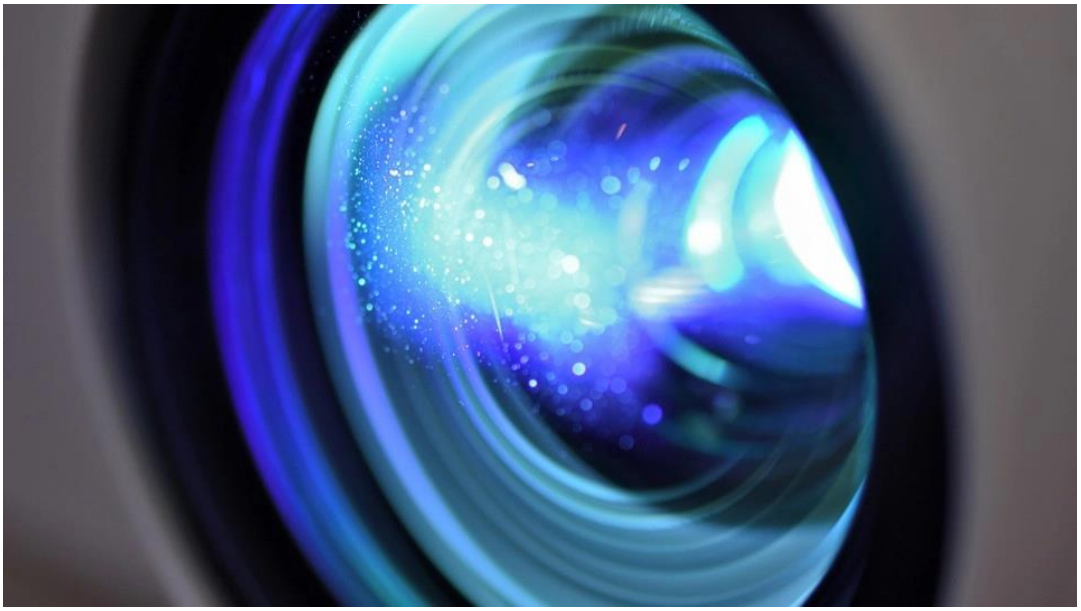
UCF Senior Design II

ALP – Autofocusing LED Projector



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Senior Design 2 Documentation July 2023

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1 Executive Summary

This project aimed to develop an autofocusing LED projector that is affordable, user-friendly, and can be controlled by voice commands. The design involved a multidisciplinary approach, integrating optics, software, and electrical engineering to create a functional prototype. This approach enabled each team member to familiarize themselves with how a team of multidisciplinary engineers can design a new product in a team environment with deadlines, constraints, and various time schedules. The projector system is battery-powered, eliminating the need for a power outlet and making it portable. This feature makes it ideal for outdoor use, presentations, and events. Furthermore, this design makes it a more diverse friendly product that people of all ages, health conditions, or impairments can enjoy. The autofocusing capability enhances the user experience, eliminating the need for manual adjustments and ensuring sharp and clear projections. The desired image is in high quality 1080p with a resolution of 60Hz and contains plenty of brightness of at least 5,000 LM.

To achieve the desired results, the project involved the development of specialized software that was integrated with the voice command system. The software enabled the user to control the projector's functions such as turning it off and adjusting focus. The electrical engineering aspect of the project involved the development of a power-efficient system that accommodated the battery power source and the LED light source. The system also integrated with the software and voice command system, ensuring seamless functionality. At the heart of the projector system is the microcontroller which acts as the brains of the system where the programming is optimized. A printed circuit board was also built to supplement the microcontroller where the PCB can manipulate power, voltage, and contain LED lights for various applications.

This paper will document the design process of the Autofocusing LED Projector, including relevant technologies, theory, design approach, testing, and prototyping. The project sought to develop a cost-friendly, user-friendly, Autofocusing LED projector that is battery-powered and can be controlled by voice commands. The integration of optics, software, and electrical engineering was critical in achieving the desired outcomes. The final product offered an innovative solution that enhances the user experience and expands the possibilities of portable projection technology. The hope of this project is to make an impact on the projector industry market of today so that projector technologies can incorporate some of the engineering designs that our senior design team to integrated and showcased.

2 Project Description

Chapter 2 provides the reader with a general understanding of our senior design project the Auto-Focusing LED Projector. Throughout this section our team discusses the projector motivation, goals, objectives, requirements and specifications, marketing and engineering requirements, and a component project illustration. The milestone discussion, budget and finance, and distribution of work will be discussed in further detail in the administrative content chapter at the end of the document. Thus, chapter 2 lays the foundation of the design and engineering of this unique technology.

2.1 Motivation

The Autofocusing LED Projector is the future of projection technology, which has endless applications to all industries. Although projector technology has made various advancements over the recent years, we believe there are many drawbacks that persist. This project enabled us to get hands on experience with optical and electrical hardware engineering design. Furthermore, development of computer software engineering algorithms expanded our knowledge of the processes and implementations associated with design. It is our mission to improve on the limitations of current projector technology and expand the market beyond that of today.

The motivation for this project was to make an affordable, mobile, and user-friendly projector for the common consumer. The main technology behind the projector is the creation of a light emitting diode light projection, laser range finder, voice commands, and a low power consumption system. Furthermore, we designed our projector system to remain lightweight, fast, and portable to meet consumer needs. It is intended that the prototype we developed over the course of senior design will be a steppingstone that can be used to further the technology and begin mass production and manufacturing. The project was internally funded by each member of the group, so we have established section 2.6 for budget and funding. However, with an increased budget along with time, this system can incorporate more design capabilities for further advancement and application.

2.2 Goals and Objectives

The team has developed objectives for each goal that our senior design project accomplished. Included are core goals which are what our project showcases, advanced goals which elevate our system above the competition, and stretch goals which is what we aimed to achieve in our limited time this year. The core goals of the projector were to successfully create a projector that can render images and video with spatially uniform intensity. These images and movies were generated by a smartphone connected to the liquid crystal display via an HDMI cable.

Furthermore, an automated focusing system acts based on the information from a laser range finder. To achieve this, we have a stepper motor connected to a translatable focusing lens for the projector. From the distance determined by the rangefinder, the stepper motor will then adjust the focusing lens position accordingly so that the rendered image is in focus. Additionally, hands-free projector control via voice commands and power consumption less than industry standard were our final core goals. The voice commands enable auto focusing of the projector system. The execution of this was enabled by a microphone with specific commands recognized by the Voice Recognition V3 Module Compatible Board for Arduino, described later in this document. The advanced goal for our project was to have stepper motor rotations on the projection lens gears. This enabled the adjustment of the focusing lens by the stepper motor so that the image is always in focus. Furthermore, video and audio input to the projector can be accomplished with a mobile device. Finally, our last advanced goal was fast turn on time of the projector. The stretch goals of our senior design project included fast focusing speed with high image accuracy; little to no distortion or aberration present in the final image. Additionally, the final image size could auto adjust with various distances including automated brightness manipulation. Furthermore, the final stretch goal of our projector was to include a feature in which voice commands can be activated even when not projecting.

There are many key functions of the projector that were incorporated and initiated. A power supply gives power to a printed circuit board along with a microcontroller that can control our system. Voltage regulators were implemented to control the amount of voltage sent to each component. A fan cools off the projector to prevent overheating and speakers enabled the sound of the system. The team has established section 2.2 list of requirements and specifications that showcase the engineering of our project. Along with the section on project block diagram and software flowchart to showcase the work divided among each group member that made this projector a reality.

When setting up a projector, typically a contractor is needed, and a lot of time and money is spent getting it just right. With the weight and focusing time cut down, the instillation period and setup time were therefore drastically improved. As a result, the dimensions of the system remain relatively compact while maintaining robustness. Furthermore, the costs associated with this system provided such an economic benefit. Thereby diversifying the market to allow for all types of consumers to enjoy this technology. The Autofocusing LED Projector will find itself in every industry and used amongst all ages. We believe the design of our light emitting diode and laser projector system will have a significant impact on the technology and market of our consumers.

2.3 List of Requirements and Specifications

In the table below, *Table 1*, you will see the engineering requirements for our project, The Smart Projector, and the specifications we used to test the requirements. Additionally, you will see we have separated our requirements by priority based on the goals we have set for our project. Our decision making in choosing the engineering requirements and specifications for our project were based on what we believe will contribute to make a quality projector as well as what respective area of topics we were interested in learning more about.

Table 1. Requirements and Specifications

Component(s)	**Requirement**	**Specification**	**Unit(s)**
LED	Uniform Image Brightness	5,000	LM
Ground Glass	Light Collimation	100 x 100	mm
LCD Screen	Image Resolution	1440 x 2560	pixels
Final Image	Size	50 x 50	cm
Projection Lens	Autofocus	360 turns	degree
Rangefinder	Detection Range	5	m
Stepper Motor	Focusing Speed	<10	s
Projector	Power Consumption	<50	W
Microphone	Voice Commands	2	unitless
Batteries	Lifespan	60	minutes

2.4 Project Block Diagram

Figure 1. Project Block Diagram

2.5 Software Flowchart

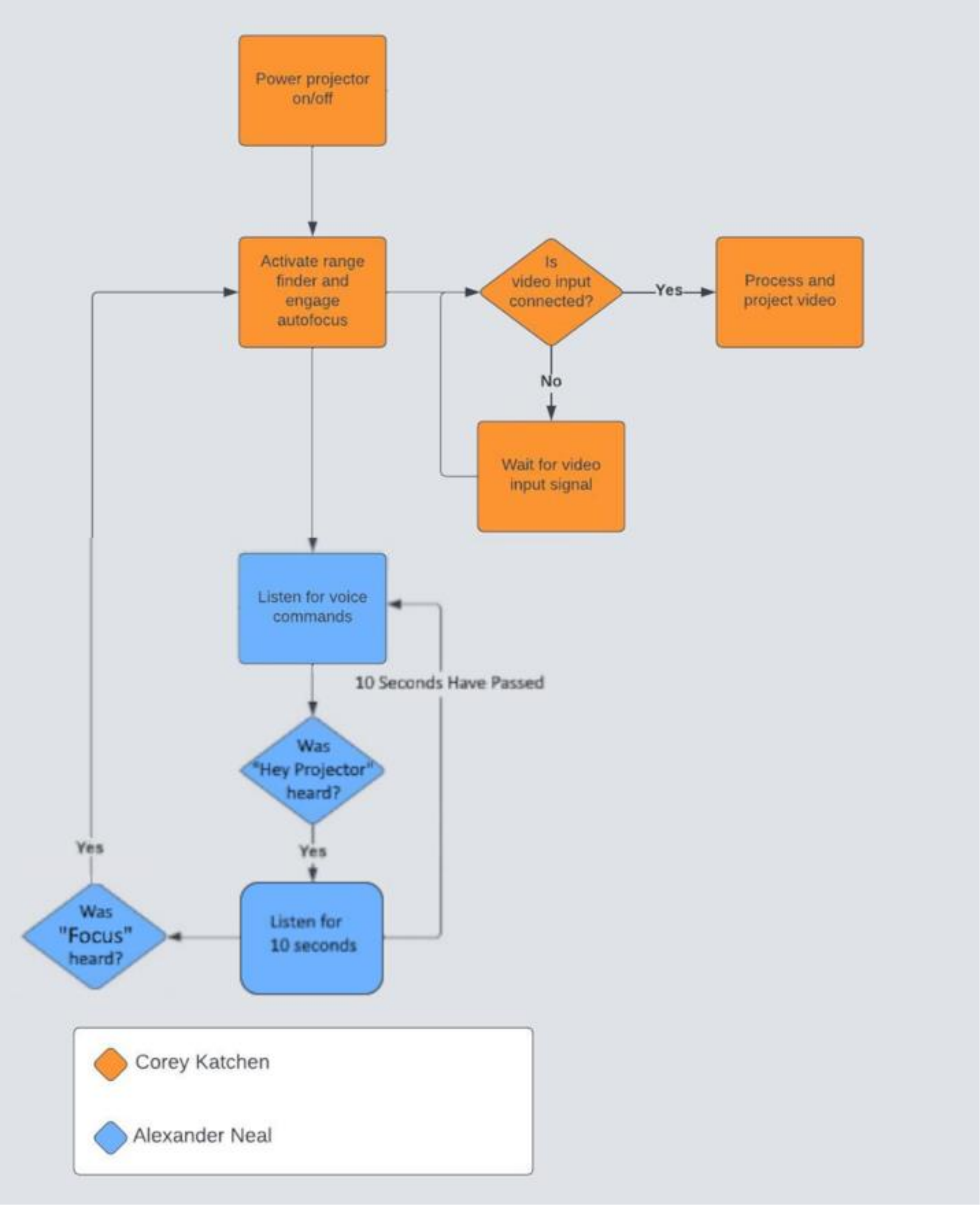
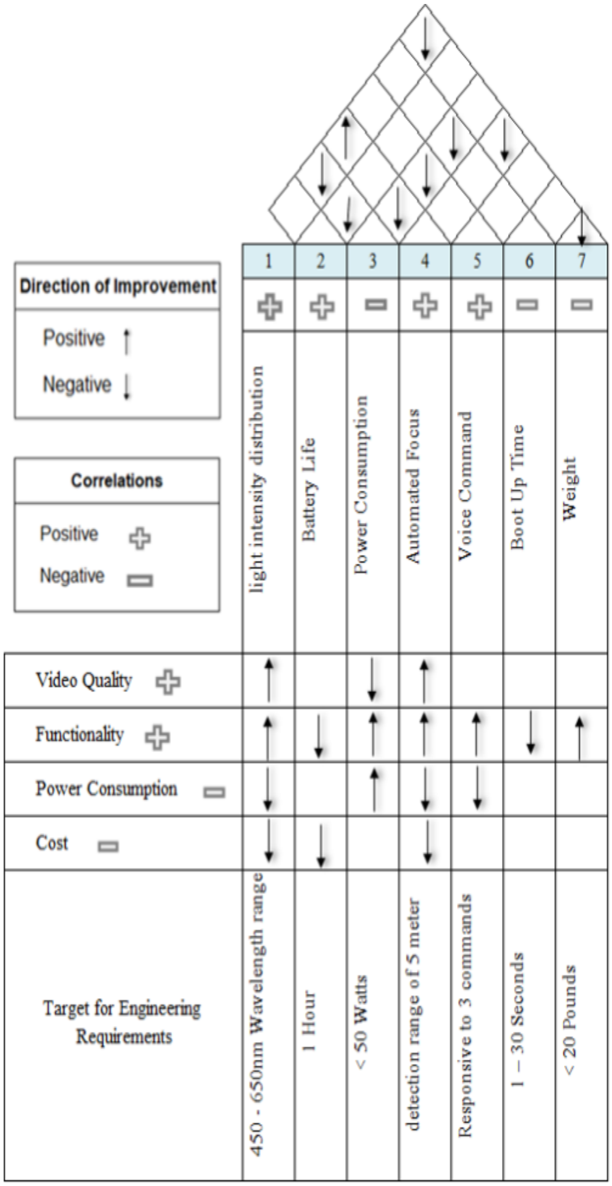


Figure 2. Software Flowchart

2.6 Marketing and Engineering Requirements

Figure 3. House of Quality Diagram



The House of Quality Diagram (Figure 3) is used to relate the engineering requirements we have for the projector compared to the requirements the market would have for this product. The engineering requirements we have listed in the diagram are, as listed in *Table 1*, uniform light intensity distribution, range detection, power consumption, automated focus, voice commands, boot up time, weight, and battery life. The corresponding market requirements are video quality, cost, power consumption and functionality. Video quality and cost are the two very important marketing requirements for projectors because when comes to any device displaying an image/video the resolution of the picture controls the overall experience and for a consumer to even consider your product it must be within an optimal price range in accordance with its features. Power consumption is important because by maximizing your power consumption you extend your battery life and reduce the risk of maintenance cost of the system. Functionality, defined in regard to this section as a part of the system that aids the product to serve its purpose more effectively, is an important requirement because it demonstrates qualities that may separate our product from other similar products and implementing parts of our product that improves its functionality helps enhance the consumer's experience.

2.7 Project Illustration

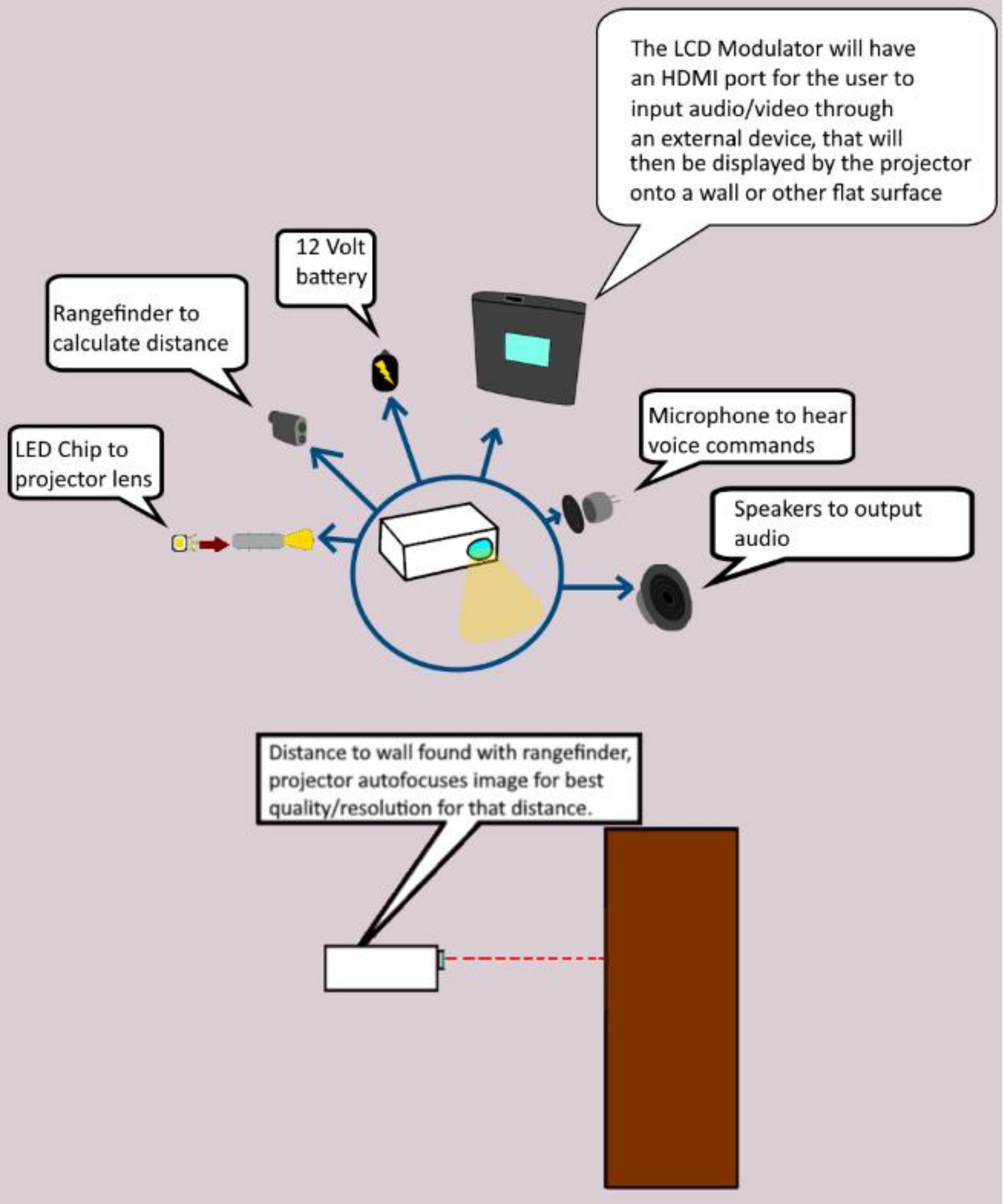


Figure 4. Project Illustration

3 Technology Comparison and Part Selection

Chapter 3 covers the technological investigation our senior design team has conducted on the projector market of today along with the various components that make up each system. This chapter lays the foundation for our engineering design and component selection for our projector system.

3.1 Light Source Technology Comparison

In this section we will discuss the four common projector light source technology methods. Focusing on parameters such as quality, costs, lifespan, power, and maintenance for each of the light generating sources. The sources covered are lamp, fiber optic, laser, and light emitting diode projectors. The various light sources and image sources (discussed in Section 3.2) can be mismatched, lending to complete design control. It is important to keep in mind the various lens, mirror, and prism combinations that supplement implementation.

3.1.1 Incandescent Light Bulb (Lamp)

The most traditional projector light source setup that everyone is familiar with is the incandescent light bulb or otherwise known as a lamp. The main advantages to using a lamp projector is their high brightness and low bulb costs of roughly five dollars. However, lamp projectors exhibit the most severe disadvantages out of any of the other light source technologies. Such as consuming large amounts of power around sixty watts with exhibits strain to all other electrical and optical components. The lifespan is extremely short compared to the competition with bulbs needing replacement around every seven hundred and fifty hours thus driving up the maintenance requirements.

3.1.2 Fiber Optic

Typical fiber optic projectors work by having a fiber optic laser branch for each red, green, and blue color. The main advantage to using fiber optics as the light source is their ability to provide the widest color gamut. Increasing in costs from the lamp, these fiber optic cables can range from two hundred and fifty to five hundred dollars. In that price range the desired power output needed for projector illumination is roughly five watts. The major downside of using fiber optics is the extreme delicacy needed when handling and installing. Thus, damage is common and likely to occur driving up maintenance time and money.

3.1.3 Laser

Laser projectors typically function by utilizing a singular blue laser or laser diode as the light source. Typically, a yellow/green phosphor wheel is used to generate yellow light incident upon a color wheel. The advantages to lasers are that they produce the finest image quality. The lifespan of a typical TTL laser range from twenty five thousand to fifty thousand hours with costs remaining relatively low around fifty to one hundred dollars. The typical power of a TTL laser needed for a projector will hover over the range of five milliwatts. Although maintenance is low, using a laser as the light source brings in the nagging issue where slight misalignment of the laser can malfunction the illumination, leading to increased maintenance issues.

3.1.4 Light Emitting Diode (LED)

There were many key advantages to using light emitting diodes or a light emitting diode chip as the light source of our projector. Firstly, they offer the most vibrant and saturated colors which are very pleasing from a viewer's perspective. The lifespan of typical LEDS is greater than fifty thousand hours with many relators claiming greater than one hundred thousand hours. Furthermore, practically zero maintenance is required for this technology. Combining that fact with the low costs of around ten to fifty dollars and relatively moderate power consumption of ten watts. Light emitting diodes are a great choice when attempting to engineer and build your own projector.

Table 2. Summary of Light Source Technology Comparison

Light Sources	**Quality**	**Costs**	**Lifespan**	**Power**	**Maintenance**
Lamp	Highest brightness	~ $5	~ 750 Hours	60 Watts	High – constant replacements needed
Fiber Optic	Widest color gamut	$250 - $500	Up to 100,000 Hours	5 Watt	Frequent - if handled/installed incorrectly
Laser	Finest image quality	$50 - $100	25, 000 – 50,000 Hours	5 Milliwatts	Low – alignment correction when applicable
LED	Best vibrant and saturated colors	$10 - $50	> 50,000 hours	10 Watts	Zero

3.1.5 Light Emitting Diode Part Selection

After our senior design project group decided on a light emitting diode as our light source, it was time to select what kind of light emitting diode would best fit the requirements and specifications of our engineering design. Discussed in the section are the various positives and negatives to each of the light emitting diodes on the market today after careful consideration was taken when conducting our technology information research and selection.

Fundamentally there are three main types of light emitting diodes on the market currently that have gained immense popularity and rightfully so. Which include the dual in-line package (DIP) LEDs, surface mounted diode (SMD) LEDs, and chip on board (COB) LEDs. All three present unique characteristics and advantages over each other, so selecting the correct light emitting diode for our Autofocusing LED Projector was very important.

Dual in-line package LEDs or otherwise known as through-hole LEDs are the oldest of the three and are what probably comes to mind when you picture a light emitting diode in your head. The bullet-like design with two or three contacts that extend from the bottom. They are sold in a variety of colors such as red, green, blue, white, and so on. The most common sizes are three, five, and eight millimeters. With the limited size also comes limited power so they are a great choice for simple consumer electronics and breadboards. Mainly finding applications in rope lighting. When put into arrays of each other they are heavier and wider than their counterparts. However, for our engineering design the limited power is not wanted because that means limited brightness. The limited brightness is not good for a projector because the light source needs to be strong enough to illuminate the image source to the wall or screen at various distances. If the image is not bright enough, the viewers of the projector will not be able to see and enjoy the product therefore rendering it useless.

Surface mounted diode (SMD) LEDs were a massive development in the light emitting diode market and are the most popular light emitting diode of the three. Typically, these LEDs are in special packaging and are mounted or soldered onto a printed circuit board which enables manufacturers to place arrays of diodes in very close succession to one another. The two most common sizes are the three and a half millimeter SMD 3528 and the five-millimeter SMD 5050. Which shows how much more compact and lighter they are than dual in-line LEDs. These light emitting diodes are significantly brighter than dual in-line package LEDs. Furthermore, a SMD LED chip enables a vast color range of availability for consumers. As a result, this technology is very versatile for more consumer electronics where strong lighting is desired such as industrial lighting systems. Making them a great choice for the lighting source of our senior design project the Autofocusing LED Projector.

Chip on board (COB) LEDs are the latest and greatest development in the light emitting diode market and outperform its predecessors. These chips are able to pack nine or more diodes onto each single row on a chip, enabling very powerful brightness. This technology is brightest of three making it the primer choice for the light source of our projector where brightness is one of the most important if not the most important parameter. Furthermore, when lit you cannot see the individual chips but rather the appearance of lighting panel which is significant over the dual in-line and surface mounted diode LEDs. The brightness to energy output is significantly increased therefore making this technology extremely lighting efficient. Due to the circuity makeup of the chip on board LED, they are only really suitable and best at generating white or yellow light which is the perfect case for our application. They are found in many applications used every day, for example streetlamps use chip on board LEDs. As a result, the team decided to select the chip on board light emitting diode as our light source due to the high brightness, natural emitted white color, lighting efficiency, size, weight, and costs.

Table 3. Summary of LED Part Selection

LED	Brightness	Energy Efficiency	Size and Weight	Cost
Dual In-Line	Superior in outdoor direct sunlight exposure	Worst	Smallest singular component	Most expensive currently in the market
Surface Mounted Diode	Brighter than Dual In-Line	Low optical decay	Bigger and heavier array of diodes	Moderate upfront and maintenance pricing
Chip on Board	Best	Premier lumen to watt ratio	Smallest and lightest array of diodes	Lowest upfront and no maintenance

3.1.6 Chip on Board LED

After deciding which type of light emitting diode to use as our light source – the chip on board LED, we then had to select the appropriate design that would make the light generation of our projector a success. Our group has selected the COB LED from Ch_Town Electronic on eBay as shown in Figure 5. The condition of our light emitting diode is brand new. It is paramount we selected a light source that is in brand-new condition, preferably with the original manufacturing packaging. This is due to the fact that a pre-owned or used light emitting diode may contain complications not stated by the seller or even the complete malfunction of the device. Additionally, we would need the light emitting diode to contain only a two pin connector system. Therefore, when it comes to connecting the light source with electrical wires, it is clearly distinguishable between the positive node and negative (ground) node versus a three lead (connector) LED where confusion and misalignment can more easily occur. The design of our purchased light emitting diode is perfect due to the three rows of ten diodes which will produce enough brightness where only one quantity is needed. The price of the LED was seven dollars, thereby contributing to the goal of a projector with a cost constraint of under five hundred dollars.

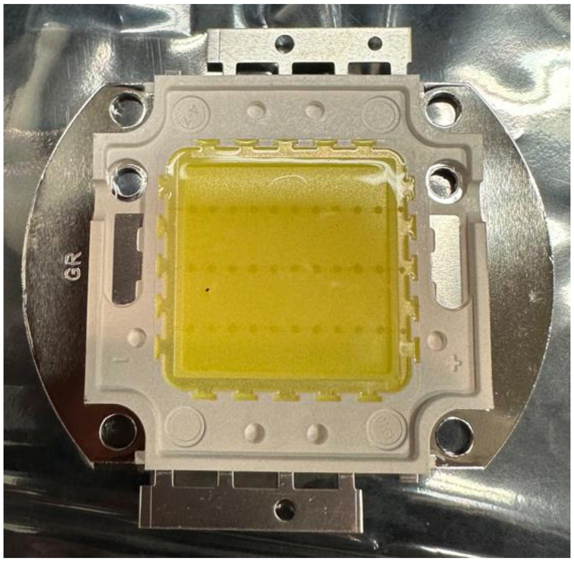


Figure 5. CH_Town Projector COB LED 30W

Manufactured in the year of 2019, this product is energy star rated A++ and also features a manufacturer warranty of two years with a bulb lifetime of ten thousand to fifteen thousand hours. Making this a suitable long last light emitting diode for our projector. The light emitting diode is forty millimeters in length, forty milliliters in width, and four point two millimeters in depth. The dimensions of this LED are desired for the compact design of our projector. The housing material is bronze enabling a sturdy base for assembly. As shown in Figure 5, you can clearly see the large conducting area for both the positive and negative terminals of the LED. This is great for being able to easily solder electrical wires to both sides and connecting the light emitting diode to the electrical circuitry.

The wattage we have selected for our LED is thirty watts with a forward voltage of thirty to thirty-two volts and a forward current of one thousand milliamps. Furthermore, we selected a color of white with wavelength temperature from six thousand to six thousand five hundred kelvin. This is due to the fact that is desired for a projector to generate white light in the wavelength temperature range of six thousand kelvin for pleasant illumination of the imaging source for color projection. As shown in Figure 6, is the nice gaussian coverage of the visible spectrum from six thousand and five hundred kelvin wavelength temperature. Also shown are the hue differences or the whitishness differences between the different wavelength temperatures.

