

Specifications	Lead-Acid	Lithium-Ion	Nickel-Cadmium	Nickel-Metal Hydride
Average Lifespan	3-5 years	2-3 years	2-5 years	2-3 years
Total Voltage (per cell)	2 V	3.7 V	1.2 V	1.2 V
Size	Large	Small	Small	Small
Discharge Rate (per month)	1-3%	1-2%	10-20%	30%

Using the knowledge gathered above regarding the types of rechargeable batteries, the final decision for the best option for our device's configuration is the Lithium Ion battery. Based on the currently known power requirements we have chosen a 9 volt lithium battery, whose average cost is around $4 per unit. The manufacturer has not been determined yet but could be any generic brand such as Energizer or Duracell.

3.10 Server

To host a website on the internet, a server is needed. A server is a fancy name for a machine that is always on and open to a network. Therefore, a server can be as small as a PCB or as large as a desktop tower. In considering how the server should best be organized, the behavior and parts are of importance. The server's behavior is described qualitatively. Conversely, the server's parts are described quantitatively. From humble beginnings, the server for this project is hosted on a Raspberry Pi 4 Model B ("RPi4B"). Scaling the computing power or storage of the server is possible by either upgrading the individual hardware or paying for cloud resources. These options are organized in the decision matrix below:

Table 20: Server Decision Matrix

Decision Factors		RPi2B	RPi4B	Cloud (AWS)
Criteria	**Weight**			
Overall Qualities				
Reliability	High	Prone to grid blackouts	Prone to grid blackouts	Nearly 24/7, 365 service
Availability	High	Low	Low	High
Cost	Medium	$67.55 (from amazon)	$197.90 (from amazon)	$15/month
Capability	Medium	Pitifully low	Passable	Abundant
Security	Low	Weak	Weak	Tough
Flexibility	Low	Low	Low	High
Scalability	Low	Low	Low	High
Hardware Specifications				
Architecture	High	ARMv7	ARMv8	ARM Neoverse
CPU	Medium	900 MHz quad-core	1.5 GHz quad-core	1 core
RAM	Medium	1 GB	8 GB	1 GB
I/O	Low	4 USB 2.0	2 USB 3.0, 2 USB 2.0	100 GB Transfer

Reliability and availability are tied for highest weight in the decision matrix. This is because an unreliable server is a useless server. That is to say, the website being accessible 24/7 is not an ideal but a bare minimum. The RPi4B lives in a bedroom. As such, it relies on the power of Florida's local grid. To combat blackouts, an intermediate storm surge battery is in place to power the Pi for an hour if the grid momentarily fails. As for availability, there is no server if there is no server hardware. As of March 2023, the RPi4B is out of stock from all approved resellers ("Cytron Technologies" and "ThePiHut"). However, it is available on Amazon for $197. Only 560% more expensive than the MSRP ($35).

Which transitions well into the criteria of cost. There is a serious consideration for hosting the website with Amazon's "Lightsail" due to the economic cost and convenience. At $15 a month, hosting the server with Amazon Web Services ("AWS") for ten months – almost an entire year - is cheaper than buying the RPi4B. However, the computing power of the $15 plan is laughable. Amazon offers 1 GB of RAM, a single core processor, and 40 GB of hard drive space for $15 a month. Even though the capability of the RPi2B is described as "pitifully low", the RPi2B comes with equivalent RAM, a quad core processor and a micro-SD card slot (which currently houses a card of 128 GB capacity). The RPi2B was released in the beginning of 2015 which means the $15 per hour plan is worse than hardware from eight years ago.

Of course, that judgment assumes AWS's single-core processor is as old as a Cortex-A7 chip. In reality, it is a chip specifically designed to handle the strenuous loads of a server. These chips, like those seen in Intel's "Xeon" series, vastly outperform chips designed for consumer desktop use with at least a magnitude or up to five magnitudes of improvement in computing power. On flexibility, as well, nothing beats the cloud. By design, cloud computing is modular. This is reflected in Lightsail's "pick and choose" style of server design. For example, instead of the $15 deal mentioned above, a virtual server running on a Linux operating system can be bought for $10 per month. The 1 GB memory is upgraded to 2 GB and the storage capacity is upgraded from 40 GB to 60 GB. To easily increase storage capacity, $3.20 can be added to the $10 per month for another 32 GB. That's $13.20 now for an extra gigabyte of RAM and an extra 52 GB of storage.

Additionally, hosting the server on the cloud provides unparalleled security and scalability. Trying to hack into the cloud involves bypassing multiple layers of enterprise-level networking. Trying to hack into a server hosted in somebody's bedroom involves running a password cracker for a day. To remedy this discrepancy, following the best practices outlined in the NIST 800-123 will help bolster the server's defenses. If the prototype camera's resolution or frames per second were increased, the server's capacity would need to be increased. This can be done by connecting a hard drive to the server via a SATA to USB cable. Or, much easier, a command can be typed into a console to allocate more resources to a virtual server. This is the way of the cloud. Some of Amazon's plans even dynamically scale resources based on the server's load.

If hosting a server on the cloud is economically superior, easily customizable, and secure, why choose locally hosting? Being a senior design project, the honest answer is curiosity.

The experience is answering the question: how is a server hosted from the ground up? In other words, exploration is being prioritized over efficiency. With the benefits of centralized computing power becoming ever more apparent, the future of hosting servers is convincingly in the cloud. However, it doesn't hurt to know.

Finally, the hardware. The server's architecture has the highest weight because of compatibility concerns with the server's core processes. Its database, for example, only runs on 64-bit x86 platforms. This renders 32-bit architectures, like the RPi2B's ARMx7, incompatible. The CPU is of medium weight since the main purpose of the server is to process HTML requests and serve content. Eight gigabytes of RAM are useful for the server-side calculations necessary to translate camera data into visual maps and geotags. The I/O is also worth mentioning since the RPi4B supports USB 3.0 ports. USB 3.0 ports can transmit data up to ten times faster than USB 2.0 ports. Pragmatically, this means the RPi4B can read and write to external hard drives up to a magnitude faster.
Since the RPi4B has a 64-bit architecture, 64-bit operating systems are supported. The Raspberry Pi Foundation recommends the "Raspberry Pi OS", but the server will be run on "Ubuntu Server 22.04.2 LTS". This is because Ubuntu is a familiar option. Ubuntu Server is also lightweight, only requiring a 1 GHz processor and 1 GB of RAM to run. The entire OS takes up around 2.5 GB. Although the RPi4B is fully capable of running Ubuntu Desktop, the purpose of the server is to host a website. Thus, all the flavor of graphical interfaces is unnecessary.

3.11 Database

The purpose of the database is to store the data generated from the camera. In academia, there are two popular database management systems: MySQL and MongoDB. MySQL was released in 1995 and organizes data according to a relational model (mainly). After almost three decades, it has become well-established in full-stack applications. On the other hand, MongoDB was released in 2009. MongoDB organizes data in collections of "documents" instead of relational tables. Despite MySQL's widespread adoption, MongoDB has become a staple in modern tech stacks. For this project, MongoDB is used. Why MongoDB was chosen in comparison to MySQL is summarized in the decision matrix below:

Table 21: Database Decision Matrix

Decision Factors		MySQL	MongoDB
Criteria	**Weight**		
Intuitivenes s	High	Medium	High
Flexibility	High	Medium	High
Capability	Low	High	High
Security	Low	High	Medium

One database is not a direct upgrade of another. In other words, the database management system should be chosen based on the use case. The use case of this project is storing images taken from a camera and storing GPS data. To illustrate how MongoDB is “intuitive”, here is an example: The database will need to store data generated from the camera. This data might be in the form of a grid of raw pixels. The pixels might be represented as a three-tuple (e.g., r, g, b) or a four-tuple (e.g., r, g, b, a). This is easily represented in MongoDB as an object that has three or four {key: value} pairs. Each pair represents the red, green, blue, and alpha of a pixel. This is what is meant by “intuitiveness.” The shape of the input data translates almost directly with how it is stored in the database. In comparison, instead of thinking in terms of {key: values}, MySQL relates the intersection of a “red” column and a number in a row to the red value for the pixel that row represents.

As implementations change to satisfy the project’s requirements, so does the structure – or “schema” - of the database’s input data. MongoDB elegantly handles this by allowing documents of different shapes to be stored in the same collection. For example, a document that is missing longitude and latitude values can be stored with other documents that have GPS data. If it is discovered that a new input needs to be stored in the database, it will not be necessary to create a new collection. Generally, MongoDB is useful for managing semi-structured data such as the data sourced from the GPS sensor and camera.

As for capability, both MySQL and MongoDB are efficient at storing and querying data. MySQL, by default, uses the “InnoDB” database engine to perform CRUD operations for the database and MongoDB uses the “WiredTiger” database engine. The discussion of which database engine is more efficient becomes convoluted such that blanket statements such as “1 GB of data in MySQL is equal to 1 GB of data in MongoDB” quickly lose meaning. As such, the weight of capability is low. To answer the question of which database management system has higher performance: both are sufficient in storing and retrieving the data for this project.

Originally, MySQL was only capable of organizing data relationally. Structured data, like waiver forms or credit card information, fits nicely into the relational structure. As people took on new challenges, like facial recognition, individual data points became less meaningful. In response, MySQL not only handles structured data, but it is now also capable of organizing semi-structured data like the Binary Encoded JSON (“BSON”) documents seen in MongoDB. In other words, its flexibility in recognizing and managing different data has increased over time. Additionally, MySQL fundamentally implements data authentication and secure socket layer (SSL) security. In terms of flexibility and security, MySQL provides many attractive features. Overall, however, the intuitiveness of MongoDB’s document-based approach is the deciding factor in being the chosen management system for this project.

3.12 Front-End Frameworks

The “front-end” in a full-stack app refers to what the clients see. Front-End frameworks are libraries that seek to accelerate the development process of transforming data to a graphical interface by advocating for codebases to adhere to a certain paradigm. By following a certain structure of code, optimizations can be made by the framework to minimize re-renders, synchronize state changes, and enhance code semantics. For example, following the “declarative” paradigm of the “React” library allows for websites to be rendered using the “Virtual DOM.” The virtual DOM greatly enhances the performance of a website by calculating what elements change in response to an event and re-rendering only those changed elements instead of the entire website.

Table 22: Front-End Frameworks Decision Matrix

Decision Factors		Vanilla	React	Angular	Svelte
Criteria	**Weight**				
Documentation	High	Well documented	Well documented	Well documented	Sparse documentation
Familiarity	High	Familiar	Familiar	No experience	No experience
Development Speed	High	Slow	Quick	Slow	Quick
Performance	Medium	Terrible	Quick	Quick	Quickest
Flexibility	Medium	Flexible	Flexible	Rigid	Flexible
Scalability	Low	Terrible	Good	Best	Good

As visualized in the preceding decision matrix, the most important factor in choosing a front-end framework is ease of use. All these frameworks are different shapes of the JavaScript programming language. Ancient and monolithic stands Vanilla JavaScript, JavaScript without a framework. Although not a framework, it is included for the sake of comparison. Being the quasi-source of web scripting, Vanilla JavaScript is the best documented. This includes decade-old Stack Overflow questions, the professional Mozilla Developer Network ("MDN"), countless forum posts, and tutorials on personal blogs. Coding in Vanilla JavaScript is fun until finding a function becomes equivalent to whacking the grass with a machete in an attempt to traverse a jungle. This is because Vanilla JavaScript source files quickly degenerate into a wasteland of global variables and functions. After 300 or so lines of code it becomes cumbersome to keep working on a website coded in Vanilla JavaScript. Everything being global also takes a big hit on performance as the browser struggles to stuff everything into the client's RAM.

This is where front-end frameworks step in. The front-end framework used in this project is React. React was created by Facebook developers and released as an open-source library in 2013. Although this section is about front-end "frameworks," React describes itself as a library. The difference is a framework enforces an, often rigid, structure on a codebase. React JavaScript, on the other hand, can be flexibly interwoven into Vanilla JavaScript. It can be sprinkled in with or without accompanying libraries like JavaScript XML ("JSX"). Instead of using React here and there, however, it is more common for an entire codebase to follow React's declarative paradigm, bundling code into structures called "components."

A component is a small, reusable building block of a user interface that can be composed to create more complex components. React components have their own state and can manage their own rendering based on that state. This solves the Vanilla JavaScript of everything being global. Framing the website in terms of components also increases scalability as, once a basic component is defined like a counter is defined, making as many counters as desired is as simple as typing “<Counter />” in the code.

React uses a Virtual Document Object Model (“DOM”) to efficiently update and render components. The Virtual DOM is a copy of the actual DOM that React uses to keep track of changes in the state of the application. WHen there is an update in the state of the application, React compares the Virtual DOM with the actual DOM and makes the necessary changes in the actual DOM, which results in an instant update of the user interface.

React is lightweight, fast, and easy to learn, which is why it has become one the most popular front-end frameworks in recent years. It also has a huge community of developers that constantly contributes to the growth and development of the library. The “State of JS” took a survey of 39,472 JavaScript Developers in 2022 and 82% of the 39,472 developers said they use React. React’s usage statistics in comparison to other front-end frameworks is included below.

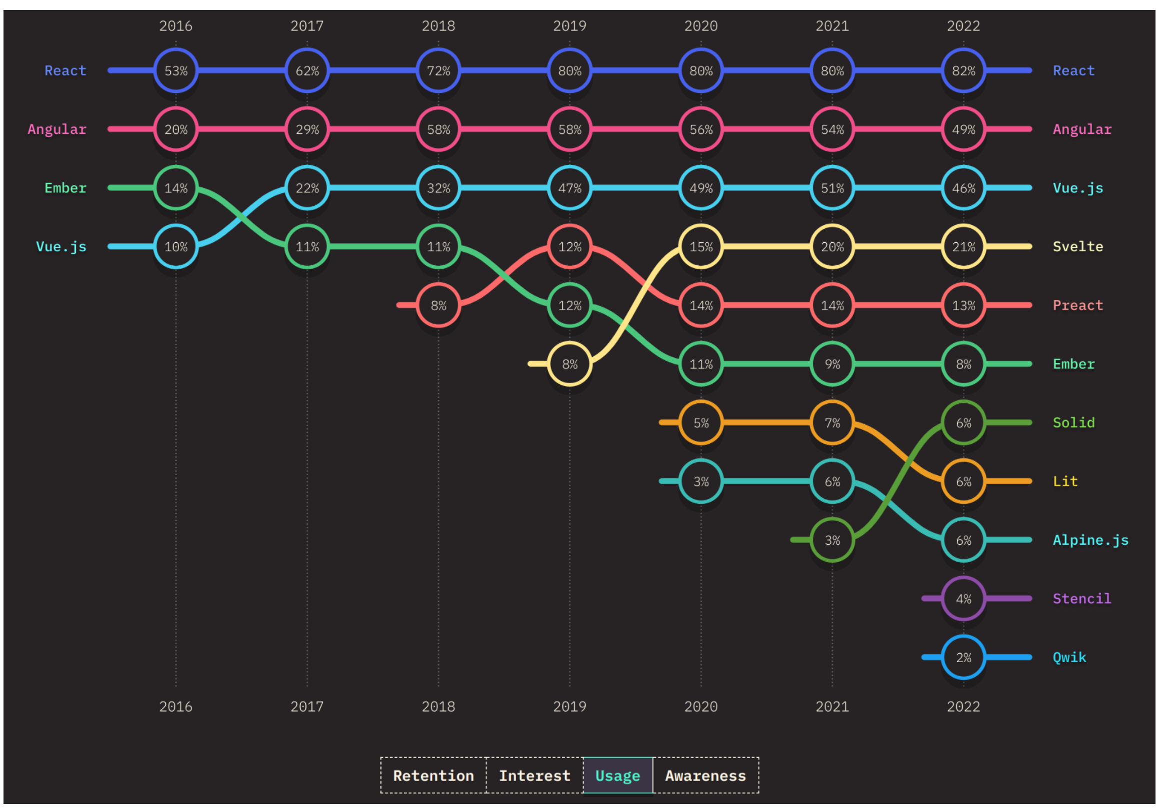


Figure 20: Front-End Framework Usage Statistics from 2016 to 2022

Like React, 100% of JavaScript developers in the State of JS survey reported they were aware of Angular's existence in 2022. Angular is a comprehensive open-source development framework used for building modern web applications. It is developed and maintained by Google. Its popularity and enterprise support allow many examples of Angular code to be found online. By design, Angular is used to create dynamic and responsive single-page web applications that offer an improved user experience. Unlike React, Angular uses TypeScript, a more strict and strongly-typed language. Angular is also different in having its own templating language. These features make Angular more attractive for large-scale, enterprise-level projects. Relating back to the small scale of this project, the robust nature of Angular becomes more of a hindrance than a feature.