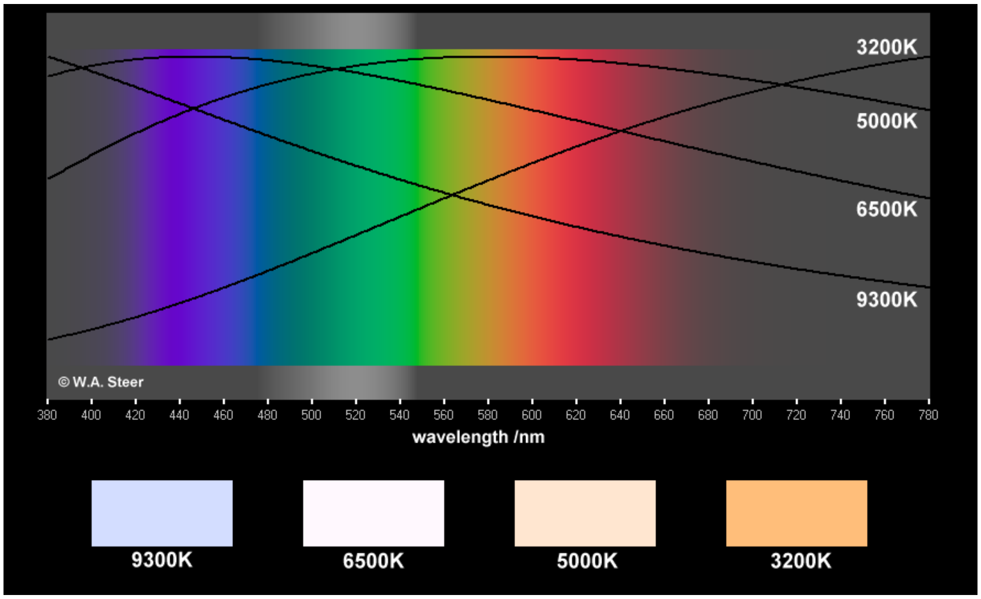


Figure 6. Hue Differences

Another popular option for our chip on board light emitting diode wavelength temperature is in the five thousand to five thousand five hundred kelvin range. Which from Figure 6, it can easily be observed that choosing that wavelength temperature leads to a more yellowish look to the light which is not desired for our project because we wanted the nice crisp original pixel color from the liquid crystal display to be illuminated. The lens angle of LED is one hundred and twenty degrees. This lens angle gives a very wide illumination angle from the source for the collimating lenses to collimate and direct the collimated beam to the LCD imaging source.

If our design and/or power supply could not handle the high power wattage of this LED, we could have instead selected the ten watt LED with a forward voltage of nine to eleven volts and a forward current of one thousand milliamps. While still maintaining parameters such as the white wavelength temperature from six thousand to six thousand and five hundred kelvin and one hundred and twenty lens angle. The only constraint to selecting the lower power light emitting diode is the reduced luminous flux to roughly three times as less which is around nine hundred to one thousand LM. As a result the overall brightness from the light emitting diode would decrease, however, it may be the case where it is sufficient to generate the spatially uniform gaussian LED projection spectrum.

3.2 Image Source Technology Comparison

In this section we will discuss the three main types of image sources for projectors, which include a digital light processing chip, liquid crystal on silicon, and liquid crystal display, focusing on parameters such quality, costs, lifespan, power, and maintenance. Selecting the best image source for our desired light emitting diode light source was paramount for a successful design and engineering of the Autofocusing LED Projector.

3.2.1 Digital Light Processing Chip

A digital light processing chip is based off the digital micromirror device which has thousands of microscopic mirrors on the surface corresponding to each pixel. As light is incident on the mirrors, the reflected light is manipulated to form the color images. DLPs have the highest brightness with costs around fifty to two hundred dollars. Furthermore, a lifespan of up to thirty thousand hours and power under three hundred and fifty milliwatts. Most importantly, the maintenance of this technology is roughly zero. However, the contrast ratio of this device is considerable poor.

3.2.2 Liquid Crystal on Silicon

Liquid crystal on silicon is commonly referred to as a spatial light modulator, which has a liquid crystal layer on top of a silicon backplane. They come in reflective panels usually red, green, and blue. Typically, a dichroic prism is used to then recombine the reflected light into a single full color image. LCoS offers the finest resolution out of the three image sources. However, that comes with a price tag ranging from two hundred to four hundred dollars along with a short lifespan of roughly five thousand hours. The maintenance is high due to the constant degradation of the panels. This technology has reasonable power consumption of around five hundred milliwatts to three watts.

3.2.3 Liquid Crystal Display

A liquid crystal display is a flat panel display that modulates the transmitted light by using the properties of liquid crystals and polarizers. LCDs are the premier choice when movie watching due to enabling the best contrast ratio between the three image sources. Furthermore, the costs of LCDs are relatively cheap compared to its counterpart liquid crystal on silicon, with a price range of roughly fifty to three hundred and fifty dollars. They offer the highest lifetime of roughly fifty thousand hours while maintaining low power of under two hundred milliwatts. However, a negative of liquid crystal displays is the moderate maintenance required from filter and dust upkeep. The pairing between a light emitting diode and a liquid crystal display made it the premier choice when designing and engineering our own projector light and image source.

Table 4. Summary of Image Source Technology Comparison

Image Sources	Quality	Costs	Lifespan	Power	Maintenance
DLP Chip	Highest brightness	\$50 - \$200	Up to 30,000 Hours	Under 350 Milliwatts	Zero
LCoS	Finest resolution	\$200 - \$400	~ 5,000 Hours	500 Milliwatts to 3 Watts	High – constant degradation
LCD	Best contrast ratio	\$50 - \$350	~ 50,000 Hours	Under 200 Milliwatts	Moderate – filter and dust upkeep

3.2.4 Liquid Crystal Display Part Selection

As discussed above in Section 4.6 Image Source Technology Comparison the liquid crystal display was the best option for us to use as our image source for the Autofocusing LED Projector. From having the best contrast ratio, relatively cheap price, long lifespan, low power consumption, and low maintenance the liquid crystal display is just what our senior design project needed to be successful. Liquid crystal displays come in various forms that we will discuss below, selecting the correct part was crucial to enabling crisp image generation for our projector.

Briefly, we will discuss the importance of understanding how liquid crystal display screens generate images because had to manipulate the design for our projector. The liquid crystal display screen contains a frame display surface where the pixels are color illuminated forming the images. Followed by a liquid crystal panel which contains a polarizer, color filter, and liquid crystal layer. Then a back light unit is used to shine light through the liquid crystal panel and onto display surface to project images. All layers of the liquid crystal display screen are manipulated by a printed circuit board driver. Thus, our senior design team needed to select a liquid crystal display screen along with a printed circuit board driver to control the screen.

Maintaining the engineering design and specifications of our projector such as compactness, low power, bright uniform light projection, the liquid crystal display technology that our senior design team decided on is the 5.5” 2K Sharp LS055R1SX04 Screen for 3D HDMI-Compatible to MIPI to Printer board from the supplier 5_BESTCELL as shown in Figure 7 and Figure 8. Figure 7 shows the liquid crystal display screen and Figure 8 shows the liquid crystal display printed circuit board driver. In next paragraphs we will discuss the significant engineering design of each component and how they were applicable to our senior design project.

The liquid crystal display screen had the display surface and backlight unit as discussed previously. Our team then carefully and meticulously removed the backlight unit because our projector uses the chip on board light emitting diode discussed in section 4.5.1 as our light source. The process of removing the backlight while not interfering with the liquid crystal display panel will be further discussed and investigated in our report later in project hardware design details section.

The screen is one hundred and twenty millimeters long and seventy millimeters in length. Therefore from one corner of the screen to the other is five and a half inches giving us a nice big screen for image generation. The team wanted to maximize the surface area of the liquid crystal display while maintaining the small portable projector design. The display type is new mode 2 with a normally black transmissive display as shown in Figure 7. The resolution is 1440 by 2560 pixels enabling a beautiful 2K display. The brightness is four hundred and fifty cd per meter squared along with a contrast ratio of thirteen hundred to one. Given this resolution, brightness, and contrast ratio, the consumer of our projector will have an extremely pleasant image to look at with beautiful illumination giving our product an advantage over the competition. The viewing angle is eighty in all directions with a signal interface MIPI of two channels, four data lanes, fifty pins, and a connector for the driver. The MIPI is the yellow flex cable attached to the screen as shown below.

Figure 7. IPS LCD Screen + HDMI to Mipi LCD Controller Board

The other important component to the liquid crystal display screen is the printed circuit board driver as discussed previously and shown below in Figure 8. The control board is HDMI-compatible with the 40 pin MIPI screen. This was a very important factor within our part selection process because we wanted to be able to easily connect a device from which the images can be projected from, which is further discussed in section 4.8 Video Processing Connection Technology Comparison. The input micro USB power adapter uses five volts of direct current voltage and more than one amp of current. The audio output can be connected to and from speakers. This is an important aspect of our projector because along with the visual images we needed the sound to go with it. The speaker selection for our project will be discussed in section 4.20. The board size is sixty millimeters in length by forty millimeters in width and three millimeters in depth, further enabling the compact lightweight design of our Autofocusing LED Projector.

The control board and display screen are connected via their flex cables which contain a sixty pin connection clip on. The two of these products being sold together for the low cost of fifty-five dollars made them the perfect choice for our senior design project enhancing the low costs effort our team financial goal. Further on in our report during the project hardware design details we will discuss the methods of collimating the light through the screen and then projecting it to create the enlarged image.

3.3 Video Processing Technology Comparison

In this section we will look at the different ways in which we can input video sources to the projector. Our project uses a liquid crystal display screen which takes an HDMI input through a control board driver. Therefore, we needed a way to connect this to the video source and display it in at least 1080p HD with a 60 Hz frame rate video processing connection. Below are a couple of the options that we found to achieve this. Section 3.4 is an important section to understanding where the video signals originate from that are formed on the pixels of the liquid crystal display screen.

3.3.1 Apple Lightning to HDMI

The easiest way that we have found to get the video source transmitted to the projector is to use an Apple lightning to HDMI cord. The HDMI connects to the liquid crystal display control board driver and then any iPhone is able to connect to the lightning port in order to mirror their phones screen onto the projector.

A benefit to this kind of technology is the length provided by the cables so the video device can be inside, next to, or a significant distance away from the projector while still being connected. Furthermore, they are featured at really low costs and weight making them a great option for our compact and lightweight Autofocusing LED Projector. The only real disadvantage of this method is the fact that we are only be able to project video from Apple products and not any other devices such as a Samsung or Google, or any normal HDMI input device.

3.3.2 Apple Lightning to Digital AV Adapter

Another option that we found for transmitting the video source to the liquid crystal display is to use an Apple lightning to digital AV adapter. This allows us to connect a regular HDMI cable to the liquid crystal display control board driver. This enables us to display video from any regular HDMI video source. Then we still have the option to use an iPhone as the video source by connecting this HDMI cable to the lightning adapter.

One of the major downsides of this method is that the adapter requires a power source unlike the lighting to HDMI cable, which would have added extra complexity and hinder battery life of our entire projector system. The length of this connector was also very underwhelming as it is very compact thus the only way to connect a device to a projector would be to leave it inside would have been dangerous and/or very annoying. In addition to the adapter, we also would have also needed to purchase a standard HMDI cable that would connect the adapter to the liquid crystal display. Furthermore, this technology comes at an increased price, and it was considerably more expensive than other options when trying to design a low-cost affordable projector.

Table 5. Summary of Video and Audio Processing Connector

Video Processing Connection	**Resolution & Frame Rate**	**Length**	**Cost**
Apple Lightning to HDMI	1080P HD 60 Hz	~ 1.5 meters	~ $15
Apple Lightning to Digital AV Adapter	1080P HD 60 Hz	~ 15 centimeters	~ $45

3.3.3 Video Processing Connection Part Selection

As discussed in section 2.4, there are two main ways we could send video signals to our liquid crystal display control board. Our senior design team decided to implement the Apple lightning to HDMI as our video processing connection technology. As a result, any apple product is capable of being used with our projector such as iPhones, iPads, and MacBooks. There is not much variation in these types of products, and they are pretty much sold the same exact way so we will not dive deep into different kinds of manufactures.

The video processing connection product we chose is the Mixfly Lightning to HDMI Adapter for iPhone. The resolution is 1080P HD and the frame rate is 60 Hz, making this an excellent choice to send the video signals from an apple product to the liquid crystal display control board driver. The color of the cable is white giving it the sleek Apple look. The dimensions of the cable are zero point thirty-nine inches by zero point thirty-nine inches. This continued to enable the compact design of our Autofocusing LED Projector. The length of the cable is one and a half meters, enabling significant slack from your desired device to the projector. Keeping the costs low to enable a more diverse projector technology; this cable is only fifteen dollars. With the ease of use and conveniency, the plug and play of this connector is not to be overshadowed.

This lightning speed adapter supports the input of an Apple product on the right with the USB-C cable. On the left is the HDMI output port that connects to the liquid crystal display control board driver. The picture really paints a good illustration of our consumer friendly, fast, and reliable way to easily utilize and implement our projector technology into your everyday needs.

3.4 Range Finding Technology Comparison

In this section we will be comparing the different technologies that were considered in providing us the capabilities of autofocusing the projector. These options are a range of distance sensors such as ultrasonic, LiDAR, and Infrared. The goal with these distance sensors was to have the information that is gathered from them be sent to the servo motor, and based on the given distance read, focus the projecting lens accordingly. There was also an alternative method discussed that would use a CMOS camera to compare the projected image with the desired image quality. First, we must understand how these distance sensors work; these commonly function by outputting a signal and measuring a change when the signal returns, some commonly used changes in signal are time it takes for the signal to return, intensity of returned signal, or phase change of the returned signal. For our selection, some things that were considered were safety, detection range, and resolution.

3.4.1 Ultrasonic Range Finder

The Ultrasonic, or Sonar sensor detects objects by emitting a high frequency sound wave towards the desired object, with a timer starting at the same time as well. Then, the receiver picks up the reflected sound wave which stops the timer, and the time taken for the wave’s return is calculated against the speed of sound to determine the distance travelled. Advantages of this method are that it is not affected by the color or transparency of the object, works well in poor lighting conditions, tends to consume lower current and power, and can easily be paired with a microcontroller. Disadvantages for it is that it has difficulty measuring extreme differences in the surface, has a limited detection range, low resolution, and slow refresh rate. These disadvantages made this system not the ideal candidate since we would need at least a few meters of detection range and good resolution for our application.

3.4.2 Infrared Range Finder

Infrared sensors can do both distance or proximity sensing. They typically come with two lenses, An IR LED emitter lens that helps emit a light beam, and a position-sensible photodetector where the reflected beam will fall into. These sensors typically will use the principle of triangulation to achieve their goal, this is done by first emitting from the LED emitter, this beam of light will hit the desired object and reflect off at a certain angle, the reflected light will reach the position-sensible photodetector, and that sensor will determine the position and distance of the reflected object. Advantages of this system are its small form factor, can be used in daytime and nighttime with equal success, and can measure objects with complex surfaces. The disadvantages are it can be affected by environmental conditions and has a limited measurement range.

3.4.3 LiDAR Range Finder

LiDAR, short for light detection and ranging, can be classified as a laser distance sensor. The simplest method that LiDAR uses is it measures the range of the given target using the time-of-flight method. This can be described as the transmitter on the LiDAR device emits laser light at the target object, the pulse of the laser is reflected by the target object, and the distance between them is calculated using the relationship between the constant speed of light in air and the time between sending and then receiving the given signal. In terms of cost, LiDAR is the most expensive compared to its competitors, however, it provides high measurement range and accuracy, fast update rate, can detect small objects, and can be used in the day and night, which made it the prime candidate for our given use case.

3.4.4 CMOS Camera

An alternative method to distance sensors would have been to use a CMOS camera to compare the projected image and the actual image. To capture these images, a camera would be placed where the projection lens is, and then images would be captured in a focused and unfocused scenario, then image processing techniques would need to be employed, these could be things such as the correlation coefficient or the mean squared error. An algorithm could also have been implemented to compare them and use things such as edge detection, image filtering and feature detection.

This approach would have required a powerful microcontroller or computer as it is computationally intensive, and the images could be affected by factors such as the ambient light, the surface of the projection location, and the quality of the camera. The benefit to this approach is that it would not have required calibration for the stepper motors as it would have all been done through software.

Table 6. Summary of Candidates of Autofocusing System

Distance sensors	**Detection range**	**Costs**	**Sensitive to external conditions**	**Operating current**
Ultrasonic	Up to 400 centimeters	\$3 - \$10	Yes	8 to 15 milliamps
Infrared	10 to 80 centimeters	\$10 - \$30	No	30 to 50 milliamps
LiDAR	Up to hundreds of meters	\$25 - \$200	No	150 to 800 milliamps

3.5 LiDAR component and module selection

The following section will be focusing on comparing the necessary components that go into making a functional LiDAR unit as well as comparing the potential LiDAR units that were selected.

3.5.1 Sensor selection

When selecting a sensor for the particular application of range finding, it's important to consider a range of factors such as the required sensing range, accuracy, power consumption, cost, and physical size. The OPT3101, STM VL53L1X, and AMS TMD3700 sensors are all time-of-flight sensors that can be used for distance measurement applications, but they differ in terms of their range, frequency, and features. The OPT3101 is ideal for longer-range sensing applications, while the VL53L1X is a good choice for shorter-range applications that require high frequency operation and programmable field-of-view. The TMD3700 is a proximity sensor that is suitable for short-range applications with lower frequency requirements and lower cost. Ultimately, the selection of a particular sensor depends on the specific needs of the application, and careful consideration of the sensor's specifications, advantages, and disadvantages is necessary to make an informed decision.

3.5.1.1 STM VL53L1X

The VL531X by STMicroelectronics is a Time-of-Flight (ToF), laser ranging sensor. This sensor comes with an integrated emitter and detector, with the emitter being a 940 nanometer (Class 1) laser, and the detector being a single photon avalanche diode (SPAD). The specifications of this sensor are a detection range of four meters, a frequency of up to 60Hz, a programmable Field-of-View with a typical Field-of-View of 27 degrees, an available low power consumption mode, and can reject ambient light. However, this sensor is a bit more expensive than the other two because of its use of an avalanche photodiode which are quite expensive.

3.5.1.2 AMS TMD3700

The TMD3700 by AMS is a proximity sensor that uses a combination of infrared and ambient light sensing to detect the presence of an object. It is usually designed to use in mobile devices such as smartphones and tablets, where it is used to turn off the display when the device is held up to the user’s ear. The TMD3700 has a range of up to 10mm and features a built-in IR LED and photodiode. It also includes a programmable interrupt function that can be used to trigger an event when an object is detected. it has a low power consumption mode as well, can reject ambient light, and the LED wavelength is 940 nm. The advantages to this device are its lower cost compared to the VL531X, and does well in short range applications, however it does have a very limited range compared to the other options as well as a lower frequency operation.

3.5.1.3 OPT 3101

The sensor that will be used is the OPT 3101 from Texas Instruments, below is a simple diagram of the setup that will be used. In the below sections will discuss the Emitter and Receiver selection, while this section will briefly discuss the inner workings of the OPT3101. This sensor connects to the external illuminator to transmit modulated optical signals, and reflected signals are received by an external photodiode which connects to the input of the sensor, this signal is converted to amplitude and phase information, which is stored in registers and read out through the device in the I^2C interface.

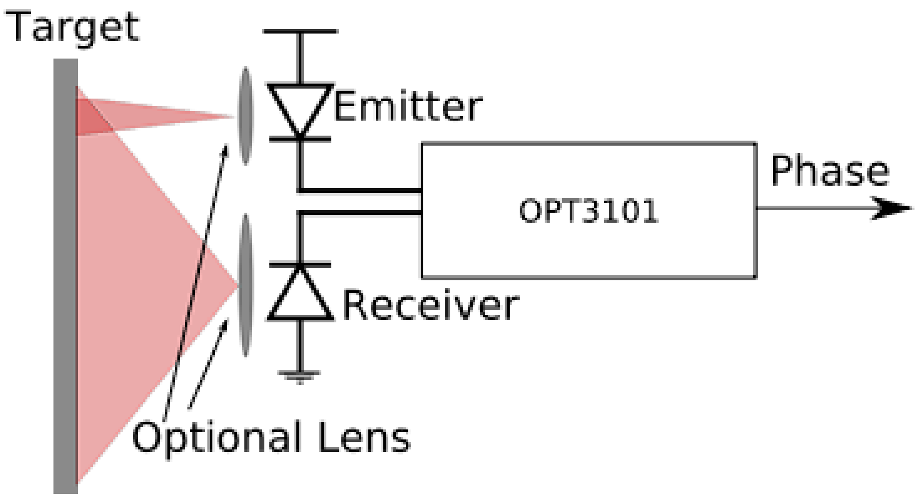


Figure 8. OPT3101 Based Rangefinder System

Some notable features of this device are a timing generator, which generates the timing sequence for each frame, can operate in various modes of operation such as Continuous or mono-shot mode, Auto high-dynamic range (HDR) or non-HDR mode, and can support a single emitter or multiple emitters. It also comes with an illumination driver to turn on and off the emitter, with support of up to three illumination channels, but for this application, only one would be necessary. Most importantly is the output data, the phase and amplitude information is stored in registers, the device gives the data after computation on the general purpose I/O. Distance can be calculated using the following equation.

$$\text{Distance} = \frac{\text{PHASE\_OUT}}{2^{16}} \times \frac{c}{2f_{MOD}} \text{meters}$$

where

- c = Speed of light
- f_{MOD} = 10 MHz, modulation frequency

3.5.2 Emitter Selection

Of the emitter options that are available, the following four were considered, VCSEL (Vertical-Cavity surface emitting laser), Laser Diodes, EEL (Edge-Emitting Laser), and LED (Light Emitting Diode). All of these devices are semiconductor devices that emit light, but have different structures, operating principles, applications, advantages and disadvantages, which will be reviewed in the following section.

3.5.2.1 Edge-Emitting Laser

Advantages of the Edge-Emitting Laser are that it has a high-power output, long lifetime, high temperature operation, and are highly reliable. Disadvantages are that they are only able to produce narrow beams, it suffers from high divergence, which makes it spread out over long distances, and they are relatively difficult to fabricate and make, making them more expensive to purchase.

Structure: Edge-emitting lasers typically have a single active layer located between two cladding layers. The device structure is designed so that the light generated in the active layer is emitted from the edge of the device.

Operating principle: Edge-emitting lasers also operate on the principle of stimulated emission, but the light generated in the active layer is emitted from the edge of the device.

Performance: Edge-emitting lasers have higher output power than VCSELs, but they require more current to operate and have a broader beam pattern. They are commonly used in applications such as fiber optic communication, printing, and materials processing.

3.5.2.2 Vertical-Cavity Surface Emitting Laser

Advantages of the VCSEL laser is that they have low power consumption, have a low threshold current, low cost, and are highly reliable. Disadvantages are that it has a limited power output, has a narrower beam divergence, and can be more sensitive to temperature changes. But given the advantages present in the VCSEL Laser, it is the clear candidate as it aligned with so many of our goals, such as low power consumption and low cost.

Structure: VCSELs are typically composed of multiple layers of semiconductor materials grown on a substrate. The active region is located between two distributed Bragg reflectors (DBRs) that are perpendicular to the substrate. The current injected into the device passes through a small aperture in the center of the top DBR and produces light that is emitted perpendicular to the substrate.

Operating principle: VCSELs operate on the principle of stimulated emission, in which light is generated when excited electrons in the active region of the device relax to a lower energy state and emit photons with the same energy and phase.

Performance: VCSELs typically have high efficiency, low threshold current, and can be modulated at high frequencies. They emit light in a narrow beam, making them suitable for applications such as optical communication, sensing, and imaging.

3.5.2.3 Laser Diode

Laser Diodes are semiconductor devices that produce coherent light through stimulated emission. The advantages that this device has is they have high power densities, meaning they can produce a lot of power in a little bit of space. Narrow beam, which gives them the ability to be very precise. Low divergence, so it can stay focused over long distances. Spectral Purity, meaning a narrow linewidth so they produce only the specific given wavelength of light. And high efficiency, converting a large percentage of the input energy into light. The disadvantage to this use case is that additional driver circuitry would have been required to use with our given sensor, making the design process more complicated than is necessary.

Structure: The structure of a laser diode usually consists of layers of semiconductor material, with an active region where stimulated emission occurs. The active region is cushioned between two layers of semiconductor materials that work as mirrors, reflecting the light back and forth through the active region to amplify it. The mirrors are created in a process called cleaving, which makes a flat and smooth surface at each end of the laser diode.

Operating Principle: When a voltage is applied to a laser diode, it causes electrons to flow from the negative terminal to the positive terminal. As the electrons move through the active region, they interact with positively charged holes, releasing energy in the form of photons. These photons are initially produced in a random manner, but as they travel back and forth through the active region, they interact with other excited electrons, causing them to emit photons in the same phase and direction. This process is known as stimulated emission and results in the production of coherent light.

Performance: Laser diodes offer several performance advantages over other types of lasers. One of the most significant advantages is their high power density. Laser diodes also produce a narrow beam of light, which makes them useful for applications where precision is required. Additionally, the beam of light produced by a laser diode has low divergence, which means it stays focused over long distances. Laser diodes also produce light that is very pure, which makes them useful for applications that require a specific wavelength of light. Finally, laser diodes are highly efficient, converting a high percentage of the input energy into light.

3.5.2.4 Light Emitting Diode

Advantages to LEDs is that they require low power consumption, are low in cost, have a long lifetime, and produce very little heat. Disadvantages include limited brightness, Limited color range, and they are also sensitive to changes in temperature. While LEDs are a good potential candidate due to its low power consumption, because of the limited brightness compared to the VCSEL laser, it makes it the inferior choice.

Structure: LEDs consist of a p-n junction formed by combining p-type and n-type semiconductor materials. The junction is sandwiched between two electrodes, and when a voltage is applied to the device, electrons and holes recombine, releasing energy in the form of photons.

Operating principle: LEDs operate on the principle of electroluminescence, in which light is generated when electrons and holes recombine at the p-n junction of the device.

Performance: LEDs have lower output power than lasers, but they are more efficient, require less current to operate, and have a wider beam pattern

Table 7. Emitter Comparison

Emitter source	**Brightness**	**Costs**	**Operating Principle**	**Beam quality**
Edge-Emitting Laser	Brighter than LED	Most expensive	Stimulated emission	Slightly wider beam than LD and VCSEL
Light Emitting Diode	Least bright	Least expensive	Electroluminescence	Broad beam, significant divergence
Laser Diode	Brightest	Moderately expensive	Stimulated emission	Narrow beam, minimal divergence
Vertical-Cavity Surface Emitting Laser	Brighter than EEL but less than LD	Moderately expensive	Stimulated emission	Narrow beam, minimal divergence

3.5.3 Detector Selection

There was a plethora of different Photodiodes that were researched, these include PIN, avalanche, Schottky, Metal-Semiconductor-Metal (M-S-M). and Schottky-barrier Photodiode. The sensor is responsible for detecting the photons that were used to make the time-of-flight calculations, a vital part in the process of the rangefinder.

3.5.3.1 PIN Photodiode

Advantages of the PIN Photodiode is that it is highly sensitive to light, has low noise, a wide spectral response range, low cost, low dark current, and are easy to use and integrate into circuitry. Disadvantages are that it has a slower response time compared to some other photodiodes, and has a lower gain compared to the Avalanche Photodiode

3.5.3.2 Avalanche Photodiode

The advantages to using an avalanche photodiode is that it is highly sensitive to light, has an internal gain mechanism which results in higher signal output, has a high speed and fast response time, a wide spectral response range, and is suitable for high-speed communication and sensing applications. The Disadvantage to this diode is that it suffers from higher noise levels compared to PIN photodiodes, has a more complex structure, which requires more voltage, and is more expensive compared to PIN photodiodes.

3.5.3.3 Schottky Photodiode

The advantages to the Schottky photodiode are that it has a fast response time, a high-speed operation and high frequency response. High efficiency in the ultraviolet and visible wavelengths, are small in size, and have low capacitance. The disadvantages in using Schottky Photodiodes is they have a lower sensitivity to light compared to PIN and Avalanche Photodiodes, have a limited spectral range, a higher dark current, and are more expensive compared to PIN photodiodes.

3.5.3.4 Metal-Semiconductor-Metal photodiode

Metal-Semiconductor-Metal Photodiodes have the advantages of a fast response time, high speed operation and high frequency response, a large active area to detect photons, low capacitance, and a low dark current. The disadvantages to this option are its low sensitivity to light, limited spectral range, and higher noise levels compared to PIN photodiodes.

3.5.3.5 Schottky-barrier Photodiode

Schottky-Barrier Photodiodes have the advantage of low noise levels, high efficiency for ultraviolet and visible wavelengths, low capacitance, and a fast response time. The disadvantages of the Schottky-barrier Photodiode are its limited spectral range, lower sensitivity to light, and is more expensive.

Table 8. Detector Comparison

Detector	Sensitivity	Costs	Response time	Noise
Schottky-barrier photodiode	Medium	Medium	Very fast	Low
Metal-Semiconductor-Metal photodiode	Medium	Medium	Very fast	Medium
Schottky Photodiode	Medium	Medium	Very fast	Medium
Avalanche Photodiode	Very high	High	Very fast	High
PIN photodiode	High	Low	Medium	Low

3.5.4 Lidar module selection

When selecting a LiDAR sensor for range finding, there are several factors that one should consider. One of the most important factors is the range of the sensor, which determines the maximum distance at which the sensor can accurately measure the distance to an object. The field-of-view of the sensor is also important, as it determines the area that the sensor can cover and the angle at which it can detect objects. Additionally, the points-per-second rate of the sensor is important, as it determines how quickly the sensor can generate data and how quickly it can update its measurements. Other important factors to consider when selecting a LiDAR sensor for range finding include the power consumption of the sensor, the size and weight of the sensor, and the ease of integration with other systems. The cost of the sensor is also an important consideration, as some high-end sensors can be quite expensive. Finally, the reliability and durability of the sensor are important factors to consider, as they can impact the performance and longevity of the sensor over time. Overall, selecting the right LiDAR sensor for range finding requires careful consideration of these and other factors, as well as an understanding of the specific requirements of the application. By carefully evaluating the various options and weighing the trade-offs between performance, cost, and other factors, it is possible to find a sensor that meets the needs of the application and provides accurate and reliable range finding data.

3.5.4.1 Velodyne VLP-16

The Velodyne VLP-16 is a high-end LiDAR sensor that is suitable for a range of high-performance scanning applications. It has a range of up to 100 meters and a wide field-of-view of 360 degrees horizontal and 30 degrees vertical, making it ideal for use in applications where long-range sensing and a large field-of-view are required. With a high points-per-second rate of up to 300,000, the VLP-16 is also suitable for high-speed scanning applications. It includes a software development kit (SDK) for easy integration, and its high-end specifications make it a popular choice for autonomous vehicle applications. However, the VLP-16 is a high-cost option compared to some other sensors, and its large and heavy form factor may not be suitable for small drones or robots. Additionally, its high-power consumption would have required a high-capacity battery or power supply.

3.5.4.2 Livox Mid-40

The Livox Mid-40 is a lightweight and compact LiDAR sensor that is suitable for small drones and portable applications. It has a range of up to 40 meters and a field-of-view of 38.4 degrees horizontal and 2.4 degrees vertical, making it ideal for applications that require a more limited field-of-view. With a low power consumption of only 4W, the Mid-40 is also suitable for battery-powered applications. It includes a software development kit (SDK) for easy integration and its lightweight and compact form factor make it an attractive option for small drones and other portable devices. However, the Mid-40 has a more limited field-of-view and lower points-per-second rate compared to some other sensors, which may limit its suitability for certain applications. Its lower cost and power consumption make it a more budget-friendly option compared to some other sensors, but it may not be suitable for high-end applications that require long-range sensing or a wide field-of-view.

3.5.4.3 TF mini-S

The desired device that meets the specifications listed previously in the sensor, emitter and detector section is the TFmini-S LiDAR Module. The device operates on the OPT 3101 time-of-flight sensor, uses a VCSEL laser at a wavelength of 850 nanometers, which makes it a class 1 laser, which is required for consumer safety. It also uses a PIN photodiode to the receive the reflected signal, meeting all the product selection done prior to this section.

This device has an operating range of 0.1 meters to 12 meters, with an accuracy of +/- six centimeters from 0.1 meters to six meters, and +/- 1% from six meters to 12 meters. This device also has a distance resolution of 1 centimeter, a frame rate of 100 Hertz, and an ambient light immunity of 70 Klux.

The devices electrical parameters are that it has a supply voltage of 5V, an average current less than or equal to 140 milliamps, power consumption less than or equal to 0.7 Watts, a peak current of 200 milliamps, and can use the UART or I2C as the communication interface.

The dimensions of the Housing are 42mm*15mm*16mm (L*W*H), with a weight of around five grams, with its small size, light weight and low power consumption, and low cost, it was the ideal candidate for our rangefinder application. Below is the TFmini-S LiDAR module that was used.

Figure 9. TFmini-S LiDAR Module

3.6 Motor Technology Comparison

In this section we will discuss and compare the following 3 motors: Brushed DC Motor, Servo motor and stepper motor; and their functions to evaluate how well they would suit their role for the projector. The motors were used to automatically focus the image by adjusting the lens inside the projector. When adjusting a lens to improve the clarity of what you are observing you want to make minor adjustments to make sure that what you are viewing is at optimal clarity. From this the most important factor we looked for from the motor is turn control, which can be measured in pole count, so we could have the most precise incremental adjustments to avoid overshooting the desired lens position.

Some other factors we used for motor selection are power consumption cost and efficiency. When comparing these factors, we ranked them instead of using specific values due to the fact that in this section we are just comparing the different types of motors, but within each of these types of motors the values of power consumption, efficiency, cost and turn control will vary. Therefore, it is better just to compare the motors in terms of their general characteristics.

3.6.1 Brushed DC Motor

A Brushed DC Motor is one the most popular components in many RC projects because of its simple implementation. The motor works by using electrode brushes inside the motor to charge a coil on the rotor when in contact with the commutator. The coil is then attracted to one side of the permanent magnet and rotates to it until the brush is no longer touching the coils commutator and comes into contact with next coils commutator and then repeats the process. This design allows for a high starting torque for the motor but for this project we were more focused on the control within each rotation, so we would have needed a motor controller if we used a brushed dc motor. When compared to the stepper and servo motors it falls short in turn control and efficiency because of its relative simplified design compared to the other two; but when it comes to power consumption and cost the brushed motor is the best option. With a motor controller, we believe the brushed motor might be able to adjust the lens well enough to focus the image and would have saved us money and power in the process, making it viable option.

3.6.2 Stepper Motor

Regarding what we needed the motor to do in the projector right off the bat the stepper motor seemed like the best option since the stepper motors move in discrete steps that the user can adjust. The stepper motor sends current through coils surrounding a magnet rotor and these coils attract the one side of the magnet causing the rotor to rotate a certain number of degrees depending on which coils are charged. The stepper motor is great at controlling speed, having precise positioning and repeatability of movement. These qualities made it a lot easier for us to properly adjust the lens to the most precise clarity possible, improving our picture quality. Although there would be many pros if we chose the stepper motor, some things to consider are outside of turn control the other two motors out preform the stepper motor in all the other characteristics even though turn control is the most important factor.

3.6.3 Servo Motor

Out of the three motors, the servo motor was the most well-rounded option. The stepper motor may have better turn control and the brushed motor may be more economic, but the servo motor is the best combination of the 3. It draws less power than the stepper motor, has much better turn control than the brushed motor and is more efficient than both. However, the most attractive quality of the servo is unlike the other two motors the servo motor does not need drivers to control it. The motor inside the servo is similar to a regular dc brushed motor, except that it also has a built-in integrated circuit inside it that uses feedback to communicate a measured value (voltage, current, positioning, velocity etc.) to the control module. The only drawback to the servo is the unit price more expensive than the other two but when considering that each motor will most likely be within the \$1 to \$5 price range the cost would not have been as much of a drawback.

Table 9. Summary of Motor Technology Comparison

Motors	**Power Consumption**	**Costs Ranking**	**Turn Control**	**Efficiency**
Brushed DC Motor	Lowest	Lowest	Lowest pole count	Lowest
Stepper Motor	Highest	2nd Highest	Highest pole count	2nd Highest
Servo Motor	2nd Highest	Highest	2nd Highest pole count	Highest

3.7 Stepper Motor Selection

The motor we used for our projector is a stepper motor. We chose the stepper motor because all options are affordable, and the stepper motor had the best turn control. A stepper motor is a motor that moves a full rotation in discrete steps. Like explained before inside a stepper motor there is a magnet rotor surrounded by a certain number of coils. When a coil is charged it attracts one side of the magnet and moves to rotor toward the coil which causes the motor shaft to turn. You then can adjust each step by adding more coils or charging multiple coils making the rotor move in the rotor move in smaller steps.

For determining which stepper motor to select, a few things to consider are motor size, a good indicator of the amount of power the motor delivers, and step count/gearing, which determines the number of steps per revolutions. These are important factors because they will determine the speed, torque, and resolution that the stepper motor will be able to provide. Another thing to consider is the type of stepper motor to use. There are two main types of stepper motors: unipolar and bipolar and below we will compare each type of stepper motor as well as compare the purchasable motors from each type to explain why we selected what we did for the projector.

Unipolar – In the unipolar configuration the current flows through the coils in one direction using transistor circuitry. Each of the coils in the motor is assigned to one direction of current and because of this the unipolar motor can only use half of the coils at the same. Unipolar motors can come in a variety of phases and voltage ratings but the one we chose to evaluate is the 28byj-48 unipolar stepper motor manufactured by MikroElektronika from Digi-key Electronics. This stepper motor operates at 5 volts and has 4 phases. One of the main advantages of this stepper motor is that it is arduino compatible alongside the ULN2003 motor driver. This was important considering we used the Arduino mega development board for our project, so having a stepper motor that is known to be compatible would have helped us integrate the motor a lot smoother and provide us with more specific resources to our situation if we ran into problems. Below is a chart that summarizes the important specs for this unipolar motor.

Table 10. Unipolar Stepper Motor Specs

Voltage:	5 Vdc		Step Angle:	5.625 deg /64
Resistance:	50Ω		Weight:	33.3 g
Phase:	4		Insulation Grade:	A
Price:	$8.00		Size:	34*18*10 mm

Bipolar - The bipolar stepper is called bipolar because unlike the unipolar motor it charges the phases in both directions. The current in each coil of the bipolar motor can flow in both directions utilizing all coils in the motor. The bipolar motor uses H bridge circuit to perform these functions and the only drawback of the Bipolar compared to the unipolar is that it is usually more expensive because of the more complicated design required to reverse the current to step the motor. The bipolar motor we will be evaluating is the *24BYJ-48* bipolar stepper motor manufactured by Seeed Technology from Digi-Key Electronics. This also is a 4 Phase stepper motor that operates at 5 volts like the unipolar motor, however this motor has half the reduction ratio (Unipolar: 1/64, Bipolar: 1/32) which means it has half the total steps. Below is a chart that summarizes the important specs for this Bipolar motor.

Table 11. Bipolar Stepper Motor Specs

Voltage:	5 Vdc		Step Angle:	5.625 deg / 32
Resistance:	25Ω		Weight:	35 g
Phase:	4		Insulation Grade:	A
Price:	$4.50		Size:	32*25*20 mm

Figure 10. 28BYJ-48 Stepper Motor

The stepper motor we ended up choosing for our projector is the *28BYJ-48 5-volt 4 phase Stepper Motor* (displayed in image above). We chose this motor because it had more total steps than the bipolar motor and it was more compatible with the development board we used. From the two charts we see that the specifications are nearly identical except for the price, which we were willing to pay the 3.50 extra for. From the image of the motor below you can see there are 5 wires: red, orange, yellow, pink, and blue. The red wire is for the 5 volts to power the motor and the other colors represent one of each of the 4 coils. In the next sections we will look at the motor driver and its component

3.7.1 Motor Driver

The motor driver we used to control the stepper motors is the 4 Phase ULN2003 Stepper motor driver board. This board is compatible with Arduino and is the board most used with the 28byj-48 stepper motor we selected. We use a motor driver because the stepper motor consumes a significant amount of power which could have been too demanding for the Arduino to safely handle. To use the controller board, you need to:

- Connect the stepper motor outputs to the white block on the controller board

- Use the IN pins on the controller board to connect to the Arduino GPIO

- Connect the power inputs to an external power supply (not Arduino 5-volt pin)

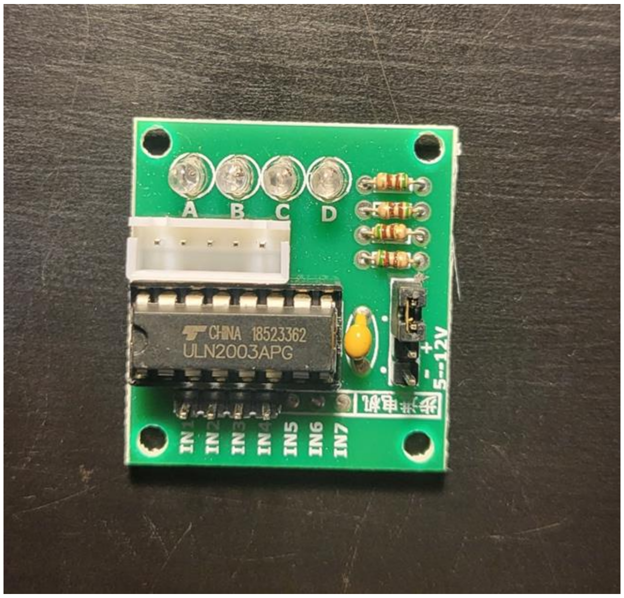


Figure 11. ULN2003 Stepper Motor Driver

LEDs: The lights at the top of the board labeled ABCD are step state LEDs used to display the channel which is currently active.

Stepper Motor Connection: The white block on the board is used to connect the motor controller with the stepper motor.

PINS: The board has 7 input pins (IN 1-7), two voltage pins and two on/off pins. The pins IN 1-7 are for microcontroller connection and are used to drive the motor. The two voltage pins (bottom two pins next to 5-12) are for connection of external (not Arduino) power supply of 5 to 12 volts.

ULN2003: The black chip on the motor driver that says ULN2003 is an integrated circuit developed by Texas Instruments. It is a high voltage/current NPN transistor with 7 drivers per package.

3.8 Development Board Technology Comparison

A development board is a small computer on an integrated circuit which contains a processor, memory, and input/output peripherals. They are programmed using different specialized programming languages and are used to control a number of different devices and systems. For this project, the microcontroller acts as the central hub in order to control the various different components like the power source, servo motor, rangefinder, microphone, etc. The different functionalities needed for this project could have been accomplished using most microcontrollers available, however it was still important to compare several options in order to select the microcontroller that worked best for us. Some of the most important specifications that we needed to consider when comparing the different options are the cost, size, and power consumption. It is also good to consider the software development languages that are supported, as well as the number of general-purpose input/output pins that are provided for connecting to different components. Below is a table that outlines the different development boards that we identified as potential options.

Table 12. Summary of Development Board Technology Comparison

Development Board	Costs	Size	Maximum Clock Speed	Power Consumption	Languages Supported	GPIO Pins
Arduino Mega R3	$40-$50	102 mm x 53 mm	16 MHz	20 mA – 200 mA	C++	54
Arduino Uno R3	$20 - $30	69 mm x 53 mm	16 MHz	20 mA – 100 mA	C++	14

MSP430 Launchpad	\$20 - \$30	69 mm x 51 mm	25 MHz	1 µA – 20 mA	C and C++	16
Raspberry Pi 4	\$40 - \$50	86 mm x 57 mm	1.5 GHz	600 mA – 1200 mA	C, C++, and Python by default	26

3.8.1 Arduino Mega R3

The first development board option that we decided to research was the Arduino Mega R3. The Arduino Mega R3 has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It also provides plenty of processing power and memory with 256 KB of flash memory and 8 KB of RAM. The processing power and numerous digital input/output pins make the Arduino Mega R3 a great microcontroller to tackle almost any complex project.

There are quite a few advantages that we considered to using the Arduino Mega R3 development board. One of the largest advantages of the Arduino Mega R3 is the 54 digital input/output pins that it provides. This is far greater than any of the other microcontrollers that have been considered and was more than enough to connect all the components that we needed for our Autofocusing LED Projector. Another advantage of the Arduino Mega R3 is the plentiful memory and processing power provided (second only to the Raspberry Pi 4). There are also many libraries and modules, as well as a lot of community support that helped to make the software development process much easier for us. Additionally, one more great advantage of using the Arduino Mega R3 to consider is that one of the team members already had one, so we saved some money on our budget.

On the other hand, there are also several downsides we had to consider when using the Arduino Mega R3 development board. Although the large number of input/output pins is a bonus, it also makes the software development process more complex. Another major disadvantage that we considered is the increased power consumption when compared to the other microcontroller options that we have looked at. One more disadvantage with using the Arduino Mega R3 is that it is the largest of all of the microcontrollers we researched, so it takes up more space in our design. One of the disadvantages that we didn’t have to consider is its increased cost compared to the other options, since the team already had one that we used.

3.8.2 Arduino Uno R3

Another one of the options that we decided to have a look at was the Arduino Uno R3. The Arduino Uno R3 is a versatile and popular development board that is widely used by hobbyists and professionals alike for a variety of electronic projects. The Arduino Uno R3 has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. Its compact size and numerous features, including a number of both digital and analog input/output pins, make it an ideal choice for experimenting, building prototypes, and ultimately implementing electronic circuit projects.

There are several advantages we consided that come with using the Arduino Uno R3 for the Autofocusing LED Projector. One of the major advantages of the Arduino Uno R3 is that it is a very popular and relatively inexpensive development board that is both open source and easy to use. It provides many various libraries and modules that can be used in order to accomplish a wide range of capabilities. Additionally, the Arduino Uno is the most used and documented board of the whole Arduino family, so there is a large online community with plenty of examples and support.

On the other hand, there are also a number of downsides when it comes to using the Arduino Uno R3 for the Autofocusing LED Projector. The most important disadvantages that were considered include limited memory and processing power, a limited number of I/O pins, and limited power output. These are all very important to consider when designing a project, although it should have more than met the needs of our Autofocusing LED projector. One more large disadvantage that needed to be considered is that it is limited to using the Arduino IDE for software development.

3.8.3 MSP430 Launchpad

The MSP430 Launchpad is another option that we looked into. It is another relatively inexpensive development board that is designed to be easy to use. The MSP430 Launchpad also includes a USB interface for programming and debugging, as well as a number of input/output pins and peripherals, such as LEDs, pushbuttons, and a UART interface.

There are a few advantages that can be considered when working with the MSP30 Launchpad for the Autofocusing LED Projector. The largest advantage of the MSP430 that we took into consideration is its extremely low power consumption when compared to the other development boards that were considered. Another advantage to using the MSP430 Launchpad that we took into consideration is that the MSP430 has been used in a few of the ECE courses we have been required to take, so everyone was at least somewhat familiar with how to use it.

On the other hand, one of the major downsides of the MSP430 Launchpad is that it can be much more difficult to program in a lot of scenarios when compared to the other microcontrollers we have looked at. Additionally, there is not as much community support and helpful libraries for us to use in the software development process when compared to other options we researched. Another one of the other large drawbacks of using the MSP430 Launchpad to consider is its limited memory and processing power.

3.8.4 Raspberry Pi 4

One more option that we investigated was the Raspberry Pi 4. The Raspberry Pi 4 is an extremely powerful and versatile single-board computer that is suitable for a wide range of applications and projects. It is the latest addition to the Raspberry Pi family and features a more powerful processor and memory capacity when compared to the other development boards we have looked at. Even though the Raspberry Pi 4 is by far the most powerful development board of the options that we have looked at, it was still important that we looked at the other aspects involved with using this for our project.

There are a number of great advantages that were taken into consideration when using the Raspberry Pi 4 for the Autofocusing LED Projector. Although this is the most expensive of the options, it provides the most features and flexibility. It has much greater memory and processing power than all the other options we have looked at, which would have given us the flexibility to implement just about anything that may have been needed for this project. Additionally, it supports a number of operating systems and programming languages. By default, it supports C, C++, and Python, however nearly any programming language can be used by installing the respective compiler or interpreter. This would have given us a lot of flexibility in order to develop the software in whatever way we are most comfortable. Additionally, like the Arduino microcontrollers that we have looked at, the Raspberry Pi has a ton of examples and community support that would have aided us in the software development process.

Even though the Raspberry Pi 4 has a lot of great advantages, there are also a couple of major disadvantages that we needed to take into consideration when using it for the Autofocusing LED Projector. The greatest disadvantage being that it consumes a lot more power than the other options, which could have become an issue. It is important to consider that the Raspberry Pi 4 would likely have been overkill for our Autofocusing LED Projector, as it is able to do much more than what we needed from a development board for this project. Another thing to take into consideration is that the Raspberry Pi 4 is a bit more expensive than the other development boards we have looked at.

3.9 Development Board Selection

As discussed in the previous section, the main specifications that we looked at for our development board selection were the cost, size, power consumption, the software development languages that are supported, as well as ensuring that there were enough general-purpose input/output ports to control all of our components. Ultimately the largest contributing specification that influenced our selection was the cost of the development board. As a result, we decided to use the Arduino Mega R3 development board that our group already had available to us. This helped to free up some room in the budget, which allowed us to allocate some more money elsewhere. Additionally, it more than met the requirements needed for our project.

Not only was the cost for the team $0, but the Arduino Mega R3 has 54 digital input/output ports, which was more than enough to connect all of the components needed for the Autofocusing LED Projector. Additionally, the Arduino Mega R3 also provided more than enough processing power and memory for our project, with 256 KB of flash memory and 8 KB of RAM. In addition to the plentiful processing power and memory, the community support for Arduino is vast and there were plenty of libraries and examples that we were able to use in order to help us along in the software development process. The only major downsides that we faced with this selection is the added complexity of the software given the extremely large number of digital input/output pins provide, and the fact that the Arduino Mega R3 is relatively large in size when compared to the other development boards that we researched.

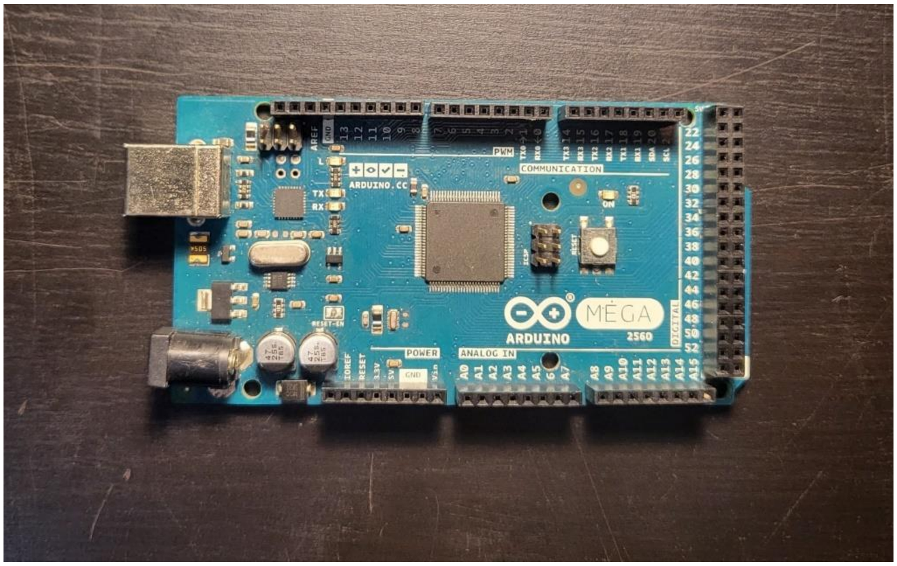


Figure 12. Arduino Mega R3 Development Board

The Arduino Mega R3 development board that we used for our Autofocusing LED projector is shown above in Figure 13. As you can see there are numerous input/output ports that were more than enough to connect all of the necessary components for our project. The Arduino Mega R3 measures in at with a width of 102 mm and a height of 53 mm. This makes it quite large for a microcontroller, however there wasn’t any issue including it within our projector system as it was still a relatively small component. Overall, the Arduino Mega R3 met all the requirements that we were looking for in our development board.

3.10 Fan Technology Comparison

In this section, we will be looking at and comparing the different options we have for cooling fans. It is very important that we chose a fan that ensured that all of the internal components of the entire projector system were kept at a reasonable temperature. There are numerous factors that needed to be taken into consideration when choosing the right fan, including:

Size: Obviously one of the first factors that need to be considered when looking for a fan for the Autofocusing LED Projector is the size of the fan itself. The fan needed to be large enough to ensure all the internal components of the projector system are kept cool, but also needed to be small enough that it did not take up an unreasonable amount of space in our system.

Noise Level: Another very important and obvious factor that we needed to take into consideration when selecting a cooling fan for the Autofocusing LED projector is the amount of noise the fan is going to make. Given that the projector is going to be used to display videos and movies, presumably in a quiet room, it was crucial that the fan wasn’t too loud. If the fan was too loud and drowned out the video or movie audio, it would have negatively impacted the overall user experience.

Airflow: The airflow was another crucial factor that we needed to consider when researching cooling fans for the Autofocusing LED Projector. The airflow rating of cooling fans is typically measured in CFM (cubic feet per minute). It was very important that we selected a fan which had a high enough CFM rating to keep the entire projector system cool.

Power Consumption: Another important factor that was taken into consideration when selecting the fan for the Autofocusing LED Projector is the amount of power the fan would consume. It was crucial that the fan consumes as little power as possible, to avoid the fan having the complete opposite effect and potentially overheating the projector.

Costs: The cost of the fan is one more factor that needed to be taken into consideration while selecting the cooling fan for the Autofocusing LED Projector. Given that we were working on a limited budget, it was very important that we selected a cooling fan which met all of the previously listed requirements, while still being within our price range.

Below you will see a table that contains an outline of the general comparison of all the different cooling fans that we have researched for use in our Autofocusing LED Projector.

Table 13. Summary of Fan Technology Comparison

Fan	Costs	Size	Noise Level	CFM	Power Consumption
Pure Wings 2 120 mm	$10 - $15	12 cm x 12 cm x 1cm	19.2 dB	87 CFM	1.1 W
Multifan S4	$15 - $20	14 cm x 14 cm x 1 cm	18 dB	57 CFM	1.5 W
Pure Wings 2 80 mm	$10 - $15	8 cm x 8 cm x 1 cm	18.2 dB	45 CFM	1.8 W

3.10.1 Pure Wings-2 120 mm

The first cooling fan that we had a look at for our Autofocusing LED Projector was the Pure Wings 2 120 mm. The Pure Wings 2 120 mm is an ultra-quiet cooling fan commonly used for cooling desktop computers. Pure Wings 2 120 mm is powered using a 3-pin connection and consists of 9 airflow-optimized fan blades that are designed to reduce the noise level.

There are various advantages that were taken into consideration regarding using the Pure Wings 2 120 mm cooling fan for our Autofocusing LED Projector. The largest advantage of using the Pure Wings 2 120 mm is the fact that it provides an airflow of 87 cubic feet per minute which is by far the most airflow out of all the fans we have looked at. In addition to providing the most airflow, the Pure Wings 2 120 mm also has the lowest wattage of all the fans that we have looked at with only 1.1 watts. Another advantage of using the Pure Wings 2 120 mm is that even though it was the loudest of all of the cooling fans that we looked at, it was still very quiet with a noise level of 19.2 dB. One more advantage of the Pure Wings 2 120 mm is that it is by far the most powerful fan that we have looked at, even though it is considerably smaller than the Multifan S4.

Although there are a lot of great advantages to using the Pure Wings 2 120 mm, there were still a number of disadvantages that we needed to take into consideration. The largest disadvantage of using the Pure Wings 2 120 mm for our Autofocusing LED Projector is that it was the loudest of all the cooling fans that we looked at, with a noise level of 19.2 dB. Even though this was only slightly louder than the other cooling fans we have looked at, it was very important to take into consideration given the possible effects on the user experience. In addition to being the loudest fan, the Pure Wings 2 120 mm was also considerably larger, measuring at 12 cm x 12 cm x 1 cm, than the smallest fan that we looked at (it's little sister the Pure Wings 2 80mm).

3.10.2 Multifan S4

The second cooling fan that we had a look at for our Autofocusing LED Projector was the AC Infinity Multifan S4. The Multifan S4 is an extremely quiet cooling fan that is applicable to a variety of different kinds of electronics. It comes with a six-foot power cord which is powered using a USB connection. The power cord also has an inline controller that would have allowed us to choose the fan speed using three different settings: low, medium, and high.

There are a few advantages that were taken into consideration when considering using the Multifan S4 for our Autofocusing LED Projector. The largest advantage being that it was the quietest of all the fans we looked at (although not by much), with a noise level of only 18 dB. One more advantage of potentially using the Multifan S4 for our project was the relatively low wattage at only 1.5 watts.

On the other hand, there were also a number of disadvantages that we needed to consider when using the Multifan S4 for our Autofocusing LED Projector. The first disadvantage to consider is the fact that it is the largest of all the fans we have looked at, measuring 14 cm x 14 cm x 1 cm. In addition to being the largest cooling fan that we looked at, the airflow is rather lackluster at only 57 cubic feet per minute. When comparing to the other two fans which are considerably smaller, the Multifan S4 produces only slightly more airflow than the smallest fan (Pure Wings 2 80 mm) that we looked at, and significantly less airflow than the mid-sized cooling fan (Pure Wings 2 120 mm) that we looked at.

3.10.3 Pure Wings 2 80 mm

One more cooling fan that we considered using for the Autofocusing LED Projector is the Pure Wings 2 80 mm. The Pure Wings 2 80 mm is another ultra-quiet cooling fan commonly used for cooling desktop computers. Pure Wings 2 80 mm is very similar to the Pure Wings 2 120 mm that we have also looked into using for our Autofocusing LED Projector. The Pure Wings 2 80 mm is powered using a 3-pin connection and consists of 7 airflow-optimized fan blades that are designed to reduce the noise level.

There are a number of advantages that we took into consideration when considering the Pure Wings 2 80 mm for use in our Autofocusing LED Projector. The largest advantage of using the Pure Wings 2 80 mm is its very small size relative to the other cooling fans we have researched, measuring 8 cm x 8 cm x 1 cm. This was an important factor considering we wanted to make the Autofocusing

LED Projector as small as possible. Another advantage of using the Pure Wings 2 80 mm that was considered is that it is very quiet with a noise level of just 18.2 dB. This noise level is just slightly higher than the quietest fan that we looked at (Multifan S4) but is still low enough to not have a negative impact on the user experience. One more advantage of using the Pure Wings 2 80 mm that we considered is that even though it is the smallest of the cooling fans we have looked at, it still provides a reasonable amount of cooling with an airflow of 45 cubic feet per minute.

Although there are a lot of great advantages to using the Pure Wings 2 80 mm, there were still a couple of disadvantages that we needed to take into consideration. The largest disadvantage of using the Pure Wings 2 80 mm is that it provides the least amount of cooling with an airflow of 45 cubic feet per minute. One more disadvantage of using the Pure Wings 2 80 mm is that even though it provides the least amount of cooling, it still has the highest wattage with 1.8 watts.

3.11 Fan Selection

As we discussed in the previous section, the main specifications that we were looking at in order to select the right cooling fan for the Autofocusing LED Projector were size, noise level, airflow, power consumption and costs. Ultimately the factor that had the greatest impact on our decision for the cooling fan was the airflow and power consumption. For this reason, we decided that the cooling fan we decided to use for the Autofocusing LED Projector is the Pure Wings 2 120 mm. The Pure Wings 2 120 mm provides an the most airflow out of all the fans we looked at with 87 cubic feet per minute, while also using the least amount of power compared to the other fans with only 1.1 watts. This helped us to avoid overheating and ensured that all the internal components of the Autofocusing LED Projector are kept at reasonable temperatures. An image showing the Pure Wings 2 120 mm is provided below.

Figure 13. Pure Wings 2 120 mm Cooling Fan

As you can see in the figure above, the Pure Wings 2 120 mm cooling fan measures at 12 cm x 12 cm x 1cm. This was a good size for the Autofocusing LED Projector and the fan fit into the system without any issues. The design of the fan consists of 9 airflow-optimized fan blades that produce an airflow of 87 cubic feet per minute. This was more than enough to keep the internal components of the Autofocusing LED Projector from overheating. In addition to the great airflow, the fan blades are designed to reduce the noise level as much as possible. The Pure Wings 2 120 mm has a max noise level of just 19.2 dB at its fastest speed. Although this makes it the loudest of all the fans we have looked at, it is not by much and the fan is still very quiet. 20 dB is rated equivalent to the sound of “whispering from 5 feet away”. Therefore, with our cooling fan having a max noise level of just 19.2 dB, we found that the noise from the fan did not negatively impact the user experience.