The differences in React and Angular make it perhaps the most important part in planning how data is presented in this project. To go into more detail, there are seven key differences between the two: architecture, learning curve, performance, reusability, state management, development speed, and community support.

The architecture of React only provides a set of tools for building user interface ("UI") components. Angular, on the other hand, is a full-featured framework that provides a more opinionated approach to building web applications. Both are capable of building complex single-page applications, but React gives developers more room for integrating the codebase with other tools. This aligns more with the uncertainty of this project as the team gradually agrees on what works and what is unnecessary.

The learning curve of React is relatively easy to learn compared to Angular. React uses JavaScript and JSX, which are both familiar to most developers. JavaScript is a high-level scripting language that, when written well, can be understood without any documentation. That is, it can be read as if it were prose. JSX mirrors HTML which, adjunct to JavaScript and CSS, was the backbone of the web since the 2000s. Angular, however, has a steeper learning curve due to its complex architecture and TypeScript syntax. TypeScript is akin to a compiled language like C where programmers are required to specify the data type of a variable. This allows for extraordinary compile-time optimizations and easier debugging at the trade-off of slower development. Since ease of use is more important than scalability in this project, React's lower learning curve is a better fit.

In terms of performance, React is fast and efficient because of the virtual DOM. Angular also uses a virtual DOM, but its change detection algorithm is more complex and can sometimes result in slower performance. Performance is important for our project's website because of the data that is being presented. The semi-structured data sourced from the camera and GPS will require more "creative" means of presentation compared to something like strings, for example. Modern web browsers have come a long way mainly thanks to monumental leaps in hardware. While full 3D games can be played in the browser, something akin to how a stretch of road might be visualized with all its curves and elevations, performance is largely dependent on the client's machine. To ensure the project's website runs on as many computers as possible, leverage of a framework's rendering optimizations is key.

React's components are more reusable than Angular's "directives" because they are simpler and more flexible. React components must be pure (a certain input always maps to the same output) and are encouraged to be as "atomic," as conceptually straightforward, as possible. For this project, there will likely be a few types of objects repeated millions of times. For example, pixels or GPS locations. Without reusable and flexible components, coding the UI would be a nightmare.

Even in Vanilla Javascript, an interactable website exists in one of many possible states. For example, a website that displays a counter that counts from zero to infinity has the state where the counter is one, counter is two, ad infinitum. React formalizes the idea of state by providing a function that initializes and updates a component's state. As the logic of a website increases, however, managing state becomes increasingly complex. React does not provide a built-in solution for managing application state, but there are several popular libraries such as Redux and MobX. Angular has its own built-in solution called RxJS, which helps to manage application state and handle events. For this project's website managing state will not grow to be overly complex. The purpose of the website is to visualize data sourced from the camera and GPS. It will query the database and render the queries. As such, the state of the "world" (the website's 3D coordinate space) is pre-processed and immutable to the client. However, the camera's 3D orientation as well as any transformations on the world will need to be stored as state.

A particularly important factor for this project is development speed. React allows for quick and iterative development because its library of components is lightweight and easy to use. Angular, however, takes a more structured approach and requires more time to set up and configure. React provides an easy way to hit the ground running by typing the command "npx create-react-app" into the console. After this command is executed, a directory with an already-working app is available. From there, the developer can simply insert their code to create the app they want. What enables a full app to be created with create-react-app is the provision of a complete toolchain. A toolchain in a bundle of programs that work together to optimize, organize, and modularize a project. Exploring what tools comprise the toolchain is interesting but complex. For the scope of this project, the default toolchain is sufficient. Many great features like content hydration from the server, however, are not possible without configuring the toolchain.

As an open-source project, React has a large and active community. Angular also has a robust community, but it is smaller compared to React. Both React and Angular are powerful and well-established front-end frameworks, each with its own strengths and weaknesses. For React's strengths in flexibility, development speed, and community, it is the chosen front-end framework for this project.

While React and Angular have been the most popular front-end frameworks for almost a decade straight, there are many other front-end frameworks with high performance and unique features. One of these that is worth exploring is Svelte. Despite releasing four years after React and Angular, 21% of JavaScript developers used Svelte in 2022. At 70%, Svelte is also the front-end framework most JavaScript developers are interested in.

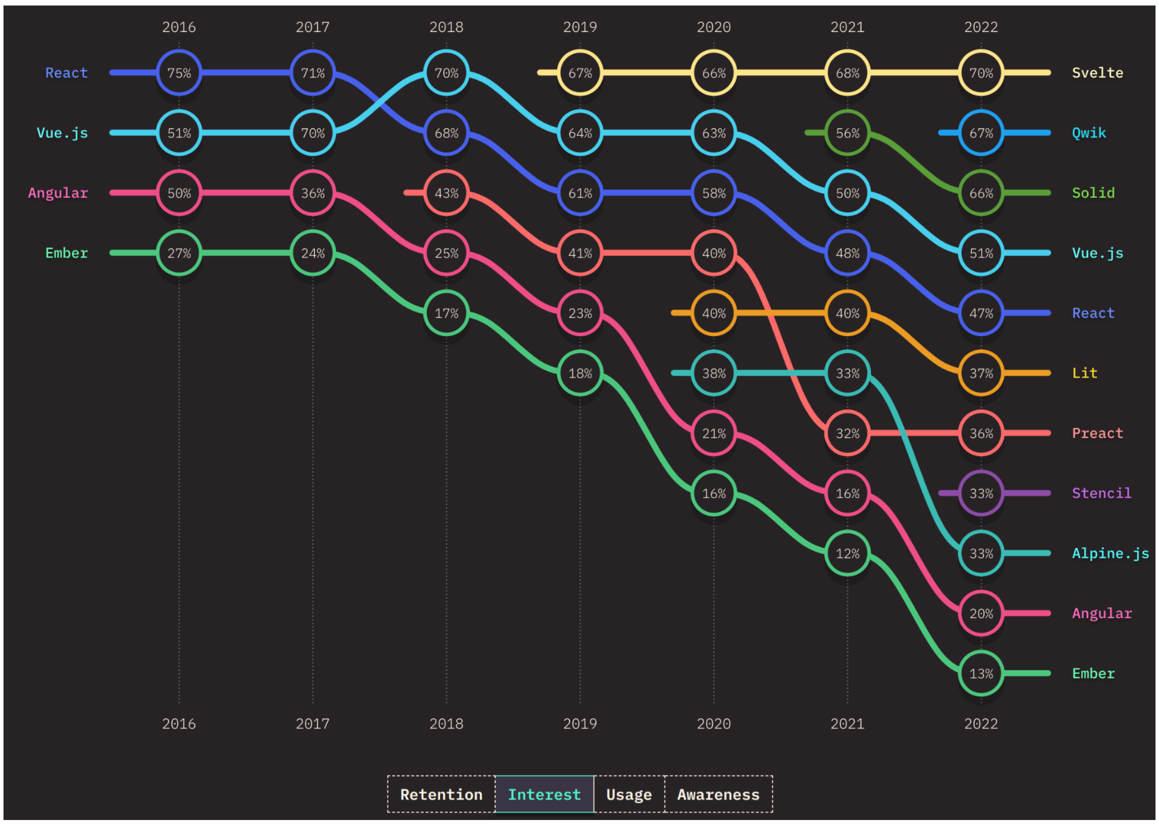


Figure 21: Front-End Framework Interest Statistics from 2016 to 2022

In general, Svelte is a new-generation JavaScript framework designed to create reactive, dynamic, and fast web apps with ease. It boasts a simplistic approach and is different from React and Angular, which rely on a virtual DOM, as Svelte compiles code at build time and eliminates the need for a virtual DOM. Svelte focuses on moving the logic of a web application away from the runtime and into the compile-time, offering better performance as it converts code into highly efficient Vanilla JavaScript. This minimizes the amount of code sent to the browser, leading to faster load times and better performance.

Svelte simplifies the development process of web apps, thanks to its intuitive templating engine, which enables developers to manipulate the DOM with declarative syntax. This is similar to reusable components in React. Svelte also allows developers to include CSS or any other text-based files directly into their components, reducing file size and easing the development process.

In terms of functionality, Svelte supports reactive programming, allowing developers to create web apps that react to user interactions, data changes, and other variables in real-time. It also integrates well with other technologies such as TypeScript, making it easier to incorporate into existing projects. This makes porting React or Angular code to Svelte easy.

Although the legends of Svelte's compiler-based approach being faster than React or Angular are enticing, it ultimately was not chosen because of its lack of support. There exist many more tools for React. If performance becomes an issue in the future, porting the codebase to Svelte would be a painstaking but possible solution.

3.13 Back-end

If a website has code that queries a database injected into its source file, the website would crash. If that did work it would be both hilariously and infuriatingly easy to extract anybody's information. To prevent this, encryption and connection protocols have been defined to provide data security and data integrity. In a "full-stack" application, these protocols are implemented in the "back-end" of the application. The back-end is an abstraction representing a suite of programs that connect the front-end to the database. In the project, the back-end involves "Express" and "Node". By the end of this section, all parts for the project's online application will have been discussed.

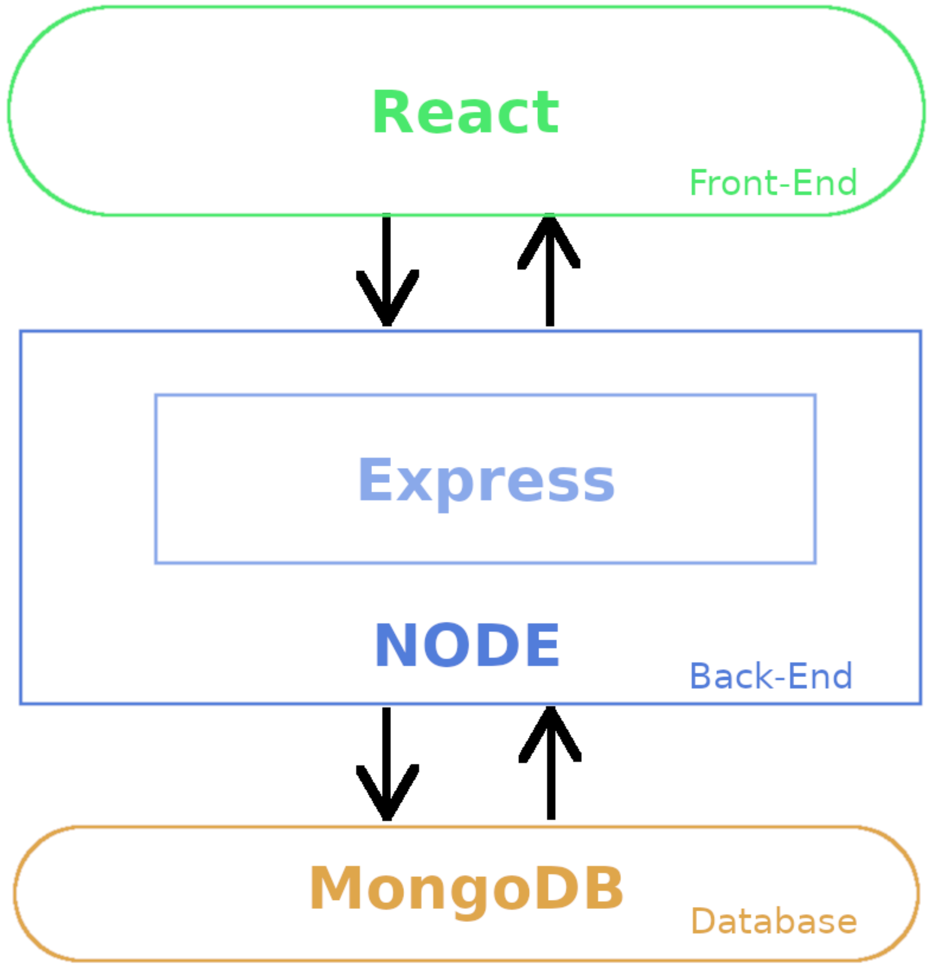


Figure 22: Front-End, Back-End, Database Flowchart

Originally, JavaScript was designed to enable interactivity in websites. That is, JavaScript was simply a script that linked a mouse click to an HTML element in a client's browser, for instance. This was in 1995. It was not until 14 years later, in 2009, when JavaScript was able to be run outside the browser, as a process, through Node. Node, often referred to as "node js", is an open-source, cross-platform JavaScript runtime environment. Before Node, full-stack applications used scripting languages like PHP (e.g., the "LAMP" stack) to connect the front end to the database. In the past decade, web developers have expended great effort to centralize all of web development under one language: JavaScript. The techstack used in this project, the "MERN" (MongoDB, Express, React, Node) stack has 75% of its components implemented in JavaScript.

Centralization of web development under JavaScript allows for a faster development cycle as the same JavaScript fundamentals underlie all parts. Learn one language to know the basics of most of the stack. Express, often referred to as "express js" runs inside a Node server. Express is a fast, unopinionated, minimalist web framework. Express can be described as the "middleware" of the application, handling requests, responses, and routing application logic. It provides powerful models for handling data exchange via the HTTP protocol. Adjunctly, the TCP/IP protocol is followed to ensure all data arrives at the destination in order and without gaps. Alternatively, the UDP protocol can be followed to exchange packets over a network. With less overhead, UDP is faster than TCP; however, the extra speed comes at the cost of data integrity. Most commonly, a client is satisfied waiting a little while longer, maybe a difference in milliseconds, to ensure they receive 100% of their requested data.

4 Standards and Constraints

4.1 Standards

While researching, creating, then building a prototype engineers must adhere to certain standards put forth by the government, such as OSHA, or other industry governing organizations that produce National Consensus Standards. Table 4 outlines standards that our group must follow when producing the LiDAR Surface Mapping System.

Table 23: Standards

Standard	Description
ANSI Z136.1	Safe Use of Lasers
ANSI Z136.6	Safe Use of Lasers Outdoors
IEC 60825-1	Safety of Laser Products
IEEE 802.15.1	Bluetooth Communication Standard
RFC 9110	HTTP Standard
ICD-GPS-200C	Signal Specification and Performance Standard
NIST 800-123	Best Practices for Hosting Secure Servers

4.1.1 Laser Safety Standards

There are many standards formed by agencies that apply to laser safety. For example, the American National Standards Institute (ANSI) facilitates consensus based technological standards in the US. Within ANSI the Laser Institute of America worked with a government agency OSHA, the Occupational Safety and Health Administration, to produce standards to ensure a workplace would be safe from any laser hazards. When building our prototype we will have to take into account ANSI Z136.1, safe use of lasers, and ANSI Z136.6, safe use of lasers outdoors. The International Electrotechnical Commission (IEC) is an international organization that produces standards for electrical and electronic technologies. ICE 60825-1, safety of laser products, will also be followed during the design and build phase of the project.

ANSI Z136.1 classifies lasers and laser systems based on the biological harm they may cause. Table 5 below shows requirements for each class of laser denoted by 1, 1M, 2, 2M, 3R, 3B, and 4. Classes that are denoted with a M are only hazardous when viewed through any optical device that will magnify. Class 1M and 2M replaced Class 3A. Class 3R lasers have relaxed rules as this class does not require the same safety standards as Class 3B or 4. Another ANSI standard that will affect our project is Z136.6, which puts forths guidelines for using lasers outdoors specifically when using an open beam.