3.12 Microphone Technology Comparison

In this section we will discuss the three main microphone types that were considered for this device. Focusing on parameters such as sound quality, cost, lifespan, power, durability, and maintenance. The types of microphones compared are dynamic microphones, condenser microphones, and ribbon microphones. Each type has a different method for converting sound into electrical signals, thus interpreting different levels of audio quality, but can be further specified by the direction(s) they can pick up audio from, or their “polar pattern”. The three types of polar patterns are cardioid, omnidirectional, and bi-directional.

3.12.1 Dynamic Microphone

Dynamic microphones are the cheap and reliable standard of microphones. They have a capsule with a conductive coil inside of it. When vibrated by sound waves, the coil moves in a magnetic field, creating electrical voltage. Dynamic mics tend to need louder audio input than ribbon or condenser to operate, but because of this they are durable and less likely to distort noises at higher sound pressure levels.

3.12.2 Condenser Microphone

Condenser microphones have a thin membrane attached to a metal plate, with both being charged and having attached electrodes. When vibrated by sound waves, the distance between the membrane and the plate changes, creating small electrical voltage. The more precise voltages changes mean that condenser mics are excellent at reproducing high-frequency audio, although they do distort especially loud sounds. The main downside is that they generally need an external power source, and even before buying that they are more expensive than dynamic microphones. Most phones use condenser microphones, as they can use the phone’s battery as their power source.

3.12.3 Ribbon Microphone

Ribbon microphones are a type of dynamic microphone, but instead of a conductive coil, they use a thin ribbon of some conductive material between poles of a magnet or between two magnets. Sound waves cause the ribbon to vibrate in this magnetic field, creating an electrical charge. The delicacy of the ribbon causes it to be the best microphone for balancing audio, also known as equalization, meaning that they pick up the most detailed audio and can reproduce that sound in a way that sounds clear and natural to human ears. However, having such a delicate ribbon means that they are much easier to break, with something as simple as a very loud sound being able to cause the ribbon to vibrate too much and snap. Like condenser microphones, most types of ribbon microphones are expensive and require an external power source.

3.12.4 Polar Pattern

All three types of microphones can have one of the three aforementioned polar patterns. Cardioid microphones excel at picking up sound from one direction, the front of the capsule, while picking up less sound from the sides and almost none from the back. This is useful when you want to cut out the ambient noise of the environment, or more generally any situations where you only want to focus on one of multiple sounds.

An omnidirectional microphone is the exact opposite, recording sounds from all directions. This generally needs a more specific recording setting where the goal is to record everything happening. For example, an omnidirectional microphone could be used to record all the sounds in nature from the river flowing on your left, the birds tweeting behind you, and the bugs buzzing on your right.

Bi-directional mics pick up audio from two directions, the sides of the capsule, at equal levels but almost no sound from the front or back of the capsule. Most ribbon microphones are bi-directional simply by the nature of their design. Bi-directional microphones have more specific uses than cardioid or omnidirectional microphones, as wanting to record one sound or every sound applies to most situations, but wanting to record exactly two sounds together is rarely used outside of the music industry.

Table 14. Summary of Microphone Technology Comparison

Microphone Type	**Audio Quality**	**Costs**	**Sensitive to external conditions**	**External Power Required**
Dynamic	Lowest Less likely to distort loud noises	\$15-\$25	No	No
Condenser	Middle Can distort loud noises	\$25-\$35	No	Yes
Ribbon	Highest Can snap due to loud noises	\$50-\$65	Yes	Yes

3.12.5 Microphone Part Selection

For the goals of this project, we decided that the best choice to go with was an omnidirectional condenser microphone. In choosing the polar pattern of the microphone, the decision was between cardioid and omnidirectional. We had to choose if we wanted an omnidirectional polar pattern that risked the microphone picking up commands from whatever audio it was playing, or force the users to only be able to give voice commands from the one side of the projector that the capsule of a cardioid microphone would face. We decided that an omnidirectional microphone was the best choice for a few reasons. If voice commands were only consistent for one direction, even if specified in a user manual or instructions of some sort, users might not realize this and assume that the voice command feature itself is inconsistent. In addition, a common scenario to use this product would be to show multiple people something from your phone without them having to crowd around such a small screen. This, and many other scenarios where more than 2 or 3 people are watching the projected image/video at the same time, would mean they would be spread around the room or other area the projector is in. There would be no one correct direction for a cardioid microphone to face if a voice command could potentially come from any direction from any of the multiple viewers. The downside to choosing an omnidirectional microphone is the risk posed by hearing the projector's own audio output. If a character in a movie said "turn off" and the projector heard this and turned off, then voice commands go from a novel feature to a risk that detracts from the product. We addressed this twofold; first of all, we added a command that the projector has to hear before it executes other commands. Instead of saying "turn off", a user must say "Hey projector" first to ready the projector for an incoming command to follow, and then say "turn off" to turn the projector off. Secondly, the speaker was pointed away from the projector so that audio is sent towards people around the projector, so the overall risk of any audio played accidentally setting off a voice command was.

The main factors considered when choosing the type of microphone were audio quality and durability. Ribbon was immediately out due to its relatively fragile nature, so it was between condenser and dynamic microphones. Energy consumption was initially thought to be a factor, but we were already connecting this microphone to the microcontroller which will be connected to our 12V battery power source, so as long as it remained under 12V the condenser microphone's extra power consumption was a negligible factor in deciding between the two. Both are durable in different ways; since dynamic microphones relate to the velocity of a sound wave, they are more sensitive to temperature and humidity, and since condenser microphones have more precise parts, they are slightly more prone to physical damage from things like being dropped or bumped against a wall. It is important to note that these are all generalizations, there are condenser microphones that are more physically resistant than dynamic microphones, and there are dynamic microphones that produce higher audio quality than condenser microphones. Thus, it mostly came down to the specifics of the available microphones in our price range. Filtering by "Omnidirectional Microphones with USB Connection", as we originally planned to connect to the Microcontroller via USB, we used the above parameters to narrow our selection down to the following options: The Blue Yeti Electret Condenser, the Kaysuda USB Speaker Phone 360, and the Cheers.US K3 Omnidirectional Microphone.

3.12.6 Blue Yeti Electret Condenser

The Blue Yeti boasts some very impressive features and statistics, that led to them being the #1 bestselling USB microphone from April 2019 to March 2020 (based on independent sales data). The Blue Yeti has very good sound quality compared to other, non-studio microphones, but one of the major factors contributing to its commercial success is its ability to change its polar pattern. It has dial knobs that let you not only adjust the gain, but also the polar pattern that the Blue Yeti will pick up. This was especially useful for online content creators who mostly used its cardioid pattern to pick up a single voice clearly, but could switch to bi-directional if they had a guest speaker, and could switch to omnidirectional if they were doing a podcast or similar activity that involved recording multiple people. However, their popularity in the online world has meant that every possible flaw was discovered and discussed. A major failing of the Blue Yeti is its durability, the USB connector is so easy to break that many technical repair shops are familiar with and ready to replace that specific port on this specific microphone. Another issue is its omnidirectional status; while it seems like a valuable feature to be able to switch polar patterns, our projector only needs the omnidirectional pattern, and the Blue Yeti is specifically built for cardioid. Its audio quality in the other patterns is noticeably worse. In addition to the issues with different polar pattern, the Blue Yeti is quite pricey averaging around $100, meaning that despite its great audio quality, it’s very expensive and quite a bit outside of our price range for this project.

3.12.7 Kaysuda USB Speaker Phone 360

The Kaysuda USB Speaker Phone 360 Omnidirectional Microphone is, as the name suggests, a dedicated omnidirectional microphone and speaker. While it would have been nice to have the speaker and the microphone be one part to save on physical space inside the projector, we were not pressed for space. Having to interact with and program one object as both the speaker and microphone seemed like it would be much more difficult for both the hardware side of connections and the software side of programming but using it just for its microphone features shouldn’t have been an issue. At 12cm by 12cm by 3.5cm it would have been by far be the largest single component in our projector, likely not detracting from our goal of a small lightweight projector by too much, but still was a factor worth considering. After watching demonstrations of the product, I can conclude that its speaker audio quality is good, so despite being unable to find a clear answer online I assumed its microphone audio input quality is comparable and thus would have been good for our project. The major deterrent is its complexity. We didn’t need all the fancy bells and whistles that came with it such as a mute button and volume controls, since it would have been inside the projector box and thus those buttons would only be able to be pushed in the first place if we redesigned around them. However, ignoring them is dangerous as there’s always the risk of a user bumping the box in such a way that somehow the mute button is pressed, and now voice commands no longer function at all unless the projector can somehow be bumped again in the same way to push the button again. Overall, not a bad choice, but its complexity and large size detracted from our goals, in addition to the $50 price tag being a bit out of our price range, but low enough to consider if no other options were available.

3.12.8 Cheers.US K3 Omnidirectional Microphone

The Cheers.US K3 Omnidirectional Microphone is a condenser microphone measuring 7cm by 7cm with a height of 1.15cm, so it did not infringe on our goal of a lightweight and portable projector. One of its more alluring features was its audio pickup range, up to 2m. Many of the mics available, while omnidirectional and with good audio quality, were intended for personal use and thus did not perform well from such a great distance. This way, voice commands could be interpreted from a comfortable distance away from the projector. With an input voltage of 5V, it was well below our power supply's 12V output. It also came with a built-in sound card and intelligent noise reduction, which helped mitigate the risk of the projector accidentally performing a voice command by processing audio that it is outputting. It is quite durable, being made of metal and ABS (Acrylonitrile Butadiene Styrene), a thermoplastic polymer that is resistant to heat and electrical characteristics while remaining physically durable, leading it to being used as a substitute for metal in hard hats, helmets, and certain car parts. While specific audio quality of Cheers.US K3 Omnidirectional Microphone was worth scrutinizing at its cost of only $11, it was hard to determine without hands-on testing and we were confident that due to it only needing to properly interpret a few commands, and the user never hearing the quality of the interpreted audio, this was the best choice for our project, keeping in mind our goal of an under $500 build cost.

Figure 14. Cheers.US K3 Omnidirectional Microphone

3.13 Speaker Part Selection

Since we used the Liquid Crystal Display Printed Circuit Board Driver, we had an HDMI connection to provide video and audio transfer to the LCD from the connected source. However, the PCB did not inherently have any way to output that audio, and therefore needed external speakers. The PCB did not inherently have an earphone jack, so we planned to solder the part of the PCB where the audio comes out of. However, in that process we were unsuccessful, so we instead decided to use Bluetooth speakers and have users connect to them via another

Bluetooth compatible device such as their smartphone. It did run slightly contrary to our goal of the projector being simple and portable as it added complexity, but it is a reasonable amount and pretty much the only way we could implement audio at that point in the design.

We'll describe the speaker selection below as we still compared and purchase what we believed to be the best possible speaker, we just did not end up using it in the project. In choosing the speakers, we were limited by the usual factors of space, weight, and energy consumption, and were looking for parameters such as sound quality, cost, lifespan, durability, and maintenance. A factor unique to speakers that affected our decision was the presence of a volume knob. Our original plans did not have any way of adjusting volume through an external source, such as through the connected device or voice commands. Thus, we believed at the time that the only way to change the volume of the displayed video would be through volume control easily accessible on the speaker from a user outside of the projector. Because of this, many speakers that met the other requirements were not chosen.

3.13.1 Speaker Part Comparison

USB Mini speakers such as the HONKYOB USB Mini Speaker, the Logitech Z50 Multimedia Speaker, and the Yirtree Mini Speaker System all had the potential to be selected for this project, but to maximize simplicity and portability did not have external volume controls, and thus could not be chosen. The Creative Pebble 2.0 USB-Powered Desktop Speakers were considered as they had relatively good audio quality and an external volume knob, but they were designed in such a round, concave way, that their volume control knob did not stick out far enough. We could have worked around this by physically making the knob longer, but at 9.57 inches tall it was already pushing the limits of how big any item in the projector box could be, and thus they were deemed not worth the effort it would take to make them work in our design. If a speaker had the volume control on the opposite side of the speaker, or not sticking out far enough, then there'd be no way for a user to access it while the speaker was contained inside the projector, and it would be as futile as not having any volume control. Unfortunately, it still needed to meet all the other specific restraints, most specifically size, weight, and power consumption under 12V, so our pool of options was rather limited.

Adding to the power difficulty was the fact that many speakers don't list their input voltage, as most users are far more concerned with the max amount of Watts that the speaker can be burdened with. We also had to specify that the speaker needed to be USB powered, as having a power plug wouldn't work under our goal of the projector being portable. Audio quality was a much more important factor than it was when comparing microphones, since all that was necessary there was that the commands could be understood, but in the case of a speaker there is no similar threshold to clear. The better the audio quality, the better the product is overall, and unfortunately USB powered speakers in general have below average sound quality. Under these restrictions, we found the best choice to be the Amazon Basics A100 USB Powered Computer Speakers.

Figure 15. Amazon Basics A100 USB Powered Computer Speakers

From all reviews these seem to be the best USB powered speakers for their price and have a long volume knob. Measuring 3.1 inches by 3.1 inches and being 4.9 inches tall, it will be one of the largest components, but still neatly fits in our 12 inches by 12 inches by 12 inches projector case. By cutting out multiple small holes in the projector case in front of the speakers, we ensured the audio isn't muffled and that the speakers remained relatively safe from external damage, without compromising the overall aesthetic of the projector.

3.14 Voice Command Technology Comparison

In this section we will discuss the voice recognition software we researched for this device. As we were originally coding this project in Java, we researched speech recognition algorithms that were compatible with Java or already had Java packages. While modern programs like Siri and Alexa use the intelligent assistant method, letting users speak naturally when giving commands, we found that our project was more suited to the finite grammar model. Intelligent assistant requires intent parsing and database knowledge, while also needing speech training to develop acoustic models that are then used to build language and phonetic models. Our device only needed to recognize a few commands, so that much overhead was unreasonable for the scope of this project. The finite grammar model essentially means the system has a list of specific commands it recognizes, rather than inferring intent from a spoken sentence.

3.14.1 CMU Sphinx

CMU Sphinx has two different versions, PocketSphinx and Sphinx4. PocketSphinx is the more efficient, faster choice, whereas Sphinx4 has more flexibility and manageability. Both have about the same level of audio input accuracy so that is not much of a factor when deciding between the two. PocketSphinx also comes with keyword search functionality, which allows the application to ignore audio that is not the keyword(s). This would have been very useful for our project, as we did not want all the audio from the speakers to be interpreted by the speech recognition software. Sphinx4 has more customizability and advanced features, but due to keyword search being the only functionality we need and the speed advantage, PocketSphinx would have been the better choice for our project.

3.14.2 Google Speech to Text

Google’s speech recognition, used in systems like Google Speech to Text, is arguably the best speech recognition software available to the public. It has advanced features such as speech adaptation that allows you to increase the accuracy in listening for specific terms or words that aren’t as common, and streaming speech recognition allows for real time results. This means that the system can constantly process background audio and listening for specific keyword(s), which would have been ideal for our project. The main downside is that Google’s speech recognition API uses an online cloud database, meaning that an internet connection is required.

3.14.3 IBM Speech to Text

IBM speech to text has many of the same benefits and downsides as Google. It has many useful features like real time recognition and keyword searching, but also the downside of needing an internet connection, and neither are free to use. IBM does have the ability to improve its response time by processing speech as it is being heard, rather than waiting to see if the user is done speaking and then processing their entire statement. However, our commands are 1-2 words and thus this feature wasn’t especially attractive to us.

Table 15. Summary of Voice Recognition Technology Comparison

Software	**Voice Recognition Accuracy**	**Internet Required**	**Free**
CMU Sphinx	Relatively low	No	Yes
Google	Very high	Yes	No
IBM	Very high	Yes	No

Table 16. Voice Commands

Command	**Function**
Hey Projector	Initializes the projector to take in the other voice commands.
Focus	Activates rangefinder, and use that found range to focus the projected image/video to the best possible focus
Turn Off	Powers off the projector

3.15 Power Supply Technology Comparison

In this section we compared different power supplies to determine which would have better fulfilled the requirements for our projector. The power supply is one of the most important devices in any project because it can set limits on how much power, voltage and current will be available to the electrical components within a project. The power supply can control what features and devices you can implement in your project and requires us as engineers to make tough decisions relating to cost, performance, and function.

Two common power supplies are plug-in power supplies and batteries. Plug in power supplies typically obtains its power directly from wall outlets and distributes it instantly to a load. These power supplies have transformers built into them which allows them to take the AC voltage from the outlets, around 120 volts, and lower it to a voltage the device is capable of handling, in this case 12 volts, then uses a rectifier to convert the AC voltage to DC voltage before entering your device. On the other hand, batteries store power from a power source, then can distribute that power stored at any time.

Both power supplies can serve their intended purpose of delivering power to our projector but in order to determine which one was selected we looked at the advantages each brought. The advantages of using a plug-in power supply are that the simpler ones, that are used to power household devices, are significantly cheaper than a battery for the same voltage rating and the more expensive ones, like a laptop charger, has better amperage and voltage than batteries of the same price range. The main advantage for using a battery over a plug-in power supply is that batteries provide portable power. This was an important factor because it allowed the consumer to enjoy their projector at any location they please. Also considering that a projector produces such a large the image and it needs a clear path to project this image, this can limit the locations the projector will be best utilized at and there might not be an outlet around these areas. Based on these advantages this decision came down to the value of cost vs consumer experience and one of the purposes for this project was to create the best projector possible within our capabilities. Therefore, we decided to use the battery for the power supply of the projector.

3.15.1 Battery Technology Comparison

The different types of batteries we considered are multiple single cell batteries or a rechargeable battery. We could have used multiple sing cell batteries in a battery pack which would be a more affordable option up front and would make sense if we were only going to use the projector once for a short period of time for something like testing a prototype. However, our projector is made for long term use and because we care about the marketability of the projector, which is why we chose a battery over the plug-in power supply in the first place, when you consider how frequently they would need to be replaced it would not make sense to use multiple singe cell batteries.

Due to this the battery that we used for our projector is a rechargeable battery. The two standard rechargeable batteries we considered that are often used in most electronics are Lithium Ion and Lead acid batteries. For our projector, the two requirements we had relating to the battery were that the projector must consume under 50 watts of power and the battery must last an hour per charge. We had also decided that our power source will be 12 volts, so in order to meet the two conditions the battery needed a rating of at least 4200 mAh. There are both lithium ion and lead acid batteries that meet this requirement, that are available for purchase, so when comparing both batteries they needed the same rating of 4200 mAh or higher. The specifications we used to compare the two batteries are life span, price, weight/size, and charge time. These specs were selected to determine which battery provided the most benefits to us and a potential consumer.

Table 17. Summary of Battery Technology Comparison

Batteries	**Life Span**	**Price**	**Weight/Size**	**Charging**
Lead Acid Battery	Shorter	Less Expensive	Bigger	More Time
Lithium-Ion Battery Pack	Longer	More Expensive	Smaller	Less Time

From the table we can see that the Lithium-Ion battery was a better-quality option than the lead acid battery. Apart from performance, the implementation was easier for lithium-ion batteries as most lithium-ion battery packs has an area of connection for both input and output power while lead acid batteries just have a positive and negative lead. Although price was an important factor, the lithium-Ion battery is the best option for the projector. However, something to consider is that if something was to change later, it is easier for us to simply add another lead acid battery in either parallel or series to increase the voltage or current output. While for the lithium-ion battery it may require an external PCB or for us to buy another power supply.

3.15.2 Battery Selection

The battery we used for the projector is a lithium-Ion battery. There were many more advantages for the lithium-ion battery over the lead acid battery that made it worth paying the extra money for it. The lithium-ion batteries are made of lithium-ion cells, that conduct the electricity, and an integrated circuit, used for protective purposes like overcharging and surges. The lithium-ion cells are made up of a positive electrode (cathode), negative electrode (anode), conductive separator (electrolyte gel) and current collectors (on each electrode). When the battery is receiving power the cathode releases its lithium-ions which flow through the electrolyte medium and is received by the anode. When the battery is distributing power the opposite happens, the anode releases its lithium-ions, and the cathode receives them. While this is happening, the electrons flow through the circuit in the opposite direction of the lithium ions to the electrodes, creating a current.

After researching some potential options on the market, the Lithium-Ion batteries we considered are power banks and battery packs. The two we are going to compare is ABENIC Battery Pack and Talentcell Power Bank. Some positives of the power bank are that it has LEDs on them to display battery level, an on/off switch to turn off the battery and has a USB port for output power which is better because male USB cables are much more common than DC5521. The Battery packs' advantages are that it has a higher amp our rating and the Arduino development board uses DC5521power input connector. Below are the key specifications for each battery.

Table 18. Lithium-Ion Battery Comparison

ABENIC Battery Pack	
Voltage:	12 Vdc
Amp Hours:	6800 mAh
Size:	0.9*2.2*4.5 in
Price:	$39.99

Talentcell Power bank	
Voltage:	12 Vdc
Amp Hours	6000 mAh
Size:	1.1*3.4*5.7 in
Price:	$39.99

The one we finally decided on is the *12V Rechargeable Battery Pack* from ABENIC because of the higher amp hour rating and smaller size. The picture below shows the battery we used for the projector and in the next section we will go over some of the specs of the battery.

3.15.2.1 Battery Specifications

Figure 16. ABENIC Lithium-Ion Battery Pack

Connection: The battery comes with DC5521, 55mm by 21mm, male and female jacks for output power and charging (in picture below).

Safety and protection: It has an on and off switch and is equipped with overcharge and discharge protection to preserve the batteries' life.

Power: The battery has an output rating of 12 volts and 2 amps and has a capacity of 6800 mAh. Considering our 50-watt power limit this battery has the capacity to last a quarter past an hour, which is above our one-hour requirement.

Cost: The battery costs $31.99

Size/Weight: The battery is 4.5 inches long, 2.25 inches wide and 1 inch high; and weighs around 1 pound and 2 ounces.

Charge Time: The battery takes approximately a little over 8 hours to fully charge.

3.16 Voltage Regulators Part Selection

In the Autofocusing LED Projector we used 3 different voltage regulators to step up, step down and regulate the 12 volts from our power supply. The 3 different regulators we used are a buck boost converter module, Linear low dropout regulator (LDO) and a buck switching regulator. The first regulator we will discuss is the LF120ABDT-TR from STMicroelectronics. This LDO is a fixed regulator that can take an input of 2.5 to 16 volts and output 12 volts and 0.5 amps. The LDO has 3 pins Input voltage, output voltage and a ground pin. We used this regulator to maintain a steady 12-volt supply to the fan to ensure it gets enough power so the fan can operate at its maximum capabilities.

The next regulator we used is TPS562208DDCR by Texas Instruments. The regulator can take an input of 4.5 to 17 volts and output 0.8 to 7 volts, with a max current rating of 2 amps. The regulator has 6 pins Vin, EN, SW, VBST, VFB and GND. Vin is the input voltage, EN is the enable input control pin, SW is the switch node connected to the high and low side of the n channel mosfet (NFET), VBST is the supply to the NFET, VFB is feedback input and GND is the ground pin. We used these regulators in two switching regulator circuits to power the majority of our components including the LiDAR, stepper motor/driver, speaker, LCD, microcontroller, and microphone. This fixed switching regulator circuit, shown in Figure 17, takes a voltage input of 5 to 15 volts and output 5 volts and two amps. This circuit was designed in Texas Instruments WEBENCH Power Designer and has the characteristics of 92 percent efficiency, 600k hertz switching frequency, bill of materials count of 9 and approximate bill of materials cost of $1.50.

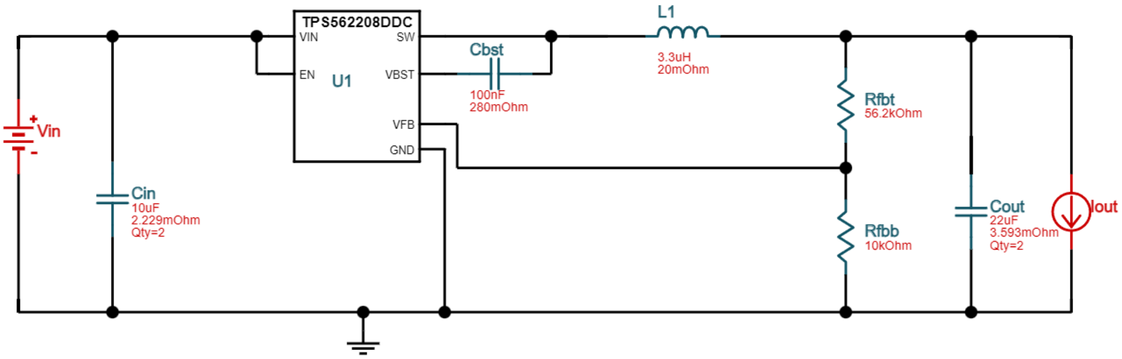


Figure 17. Switching Regulator Circuit

Finally, we needed a voltage regulator to control the voltage and current to the light emitting diode. As discussed in section 3.2.1 Chip on Board LED, the required voltage for the light source is around 30 volts and the current is 500 milliamps. Furthermore, controlling the amount of power outputting from the power source helped keep our battery time high and power consumption low, furthering our commitment to the requirements and specifications of our projector. The LED voltage regulator we have decided on is the DZS Elec DC-DC Buck Boost Converter Module as shown in Figure 18 below. With a cost of only twelve dollars this product is not only needed but also maintains our goal of projector costs lower than five hundred dollars. The weight is one point five eight ounces, and the dimensions of the voltage regulator is sixty-six by forty-eight by twenty-one millimeters. This voltage regulator aided in the goal of keeping the small size and light weight of our projector. The module is an adjustable step down/up converter with an input voltage between five and a half to thirty volts with an output voltage between zero point five to thirty volts. The power module constant current is between zero to four amps. The liquid crystal display screen is a great feature of this product because it can switch display inputs from voltage, output voltage, output current, and output power. With a voltage display resolution of 0.005 volts and a current display resolution of 0.005 amps. Equipped with safety protection, there is a liquid crystal filter and anti-reverse connection protection to prevent the possibility of the converter module burning down. Additionally, there are short circuits, low voltage, and output anti backflow protections. This further enhanced the team's commitment to the safety constraints as discussed in section 4.8. Finally, there are key controls for the voltage and current ON/OFF manipulation of the device.

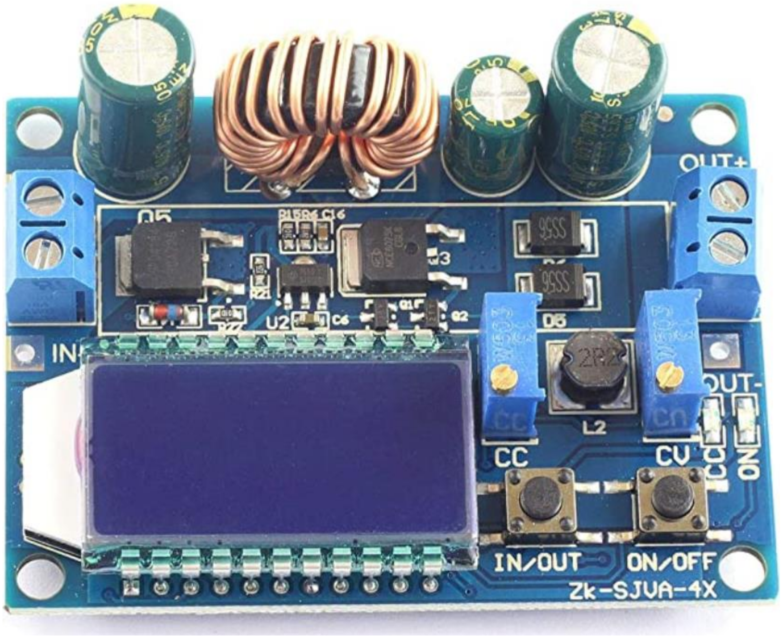


Figure 18. DZS Elec DC Buck Boost Converter Module

As shown above in Figure 18 there are many key features and specifications of our voltage regulator. There is an output indicator light along with a constant current indicator light. The operating frequency is roughly one hundred and eighty kilohertz with a transfer efficiency of eighty eight percent. There is a soft start option and a mounting hole of four millimeters. While under the constant current mode the center controller sets the potentiometer for the current and rotates clockwise to increase the setting current and counterclockwise to reduce it. When the load current reaches the set current, it enters the constant current state, and the center controller constant current indicator lights up with a red light. This converter module or voltage regulator is a crucial part of the projector, and the one selected in this section further enabled the successful outcome of our project.

4 Standards and Design Constraints

Standards are all around us and enable the advancement of technology at a much faster rate. Standards are a generally accepted formal technical document for products, procedures, and policies. The Auto-Focusing LED Projector was designed to advance the projector technology sphere while adhering to the standards in place therefore making this product easy to integrate and access. We plan to briefly discuss a few of the standards associated with our technology such as software, LED, laser, printed circuit board, and power. Abiding by the standards in place, the technology our group designs will easily transition from protype to on the shelves.

The engineering design process typically begins with a clearly defined problem to solve or need that contains certain design constraints. Design constraints are limitations on the design and conditions that need to happen for successful project outcomes. The design constraints discussed below include economic, safety, time, manufacturing, environmental, social, political, ethical, sustainability, and usefulness. Acknowledging and adhering to these design constraints led to a successful outcome of our project.

4.1 Software Standards

Software standards and regulations are extremely important to help ensure safety, security, and reliability. Compliance with industry standards developed by organizations such as the International Organization for Standards (ISO) and the International Electrotechnical Commission (IEC) is crucial for homogenous product development. For embedded systems, compliance to the standards listed below is required or highly recommended.

IEC 61508: Functional safety of electrical/electronic/programmable electronic safety-related systems. The main function of this standard is that safety-related systems must function and fail in a predictable manner.

IEC 62061: Safety of machinery: functional safety of electrical, electronic, and programmable electronic control systems. This standard is in place to be applicable to system level design and the design of devices. Including parameters such as required response time, operating modes, and fault reaction functions.

The embedded system our project utilizes is a microcontroller which adhered to the software standards listed above. If the microcontroller is in route to catch fire or pose other safety risks, the software program ensures that it fails in a predictable manner for the user to troubleshoot.