Table 24: Requirements by Laser Classification

Class	Procedural & Administrative Controls	Training	Medical Surveillance	Laser Safety Operator
1	Not Required	Not Required	Not Required	Not Required
1M	Required	Application Dependent	Application Dependent	Application Dependent
2	Not Required	Not Required	Not Required	Not Required
2M	Required	Application Dependent	Application Dependent	Application Dependent
3R	Not Required	Not Required	Not Required	Not Required
3B	Required	Required	Suggested	Required
4	Required	Required	Suggested	Required

The FDA (Food and Drug Administration) has classified lasers into groups by hazard level. Class 1 includes lasers that are eye safe under normal operating conditions. Any laser that does not emit a level of optical radiation that would harm the eye would be considered in this class. However, a more hazardous laser could be inside an enclosed area where a laser would not damage the eye and still be considered a class 1 product. Class 2 lasers are in the visible light spectrum (400 - 700 nm). If viewed momentarily it will not affect the eyes, but extended viewing will be harmful. A Class 3 includes a laser that emits any wavelength and outputs no more than 0.5W. They do not produce significant skin or fire hazards, and should not be viewed for an extended period especially at close range. A class 4 laser system is a fire and skin hazard and will cause eye damage if directly viewed. Anything that has an output of more than 0.5 W falls into this category. Below, table 5 describes the class numbers put forth by the FDA and IEC along with a brief description of the laser product hazard and a few product examples.

Table 25: Classifying Lasers

Class FDA	Class IEC	Laser Product Hazard	Product Examples
I	1, 1M	Considered non-hazardous. Hazard increases if viewed with optical aids, including magnifiers, binoculars, or telescopes.	laser printers, CD players, and DVD players
IIa, II	2, 2M	Hazard increases when viewed directly for long periods of time. Hazard barcode scanners 66 increases if viewed with optical aids.	barcode scanners
IIIa	3R	Depending on power and beam area, can be momentarily hazardous when directly viewed or when staring directly at the beam with an unaided eye. Risk of injury increases when viewed with optical aids.	laser pointers
IIIb	3B	Immediate skin hazard from direct beam and immediate eye hazard when viewed directly.	laser light show projectors, industrial lasers, and research lasers
I4	4	Immediate skin hazard and eye hazard from exposure to either the direct or reflected beam; may also present a fire hazard.	laser light show projectors, industrial lasers, research lasers, and medical device lasers for eye surgery or skin treatments

ANSI Z136.1, ANSI Z136.6, and IEC 60825-1 will be considered when building and testing the optical system of our project. The type of laser suitable for outdoors use will be determined and safety protocols will be put in place.

4.1.2 Computer Standards

GPS standard

ICD-GPS-200C defines the signal specification and the GPS SPS PS stands for the Global Positioning System Standard Positioning Service Performance Standard. The fourth edition (IS-GPS-200D) defines the levels of signal in space provided to the SPS community from the United States Government which maintains the service of GPS. This standard defines the signals that are expected from the GPS satellite including which conditions tell the user that the signal is healthy or unhealthy. The performance standards provide a way for the end user to define for themselves the performance they can expect for their application. This is important to this project since we will be needing to integrate GPS data into our design for marking the locations of road damage. Thus these standards are important to us in determining whether or not a certain GPS signal is accurate enough to mark locations, the frequency in which we will be receiving a signal, the format of the message we will be receiving as well as many other things.

The ICD-GPS-200C defines the accuracy of the transmission of data. The way it defines this accuracy is through relating the GPS time to the UTC (Universal Time Coordinated). This standard states that the GPS time provided will be within 90 nanoseconds of UTC. This standard also states that with other known delays such as time transfer error this gets increased to 97 nanoseconds. The final place that error can occur is from the GPS signal propagating to the device which is specific to the user. Having accurate data is important in accurately mapping locations of damage, which is one of our design requirements.

This standard defines the frequency which the GPS signals will operate in. These frequencies are defined as 1575.42 MHz for L1 and 1227.6 MHz for L2; these frequencies are derived from a common frequency source within the satellite. As a note the GPS module we are looking at only supports L1 signals meaning we will not be receiving any information from the L2 frequency.

This standard also defines a user range accuracy, this is a statistical indicator of the ranging accuracies obtainable with a specific satellite. This indicator includes all errors in the navigation data of the transmitting satellite for which the Space and Control segments are responsible for. This user range accuracy does not account for the error obtained from the transmission medium. The user range accuracy index which is reported in the message corresponds to the maximum value of user range accuracy anticipated over the fit interval. The satellite is undergoing normal operations whenever the fit interval flag is set to zero. Knowing the satellite is not under normal operating condition can give us the choice to not trust the information from it to protect the accuracy in our system.

This standard also defines how weeks are numbered in the message. It states that the week continuously increments and never resets, counting from a start date January 6th 1980. The standard defines the 10 most significant bits to correspond to the week's number in modulo 1024 bit representation. This also means that the week number information provided within the message might not correspond to the current week number due to rollovers. Rollovers happen about every 20 years and the government warns the public of this happening before it happens. The latest rollover was on April 7th 2019 meaning a rollover will only affect us if the device becomes successful and is still in use in 16 years

This standard defines a frame of the message structure as 1500 bits, each frame includes 5 subframes where each subframe is 300 bits long. Under this definition and knowing messages are transmitted at 50 bits per second we can calculate that it takes 30 seconds to transfer one frame of the message. This directly determines how quickly the device can start gathering locational information or “cold start”.

HTTP standard

RFC 9110 defines the semantics for HTTP also known as the Hypertext Transfer Protocol. HTTP is important because it provides a uniform way to interface with a resource by sending messages that manipulate or transfer representation. We will be using HTTP in order to create a web application that gives the end user a way to see the damage that was captured on the road. Having a web application is useful to this project because it allows clients easy access to the data. This database and web application will communicate through HTTP in order to send messages back and forth for the end user to see.

This standard defines that each message transferred on HTTP is either a request or a response. Responses can include status codes and the message from the server. Status codes are useful in this project because they provide the user and the developer with useful information, whether the information was successfully received, or if there was some sort of error like authentication. The message is what we ask the server for for our project. This message can include all of the data stored in the database as well as information from a map interface. This standard will help us when creating the website in providing us with documentation of HTTP syntax and reminding us of the important features of using HTTP.

Bluetooth standard

IEEE 802.15.1 specifies Wireless Personal Area Network (WPAN) standards for bluetooth v1.1 devices. Bluetooth is short-range radio operating unlicensed in the 2.4GHz ISM frequency band, which ISM stands for Industrial, Scientific and Medical. This is important because it creates a standard way for Bluetooth communication that all Bluetooth devices should use in order to work well. This is important to our project as we will be incorporating a Bluetooth connection to the end user's phone to give them the status of the device such as when it is ready for operation, with the possibility of transmitting data to the user’s device for storage.

This standard identifies many things that make up the bluetooth technology that make it consistent to use. Bluetooth has the ability to do frequency hopping amongst the 2.4GHz band it is given in order to reduce interference with other devices and to provide some more security with a hopping pattern that is unique to each device. Frequency hopping along with time-division duplex architecture allows for bluetooth communication to act as though it is full duplex meaning, transmitting and receiving at the same time. This standard also states that the host of the bluetooth system and the controller of the bluetooth system communicate through a Host Controller interface. Having a host controller interface provides us with some standard commands in order to call to execute bluetooth activities. Along with giving us commands it also states that the controller cannot buffer requests limitlessly.

This standard also identifies which blocks are responsible for what actions, such as the device manager is responsible for connecting to other devices, the link controller is responsible for encoding and decoding the packets. One important part of a bluetooth device is the ability to connect to other bluetooth devices and making the device discoverable to other devices, this functionality is handled by the device manager. This device manager information is important to us because we will need to connect to our personal device to fulfill our goal of providing the user with feedback.

It is also identified that the data can be transmitted multiple ways, framed data and unframed data. Frames are not necessary when the signal includes in-stream framing or when the data is a pure stream. For our application though we will be utilizing framed data, as error detection, identifying which device receives the signal as well as a bit for acknowledgement which are all important features in our project for correct data transmission.