4.2 LED Standards

The American National Standard Institute (ANSI) establishes definitions of solid-state lighting devices and components. Underwriters Laboratories (UL) writes safety standards for LED products including drivers, controllers, arrays, packaging, and modules. A UL Mark is a product identification feature that is highly desired and, in many cases, required by the government. Therefore, it is crucial to understand what the various UL marks signify.

UL Certified: The product has been certified under the UL listed mark and UL classified mark.

Figure 19. Underwriters Laboratories Certified Mark Label

UL Listed: This is one of the most common UL Marks. Samples representing the product have been tested and have met defined requirements.

Figure 20. Underwriters Laboratories Listed Mark Label

UL Classified: This mark appears on representative samples of products that UL has evaluated but only with respect to specific properties a limited range of hazards, or suitability for use under limited or special conditions.

Figure 21. Underwriters Laboratories Classified Mark Label

UL Field Evaluated: In situations in which you are unable to determine if a product has been listed by a third-party organization. This mark provides data to assist you in making your decision whether to accept the product and/or approve the installation.


EVALUATED

UL LLC © 2014

No. FE 00123456

This product has been evaluated in accordance with the procedures and limitations specified in the issued report

Contact UL 1.877.854.3577 #2
field@ul.com

Figure 22. Underwriters Laboratories Field Evaluated Mark Label

UL Component Recognition: The product was evaluated only for use in a complete system or product.

UL Performance Verified: The product has only been tested against a specific performance standard, such as an industry performance standard.

Regarding our project, The Autofocusing LED Projector utilizes a UL certified LED. Various manufacturers for black market LEDs on websites such as eBay do not feature any followed standards in their products. However, it is important to the group to adhere to standards and use technology that is appropriate for engineering and design. As a result, the product used will ideally last the stated lifetime without failure and run reliably every time without concern for issues.

4.3 Laser Safety Standards

There are a vast number of standards and regulations regarding lasers based on their maximum permissible exposure which is the maximum power density considered safe for viewing. Parameters such output power, wavelength, and pulse duration contribute to the maximum permissible exposure. These standards regulations are governed by the ANSI-US Laser Safety Standards. Furthermore, they are mandated as being properly labeled to the U.S. Food and Drug Administration FDA and/or the International Electrotechnical Commission IEC requirements. Laser technology offers a wide range of applications, from harmless laser pointers in classrooms to powerful laser cutters which can damage your skin or eyes. Therefore, the laser class system which can easily distinguish between different safety levels of lasers was put into place as shown below in Table 20. Additionally, Table 21 illustrates ANSI requirements for each laser class.

Table 19. Summary of FDA and IEC Laser Classification

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 DVD players
IIa, II	2, 2M	Hazard increases when viewed directly for long periods of time. Hazard increases if viewed with optical aids.	Bar code 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 view 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 Research lasers
IV	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 Medical device lasers for eye surgery or skin treatments

Table 20. Summary of ANSI Requirements by Laser Class

Class	Control Measures	Training	Laser Safety Officer (LSO)	Engineering Controls
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	Required	Required

As shown above, lasers have strict and easy to follow standards. The rangefinder in our project uses a class one infrared laser due to the low power and wavelength. As a result, the distance measurement from the beam of light is nonhazardous and safety standards were strictly adhered to. Our group ethically confirmed the class level stated on the laser by the supplier was correct and accurate.

4.4 IPC Product Class Standard

The Institute for Interconnecting and Packaging Electronic Circuits (IPC) has developed a classification system for circuit the quality level of each circuit board type under the IPC-6011 standard. The main discrepancies between each class are the level of inspections and the standards they are subjected to. Thus, engineering requirements, specifications, and costs are some important parameters when deciding which IPC electronic class to pursue for our project. A summary of the IPC classification level system is shown below in Table 65. The IPC class our senior design project group has chosen is IPC Class 1, because we used general simple electronics such as a microcontroller, printed circuit board, and battery. Additionally, we utilized simple optical components such as a rangefinder, light emitting diode, and liquid crystal display screen.

Table 21. Summary of IPC Classification Definitions

	IPC Class 1	**IPC Class 2**	**IPC Class 3**
Category	General electronics	Dedicated service electronics	High reliability electronics
Life Cycle	Short	Long	Very long
Quality	Cheap	Good	Fail proof
Examples	Toys, flashlights, smartphones	Laptops, microwaves, and some mining equipment	Aerospace, military, and medical applications

As shown above in Table 65, IPC Class 1 is for general electronics so they can be manufactured in mass and low costs for the producer and consumer. As a result, the lifespan and quality will decrease. IPC Class 2 is for dedicated service electronics such as televisions and smartphones. The lifespan is longer and therefore the quality of the electronics is increased. IPC Class 3 is for high reliability electronics such as military and medical equipment. Therefore, they are subjected to the harshest level of inspection and quality standards. The lifespan of electronics in this class is very long, and quality is supposed to be fail proof.

4.5 Printed Circuit Board Standards

IPC Standard 2221:

The Institute for Interconnecting and Packaging Electronic Circuits (IPC) is one of the mostly widely recognized organizations participating in developing global standards within the electronic industry. The goal of IPC is to ensure the safe, reliable, and high-quality manufacturing and design of all electronic products. Printed circuit boards (PCBs) is one area IPC has developed many standards to help improve and the standard we will be using regarding PCBs is IPC-2221.

The IPC-2221 standard was implemented to help the understanding of general requirements for creating organic PCBs. IPC-2221 discusses the effects of different voltage ratings and factors we should consider implementing on the PCB to ensure safe production such as PDN bus layouts, conductor clearance, and impedance control. For our projector we focused on conductor clearance at different voltages and the table below shows the minimum clearance for unassembled (bare) and assembled boards.

Table 22. Summary of Clearance for Bare Boards

Voltage between conductors (Volts)	**Minimum clearance for bare board**			
	Internal conductors	External conductors uncoated, up to sea level 3050 m	External conductors uncoated, over sea level 3050 m	External conductors, with permanent polymer coating (any elevation)
0 - 15	0.05 mm	0.1 mm	0.1 mm	0.05 mm
16 - 30	0.05 mm	0.1 mm	0.1 mm	0.05 mm
31 - 50	0.1 mm	0.6 mm	0.6 mm	0.13 mm
51 - 100	0.1 mm	0.6 mm	1.5 mm	0.13 mm

Table 23. Clearance for Assembled Boards

Voltage between conductors (Volts)	**Minimum clearance for assembled board**		
	External conductors, with a conformal coating	External conductors lead/termination,	External conductors lead/termination, with a conformal

	over assembly (any elevation)	uncoated, up to sea level 3050 m	coating (any elevation)
0 - 15	0.13 mm	0.13 mm	0.13 mm
16 - 30	0.13 mm	0.25 mm	0.13 mm
31 - 50	0.13 mm	0.4 mm	0.13 mm
51 - 100	0.13 mm	0.5 mm	0.13 mm

The highlighted section shows the clearance we needed for the voltage our printed circuit board will be operating at (12 volts).

4.6 Power Supply Standards

For our power supply standard, we wanted to use a standard that is related specifically to the power supply we are using instead of just the overall power or voltage within our projector. The way we did this is by making sure the power supply we used met standards that ensure what we built was a safe and reliable product. The power supply we used for the projector is a Lithium-Ion battery pack. When dealing with any type of battery whether lithium-Ion, lead acid or nickel hydride, if the battery is defective, it can not only jeopardize the project but also the lives of anyone involved. To avoid potential hazards, we used an Underwriters Laboratory certified battery.

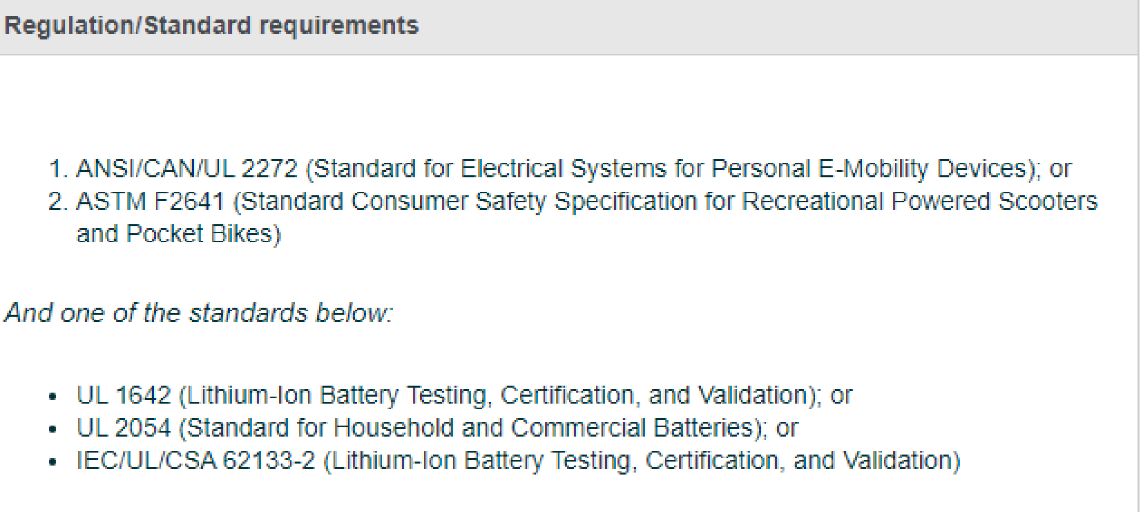
UL 1642 -
Underwriters Laboratories is a non-for-profit organization who delivers testing, inspection, and certification services within the industry. The Underwriters Laboratories standard we will use to identify an appropriate battery is Underwriters Laboratories 1642 (UL 1642). UL 1642 is a standard that discusses the use and performance of Rechargeable and non-rechargeable Lithium-Ion batteries. The standard was developed to reduce the risks of explosions, fires and any other events that could lead to severe injuries while using lithium-ion batteries. To be UL 1642 certified the product must undergo testing such as:

T.10 Short-Circuit Test
T.13 Crush Test
T.15 Shock Test
T.17 Heating Test
T.19 Low Pressure Test

T.11 Abnormal Charging Test
T.14 Impact Test
T.16 Vibration Test
T.18 Temperature Cycling Test
T.20 Project Test

Amazon -

One popular distributor who requires that their batteries be Underwriters Laboratories certified is Amazon. Below is a screenshot of their policy and because of this we chose to use the ABENIC 12V Rechargeable Lithium Battery Pack for our projectors battery to ensure we have a safe and reliable power supply.



Regulation/Standard requirements

1. ANSI/CAN/UL 2272 (Standard for Electrical Systems for Personal E-Mobility Devices); or
2. ASTM F2641 (Standard Consumer Safety Specification for Recreational Powered Scooters and Pocket Bikes)

And one of the standards below:

- UL 1642 (Lithium-Ion Battery Testing, Certification, and Validation); or
- UL 2054 (Standard for Household and Commercial Batteries); or
- IEC/UL/CSA 62133-2 (Lithium-Ion Battery Testing, Certification, and Validation)

Figure 23. Amazon Battery Policy

4.7 Economic Constraints

First, the economic constraints present in the projector space, and specifically the auto-focusing projector space, are quite narrow, as it is possible to buy an auto focusing projector for as low as $200. To be competitive with the market, our projected budget of $500 puts us in a reasonable position in terms of pricing, but with the use of large-scale manufacturing, this will lead to a reduction in pricing giving us more potential buyers.

Cost of hardware: One of the main constraints is the cost of the hardware components needed to build an auto-focusing projector. This includes the cost of the projector itself, camera or laser sensor, motorized focusing mechanism, microcontroller, and any additional components needed for image processing or control.

Production volume: The cost of components can be reduced by buying in bulk, but this requires a certain minimum production volume to be economically viable. Building a small number of projectors can be expensive due to the higher cost of individual components.

Development time: Building an auto-focusing projector requires time for research and development to create the hardware and software needed. The longer the development time, the higher the cost of labor and other expenses, which can drive up the cost of the final product.

Manufacturing complexity: The more complex the design and manufacturing process, the higher the cost of production. To keep costs low in the future, a simpler and more streamlined design may be necessary.

Competition: The market for projectors is highly competitive, with many companies offering similar products at different price points. To be successful, a cheap autofocusing projector must offer comparable or superior performance at a lower price point than existing products. Overall, building a cheap autofocusing projector requires a balance between cost and performance. To be successful, the design must be simple, the hardware components must be affordable, and the manufacturing process must be efficient, our product also has the benefit of novelty, as most autofocusing projectors use image processing to create focused images, ours uses a rangefinder, differentiating our product from others at the given price point. Additionally, the product must offer competitive performance at a lower price point than existing products on the market.

4.8 Safety Constraints

Overall, safety was the primary consideration when designing and building the Autofocusing LED Projector. Proper precautions and safety features can help prevent accidents and ensure that the projector is safe to use. This was a very important factor to consider when working with any electrical and optical project. By creating a product that is led with safety first, it will give credibility to the product and allow the consumer to trust the item that we have created.

Laser safety: Since a laser distance measurement system is used to autofocus the projector, it is important to consider laser safety. Laser beams can be harmful to human eyes, so precautions must be taken to prevent accidental exposure. This may include using a low-power laser, enclosing the laser in a protective housing, or adding safety interlocks that prevent the laser from firing when the protective housing is open.

Electrical safety: The projector is powered by electricity, so it was important to ensure that all electrical components are properly grounded and insulated. This included the power supply, motorized focusing mechanism, and any other electronic components. Proper grounding and insulation helps prevent electrical shock and reduce the risk of fire.

Mechanical safety: The motorized focusing mechanism was designed with safety in mind to prevent accidental pinching or crushing of fingers or other body parts. This could have included adding protective covers or barriers to prevent accidental contact with moving parts.

Heat safety: The projector can generate a significant amount of heat, which can pose a risk of burns or fire. Proper ventilation and cooling was provided to dissipate heat and prevent overheating.

Eye safety: Autofocusing projectors that use a lidar-based system to detect the focus will emit a bright light or flashing light that can be harmful to the eyes if exposed for prolonged periods of time. Precautions were taken to ensure that the light emitted by the projector does not pose a risk of eye damage.

4.9 Time Constraints

Time is an extremely important factor to take into consideration when working on any large project. When you combine the complexity of a large project with limited time and strict deadlines, it can lead to a lot of pressure and challenges for the team working on the project. Therefore, it is essential to plan accordingly in order to manage time constraints.

For the Autofocusing LED Projector project, time was one of the most important constraints which we had to worry about. The project must be completed by the end of Senior Design 2, which means we had approximately three months from the end of Senior Design 1 to complete the project. This included all of the designing, testing, and prototyping, as well as the construction of the final project. By that time, we needed to complete all of the main components for the project before we could decide if we had enough time to try and pursue our stretch goals.

In order to manage these kinds of time constraints, it was crucial that we planned out the project thoroughly and got a solid estimate of how much time all of the individual tasks would take. Then we needed to set priorities and goals in order to closely monitor our progress and ensure we were staying on track. It was also very important to account for various unexpected delays and setbacks to make sure that we were able to complete the project on time. Overall, it was essential that we stayed organized and motivated throughout the entire duration of the project in order to meet our deadlines.

4.10 Manufacturing Constraints

A manufacturing constraint can be described as anything that prevents our group from making progress towards the design and implementation of our smart projector. One of the largest manufacturing constraints that we considered when working on this project was the availability of the components and materials that we selected to use. Parts can easily go out of stock for long periods of time or take as long as a month to get shipped out to us. This is why it was very important that we got all of the parts needed for our Autofocusing LED Projector as soon as possible.

Often waiting on certain parts of components can lead to large delays in the overall design process. This is a huge issue when you are building the project with strict time constraints. If we ended up spending too much time waiting on certain parts then we would fail to meet our deadlines, adding even more pressure and challenges to the project. In order to avoid these kinds of problems, it was crucial that we identify these constraints as soon as possible in the design process. That way we were able to ensure everything we needed would be available, and we were able to order everything we needed early. Failure to do this would have lead to unnecessary delays which would have negatively affected the outcome of our project.

4.11 Environmental constraints

An environmental constraint is a limitation on the freedom for our group to design and build a new projector technology that may have consequential impacts to the environment. Since our group is extremely environmentally conscious, we have decided to select engineering parts and design that would impact the environment negatively the least. For example, a typical incandescent light build will use roughly eighty percent more energy than its light emitting diode equivalent. Therefore, by utilizating an LED for our light source we decreased utility costs which directly positively impacts lower levels of greenhouse gas emissions. It is estimated that roughly ninety percent of waste in the United States is dumped into landfills or burned. Thus, it is our duty as engineers to select parts that enable a long shelf time to reduce our carbon footprint and make sure our planet is still habitual for centuries to come.

4.12 Social, Political, and Ethical Constraints

The Autofocusing LED Projector is an ethical technology that our group has designed for all people of every social and political class. Social constraints are discussed in great detail in physiology. Our group doesn’t interfere with the social constraints illustrated around us in society by not limiting our target audience. We designed this projector as a technology that every social class could enjoy. Furthermore, this group and the technology we are developed does not interfere with anyone’s political beliefs and remains neutral. By writing this report of the exact design of our product, we exhibited ethical constraint and did not lie or mislead about design capabilities. Additionally, if this project was to be mass manufactured and sold to consumers, then we would not discriminate on the types of stores, cities, or people who can therefore purchase this unique, impactful, and affordable technology.

4.13 Sustainability Constraints

As our system has the potential to be used outside, we had to factor that into its sustainability. While it’s unlikely to be used in extreme weather, we still mitigated the amount of damage that can be caused by water corrosion or temperature fluctuations. Our product is able to maintain functionality throughout these weather conditions and not suffer any permanent form of damage.

The components most sensitive to these constraints are the ports, microphone, and speaker. We considered reducing the danger of water entering the HDMI port by adding a tab or some other type of open/close mechanism, but eventually decided against it. The speakers and microphone are open to the air, so we had a mesh of small holes over them instead of one large hole, and had that opening on one of the sides of the projector rather than the top (most sources of liquid, be it from spilling a drink or due to rain, tend to come from above), to reduce damage from anything short of a storm to a negligible amount.

The projector is also designed to be portable, so we had to make sure it could sustain minor impacts, such as being bumped against a wall or dropped a short distance. While the lens and microcontroller are certainly a touch fragile, having them properly secured inside the projector made them resistant to most forms of jostling, and the exterior of the projector itself was made of wood, a substance that can withstand much stronger impacts than are anticipated. In addition, while not desirable, any external dents or scratches will only affect the appearance, not the functionality of the product, and as such are permissible.

4.14 Usefulness Constraints

Our product will displays an image or video from another device onto a wall or other flat surface. Therefore, a potential user must find the act of using our projector preferrable to just watching whatever device it is projecting from. Ideally it could be used to show things like videos from a smartphone to a group without having to have everyone crowd around a tiny screen. Therefore, the projector was not allowed to be worse than that experience.

The projector heating up too much and having the room temperature go up by a significant amount as a result was also unallowable, along with simply heating up so much that it causes the user(s) concern. We prevented the device from becoming too hot by installing a fan. While there will always be exceptions (yes, the device will be too hot if submerged in lava), proper use of a fan prevented the projector from overheating under normal use and conditions. However, this led to the next concern; the fan cannot be annoyingly loud. This is subjective and hard to measure, but in general if any user is having difficulty hearing audio from the speakers over the sound of the fan whirring, then we have not made a useful product. Throughout testing, we found the fan to be incredibly quiet, and thus met the outline constraint.

While no aspect of our design was intensive enough to create an excessive amount of heat, we still reduced the load on the fan by making sure air could easily flow through the system, minimizing the amount of dust that could enter the system. Most importantly, we have added a heatsink to the LED, the greatest heat-emitting source in the design. That combined with the fan was more than enough, but as we have as little open air as possible (only openings being vents for the fan and speaker/microphone) to reduce the risk of water damage and dust entering, if heat did become problematic we experimented with the idea of opening the device up more to increase air flow. We considered capping the speed of the fan but that was a double-edged sword, as while it would guarantee the fan could never get too loud, it also would mean that the user wouldn't be alerted to the projector heating up to dangerous levels. Normally a fan whirring much louder than normal is a reliable indicator that a device is overheating or having some related problem that should be addressed as soon as possible, so we developed our project to produce so little heat that we did not need to cap the fan's speed.

5 Project Hardware and Software Design Details

The hardware design details of our senior design project the Autofocusing LED Projector system is divided into three primary sections. The sections will cover the initial overall design options of the optical, electrical, and supporting components. Additionally, we will cover the project software design details which will support and expand the many functionalities of our hardware and system. The purpose of this section is to provide the reader with a clear understanding of the engineering analysis that was into the hardware and software design decisions of our project. In the subsequent section 6 we will cover the project testing and integration of our design and the overall schematic of our project.

5.1 Design Philosophy

When organizing a team effort, the structure and plan for how each member will perform their tasks, both individually and collectively, must be considered. The pros and cons of the main three design philosophies, Waterfall, Spiral, and Agile, will be examined in this section.

5.1.1 Waterfall

Waterfall is one of the earliest design philosophies, built on the idea of asking someone for a good or service, and then receiving it. It works fine for some products, describing what you want on a cake and then receiving it from the bakery usually works out fine, but in more complicated products improvement and iteration are generally desired. This is not to say Waterfall is rushed or without nuance, each step should work in a perfect world; analyze requirements, design the hardware/software, build/code it, test it, and then deliver the finished product to the customer. The issue is that you can discover issues in the design while implementing the code, or that you've nearly finished the project, but the requirements of the customer have changed since the initial inception of the project. There are good reasons that Waterfall has fallen out of favor, and for those reasons it was not a good choice for our project.

5.1.2 Spiral

Spiral has something resembling the opposite design philosophy of Waterfall. Instead of designing the project and then following that design, Spiral works more like breaking the project into chunks to be repeatedly planned, analyzed, and tested. Risk analysis plays a much bigger role in Spiral development, which is why it is beneficial for very large projects or projects that undergo multiple iterations. It is commonly used in video game development, as each iteration of a game (Version 1.0, Version 1.1, Version 1.2, etc) can be seen as another loop of the spiral, where each change between versions had to be planned beforehand, had its impact on the current version analyzed and bug tested, implemented, and then evaluated by customers. While it helps ensure advancements are safe and can quickly adapt to new development goals, our project will not have any major changes from its original design, and there will be only one released version, so this methodology did not work for our project.

5.1.3 Agile

Agile is the middle ground between Waterfall and Spiral, built on the idea of continuous integration and continuous development. Much like Spiral, it is done by working on one chunk of the project at a time, but Spiral goes through these chunks to manage unanticipated risks, whereas Agile focuses on if each chunk is what the customer(s) desired. Spiral is better for complex projects where you don’t know what kind of risks you might run into, where multiple releases are desired, and prototypes are seen as worth creating. Agile is better for when you have a solid idea of how things are going to go. In our case, a full prototype wasn’t exactly feasible, and we knew many of the possible issues that could arise and discussed them in our documentation, but there was still plenty of room for error, so a purely Waterfall strategy might have worked but was not worth the risk. In the end, we went with the Agile Scrum development philosophy. Scrum refers to the process of planning out “Sprints”, 1~2 week periods where the team decides “this is what we’re going to get done in this sprint”, and at the end it is reviewed. We had our Sprint review meetings on Fridays at 1pm, although being a small team we were able to change the meeting day and time on a few occasions to accommodate unexpected schedule conflicts.

5.2 Optical Path Design Details

When building the Autofocusing LED Projector, the optical path design was first considered and thoroughly optimized. Failure to produce any sort of image would have rendered the projector useless as the application of a projector is to display images and movies for spectators. As a result, the needs of the optical elements in our project apprised the electrical and software components along with the supporting hardware elements. Successful implementation of the optical components provided tremendous leverage for the other hardware components, along with the software algorithms to really shine and display why our Autofocusing LED Projector is ahead of the competition in the market today.

5.2.1 Light Source Design Details

The optical path of the Autofocusing LED Projector is the path where the light source emits the light that is collimated into the image source which is then focused to the projector lens which displays the enlarged image. At the very beginning of the optical path is the chip on board light emitting diode as discussed previously in section 3.2.1 Chip on Board LED. As we all know, LEDs emit heat from the current running through and producing light. As shown below in Figure 24, the relative luminous flux emitted by a light emitting diode is plotted against the current at four different LED surface temperatures. It can clearly be observed that for a specific current the percentage of the total luminous flux or light per unit area that the LED is capable of emitting is dependent on the temperature of the diode. The higher the surface temperature of the LED the less light it will be able to produce and therefore illuminate.

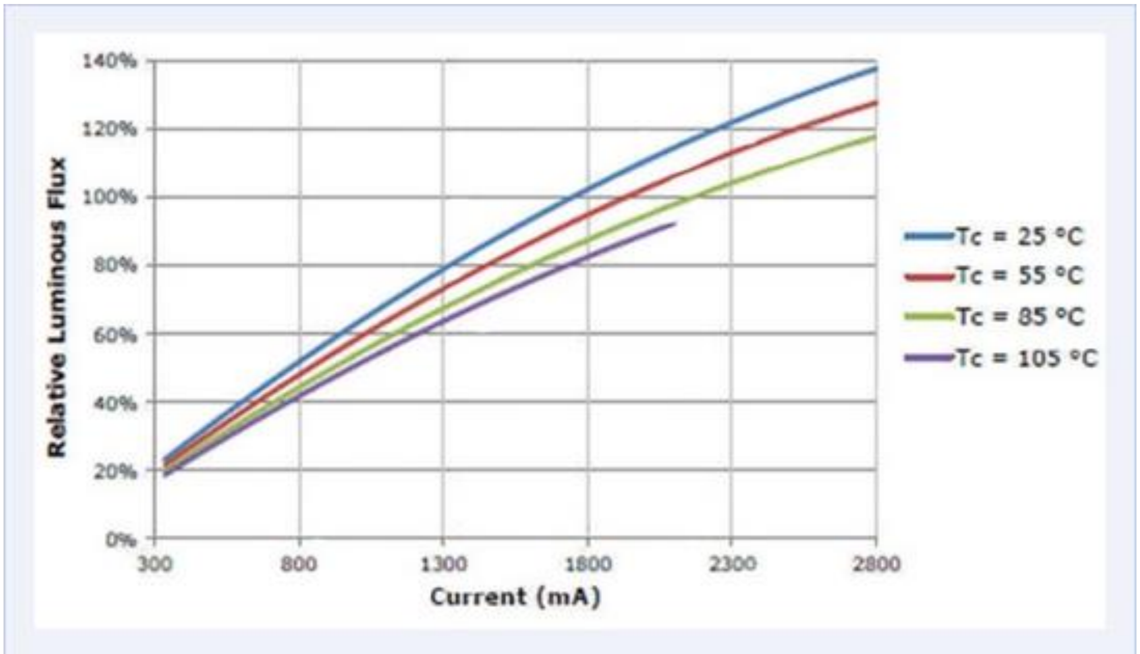


Figure 24. LED Surface Temperatures

This figure provided the team with a general guide to how hot we could have the surface of our chip on board LED while still producing the maximum luminous flux as prescribed by the manufacturer which was 28,000 LM. With our LED needing 1000 mA of current to turn on, we inferred that in order to achieve the maximum brightness or at least 80% brightness we needed to keep the surface temperature of the diode to below 25°C or 77°F.

As a result, to the above discussion about limiting the surface temperature of the LED light source of our projector, we decided to place the chip on board LED on top of a heatsink to aid in dissipating the heat expenditure. As shown in Figure 25, it is a square aluminum heat sink which was perfect for our square chip on board light emitting diode. The net weight of the heat sink shown below is roughly 200g with a length of 90mm, width of 90mm, and a height of 25mm. The design of this heat sink further enabled the lightweight compact design of our projector. Furthermore, the shape of the heatsink was extremely relevant to the project. The cube like outer shell was needed to position the light source in a horizontal manner for the optical path to continue into the collimating lens. The square patch in the center was perfect for mounting the LED onto it with silicon thermal grease or thermal paste which further contributes to heat dissipation. The specific integration design details between the LED and heatsink will be discussed further in section 6 Project Testing, Integration, and Prototype Construction.

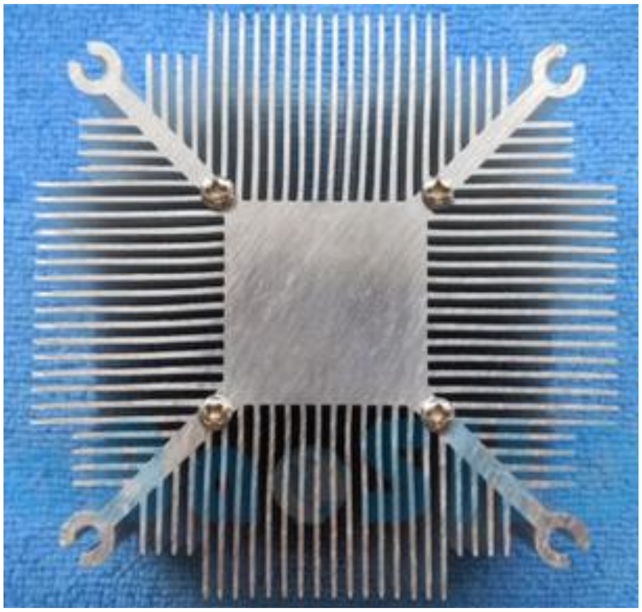


Figure 2. Projector 30W Square Aluminum Heat Sink

5.2.2 Light Collimation Design Details

Succeeding the light source position along the optical path was the need for light collimation in order to illuminate the image source uniformly. Our LED light source mounted on the aluminum heatsink has a lens angle of 120°. Therefore, the emitted light is shining in all directions from which the surface is facing. This became an issue when attempting to illuminate the light source evenly with as little loss of light as possible. As a result, our light collimation design needed to be bigger than the LED and LCD screen. As stated previously, the dimensions of the LED are 27.5mm by 27.5mm and the image dimensions are 45mm by 70mm. In order for the light to be collimated completely from LED to LCD screen we needed a lens design that is at least 45mm by 70mm, and with as small of a focal length as possible to avoid loss of light. With a small focal length, the collimating lens was placed up against the LED and then the LCD screen could directly follow the collimating lens by placing it directly behind it. The LED along with the collimating lens served as the backlight for the projector. When removing the original backlight off the LCD screen it was essential to keep the polarizing filter and back mirror layer intact or the screen would turn black and not function. Thus, precise care was taken to remove the LCD screen backlight properly while maintaining the other layers of the LCD screen intact for a quality transmissive screen where the collimated light can emerge from. There are two methods to design the light collimation that were needed for our projector; both of which will be discussed in further detail below.

The first method for designing the light collimation from our light source to our image source is through the use of a condenser lens. The condenser lens is designed to gather light from a diverging point source and collimate the light into parallel rays or converging rays. Condenser lenses are very popular in projection system designs due to their unique capabilities. They are composed of two lenses, a pair of matched convex lenses. They are placed together to form a plano-convex lens where one side of the lens is flat and the other side of the lens is spherical in shape. As a result, the significant advantage to such a lens combination is correction of aberration which is common in traditional lens types and therefore means a higher quality resultant image. Additionally, condenser lenses can be engineered to be more robust which can make them less affected by high temperatures, which can occur from our LED light source. Furthermore, they can be made with anti-reflection coating which increases the quality of transparency with the reduction of the reflected and scattered light.

The disadvantages to using a condenser lens is their size and focal length trade off. As stated above, we need the light collimating lens to completely illuminate the image uniformly. The large optic size also means a larger focal length with the optical suppliers available to us. Increasing the diameter of the of the lens also increases the focal length of the lens. Surfing through lens catalogs, we needed a 75mm diameter condenser lens which coincides with roughly an 80mm focal length. Although the size would have been perfect for our system, the long focal lengths would mean higher losses of light. This issue could have been overcome by designing and 3D printing a light tube of the prescribed focal length so that there is no loss of light.

Another disadvantage to the size and focal length of the condenser lens needed for our projector system is the cost. The average cost for such a lens will easily exceed $125, which was not the intention of our lost cost affordable projector. The average center thickness of these lenses is around 25mm. This thickness along with the focal length distance means that the overall optical path distance will have to have been significantly increased, therefore, the dimensions of the projector box will have to increase. Projectors on the market today utilize condenser lenses for the most part, so we knew that they would be effective for our senior design project and could work very well for our light collimation lens design.

The second method that our senior design team considered to implement for our light collimation lens design was to use a diffuser. Diffusers are optics that eliminate bright spots by spreading the incident light more uniformly than emitting that nice even light across a desired area. Although condenser lenses are more popular in projector systems, diffusers offered us a significant opportunity to show that our senior design group can more effectively design and engineer a projector system. There are three types of diffusers that are popular on the market today that our group could have selected from, each one containing their own unique advantages and disadvantages.

Table 26 below shows the three types of diffusers that we will discuss in this report and can choose from for our projector system. Highlighting their transmission, scattering ability, and price as the key parameters that influenced our engineering design decision.

Table 24. Diffuser Selection Guide

Type of Diffuser	**Transmission**	**Scattering Ability**	**Price**
Holographic Diffusers	Best	Best	$$$
White Diffusing Glass	Good	Better	$
Ground Glass Diffusers	Better	Good	$

With the desire for our projector system to have the best transmission at the lowest price point, the ground glass diffuser was the option our senior design team selected as our light collimation design. Ground glass diffusers are optics that are sandblasted to produce that that scattering rough surface. Furthermore, because of the sandblasting they contain high grit numbers which enable finer grain and therefore increased transmission efficiency. A ground glass diffuser forms diffused light from incident light. This was particularly important for illuminating our LCD screen because the LED light was not uniform from the center of the image to the edge of the image, due to the lens angle of it. Therefore, all we needed to do was implement an optic that can more evenly and uniformly spread that LED light onto the image source LCD screen. Ground glass diffusers also do not have a focal length. Therefore, we put the ground glass diffuser directly in front of the LED and put the image from the LCD screen directly behind the glass.

This furthered our commitment to a small compact projector with the optical path distance significantly reduced between the light source, light collimating optic, and the image source. The size of the ground glass diffuser had to be greater than the size of the LED and the image on the LCD screen as with the option of using a condenser lens. So, the ground glass diffuser had to be at least 70mm in width and 45mm in height to fully illuminate the image uniformly. They could also have been made and engineered with anti-reflection coating which can significantly improve quality of imaging by reducing reflected and scattered light from the optic. The average thickness of these optics is roughly 2mm, therefore, with no focal length and such a small thickness the compactness of our projector design can be further integrated.

The cost for ground glass diffuser plates are much less than that of a condenser lens, with the average large ground glass diffuser plate costing around $55 which is very affordable at that size. The dimensional tolerance for these plates is significantly low, which is great for building a projector imaging system. All of these advantages to ground glass diffuser plates made it a great option for our projector and gave us the opportunity to design a new and improved system over the projector systems that are on the market today and utilize a condenser lens as their light collimation design.

In Figure 26 below, the transmission percentage (efficiency) is plotted as function of wavelength (nm) showing how the float glass used for ground grass diffuser plate was perfect for the visible white spectrum that we used for our projector. The spectrum shown is a great indicator and visual from which we can clearly see which wavelengths the glass transmit light. The power of our 30W LED and the 27,000LM brightness was be plenty for the roughly 75% transmission we received through the glass. Although our desire was to receive 100% transmission from the LED onto the LCD screen to illuminate the image, the high brightness of our LED had to compensate for the ground glass diffuser plat loss and our projector was shown to have plenty of brightness for a high quality imaging experience for the consumer.

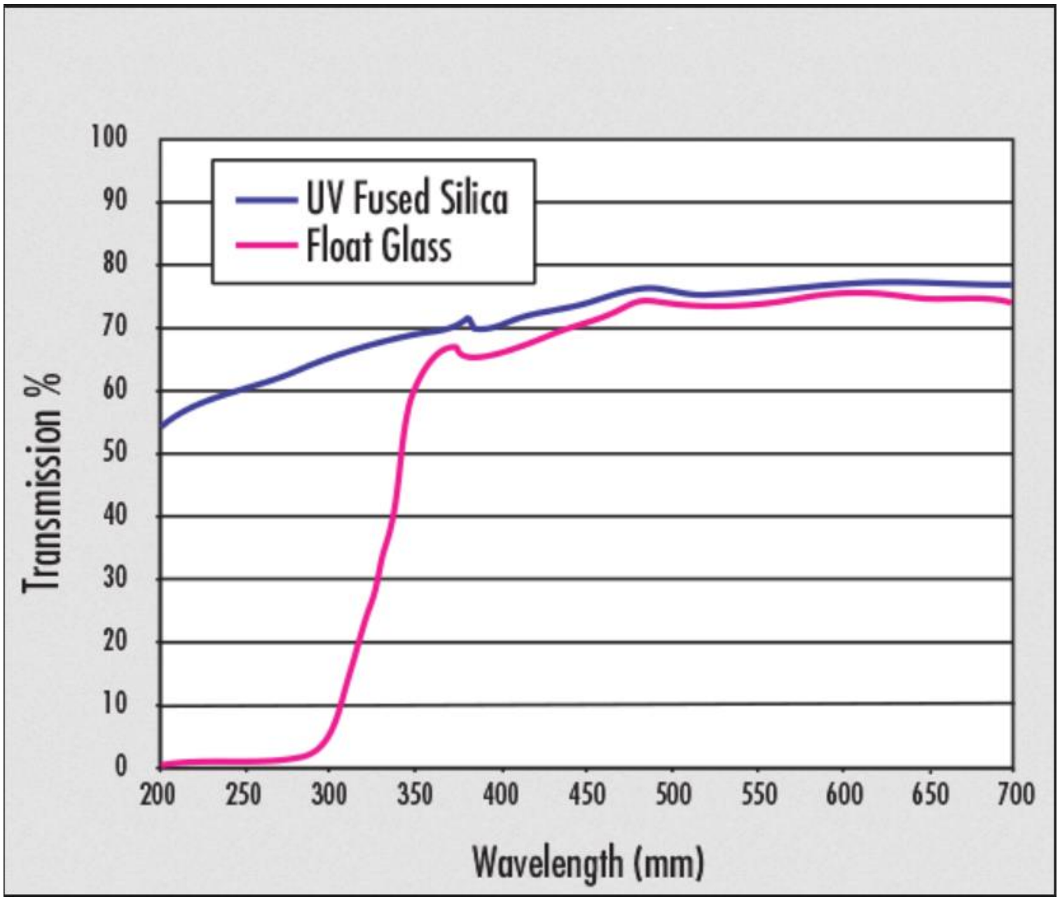


Figure 26. Transmission Spectrum of Ground Glass Diffusers

Shown above in Figure 26 is also the transmission spectrum of UV Fused Silica which is another important parameter to consider. However, since our projector is only operating in the visible spectrum the UV and IR spectrum are rendered irrelevant to our engineering design and specifications. Table 26 below shows the engineering specifications of the ground glass diffuser plate that our senior design team implemented for our light collimation design. The cons to using a ground glass diffuser plate are that the sandblasted surface has less uniformity than polished surfaces and the transmission tradeoff with diffusion pattern depending on the grit level. The main pros of ground glass diffuser plate are the low scattering loss, diffusion irradiance pattern, and fused silica plus float glass options.

Table 25. Ground Glass Diffuser Plate Engineering Specifications

Coating:	Uncoated	Dimensional Tolerance:	+/- 0.25mm
Dimensions:	100mm x 100mm	Edges:	Cut Edges

Grit:	120	Substrate:	Float Glass
Thickness:	1.60mm	Type:	Ground Glass Diffuser Plate
Wavelength Range:	350nm – 2000nm	Width:	100mm

As shown above in Table 26, are the engineering specifications of the ground grass diffuser plate our senior design team implemented into our projector system. Due to the sheer size that we needed for our diffuser, we had to select an uncoated plate for costs and timeline constraints. The dimensions are 100mm by 100mm which was plenty of surface area to illuminate our image uniformly. The girt is 120 which is a metric that used to describe the diffused surface of the substrate with a higher score meaning a better outcome of that desired surface. The wavelength range completely covers the visible spectrum which was important because we used a white 6500K wavelength temperature LED. Furthermore, this plate enables good tolerance of around 0.25mm and the square shape means that the edges are cut edges so that we can more easily 3D print a holder for this optic. As stated and shown above in Figure 26, the substrate we are using is float glass which is the perfect wavelength range for our projector system. The type of ground glass diffuser we are using is a plate rather than a circular lens which made it easier to implement into our projector and design an optic mount for. The width is 100mm which is consistent as the dimensions are 100mm by 100mm. Overall we believe the pros out way the cons of using a ground glass diffuser plate over other diffuser options and a condenser lens.

5.2.3 Projection Lens Design Details

Once the image on the LCD screen has been illuminated, the projector system needed to magnify and project that imaged light onto the desired surface. This part of our projector design needed to be carefully thought through and optimized due to the complexity of imaging optics. The two-dimensional image on the LCD screen is 4.5cm in height and 7cm in width. Considering the geometrical optics of this engineering design, the object we are trying to image while maintaining its high quality of 1080p resolution was a very difficult task. Projection lenses typically operate with three main optics – a positive focusing lens followed by a negative diverging lens then finally a positive magnifying lens. Or in other words, a convex lens will serve as the entrance aperture and focus the image onto the concave lens which will slightly diverge the image onto the final convex lens which will project and magnify the image in real space. Attempting to build this three lens system in senior design would have been a very difficult, time consuming, and expensive task that we feel will not be able to be accomplished with the imposed constraints.

Therefore, our senior design team decided we had to either buy a projection lens configuration or find an old projector system and remove its projection lens configuration. An important factor in choosing which projection lens to select for our projector system is choosing between a fixed focus and zoom projection lens. Both methods of projection will be discussed in further detail below, however, both options provide high resolution, tight color registration, low distortion, high brightness, and focus uniformity. When attempting to find an already established projection lens, we needed to make sure that the diameter of the entrance aperture was sufficiently large enough to retain the high-quality image and ensure no loss of light from the LED.

The first method we could have implemented for our projector system was the use of a fixed focus projection lens configuration. As the name suggests, the focal length is fixed on these lenses and therefore, the in order to focus the image at various projector distances we must physically move the lens. This would have required that we 3D print an opto-mechanical stage that has the projection lens mounted on top of it. The stepper motor would then have to move the entire stage so that the projection lens position moves and as a result the focal length also moves so that the image is in focus with high quality. One significant advantage to using a fixed focus projection lens is that they tend to be smaller and lighter as it only serves to provide one focal width. However, the size and weight difference between that of a zoom lens is not that much different and is in fact insignificant. However, the sheer number of disadvantages to using a fixed focus projection lens configuration far outweighs the positives and therefore, our senior design team moved forward with a zoom projection lens configuration for our projector system.

The second method considered to the engineering design of our projection lens was using a zoom lens. This approach allowed the projection lens to remain stationary and not have to be mounted on a personally 3D printed opto-mechanical stage. Already the complexity of this design was proving to be a significant advantage. Zoom lenses offer a wide range of focal lengths which was desired for our Autofocusing LED Projector. The versatility and convenience of using a zoom lens proved itself to be well worth it in the long run of our senior design project.

Some of the most common zoom lenses include a parfocal lens, varifocal lens. telescopic lens, and wide angle lens. A parfocal lens is referred to as a true zoom lens because it maintains focus throughout all its possible focal lengths. A varifocal lens is the most popular zoom lens sold to consumers. The main characteristic of this particular zoom lens is once the zoom is changed the focus must also be changed to correct to the new zoom distance. As the name suggests, a telescopic lens provides the largest range of possible focal lengths between these lenses. A wide angle lens is capable of producing wide horizontal imaging while manipulating the zoom.

The projection lens our senior design team decided to implement into our projector system was from an old overhead projector. Disassembling the overhead projector, we were able to dismount the projection lens and then incorporate it into our projector. The physical dimensions of the projection zoom lens are 17cm in length with an entrance aperture diameter of 4cm and an exit aperture diameter of 8.5cm. It was a varifocal zoom lens, so as we adjust the zoom the focus also needed to be adjusted at each distance.

The specific brand of this projection lens is unknown; however, it functions properly and has a zoom range from 22.6mm to 45.3mm. This range of distances is the range of focal lengths that the lenses are capable of moving to produce a high quality image. Therefore, the image on the LCD screen can be anywhere from roughly 2cm to 5cm from the entrance aperture corresponding to the desired projection distance. This enabled the zoom ratio of our entire projector system to be a quantitative value of two, which is shown below from the equation and was completely adequate for our projector engineering design.

$$\gamma = \frac{45.3}{22.6} \approx 2$$

Once again, since this is a zoom lens the physical component does not move, the only thing that moves are the lenses inside the lens tube which are adjusted via the knobs on the outside. There are two knobs, one for adjusting the zoom and the other for adjusting the focus. The f-number of the lens is 2.0 to 3.0 which gave us a significant amount of large entrance aperture options as shown in the equation below.

$$F - Number = \frac{f}{D}$$

Where *f* is the focal length and *D* is the diameter of the entrance aperture. At fixed focal lengths, when the f-number is 2.0 the diameter of the entrance aperture decreases by a factor of two. Increasing the f-number refers to increases the lens speed or otherwise known as the ability for the lens to focus the light. The field of view is another important metric of our design decision. The field of view (FOV) is the maximum area that the entrance aperture can capture and exit aperture can project. So, by correctly calculating the FOV of our system, we can then determine how much area our projector can image. As shown below in Figure 27 the AFOV represents the horizontal angle from the projector to the screen and the path of light from which that horizontal angle covers.

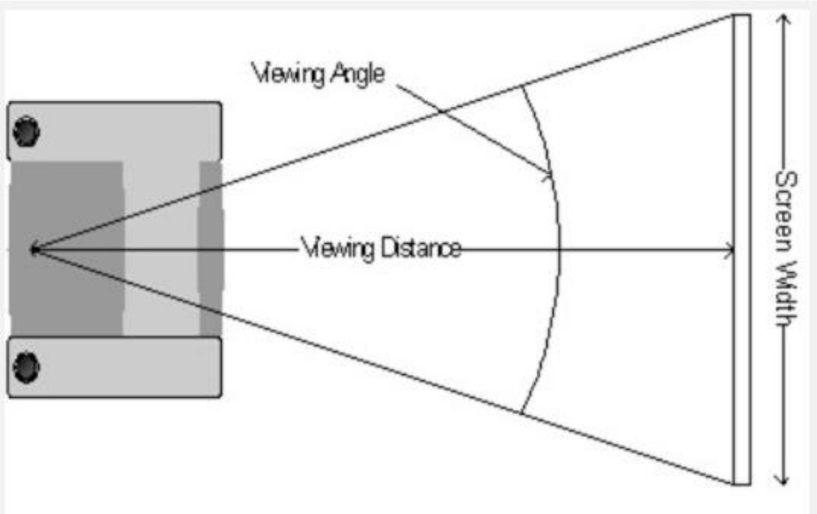


Figure 27. Angular Field of View Diagram

Additionally, we can calculate the angular field of view (AFOV) which will determine the angle of light that can be projected by the lens. The equation for the AFOV is given below where *H* is the image size at the projection lens and *f* is the viewing distance.

$$AFOV = 2 \times tan^{-1}(H/2f)$$

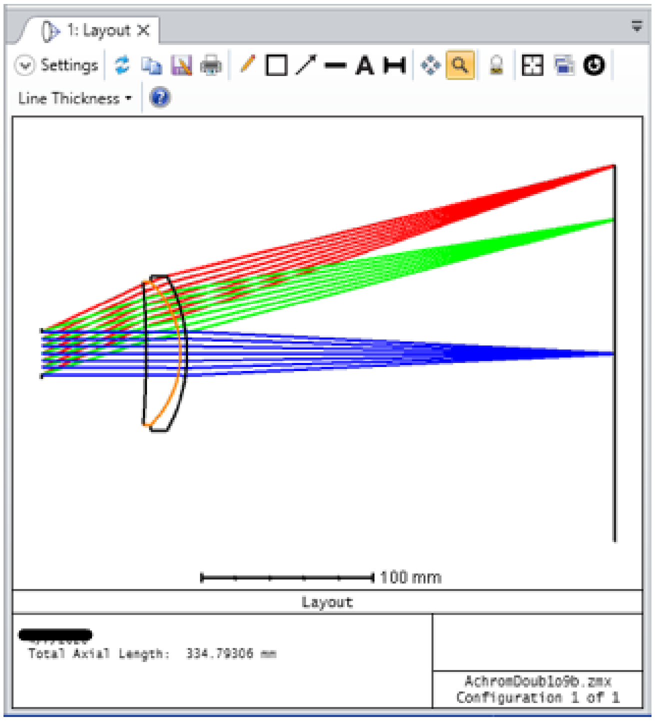
At the base viewing distance of 1m (100cm) from projector to screen and the image size at the projection lens of 7cm then the AFOV will equal a horizontal viewing angle of roughly 160° as shown in the equation below.

$$AFOV = 2 \times tan^{-1}\left(\frac{100}{14}\right) = 160°$$

When designing the projector system for our senior design project it is extremely important that we attempt to limit as much aberration as possible to maintain the desire for high quality imaging. The projection zoom lens we have selected features an achromatic doublet convex focusing lens for the magnification of the image onto the desired surface. The engineering design of an achromatic lens is to limit spherical and chromatic aberration by focusing the opposite ends of the visible spectrum onto the same plane such as red and blue wavelengths. The doublet that we have is the most common type of achromat lens which is just a convex lens with low dispersion joined together with a concave high dispersion lens so that they complement each other and offset their effective dispersion properties.

The material used for our particular achromatic doublet is unknown to us, however, the most popular optical materials used for the negative concave element is flint glass such as F2 and for the positive convex element it is crown glass such as BK7. Thus, we were able to simulate the achromatic doublet lens as our projection lens in Zemax OpticStudio. From the simulation we can observe important parameters such as the ray diagram, field curvature, focal shift, and spot diagram. All of these parameters can tell us more about the possible aberrations and distortions present in the lens design and imaging optics.

Figure 27 below shows the ray diagram of the achromatic doublet lens with the three primary wavelengths of red, green, and blue. The ray diagram is a representation of the possible paths light can take from our object (image) to our (projected) final image. You can see how they originate from an object point source and refract through the lens for a clean focus onto the image plane. The total axis length was 335mm which is roughly what we would expect for our projector if we were projecting an image 33.5cm away to a surface. The ray diagram can give us an idea of how the (object) imaged light will interact with the lens and focus on the image plane.

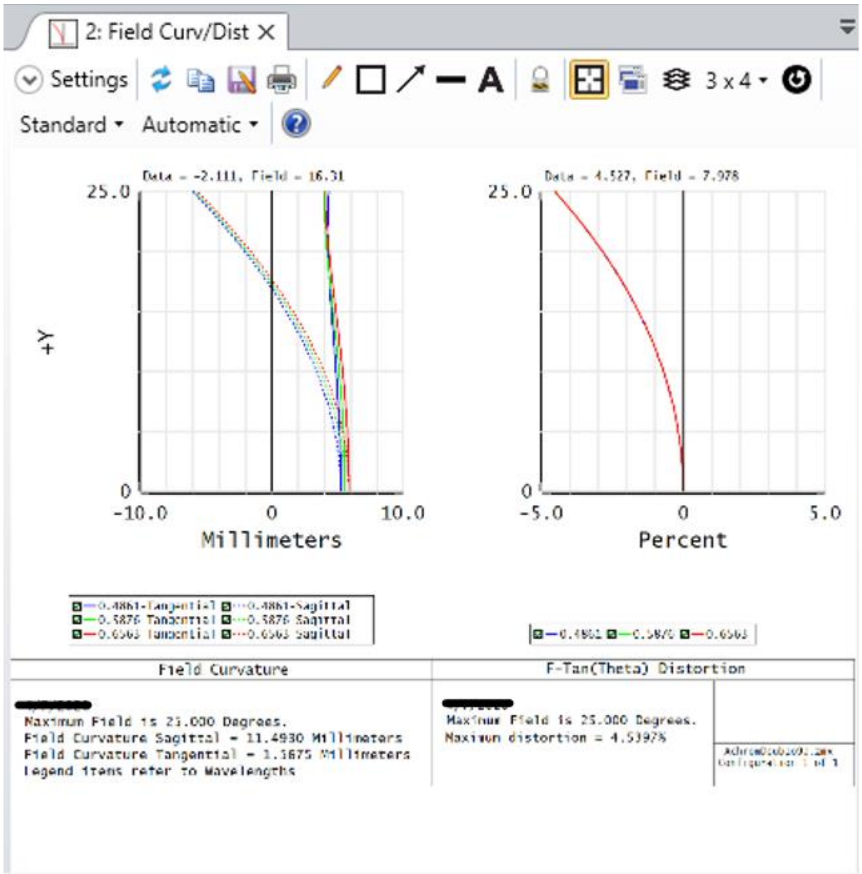


[redacted]
Total Axial Length: 334.79306 mm

AchromDoublo9b.zmx
Configuration 1 of 1

Figure 28. Achromatic Doublet Ray Diagram

The next illustration below, Figure 28 shows the field curvature diagram on the left and the distortion diagram on the right of the achromatic doublet lens. Field curvature is when the lens does not focus on the planar objects of our image entire width. Meaning the center of the projected image will be in focus while the edges will not. This is very common with projection lenses and cannot be avoided to a certain extent. With the simulation we were able to prove that the field curvature will be insignificant with a maximum field of 25°. The field curvature in the sagittal plane is roughly 11.5mm and in the tangential plane it is roughly 1.5mm. In geometric optics, distortion is the deviation from rectilinear projection. The two main distortion patterns are pincushion and barrel. Pincushion distortion is when the image looks pushed in and barrel distortion is when the image looks pushed out. The distortion in our simulation proved to be insignificant as well with a maximum field of 25° with a maximum distortion of roughly 4.5%.

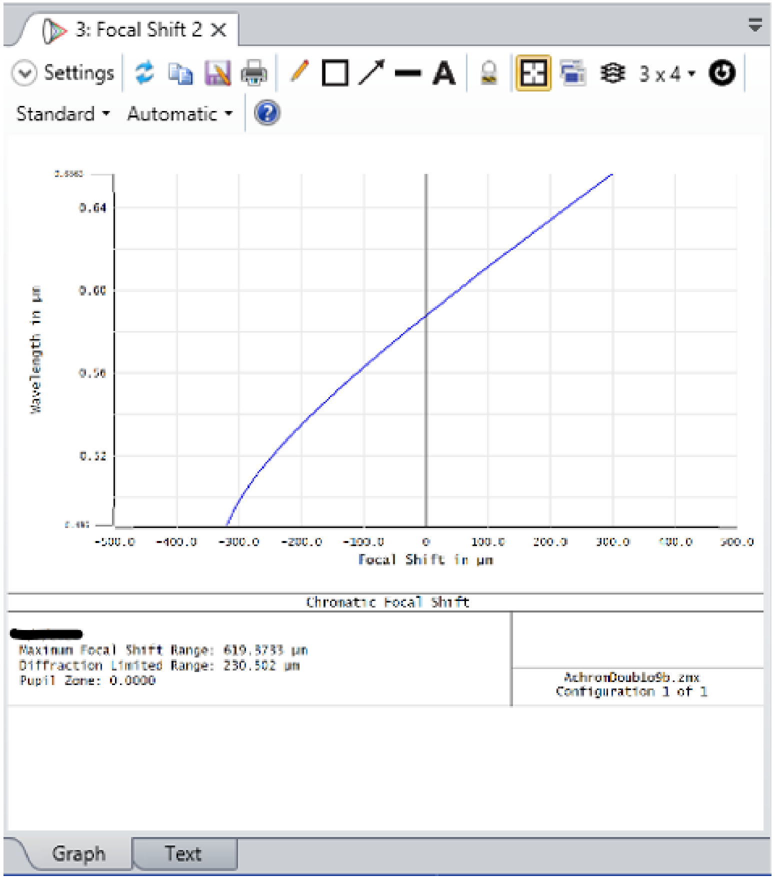


[redacted]
Maximum Field is 25.000 Degrees.
Field Curvature Sagittal = 11.4930 Millimeters
Field Curvature Tangential = 1.3675 Millimeters
Legend items refer to Wavelengths

[redacted]
Maximum Field is 25.000 Degrees.
Maximum distortion = 4.5397%

Figure 29. Achromatic Doublet Field Curvature (left) and Distortion (right)

Focal shift is an optical complication that occurs due to spherical aberration when the imaged object is brought into focus at maximum aperture and the aperture stop is minimized or stopped down. Meaning the plane of focus is shifted to the stopped down aperture size but the aperture is still at the maximum size. As a result, blurry images and focusing errors occur. This is mainly an issue with fixed focus lenses which we are not using since we are using a zoom lens. With a zoom lens the entrance aperture can be manipulated based on the desired distance therefore it can correct for any present focal shift from spherical aberration. The maximum focal shift range present in our simulation was about 620µm with a diffraction limited range of 230µm. The diffraction limit describes the smallest feature size that can be resolved by our projector imaging system. Theoretically, our projector will be able to resolve features on the image up to 230µm in size. Furthermore, we were able to neglect the pupil zone to a value of 0 because this parameter is more related to the visual optics of the human eye.



Chromatic Focal Shift

[redacted]
Maximum Focal Shift Range: 619.3733 µm
Diffraction Limited Range: 230.502 µm
Pupil Zone: 0.0000

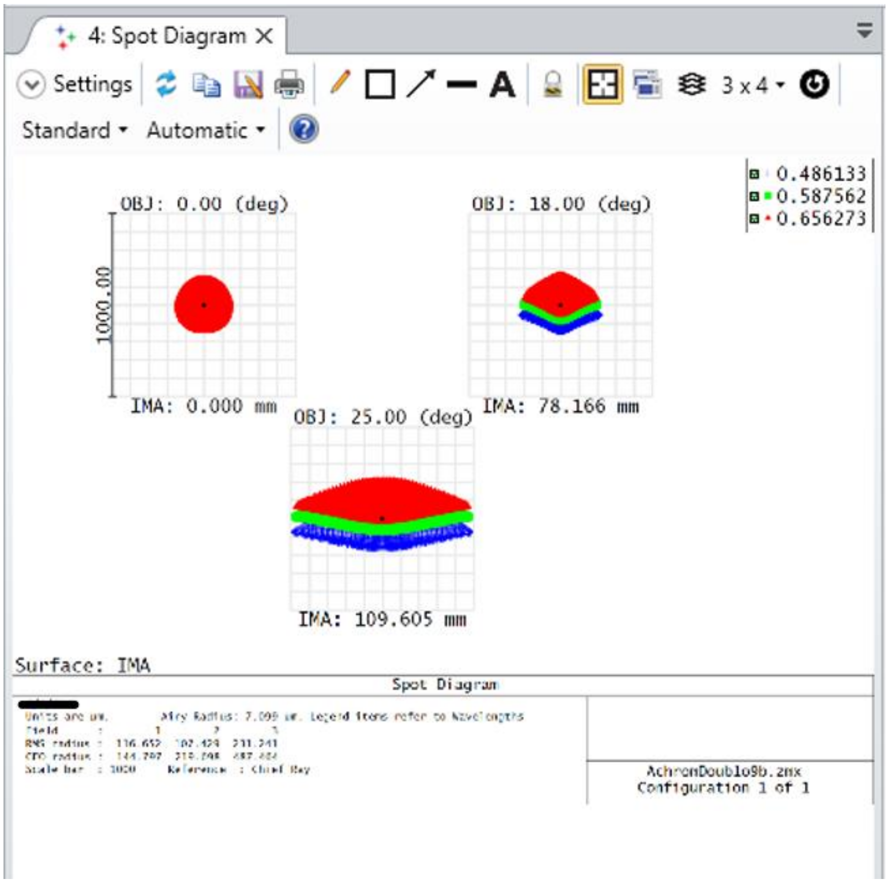
AchromDoublo9b.zmx
Configuration 1 of 1

Figure 30. Achromatic Doublet Focal Shift

The final simulation parameter that is important to the design of our projection lens is the spot diagram as shown below in Figure 30. The spot diagram shows where the rays from our object (image) will fall on the (projected) image surface. In order to form a high quality image, the rays from achromatic doublet lens must fall closely together. This is assuming the object is a point source, which is an acceptable assumption when performing a simulation for our projection lens.

The three diagrams show the spot diagram at different object angles - 0°, 18°, and 25°. The resultant airy radius is 7µm which is a very good result. The airy radius is a term that can be used to describe an image that is relatively free of aberrations. This occurs when the geometrical image point from our projector is on the same order or smaller than the airy radius. You can see that as the object angle increases so do the relative aberrations and the worse the spot diagram becomes. The root-mean-square (RMS) radius was roughly 117µm, 192µm, and 211µm respectively for each object angle.