Two devices use a shared physical channel for communication. To achieve this, their transceivers need to be tuned to the same frequency at the same time. A device can use only one of these physical channels at any given time. Time division multiplexing is used in order to utilize multiple channels for concurrent operation. With a limited number of radio frequencies used for bluetooth it is possible that two devices may use the same channel at the same time and therefore causing a physical channel collision.

Inquiry is the process of discovering nearby devices or allowing other devices to discover it. Inquiry is carried out on its own special channel and has to be balanced in terms of the commitments the connection already has. We expect the user's device to be the inquiring device in this case and the road mapping device to be the discoverable device that will listen for inquiries once it is turned on.

Another important feature of bluetooth is the ability of the device to switch roles between being a leader and a follower. This is important when establishing a bluetooth link to other devices as the initial device to establish the connection is the master until a role switch happens. Once a piconet has been established, master-slave roles may be exchanged.

The bluetooth standard defines three power classes for devices. The first power class outputs at a power of 100mW and its advertised range is 100 meter. The second power class operates at 2.5 mW and has a range of 10 meters. Power class 3 outputs at less than 1 mW of power and has a range less than one meter. For the purposes of this project power class 2 is the sweet spot since we do not expect the device to be more than ten meters away from the user's device. The advantage of using power class two is that it will take less power to use it, simplifying our power system.

Power class	Transmission power level	Advertised range
1	100 mW	100 meters
2	2.5 mW	10 meters
3	< 1 mW	< 1 meter

Figure 23: Bluetooth Power Classes

The standard states “Each IEEE 802.15.1-2005 device shall be allocated a unique 48-bit device address. This address shall be obtained from the IEEE Registration Authority”. These unique device addresses are used in determining the frequency hopping pattern which tries to avoid packet collisions in turn improving the reliability of the connection. The standard also states that all transmissions include a devices access code, a channel access code and an inquiry access code, all of which are derived from a part of the devices unique address. The channel access code helps mitigate unwanted effects of two devices operating on the same frequency at the same time as it is the first information sent in the transmission.

Another useful feature defined by this standard is that packets sent through this connection may be larger than a single time slot. This is important to our project as if we choose to transmit the data from the device to the user through bluetooth we expect the data to be quite large as it will include an image as well as some other information.

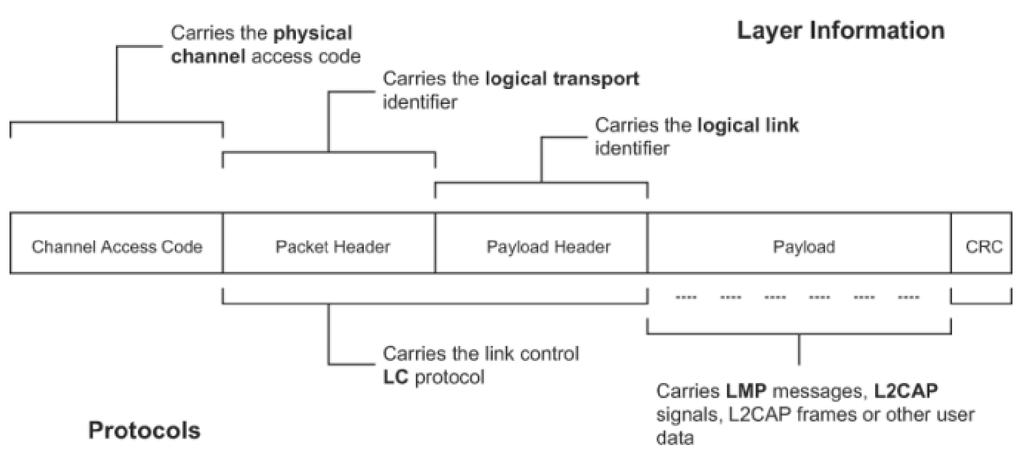


Figure 24: Packet Structure

This standard includes a section on interface primitives that can do things such as create a connection request, reading data and writing data and many more functions. These primitives are important to use as we will have to use them to do the things we want to do with the bluetooth connection as well as to help us debug the device if there are issues. This section defines the service, the parameters and what the output will be.

4.1.3 Electrical Safety Standards

There are many standards in the application of lidar development. In the case of electrical there are two aspects found through research. These applications are based on the sense of safety measurement requirements. In the sense of safety there are several different developments of standards related to our project. IEC (International Electrotechnical Commission) produced a standard specifying the importance of measurement requirements for electrical safety testing. This standard outline's that when testing or producing a product there should be the use of electrical safety equipment to ensure the laser sensors are installed and operating safely. There are multiple sections that make up the basis of what is required for ensuring that the device provides accurate and reliable readings. These are demonstrated in the table below.

Table 26: IEC Safety Standards

Section	Title	Description
Part 1	General Requirements	General Requirements for measuring instruments used for electrical quantities in low voltage installations
Part 4	Instruments of Harmonic Distortion and Power Quality	This section covers the instruments used for measuring and analyzing power quality and harmonic distortion in electrical installations
Part 5	Equipment for Testing, Measuring or Monitoring of Protective Measures	Guidelines are provided for testing and measuring the effectiveness of protectives in the electrical system
Part 6	Multifunctional Measuring Equipment	Multifunctional measuring devices that can measure multiple electrical quantities such as voltage, current and power
Part 7	Digital Communication Protocols	Outlines the protocols used for transmitting measurement data between devices
Part 8	Equipment for Testing, Measuring or Monitoring Specific Parameters	Guidelines for measuring specific parameters such as temperature, humidity, vibration, and speed

The basic definitions or what is included in the guidelines is provided in the table. The IEC does outline a further step by step requirement to meet the needs of ensuring safety when using testing equipment on electrical equipment.

Another international safety standard that applied to the electrical, electronic and programmable control equipment is the IEC 61010. The standard is a development by the IEC and is designed to ensure that the equipment is safe for use in a wide range of settings, including laboratories, medical facilities, and industrial plants. IEC 61010-1 specified the general safety requirements for electrical equipment intended for professional, industrial process and other laboratory use. This covers equipment that operates with a supply voltage not exceeding 1000V for AC or 1500V for DC. The equipment must be designed and constructed to minimize the risk of electrical shock, fire and other hazards. There are also specific requirements for protective measurements such as insulations, grounding and overcurrent protection. IEC 61010-1 also requires documentation, marking and instructions for the use, including equipment's intended use, installation, and maintenance.

The next standard we should take into consideration is ISO 26262, which specifies safety requirements for automotive system use. Because our device is designed to be mounted onto an automotive vehicle for its final demonstration or for its intended use, this standard should be met. This international standard provides guidelines for the development of safety-related systems in road vehicles, including passenger cars, trucks and buses. The ISO 26262 covers the entire safety lifecycle of a system. Included in the standards descriptions is guidance on how to assess safety risks and implement safety measures throughout the development process, including identifying potential hazards, defining safety goals and requirements, designing safety-critical components, and testing and validating safety systems. Many regulatory agencies require compliance with the standard and it is often a prerequisite for doing business in the automotive industry. The table below includes the ten parts of which the standard covers for functional safety.

Table 27: Electrical ISO Safety Standards

Section	Title	Description
Part 1	Vocabulary	Define the key terms and concepts related to functional safety
Part 2	Management of Functional Safety	Outlines the management processes and activities required to achieve functional safety, including risk management, safety planning and safety monitoring
Part 3	Concept Phase	Provides guidelines for the early stages of the development process, including hazard analysis and risk assessment
Part 4	Product Development at the system level	Covers the development of safety-critical systems and components, including design, verification and validation
Part 5	Product Development at the Hardware Level	Covers the development of hardware components, including electronic control units and sensors
Part 6	Product Development at the Software Level	Covers the development of software components, including software requirements, design and testing
Part 7	Production, operation, service and decommissioning	Covers the production, operations and maintenance of safety-critical systems
Part 8	Supporting processes	Covers supporting processes such as configuration management, change management and supplier management
Part 9	Automotive Safety Integrity Level (ASIL)	Oriented and safety-oriented analysis. This provided guidelines for safety analysis, including hazard analysis and risk assessment
Part 10	Guidelines on ISO 26262	Provides additional guidelines on how to apply ISO 26262 to specific systems and components

In the next electrical listed standard ANSI/UL 61010, which was formed by the American National Standards Institute and published by the Underwriters Laboratories, specifies the requirements for the electrical equipment use in the laboratory, industrial and healthcare settings. There are guidelines and requirements that are set to ensure the safety of the device when used in its intended environment. With our device's purpose of being used in an outdoor environment the environmental hazards can pose a large threat if our device is not properly protected. As well as the environmental aspect, our device needs to be (easy to work). With the hopes that this machine could be used by the Department of Transportation for road safety, the device needs to have all electrical and mechanical hazards designed to prevent harm of a general/untrained user. To ensure this, the device must be properly secured on its mount with conductive parts properly grounded and moving parts or sharp edges must be covered….

Demonstrated below in a table is the list of the hazards we must be aware of according to the ANSI/UL 61010 for laboratory, industrial or healthcare settings when handled by a general user.

Table 28: ANSI/UL Electrical Standards

Type of Hazard	Description
Protection Against Electrical Shock	Equipment must be designed to prevent electrical shock to the user. including protection against contact with live parts ensuring that accessible conductive parts are properly grounded
Mechanical Hazards	Equipment must be designed to prevent mechanical hazards to the user, including protection against moving parts, sharp edges, and other hazards
Fire Hazards	Equipment must be designed to prevent fire hazards including protection against overheating, ignition of materials, and other potential sources of fire
Environmental Hazards	Equipment must be designed to prevent environmental hazard, such as exposed to water, dust, and other potentially damaging substances

The ANSI/UL 61010 standards also cover specific types of equipment, including electrical measuring and test equipment, laboratory, and medical equipment. In addition to outlining the requirements of the equipment itself, the standard also includes guidelines for the installation, operation, and maintenance of the equipment to ensure ongoing safety. Overall this standard is important to ensure that the electrical equipment used in the laboratory, industrial and healthcare settings is safe for the users and meets the detailed safety requirements.

The last applicable standard to our project would be the FCC Part 15, which is a set of regulations established by the Federal Communications Commission in the United States. The regulations established govern the operation of unlicensed devices that use radio frequency energy, such as consumer electronics, industrial equipment, medical devices and other equipment that emits RF energy. The purpose of the FCC Part 15 is to limit the amount of RF energy that unlicensed devices can emit and to prevent interference with licensed communication systems. The technical standards and testing requirements relating to unintentional radiators, such as the lidar sensors, are to ensure the minimization of harmful radio-frequency interference with other electronic devices. If our device will be used by the DOT in the future it needs to meet the requirements for consumer or industrial applications to eliminate the harmful cause of interference with other electronic devices when being used on the road. The regulations included in the FCC Part 15 include:

- Personal computers and peripherals
- Wi-Fi routers and access points
- Bluetooth Devices
- Home automation systems
- Low-power devices such as remote controls
- Industrial equipment and machinery
- Wireless microphones and receivers

To comply with the regulations, devices must undergo testing and certification by an accredited testing laboratory to ensure it has met the specific technical standards for RF emissions and susceptibility to interference. The device must also include proper user instructions to ensure the user is aware of any limitations to their use and for personal safety. This standard is applicable to our project because of our inclusion of a wireless or Bluetooth device to transmit the captured data to an app or website for user viewing.

4.2 Constraints

This section will review the types of constraints our project faces and how it will affect our prototype. These constraints include safety, economical and time, environmental, manufacturability and sustainability, and power.

4.2.1 Safety Constraints

In a previous section, laser safety standards were investigated. Due to potential side effects to eyes and even skin, it was determined that a red laser with power less than 5 mW would be used. Class 1 and 2 lasers are considered eye safe due to the aversion response. A wavelength in the red spectrum will also be used due to possible effects of infrared radiation of green light or possible negative biological effects of blue light.

4.2.2 Economical and Time Constraints

This project has economical and time constraints that will affect the quality and precision of our project. This project must be completed in two semesters, one of them being a shorter semester in the summer. This constraint may not allow us to reach some of our advance and stretch goals as there may not be enough testing time. Also some additional features such as finding the volume of the pothole may not be incorporated. This project also is self funded as there is no sponsor involved. Companies such as Luminar, and the Department of Transportation were written to but no sponsorship was acquired. Since students will be funding the project, staying on budget is very important and will have effects on the level and performance of equipment that can be purchased.

In reference to the constraint in time it is wise for us to lighten the workload in places that we can in order to allow more time in places that it cannot be lightened. One such method to lighten our workload is to use a microcontroller system which already has many of the features we want. The raspberry pi zero w is a perfect example of this as it has Bluetooth, a micro-usb connector, an SD card slot as well as WI-FI and an HDMI port. Choosing this board will reduce the amount of time we spend on simply implementing these features and instead give us more time to spend incorporating such features. Having an SD card slot built in reduces the number of hours we have to spend implementing and coding a storage system such as NTFS as the raspberry pi board already has its own file system implemented. Reducing the time needed to implement this means we can focus on using it and transferring data between our device and personal computer. This is true for the other features this device already has, with the Bluetooth we will spend less time figuring out how to connect a Bluetooth module to our microcontroller and more time using it in the way we want.

We can also utilize our time effectively in choosing programming languages with which we have some familiarity in. One such programming tool we can use comes in the form of an application programming interface known as WebGL. Having taken some computer graphics courses at UCF we are confident that utilizing this technology can reduce the amount of time needed for a learning curve on a new technology or starting from scratch. WebGL is great because it offers all the useful features we need and is really straightforward once you know how to use it.

4.2.3 Environmental Constraints

This project also has a few environmental constraints. While designing the surface road mapping prototype, we need to minimize the harm that could occur to living animals and plant life on the road. Safe levels of power and wavelength of the laser will be used. Components must also stay attached. We do not want to cause any debris on the road that could cause damage to other vehicles.

Optical systems can be affected by environmental factors such as rain, fog, dust and other obstructions. These factors can cause the signal to scatter or attenuate, resulting in a decrease in accuracy. Some devices have multiple beams or adaptive filtering to compensate for the interference. In the case of our devices being mounted on top of a vehicle, it is susceptible to temperature, humidity, and vibration, so the electrical systems must be designed so that the accuracy is not impaired with these circumstances. In the case of temperature, these devices can have fluctuations in the output signal. The device's commands can expand or contract with the temperature changes affecting the accuracy of the data. It is noted to ensure the device is operated during the desired temperature range.

4.2.4 Manufacturability and Sustainability Constraints

Manufacturability constraints describe parameters on how the system will be built while sustainability constraints point to the resources that are available for manufacturing. A major impact on our project is budget. Materials for the prototype are bought solely by group members and it is very important to stick to our budget. For example, cameras can be very expensive ranging from the hundreds to the thousands of dollars. Since we are not funded, the camera will not have all the specifications to reach some of our advance and stretch goals. Our budget only allows a camera under one hundred dollars. A camera within our budget was chosen but we had to weigh the pros and cons of the camera's specifications. Resolution of the system is in a large part determined by the frames per second of the camera. This was one of the major features that we had to consider when searching for the camera. Some concessions were made to keep the cost within the constraints of the budget. The camera selected for the project is ELP-USBFHD085-MFV which runs at 260 frames per second. This camera runs fast enough to reach some of our goals while not costing thousands of dollars that many of the higher quality cameras on the market run. It achieves this by running at a lower resolution than the more expensive cameras.

Another manufacturing issue is related to the time constraint imposed upon this project. Due to recent supply chain problems that have been occurring around the world it has made getting the materials for manufacturing the device more difficult. An emphasis was placed on finding parts and materials that are readily available. Some parts have had to be disqualified from use due to delays in receiving them from factories around the world. For example the powell lens being used in the project took three weeks to arrive which is one reason it was purchased way ahead of time. The raspberry pi zero w is not in stock on many websites and has become a popular choice for resellers. The board we purchased was about fifty dollars when it is marketed as a board for everyone at fifteen dollars. Such price gouging would make manufacturing this system on a large scale a logistical nightmare.