The reference used for the spot diagram is the chief ray which is the ray that originates from an off axis point from our object (image) and passes through the center of the aperture stop in our projection zoom lens. The spot diagram shown shows relatively great results for the purpose of our projector system.



```
Surface: IMA
Spot Diagram
[redacted]
Units are µm.        Airy Radius: 7.099 µm. Legend items refer to Wavelengths
Field      :      1        2        3
RMS radius :  116.652  102.429  231.241
GEO radius :  144.797  219.098  487.404
Scale bar  : 1000     Reference  : Chief Ray

AchromDoublo9b.zmx
Configuration 1 of 1
```

Figure 31. Achromatic Doublet Spot Diagram

The projection zoom lens our senior design team has chosen has been shown to be a great option for our projector. With a wide range of distances for zoom and focus, which will enable the projector to operate at various desired distances. With the two rotating knobs on the outside of the projection lens the zoom and focus can be adjusted manually or through the use of our autofocusing system. The simulation of the projection achromatic doublet lens via Zemax OpticStudio showed great results as our lens of choice. With the ray diagram, field curvature, focal shift, distortion, and spot diagram being optimized. The expected result of our final projected image should exhibit a high quality image with relatively zero or low distortion, spherical aberration, and chromatic aberration.

5.2.4 Overview of Optical Path

This section covers the complete overview of the optical path of our projector systems with a table of design specifications and a schematic. To recap, first a light source is needed for the illumination component of our project. We have selected a chip on board light emitting diode that is 40mm in length, 40mm in width, and 2mm in thickness. This LED consumes 30W of power with a turn on voltage of 30V-34V along with a turn on current of 1A. The wavelength temperature is 6000k to 6500k which gives us that nice shade of white as seen from the color gamut. This LED can illuminate up to 27,000LM of brightness which we believe is sufficient and needed for our engineering design. This LED will dissipate a significant amount of heat, so it will be placed on the square aluminum heat sink with the use of thermal grease. With the goal of reducing the possibility of overheating and red shifting of the diode. Without the heatsink the LED produces heat in the range of roughly 215 degrees Celsius versus when it is mounted on the heatsink it produces heat in the range of roughly 70 degrees Celsius. Therefore, the heatsink helps cool down the LED by roughly 3x!

Directly following the light source will be the ground glass diffuser plate. The purpose of using such an optic as our light collimation is so that the distance between the light source and image source is as small as possible. The ground glass diffuser plate does not have a focal which can enable such a design goal. The ground glass will spread the LED light more uniformly onto the image so that the center and the edge of the image have relatively equal brightness. The length of the optic is 100mm, the width is 100mm, and the thickness is 1.60mm. The dimensional tolerance is +/- 0.25mm which gives us plenty of wiggle room with the dimensions.

As mentioned above, the goal is to place the image as close to the illumination source as possible to achieve as bright of a final image as possible. Therefore, directly behind the ground glass diffuser plate will be the liquid crystal display screen which has pixels which illuminate the image. The LCD screen height is 120mm and the screen width is 70mm. The physical image size displayed by the pixels on the screen is 45mm in height and 70mm in width. Included with the LCD screen is the need for an LCD driver which will program all the signal and image processing done by the screen. The LCD driver has a turn on voltage of 5V which is very reasonable for the output from the screen. The screen itself is completely transmissive so that the image can be propagated along the optical path.

The final optical path design component is the projection lens which is placed directly after the LCD screen image. Depending on the desired projection distance, that will determine how far the projection lens will be placed from the image source. The length of the projection lens is 17cm with an entrance aperture size of 4cm and an exit aperture size of 8.5cm. It has manually adjustable zoom and focus rotational knobs on the outside of the lens tube. Therefore, the physical lens tube will be placed up against the image source so that the entrance aperture can capture the entire image with little aberration, distortion, and high quality.

Once the entrance aperture is at the correct distance the zoom and focus can be manually adjusted to project the final image at any distance. The zoom range of the projection lens is from 22.6mm to 45.3mm with an f-number from 2.0 to 3.0.

Table 26. Optical Path Design Specifications

Component	**Size**	**Power Consumption**	**Wavelength & Linewidth**
Light & Image Source			
Light Emitting Diode	Length: 40mm Width: 40mm Thickness: 2mm	30W | 30V-34V | 1000mA	6000k – 6500k (Wavelength Temperature) 2700LM
Liquid Crystal Display	Screen Height: 120mm Screen Width: 70mm Image Height: 45mm Image Width: 70mm	5V turn on driver board voltage	Transmissive imaging screen
Component	**Size**	**Focal Length**	**Performance**
Optics			
Ground Glass Diffuser Plate	Length: 100mm Width: 100mm Thickness: 1.60mm	Dimensional Tolerance: +/- 0.25mm	Illuminate the image uniformly from the LED
Projection Lens	Entrance Aperture: 4cm Exit Aperture: 8.5cm Length: 170mm	22.6mm - 45.3mm F/#: 2.0 ~ 3.0	Manually adjustable zoom and focus knobs

Figure 31 below illustrates the complete overview of the optical path with a schematic of how each component from Table 27 above will complement each other. With the illustration below you can clearly see how the projector will form a final image on a desired surface. Starting from the LED mounted on the aluminum heatsink. Illuminating the ground glass diffuser plate which diffuses and collimates the light onto the LCD screen which contains pixels from the image formation. The signal and image processing connections from the connector port to the LCD driver. Finally, the projection lens tube which contains the entrance aperture along with the achromatic doublet exit aperture lens. The negative concave lens in the middle which is manipulated by the manually adjustable zoom and focus knobs on the outside of the lens tube. The final image can now be visualized where the optical ray paths cross and the focal point and magnify the image at a desired distance where the image is in focus on the desired surface with high quality and low aberration and distortion. The goal of the optical path is to project an image with high quality 1080p resolution for a pleasant viewing experience for the consumer.

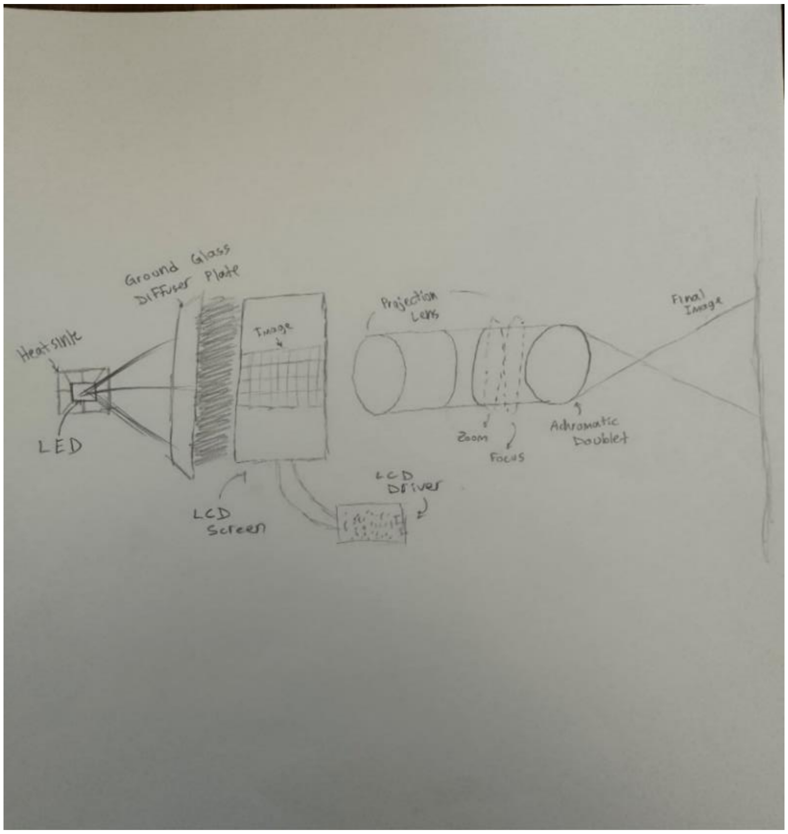


Figure 32. Optical Path Sketch

5.3 Final image design details

In using the variable zoom lens, the two values that must be determined in producing the final image are the magnification and focal length, which control how large the image will be, and how legible the image will be, the following section will discuss how we plan to determine these values using the rangefinder, as well as our design approach for autofocusing using the variable zoom lens.

5.3.1 Final Image Size

When designing a compact projector, it is important to consider the distance that the optical will cover. If the path is too long, then the projector may be too narrow without utilizing any of the space available horizontally.

Finding the final image size for our projector, the variable that will determine this outcome is magnification. The design approach to determine this value will be determined from the range finder. Using the magnification equation as follows

$$M = \frac{d_i}{d_o}$$

Where the object distance is a fixed value determined by the distance from the Fresnel Lens to the Projection Lens. And the image distance is determined by the distance reading from the rangefinder. Once the magnification is found using this method, that magnification value will then be multiplied by the height and width of the LCD screen, which was previously defined as 45 millimeters for the height and 70 millimeters for the width. By following this process, we can determine estimates of the final image size based on the projector's location relative to the wall it is being projected on. The following table are preliminary calculations in one meter increments up to our projection limit of 5 meters of the final image size.

Table 27. Values for Maximum Image Sizes

Image distance	Magnification	Image height	Image width
1 meter	5.56	0.25 meters	0.39 meters
2 meters	11.11	0.5 meters	0.78 meters
3 meters	16.67	0.75 meters	1.16 meters
4 meters	22.22	1 meters	1.56 meters
5 meters	27.78	1.25 meters	1.94 meters

5.3.2 Focal length

The other value that must be determined by our range finder is the focal length. To determine this value, a simple figure will be used for visual reference.

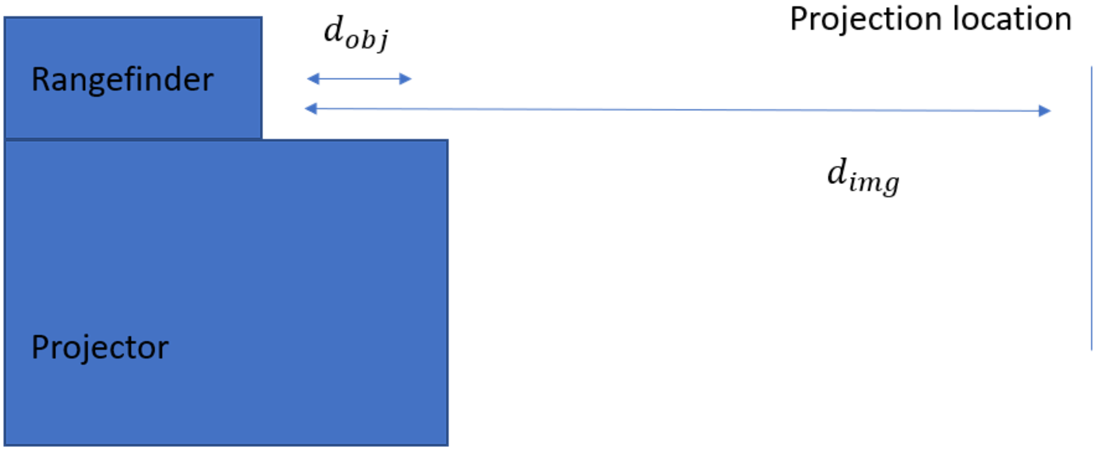


Figure 33. Projector and Rangefinder Schematic

The necessary optical equation to use to solve this system is the thin lens equation will be used, it is as follows:

$$\frac{1}{f} = \frac{1}{d_{obj}} + \frac{1}{d_{img}}$$

From this base equation, we can solve it for the focal length which results in the following equation:

$$f = \frac{d_{obj} \times d_{img}}{d_{obj} + d_{img}}$$

In this case, the object distance is the distance between the projection lens and the range finder, this will be a fixed value that we estimate to be at 50 millimeters. The image distance will be the distance from the rangefinder to the target of projection, which will just be the value determined by range finder. Now, we can determine what our desired focal length will be, based on our range finder values. The following table will have expected focal lengths at one-meter increments to our limit of five meters.

Table 28. Values for Focal Lengths

Image distance	Focal length
1 meter	47.6 millimeters
2 meters	48.8 millimeters
3 meters	49.1 millimeters
4 meters	49.4 millimeters
5 meters	49.5 millimeters

5.3.3 Autofocusing with zoom lens

For this design approach, there were a few options that were considered. The first option is to create a two-gear system, where one gear will be attached to the stepper motor, and the other will be attached to the cylindrical projection lens, this will create a simple gear train where we can preliminarily determine our spatial resolution by determining the gear ratio between the two and the circumference of our projection lens.

Another method is to use a timing belt and pulley system. A timing belt is a toothed belt that engages with a toothed pulley to transmit power and motion. By selecting a pulley with the appropriate number of teeth, the distance traveled per motor step can be adjusted to achieve the desired precision and accuracy. Timing belt and pulley systems can be designed to achieve high precision and accuracy with minimal backlash.

Another option is to use a rack and pinion system. A rack is a flat toothed bar that engages with a toothed pinion gear to convert rotary motion into linear motion. By selecting a pinion gear with the appropriate number of teeth, the distance traveled per motor step can be adjusted to achieve the desired precision and accuracy.

Whichever method is selected would also need to be repeatable as our goal is to change the focal length and the zoom, which would require our mechanical system to be implemented twice.

The design approach that was pursued was to create a two-gear system. To determine how much the large cylinder moves for every turn of the stepper motor, we need to know the gear ratio between the stepper motor and the cylinder. The gear ratio represents the relationship between the number of teeth on the gear attached to the stepper motor shaft and the number of teeth on the gear attached to the cylinder.

The circumference of the cylinder can be calculated by measuring its diameter (or radius) and using the formula:

$$Circumference = 2 \times pi \times radius$$

Once we know the gear ratio, we can use the formula:

$$Distance\ traveled\ by\ cylinder = \frac{\#\ of\ teeth\ on\ cylinder\ gear}{\#\ of\ teeth\ on\ motor\ gear}(circumference)$$

With these values, we can determine how much the large cylinder moves for every step of the stepper motor, but it will take time to find a favorable ratio that provides us with accuracy and precision that is desired. To provide an example, let us use the specifications from the projection lens, the diameter of the projection lens is nine centimeters, by plugging this in we get:

$$Circumference = 2 \times pi \times \left(\frac{9cm}{2}\right) = 28.27\ cm$$

Let us assume that the number of teeth on the stepper motor gear is 40, and the number of teeth on the cylindrical projection lens is 20, using these values we get:

$$Distance\ traveled\ by\ cylinder = \frac{20}{40}(28.27\ cm) = 14.13\ cm$$

So, in this example, the projection lens would move by 14.13 centimeters per step of the motor.

5.3.4 Autofocusing with optomechanical linear stage

For this design approach, we would have a lens responsible for adjusting the focal length, or focusing lens, and this lens would be able to move in the x-direction by being connected to a lead screw or linear actuator, to briefly explain, a linear actuator is a component of a machine that is responsible for moving and controlling a mechanism or system in a straight line, and this mechanical system would be connected to the stepper motor which would change the focal length by moving the focusing lens.

To do this, we needed to know the mechanical properties of the stepper motor and the mechanism used to move the lens. Specifically, we needed to know the step angle of the stepper motor, which is the angle that the motor shaft rotates for each step, and the gear ratio between the stepper motor and the mechanism used to move the lens.

Assuming that we are using a lead screw or a linear actuator to move the lens, we can use the following formula to calculate the linear distance that the lens will move for each motor step:

$$linear\ distance\ per\ step = \frac{motor\ step\ angle \times lead\ screw\ pitch}{gear\ ratio}$$

where the lead screw pitch is the linear distance traveled by the lead screw for each revolution, and the gear ratio is the ratio of the number of teeth on the stepper motor gear to the number of teeth on the lead screw gear.

The following is an example calculation using the motor specifications from the 28BYJ-48 stepper motor. The 28BYJ-48 has a step angle of 5.625 degrees and a gear ratio of 64:1. Assuming we have a lead screw or linear actuator with a pitch of 2 millimeters per revolution, the linear distance per step would be:

$$linear\ distance\ per\ step = \frac{5.625\ \times 2\ mm}{64} = 0.176\ mm$$

To provide an example scenario, let us assume we need to move the lens by 50 millimeters, with a linear distance per step of 0.176 millimeters, another equation can be used to determine the number of steps required which is as follows:

$$number\ of\ steps = \frac{lens\ movement}{linear\ distance\ per\ step} = \frac{50\ mm}{0.176\ mm} = 284\ steps$$

So, in this example we would need to move the stepper motor by approximately 284 steps to adjust the position of the lens to achieve the desired focal length.

5.4 Arduino Development Board Software Design Details

In this section we will be looking at the overall software design details for the Arduino Mega R3 that we will be using for the Autofocusing LED Projector. This includes discussing best practices for developing software for an Arduino development board, the development environment we will be using, useful Arduino libraries that may be used during the development process, any additional software that may be useful, and an overview of the plans for the software needed for this project.

5.4.1 Development Best Practices

Developing software for an Arduino development board typically requires a much different approach when compared to developing software for a traditional computer. Unlike most modern computers, Arduino development boards have limited resources, including memory and processing power, so it is extremely important to optimize your code to ensure it runs efficiently. When developing software for an Arduino, there are several best practices that can be used to combat these issues and help ensure the reliability, maintainability, and scalability of your code.

One of the most important best practices to keep in mind while developing software for an Arduino board is to use a modular approach. A modular approach involves breaking the code down into smaller, self-contained modules or functions that perform specific tasks. Following a modular approach for this project will make it much easier to test, modify, and maintain our code.

Another important practice is to optimize the code for memory usage, as the Arduino board has limited resources. This means avoiding dynamic memory allocation and using static variables whenever possible. Additionally, it's important to write efficient code that is optimized for speed. This includes using bit-wise operators, avoiding floating-point arithmetic, and optimizing loops to reduce execution time.

Additionally, another best practice to consider when developing the Arduino board is to test the code thoroughly. This involves testing the code on the actual hardware to ensure that everything is working correctly and reliably. Testing is critical to identify and fix any issues before they cause problems in the final product. It is also important to use debugging tools, such as a serial output, to help identify any issues that may arise during testing. Documentation is also critical to developing efficient and reliable software for the Arduino board. This includes using clear and concise comments to explain how the code works, as well as using meaningful variable and function names.

The final best practice that should be kept in mind is using a version control software, such as Git. Version control will help keep track of changes to the code and allow multiple developers to collaborate on the same project with ease. We will also store all of the code within a GitHub repository so that it can easily be viewed and accessed by the whole team. This will help us to ensure that our code is always up to date and will make it easier to manage changes to the code over time, while also keeping a working history of all the changes that have been made throughout the development process.

5.4.2 Development Environment

As a result of selecting the Arduino Mega R3 for our development board, we will need to use the Arduino Integrated Development Environment in order to program the software for our Autofocusing LED Projector. The Arduino Integrated Development Environment provides a simple programming environment based on the C++ programming language which will enable us to write and upload code to the Arduino board. The Arduino IDE is the software application that we will be using in order to write, compile and upload code to the Arduino Mega R3.

The Arduino IDE is designed to be simple and easy to use, even for those with little to no programming experience. The Arduino IDE is based on the Processing programming language and includes a code editor, a compiler, a debugger, as well as a serial monitor. The download for the Arduino IDE is available for free and it is compatible with all the common operating systems including Windows, Mac OS X, and Linux.

One of the major advantages of using the Arduino IDE is its simplicity. The Arduino IDE code editor has a user-friendly interface with features such as syntax highlighting, auto-completion, and indentation. This makes it easy for beginners to write and understand code. The compiler and debugger are also straightforward and can be used without any additional software. Additionally, the serial monitor allows users to communicate with their Arduino board, making it easy to test and debug code.

Another advantage of the Arduino IDE is its compatibility with a wide range of Arduino boards. Whether you are using an Arduino Uno, Mega, Nano, or any other board, the IDE provides a simple and consistent interface for programming. This allows users to switch between boards without having to learn a new software tool. Additionally, the IDE is open source, which means that users can modify and extend it to meet their specific needs.

Although there are a lot of great advantages that come along with using the Arduino IDE, there are also some disadvantages too. One of the major disadvantages of using the Arduino IDE that we need to consider for our project is that the Arduino IDE is not as efficient as other programming tools. This is because the Arduino IDE is not optimized for performance, but rather for ease of use. This can result in slower execution times and increased memory usage. One more disadvantage that should be considered when using the Arduino IDE is that it can be limited in terms of advanced programming features. This can be limiting when you are trying to implement software that is very complex.

Overall, the Arduino IDE is a powerful yet easy-to-use tool for programming Arduino development boards. It is widely used by hobbyists, students, and professionals alike and has a large community of users who share code and provide support. Whether you are a beginner or an experienced programmer, the Arduino IDE provides a simple and consistent interface for programming Arduino boards.

5.4.3 Arduino CLI

In addition to the Arduino IDE, Arduino also provides their own dedicated command line interface, the Arduino Command Line Interface. The Arduino Command Line Interface is a software tool that will allow us to interact with the Arduino platform using command-line commands. The Arduino CLI may help make it easier to manage our libraries, compile our code, and upload the code to our Arduino Mega R3 board.

5.4.4 Useful Arduino Libraries

The Arduino IDE will aid us greatly thanks to the thousands of libraries that it provides. These libraries can help simplify programming tasks and make it easier to add a wide range of functionalities to the project. This will help us to develop the software we need for our projector. Some examples of the libraries that we may find useful for our project are included in Table 29 on the following page.

Table 29. Useful Arduino Libraries

Arduino Library Name	**Library Description**
SoftwareSerial	An Arduino IDE library that is used for serial communications with digital pins.
Wire	An official Arduino IDE library that allows you to communicate with I2C/TWI devices like sensors or other microcontrollers.
SPI	An Arduino IDE library which is used for SPI communication, which is another common communication protocol used for connecting devices to Arduino.
Fan Controller	An Arduino IDE library that is used to controlling 3-pin and 4-pin PWM computer fans.
Servo	An official Arduino IDE library that is used for controlling a variety of servo motors.
Stepper	An official Arduino IDE library that is used for controlling a variety of stepper motors.
StepperControl	An Arduino IDE library that is used for controlling and specifying complex movement sequences for a number of supported stepper motors.
AccelStepper	An Arduino library that provides an object-oriented interface for two, three or four pin stepper motors and stepper motor drivers, which allows Arduino boards to control a variety of stepper motors.
RangingSensor	An Arduino IDE library that is used for controlling and operating range finders.
TFMini	A third-party Arduino driver used for controlling the Benewake TFMini time-of-flight distance sensor.
PocketSphinx	A library that is compatible with Arduino development boards which is a lightweight, open-source speech recognition system that can be used to recognize a limited set of commands.
EasyVR	This is a library that provides an easy-to-use interface for integrating voice recognition into Arduino projects.

5.5 Range Finder and Stepper Motor Software Design Details

For our Autofocusing LED Projector, one of the main systems that will depend heavily on software design is the interaction between the range finding module and the stepper motors. In order to achieve the autofocusing functionality that we are looking for, we must first engage the TFMini LiDAR range finding module in order to get the distance from the projector to the screen area. Once we have this range, we then need to engage the stepper motors that will be attached to gears, which allow it to adjust the projection lens accordingly. A simple flowchart diagram showing a general overview of how the software for this system will work is shown below.

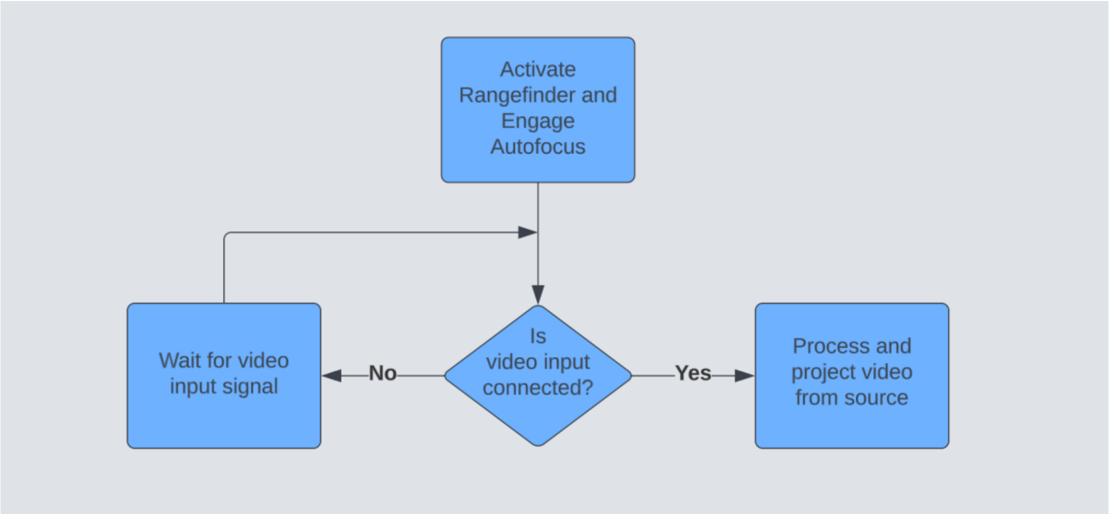


Figure 34. Software Flowchart for Rangefinder and Motor Design

The software flowchart above outlines the general behavior that we are looking for when implementing our software design for this piece of the software. The first block in the process is the activation of the auto-focus functionality and the range finder. Once the auto-focus functionality is engaged (whether by user input or a regular time interval) the range finder will then find the distance to the screening area. Next, the stepper motors will be activated in order to adjust the projection lens accordingly.

After this process is complete, we move on to the next block which is a check as to whether or not a video input is connected to the projector. If there isn't any video source connected, then we move to the block to the left where we simply wait until one has been connected. During this time, we can either have the projector remain off, or display an idle screen which will ask the user to connect a video source. Once a video source has been connected, we move to the final block on the right of the flowchart where we go ahead and process the video and project it to the screen area.

5.5.1 Initial Software Design Process

The elementary idea for this piece of the software is that it will get the range from the projector to the screen area and then use that range to determine how the stepper motors should be used to adjust the projection lens. In order to develop this software effectively we will need to break it down into a few separate steps that will outline the overall process.

The first step in the design of this piece of software would be to get our TFmini LiDAR range finding module working on the Arduino board and accurately displaying the distance results. It is crucial that we are able to get the range finding module working on its own first, as without it functioning correctly, we are unable to process any further in the software design process. Once we are able to accurately get the distance results from the range finder, we will then have to modify the code to better meet our needs for the Autofocusing LED Projector.

There are several approaches to take in order modify the range finding code for use in the Autofocusing LED Projector system. This will be discussed in further detail during the testing and integration phase. However, some of the approaches that can be considered would include taking measurements at given intervals of time, only taking a new measurement when the user engages the autofocus feature, or simply constantly scanning for the range and then setting up thresholds for different distances.

Once we have successfully set up the software for the range finder module, the next step will be to hook up the stepper motors to the Arduino development board and get them functioning. The best way to approach this step would be to first isolate the stepper motors and make sure we are able to get them moving the way we would like before worrying about any integration with the range finding module. This way if we run into issues while trying to use both the stepper motors and rangefinder simultaneously, we will know that this is due to an error in the software design and not the stepper motors themselves.

After we are able to get the stepper motors working independently, it is then important to proceed by ensuring that we are able to use both the range finding module and stepper motors simultaneously. Once we are able to successfully get the stepper motors and range finder connected to the Arduino development board, and both functioning at the same time, we can move onto working on getting these parts working together in order to achieve the autofocusing functionality for the projector.

5.5.2 Integrated Software Design Process

After successfully setting up the software in order to use both the stepper motors and range finding module simultaneously, it is time to move onto the final, and toughest, part of this piece of the software: the final integration between the two. Once again there are numerous approaches that can be taken in order to achieve the end goal of using the rangefinder and stepper motors in order to adjust and focus the projector lens. This will be covered in more detail in the testing and integration sections, but there are several approaches that we can consider from the software perspective.

5.5.2.1 Integration Approach #1

One approach that we are considered for using the rangefinder and stepper motors in order to achieve the autofocusing functionality for our projector involves using two separate stepper motors: one which would control the LCD screen position and another which would control the focus knob on the project lens.

These stepper motors would be connected to the focus knob and LCD platform via 3D printed gears which would allow them to control the knobs with precision. With this in mind, the software would first need to take the range reading using the range finder. Then it would need to control the stepper motors such that they adjust both the focus knob and the LCD position according to the range so that the projection is focused. There are a few approaches to consider in order to do this which will be discussed later in this section.

5.5.2.2 Integration Approach #2

One more approach that we are considering in order to use the rangefinder and stepper motors for focusing the projected video involves using a single servo motor. This approach would be quite similar to the first approach, however there will only be a single servo motor which controls the final lens of the projector, rather than two separate stepper motors that control the focus and LCD position of the projector.

In this configuration, the single servo motor would control the final lens of the projector. In order to do this, we would need a gear which would move the final lens along a track (both of these parts would most likely be 3D printed as discussed later in this section). From the software perspective, this option would be quite a bit simpler when compared to the first option because we only need to move one servo motor.

5.5.3 Stepper Motor and Range Finder Calculations

Regardless of which of the above two approaches we take for moving the stepper motors, we also have to consider how exactly we are going to calculate how much the stepper motor needs to be moved. The distance that the stepper motors will be moved must be based on the distance to the screening area in order to focus the projection. This is the most difficult part of this piece of the software, however once again there are a few different approaches that can be considered in order to calculate how much the stepper motors need to move such that the projector can focus accurately from a range of distances.

5.5.3.1 Using a Lookup Table

The first, and easiest, approach of calculating how much the stepper needers need to be moved based on the distance to the screening area would be to use a lookup table. A lookup table is a data structure that stores precomputed values in order to create a mapping between input and output values for efficient and quick access. It is essentially an array that contains a set of pre-calculated values or answers according to a particular set of inputs.

In order to implement this method for the first integration approach we would need create a table which contains three different columns: one for the distance from the projector to the screening area, one for the amount that the first stepper motor needs to be moved for the focus knob, and one for the amount that the second stepper motor needs to be moved in order to adjust the LCD screen for the best projection image. For this approach, we are able to get the distance from the projector to screening area using the range finding module, then we can use the lookup table in order to find the amount that the two gears need to be moved and then adjust them accordingly. A simple example of what this lookup table might look like is shown below.