Laser Safety is also a constraint put on our system. The system requires that the laser outputs enough power so the camera can pick up the projection of the line. However there are limitations on what classification of laser that is deemed safe as discussed previously. For this prototype, the laser beam will not be enclosed as it will be projected on the surface of the road. A laser with power output less than 5mW was selected so there would be no eye or skin injury if the system malfunctioned. It was also determined that a red laser color would be best so as to avoid safety issues that come with a green or blue laser. The red laser is also cheaper to procure than green or blue lasers.

The device needs to be contained within a case that will allow it to be weather resistant and safely mounted to the truck. This case will have to protect the sensitive electronics and optics held within. For this project due to time and manufacturing constraints the case will have a metal exterior that will provide weather protection. It will have a support frame on the interior that will provide structural support and provide mounting locations for the electronics and optics being used. The case will be mounted to a truck tailgate by sliding over the top of the tailgate and will be secured by a pair of tension clamps that can be tightened to prevent the case from bouncing or falling off the truck as it drives down the road.

In reference to the construction of the housing for this device we will need to ensure that adequate radio frequencies can penetrate it. Having a case which does not allow for radio frequencies to pass through easily will disrupt some functionality as both the GPS module as well as the Bluetooth module are important to this project. Creating a case that is transparent to these radio frequencies is crucial to our design. As a rule of thumb any dense material of sufficient size can affect GPS signals.

4.2.5 Power Constraints

Laser sensors require a stable and consistent power supply to operate efficiently. When it comes to the designing portion of this model the sensor and associated components need to be considered in the case of each power requirement to ensure the power supply is reliable. The amount of power needed to operate can increase depending on the distance to view the road when placed on a specific car or the angle it is mounted at. A higher powered laser could also require more power and have limitations on the size and weight of the system to compensate for this. In the case of the camera system to operate and process images captured by the laser this requires an increase in power. The power source itself can also be a limiting factor if the laser driven camera is used in a mapping system on the road. Because the system relies on batteries as a portable source the limitation of capacity and frequency charging arises. Overall, the power constraints can limit the capabilities and practicality of laser driven camera road mapping systems. This requires careful consideration and optimization of the laser, camera and power source components.

4.2.6 Electromagnetic Interface Constraint

Electromagnetic Interference (EMI) can be a significant constraint for a laser driven camera road mapping system. EMI refers to the disturbance or noise that affects the performance of electronic equipment and can occur due to various electromagnetic sources. This can affect both the laser and camera components. EMI can interfere with laser emission and reflection of the light causing an inaccuracy in the mapping data. IT can also affect the camera's image capture and processing leading to noise or data corruption. EMI results from sources such as power lines, electronic devices and radio frequencies.

Measures can be taken to mitigate the EMI effects. One method is to ensure proper grounding and shielding of the device to reduce the impact of EMI on the laser measurements especially if being used on a car with the future goal of operation at 60mph. Our device is designed to emit and receive signals to create a 3D map of the road obstruction. These signals can be affected by the electromagnetic interference from other electronic devices in the vicinity of the vehicle. It is important for us to shield the device with the mount and ensure it is not placed directly near other large electrical equipment. Another method to mitigate the effects is filtering. Filtering is the concept of reducing the amount of electromagnetic radiation that reaches the laser and camera components. Lastly, another option is the frequency selection to operate the system. Designing a proper frequency that is susceptible to EMI is an appropriate measure to take. Together these can be taken to minimize the effect on the system's performance.

4.2.7 Bandwidth Constraint

Optical devices require a high bandwidth to process and transmit the data collected. The data can be transmitted through a wired or wireless connection and the requirements depend on the amount of data collected and the speed at which it needs to be collected. Bandwidth is the amount of data that can be transmitted over this communication channel during a specified time. There are several bandwidth constraints that could apply to our device. The first is the laser driven camera captures a large amount of data in real-time, and this data has to be transmitted to a processing unit for analysis. For the system to not become overwhelmed by the volume of data the transfer rate must be high enough to ensure the mapping process does not slow down. Another issue is the mapping data captured must be processed in real time to generate accurate results in a timely fashion. To ensure this the processing speed has to be high enough to keep up with the rate of data transfer. A third bandwidth constraint is that multiple components need to communicate with each other at once to ensure it operates properly. The communication bandwidth must also be high enough to ensure data communication is transmitted quickly and effectively. To minimize these constraints we can take several approaches such as introducing data transfer protocols to reduce the amount of data transmitted to prioritize the transmission of critical data. A second method of mitigation is the use of high speed communication channels such as high speed wireless connections for data to be transmitted quickly and effectively or achieving the same goal by using a high-speed processing unit. The bandwidth can be a significant constraint for a laser driven camera system and appropriate measures should be taken to ensure this does not go unnoticed.

5 Project Hardware and Software Design

5.1 Initial Design Architectures

Projects go through multiple renditions as engineers discuss different aspects and investigate technologies. Constraints and specifications are placed on the prototype and ideas on how to reach the end product change. This project was not any different. Initially the optical engineers wanted to introduce a LiDAR system that would scan the roads surface looking for damage. However, there were many factors working against this design. The proposed design can be seen in figure #.....

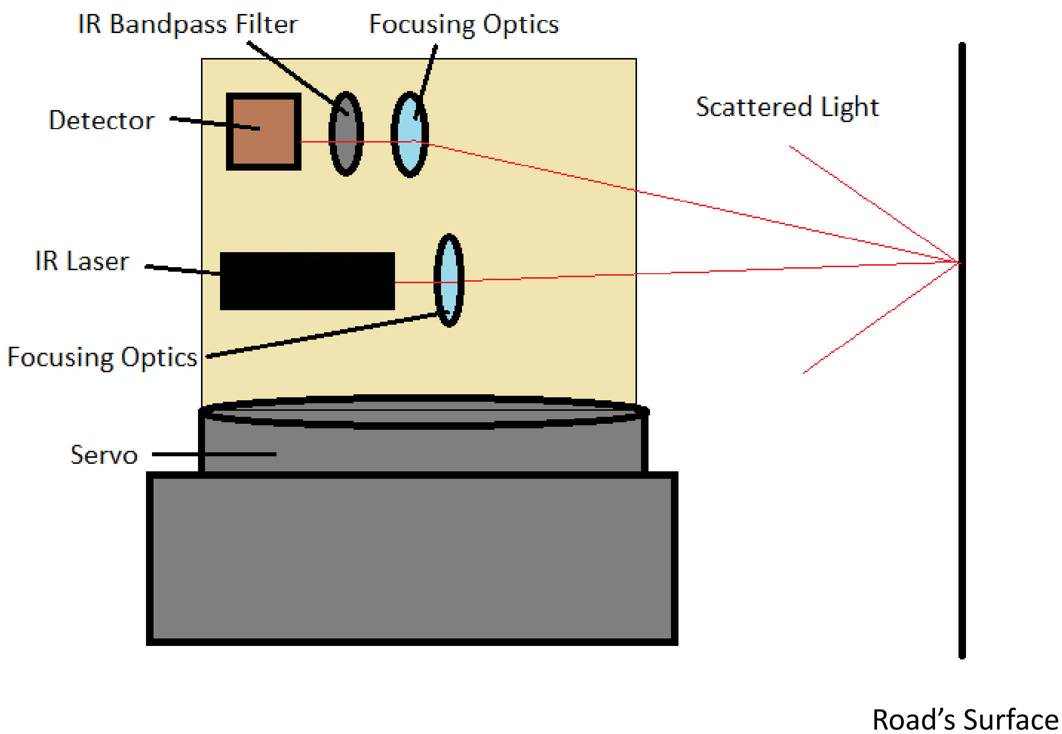


Figure #: Initial LiDAR Design.

Initially optical engineers were investigating a scanning LiDAR system as seen above. The emitting and detection optical systems are sitting on a servo. To reach our advance goal of ……, it was calculated that servo would have to spin at…. This was one obstacle to overcome as no one in the group is a mechanical engineer and we did not know the effects spin this fast would have on our optical system. The laser used in the emitting system is an IR laser with wavelength of…. To reach our goal of…., the laser would have to pulse at….

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