Table 30. Example Lookup Table for Two Stepper Motors

Distance to Screening Area	Focus Knob Stepper Motor Adjustment Value	LCD Stepper Motor Adjustment Value
5 meters	3 steps	1 step
6 meters	5 steps	2 steps
7 meters	7 steps	3 steps
8 meters	9 steps	4 steps
9 meters	11 steps	5 steps
10 meters	13 steps	6 steps

As you can see from the example table above, this approach would make the autofocusing system for our projector quite simple. Any time we would like to focus the projector, we would first initiate the range finding module in order to get the distance from the projector to the screening area. Once we have the distance to the screening area, we simply refer to the lookup table where we find the corresponding measurements for the two stepper motors. Then we can use those values in order to move the focus knob and LCD screen such that the projector is focused on the screening area.

Implementing a lookup table for the second integration approach would be almost exactly the same. However, in the case of using a single servo motor which adjusts the final lens of the projector, our lookup table would consist of only two columns. One for the distance from the projector to the screening area, and another for the amount that the single servo motor needs to move in order to properly focus the projector. An example of a lookup table that we would use for the single stepper motor approach is shown below.

Table 31. Example Lookup Table for One Stepper Motor

Distance to Screening Area	Focus Knob Stepper Motor Adjustment Value
5 meters	3 steps
6 meters	5 steps
7 meters	7 steps
8 meters	9 steps
9 meters	11 steps
10 meters	13 steps

Once again, this approach makes controlling the autofocusing system for our projector quite simple. Anytime we want to focus the project, we use the range finding module in order to find the distance from the projector to the screening area. Then we use that distance and refer to the lookup table in order to determine how much the stepper motor needs to be adjusted.

The most challenging obstacle that we will face when using a lookup table for both integration approaches is actually calculating the amount that the stepper motors need to be adjusted in order to properly focus the projector. Although we can do some math, as well as using our best judgements, it will ultimately come down to doing a ton of testing in order to find appropriate adjustment values for the stepper motors for any given distance within a certain range.

5.5.3.2 Using a Mathematical Model

A second option that we are considering in order to correlate the distance given by the rangefinder with the number of steps that stepper motors need to move in order to focus the projector, would involve creating a mathematical model that relates the distance measured by the rangefinder to the number of steps required by the stepper motor.

This option is very similar to the lookup table discussed in the previous section; however, it would build on top of it and increase the flexibility in terms of the different ranges that the projector is able to focus for. The first step in developing this would, like the lookup table, require a lot of testing in order to measure the physical relationship between the distance to the projection screening area and the number of steps required to focus the projector lens accordingly.

We would be able to find this measurement by moving the lens using the stepper motor and recording the corresponding rangefinder distance and the number of steps taken by the motor in order to properly focus the projector. Once we have ran this kind of test for a large variety of ranges, we can then use the data that we recorded in order to form our mathematical model which will correlate the distance given by the rangefinder with the number of steps the stepper motors need to move in order to properly focus the projector.

One common way of doing this is using linear regression analysis, which involves fitting a line to the data points that represents the relationship between the two variables. To give an example of how we may use this: after testing for a variety of ranges we may find that the number of steps required to move the lens increases linearly with the distance measured by the rangefinder. Using the data retrieved from testing, we could then use a simple linear regression model similar to the following form:

$$steps = a + b * distance$$

Where ‘steps’ is the number of steps required by the stepper motor, ‘distance’ is the distance measured by the rangefinder, and ‘a’ and ‘b’ are constants that represent the intercept and slope of the line, respectively. Using this model, we would be able to accurately estimate the number of steps the stepper motors would need to take in order to properly focus the projector for any range given by the range finding module. An example of a linear regression analysis graph that could be created in order to find the relationship between the rangefinder distance and the number of steps the stepper motors need to be moved is shown in the image below.

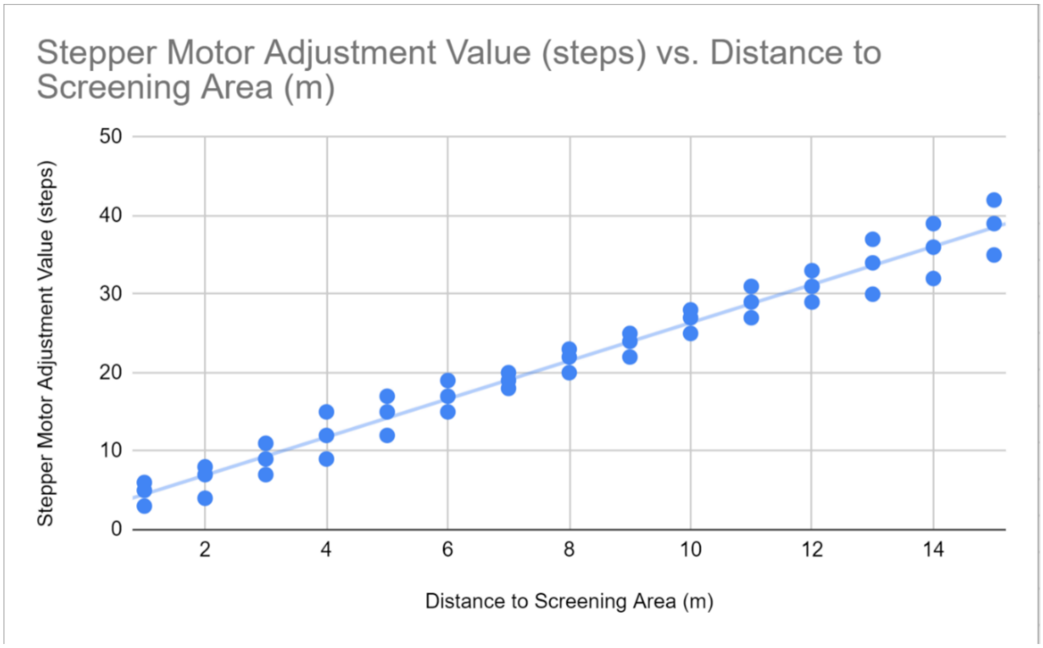


Figure 35. Example Linear Regression Model Graph

Once we have tested our projector with the stepper motor and range finder for a variety of distances, we can then create a graph similar to the one shown above. Using this graph, we would be able to establish a trendline which we could use to base our mathematical model. The trendline will give us an equation similar to the one discussed about which we can use to accurately correlate the distance to the screening area with the number of steps the stepper motors need to be adjusted in order to properly focus the projector.

5.6 Voice Command Software Design Details

As described earlier, we will be using the CMUSphinx open-source speech recognition system to interpret our voice commands. CMUSphinx works by having configuration files with pre-built phonemes, phonemes being distinct units of sound that distinguish one word from another, and then defining words as being built by those phonemes.

Essentially, if you think of a word like “dance”, despite its spelling it would be pronounced closer to “dants”, but since letters, especially vowels like “a”, can have multiple pronunciations, it is further specified through specific phonemes. This is why dictionaries have both the definition of a word and its phonemes; in the example of “dance”, it is described to be pronounced as “dän(t)s”.

CMUSphinx uses its own phoneme convention without non-alphabetic characters like “ə” or “ä” and comes with many prebuilt words. Our consistent example, “dance”, is specified as “D AE N S” in the provided “cmudict-en-us.dict” configuration file. When we got into testing how well the software could recognize specific commands, knowledge of this configuration file specifically was incredibly beneficial, as we were unable (at least without extreme effort) to change the pronunciation of the phonemes themselves but could change what phonemes the words were made up of. Defining “Focus” as both “F OW K AH S” and “F OW K IH S” helped to cover multiple pronunciations and dialects, without making completely unrelated words accidentally register a false positive.

To recognize what sounds are being made, CMUSphinx uses the Mel-frequency cepstrum representation of the power spectrum of a sound. Specifically, it uses Mel-frequency cepstral coefficients, which are derivations of cepstral representations of portions of audio. A cepstrum (plural cepstra) is the inverse Fourier transform of the logarithm of a magnitude spectrum. Essentially, this breaks down a signal in such a way that the rate of change in the different spectrum bands are easier to identify and process, making it useful in identifying things like the pitch of a musical note. Mel-frequency cepstral coefficients are found by taking the Fourier transform of a signal, mapping the power of the spectrum onto the Mel scale (pictured below), finding the logs of the power at each Mel frequency, and then performing a discrete cosine transform on the found logs of the previous step. The Mel-frequency cepstral coefficients are the amplitudes of the spectrum that result from this process.

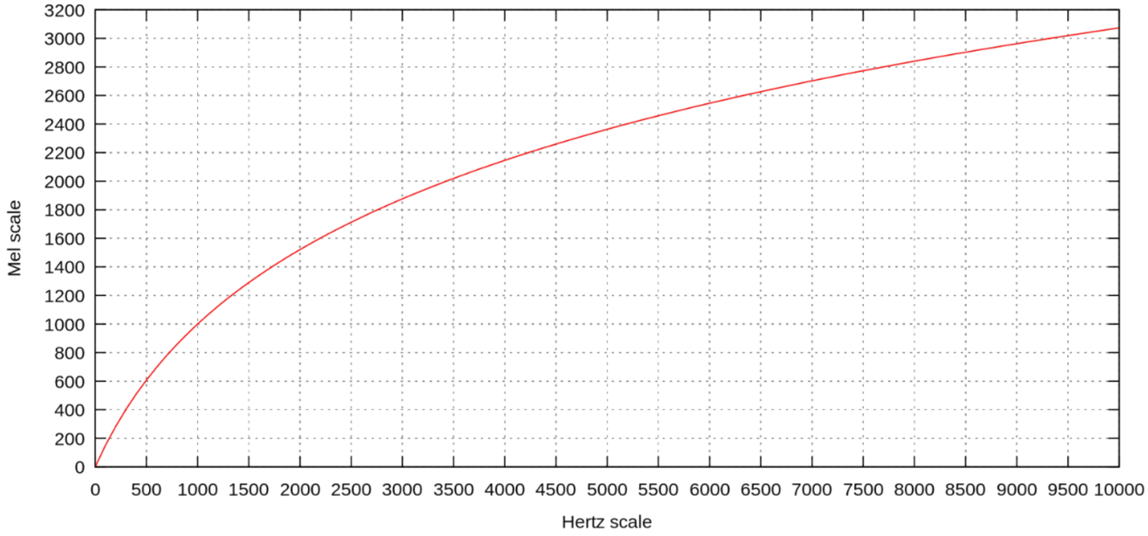


Figure 36. Plot of Mel scale vs Hertz scale

CMUSphinx specifically also employs spectral subtraction of noise; by subtracting stable noise (ambient or background noise), it is able to more clearly interpret new noises.

5.6.1 Voice Command Requirements

The goal of having voice commands was to allow the user(s) an easier way of managing the projector than physically interacting with the box itself. If a user places the projector in a high spot for example, it would be a hassle to have to use a stool or stepladder every time they wanted to adjust the focus or to even turn the projector off after they were finished using it.

This goal could've been accomplished with a remote or application of some kind, but we felt a remote with only a few buttons was both awkward and easy to misplace, and having to install an application to a separate device took away from the desired simplicity of the project. Thus, we settled on using voice commands to facilitate hands-free control of the projector.

In order for voice commands to be a desired and beneficial feature, the projector must be able to distinguish voice commands from a reasonable distance away, and not misinterpret commands. Since there is no way to disable voice commands, it would be horribly detrimental to the project if ambient sounds, general conversation in the room, or even audio from the projector's speakers were to set off functions like the "Turn Off" command.

Inversely, if it couldn't reliably pick up commands, or could only do so from an extremely close distance or loud audio source, then it would be comparable to not having voice commands at all. Granted, it would not be a negative feature like voice commands accidentally being triggered, but installing useless features is generally seen as a bad practice that represents wasted time and effort.

We chose to define a "reasonable distance" as about 2 meters, or 6.5 feet. This was partly influenced by most of the available microphones having an effective range of 3 meters or less, but also because increasing a microphone's pickup range is mostly done by increasing the gain. Gain refers to the input decibels, meaning altering gain on a microphone is more easily explained as altering its sensitivity to sound, not the volume of the sound being inputted. Volume refers to the signal strength after it has been processed, so gain occurring during the input stage means that changing the gain will change the signals the microphone is going to process, which would clearly affect the accuracy of determining specific phonemes.

5.6.2 Initial Software Design Process

As an open-source project, CMUSphinx has many publicly available resources, guides, and communities which will help us with setting up a project using their speech recognition systems. Adding their provided "core" and "data" Jar files as referenced libraries into the build path provided our Java project with all the resources necessary, and from there it was just about defining each step following the notations as described on their website.

We decided to add a “grammar.gram” file instead of having the speech recognizer able to recognize nearly every word in the English language (or any other languages we defined). The .gram file defines what words or phrases are trying to be detected, and as we were only searching for the specific words “hey”, “projector”, “turn”, “off”, and “focus”, having other words that sounded similar and could be incorrectly detected instead like “of” and “term” were not desirable to have. Since it defines the words and phrases to look for, we added “hey projector” as one phrase to the .gram file instead of having to look for the word “projector” within an “if statement” of the previous word being “hey” or some other kind of overly-complicated code of that nature. The word or phrase found is stored as a variable called “speechRecognitionResult”, and by comparing that to the desired commands we can call the associated function.

5.6.3 Integrated Software Design Process

Now that the software is able to both recognize commands and call functions dependent on the command detected, we need the called functions to actually perform their desired actions. To do this, we need to convert our existing Java code into Arduino code. Fortunately, Arduino already has PocketSphinx as a library, so many of the base function names and notations don’t have to change. Arduino code is a variant of the C++ programming language, so while a good amount of syntax must change, it is still an object-oriented language, meaning almost none of the logic itself will have to be altered. In addition, we already have the necessary Arduino code ready and tested to both activate the rangefinder and to move the stepper motors as described in the previous section, we just need to finalize the integration method (see Tables 30 and 31), and then add the voice command code so that we can call that function via the “Focus” command. Currently, the voice command “main” function is only a generously spaced 250 lines, so it makes more sense to add that to the rangefinder/stepper motor code (after being converted to Arduino code) than the other way around.

It is worth noting that our development and testing environment are very different from what the final, deployed product environment is going to be, so we are planning ahead for any possible complications. For example, our USB space is limited, among other issues, so if the Cheers.US K3 Omnidirectional mic does not work out, we have researched the Voice Recognition V3 Module Compatible Board for Arduino as a backup option. While it will most likely have lower range, its audio quality is well received, and being specifically made to be Arduino compatible makes it much easier to implement into the PCB. We are moving forward with the intent to have the Cheers.US K3 Omnidirectional mic in our final build, but it will be easier to use the Voice Recognition V3 Module Compatible Board for Arduino for testing purposes after we have converted the voice command system from Java to Arduino code, and in the rare chance it simply overall performs better in testing, then there would be no reason not to use it in the final build.

Figure 37. Voice Recognition V3 Module Compatible Board for Arduino

5.7 3D Printed Parts Design Details

There are a number of components that we are planning to 3D print for our Autofocusing LED Projector. In order to print these components, we are planning to use the Original Prusa i3 MK3 3D printer that is available to us in the Photonic Science and Engineering senior design laboratory. The first step for 3D printing these components is to create a 3D model using software such as Blender, Fusion 360, or SolidWorks. In our case we have chosen to use SolidWorks, as it is the 3D modeling software that the team is most familiar with.

When creating our 3D models in SolidWorks it is important to keep in mind that we need to create bedding for the components to be printed on so that they are printed properly. We also need to ensure that this bedding is created level so that the component sticks to it properly. Once we have prepared 3D models using SolidWorks, the next step is to export the 3D model as a .STL file, so that we can slice the model. After the model has been exported as a .STL file and slice, we then need upload it to Original Prusa i3 MK3 3D printer.

Once we have the 3D model for the component successfully uploaded to the Original Prusa i3 MK3 3D printer, the last step before finally starting the printing job is to load filament into the printer. Once the filament has been loaded up, we are good to proceed with starting the actual printing processes.

After we have started the printing job, it is important to monitor the printer closely throughout the printing process. This way if we notice any issues, we can make any necessary adjustments as soon as possible. Once the printing job is complete, we must allow the bed to cool down before removing it from the 3D printer. After cooling, the final step in the printing process is to carefully remove the component from the printing bed using a scraper or spatula. In this section, we will include schematics and discuss the design details of the different components that we are planning to 3D print for our Autofocusing LED Projector.

5.7.1 3D Printed Gear System Design Details

One component that we are considering 3D printing for our Autofocusing LED Projector is the gears needed for the stepper motors and lens knobs, which will allow the stepper motors to focus the projector based on the distance received from the range finding module. For this gear system we would need two gears: one which would attach to the servo motor and one which would attach to the projection lens. Depending on the way in which we decided to ultimately configure our autofocusing system, using one stepper motor or two stepper motors, we would need one or two of these gear systems respectively. An example schematic which was created in SolidWorks depicting what these gear systems would look like is shown in the figure below.

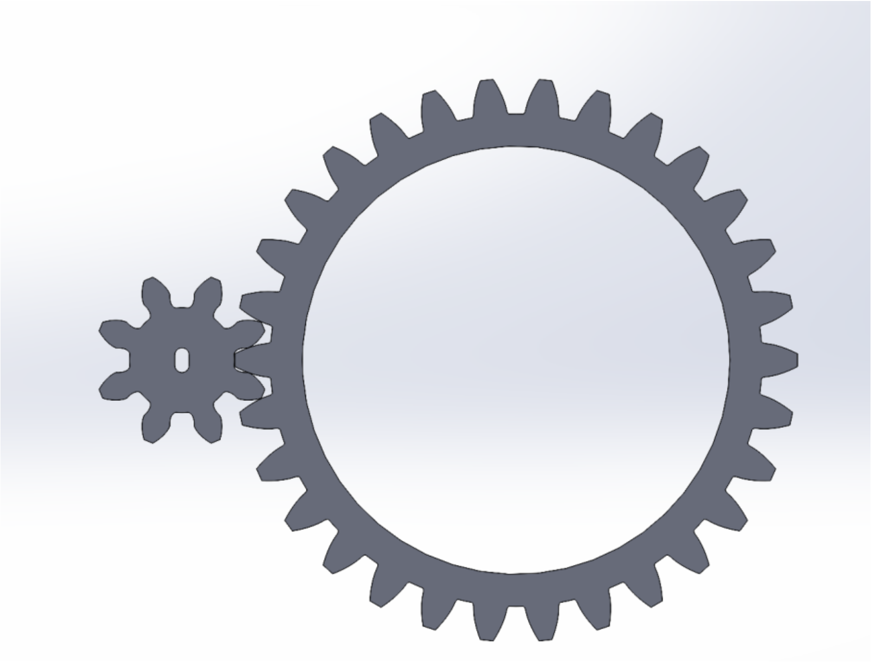
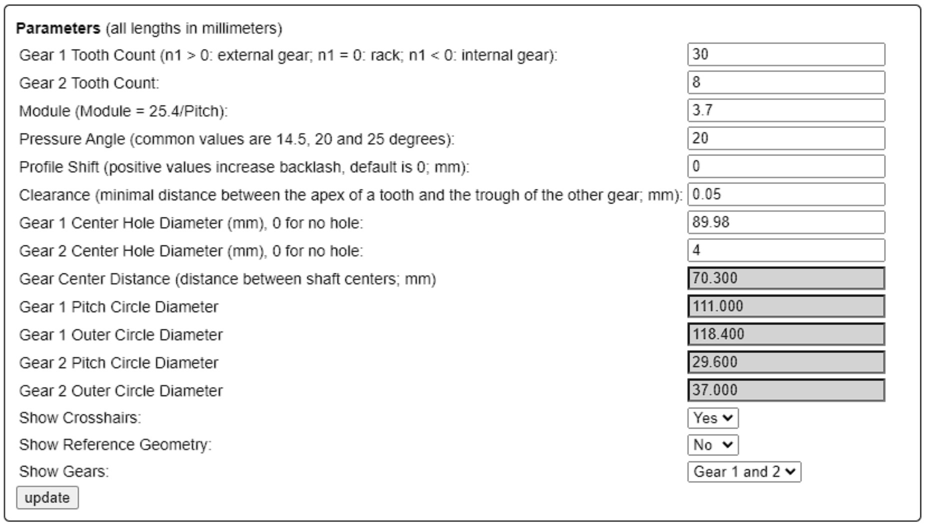


Figure 38. Example Gear System Schematic in SolidWorks

As shown in the figure above, these gear systems will consist of one small gear and one large gear. The smaller gear will be attached to a servo motor and the larger gear will be fixed to the projection lens. This allows the servo motor or servo motors to adjust the projector in order to focus the image.

The parameters for the gear system schematic shown in the previous figure are outlined in the following figure below. These parameters are likely to be changed as we continue through the design process so that the gear systems effectively meet our needs. Additionally, if we decided to go the route of using two stepper motors in order to control the zoom and focus individually, we will likely need separate schematics for the larger gears so that they properly fit where needed However, in the current design we have thirty teeth for the larger gear which will be attached to the projection lens and eight teeth for the smaller gear which will be fixed to the stepper motor. See the example parameters for our gear system in the figure below.



Parameters (all lengths in millimeters)

Gear 1 Tooth Count (n1 > 0: external gear; n1 = 0: rack; n1 < 0: internal gear):	30
Gear 2 Tooth Count:	8
Module (Module = 25.4/Pitch):	3.7
Pressure Angle (common values are 14.5, 20 and 25 degrees):	20
Profile Shift (positive values increase backlash, default is 0; mm):	0
Clearance (minimal distance between the apex of a tooth and the trough of the other gear; mm):	0.05
Gear 1 Center Hole Diameter (mm), 0 for no hole:	89.98
Gear 2 Center Hole Diameter (mm), 0 for no hole:	4
Gear Center Distance (distance between shaft centers; mm)	70.300
Gear 1 Pitch Circle Diameter	111.000
Gear 1 Outer Circle Diameter	118.400
Gear 2 Pitch Circle Diameter	29.600
Gear 2 Outer Circle Diameter	37.000
Show Crosshairs:	Yes
Show Reference Geometry:	No
Show Gears:	Gear 1 and 2

Figure 39. Example Gear System Parameters

It will be rather simple for us to adjust our gear system depending on our final design thanks to free online gear generators like the one provided by EvolventDesign. Using this generator, we are able to input the parameters as shown in the previous figure in order to automatically generate a DXF or SVG file which can then upload to SolidWorks in order to create our 3D model. This makes the design process for our gear system a whole lot easier when compared to creating the designs from scratch.

5.7.2 3D Printed Optic Mounts Design Details

A part that we have already 3D printed for our Autofocusing LED Projector is the mount for the LED attached to a heat sink. Since the heat sink has square dimensions the mount for the heatsink and LED will also have square dimensions as shown in Figure 36 below. The perimeter dimensions of the mount are 100mm in length and 100mm in width. The inner extruding lining have dimensions of 88mm in length and 88mm in width. The purpose of the inner lining is to the heatsink cannot fall out the backside of the mount. Furthermore, to hold the heatsink in place there are two screw holes where screws can be put to hold the heatsink in place. The hole has a diameter of 5mm and a depth of 4mm.

The optic holders for the ground glass and the LCD screen will follow suit with a similar design. The ground glass optic has dimensions of 100mm by 100mm, therefore, the square design shown below in Figure 36 will need to be scaled up. The perimeter of the mount will need to be 105mm by 105mm and the inner extruding part will have to be 93mm by 93mm. The holes will remain the same dimensions of having a diameter of 5mm and a depth of 4mm so screws can be implemented into the top and bottom of the square mount to hold the optic in place.

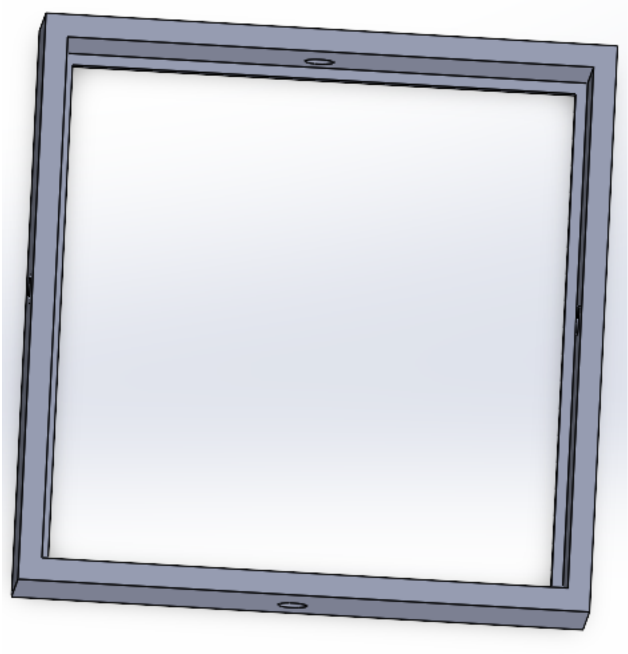


Figure 40. Optic Mount in SolidWorks

The LCD screen will also require a mount so that the image stays upright, and light is able to be transmitted through the screen. The screen will have to be placed upside down due to the inverted nature of geometrical optics as shown in the illustration below Figure 37. Where the chief ray originates from the top of the object (LCD screen image) and passes through the center of the aperture stop and hence centers of the entrance pupil and exit pupil. The marginal ray originates from the object (LCD screen image) at the optical axis and goes through the edge of the aperture stop. As a result, the image will be inverted and to compensate for this phenomenon we will place the LCD in an optic mount upside down. Therefore, in image space the image is upright so that the projector can display the image correctly.

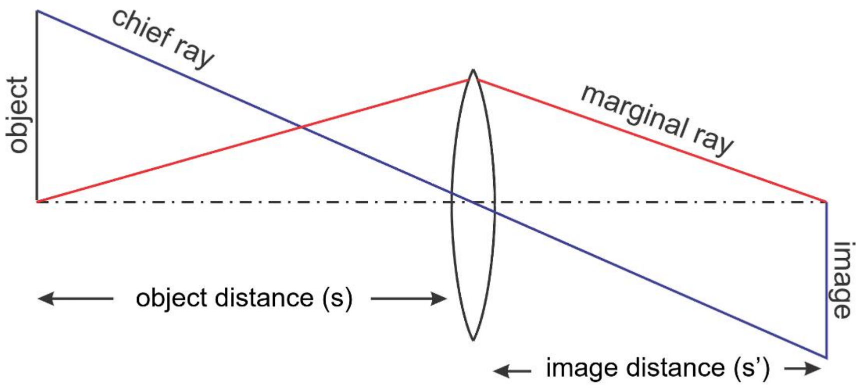


Figure 41. Inverted Image Schematic

The perimeter dimensions of the optic mount for the LCD screen will be 75mm in width and 50mm in height. Therefore, this optic mount will be more of a rectangular shape rather than a square shape as described previously for the LED and heatsink and the ground glass diffuser. Two screw holes will made to hold the screen in place and once again the diameter of the hole will be 5mm with the depth of the hold being 4mm.

5.7.3 3D Printed Projection Lens Mount Design Details

One more component which we are planning to 3D print for our Autofocusing LED Projector is a holder which will support the projector so that it is pointing straight ahead. This component will be similar to the LED and heatsink casing discussed in the previous section; however, this component will need an arch at the top which will fit tightly around the projector in order to hold it steady. As a result, the projection lens mount will have a circular hallow center instead of a square or rectangular center. The lens tube will have to fit snug around the mount to prevent vibrations and the unacquainted for movement of the lens tube. The stability of the projection lens mount can be further constructed with the use of rubber bands which can hold the lens tube firmly in the mount to prevent any amount of unwanted movement. As a result, the projected image will be stationary and not moving from any movement from the gears on the stepper motor adjusting zoom or focus knobs.

6 Project Testing and Integration

In this section we will discuss how we will test each component to make sure that the prescribed requirements are functioning properly. When engineering a new technology, this is a very important step to avoiding failure of an entire system due to a manufacturing error of a particular part of the system. Furthermore, we will discuss the integration of each hardware and software component and provide the overall schematic of our project.

6.1 Hardware Testing Facilities

There are two primary hardware testing environments which include the Electrical Engineering senior laboratory and the Photonic Science and Engineering senior design laboratory. The purpose of conducting the testing in these two environments is because of the readily available equipment such as breadboards, power meters, oscilloscopes, resistors, capacitors, soldering iron, and more. The Photonic Science and Engineering senior design laboratory also contains three stations of 3D printers which we use extensively and will discuss in further detail later.

6.2 Optical Path Design Testing

The optical path design testing is an important procedure for the successful outcome of our senior design project the Autofocusing LED Projector. Ensuring the light source and image source are functioning properly prior to their system implementation is paramount to not waste time and money. As a result, the team has put together two sections where we discuss how we tested the LED light source and the LCD screen and driver board. Once the light and image source are confirmed to be working as predicted, then we can begin to 3D print their mounts as described previously and put them into the projector box and integrate them into the entire projector system. The ground glass diffuser optic can then be placed to collimate the light from the LED and the projection lens can be placed to project the image from the LCD screen.

6.2.1 Light Emitting Diode Test

Once our LED has arrived, the first thing we need to do is test it to make sure it is working as described by the manufacturer. The picture of our light emitting diode is shown previously in figure 5, where you can see the two conducting nodes for negative (ground) and positive. Here, two copper wires will be soldered onto each node via a soldering iron to enable current to flow through the device. As stated in section 3.2.1 the LED needs 30-32V and 1000mA to turn on. A power supply will be used to supply the necessary voltage and current to the LED. As shown in Figure 31, the LED was tested with the parameters discussed and the LED was confirmed to be in working order and ready for implementation into our projector system.

Figure 42. LED Testing

6.2.2 Liquid Crystal Display Test

In order to ensure that our image source is functioning properly we must test out the liquid crystal display screen and driver. When first testing out the liquid crystal display driver we will use the Apple Lighting to HDMI cable as discussed in section 3.6 Video Processing Part Selection. That cable will send the video processing data to the driver to be displayed on the screen. A power supply along with a power cable will be used to supply the driver with the 5V needed to turn on the device. Once the device is turned on and plugged into the smartphone to send the video data, the LCD driver board will flash a red LED. Once the video is being played the LCD driver board should fix on the solid color of green as shown below in Figure 33. Therefore, we can confirm that the board is functioning properly based on the light color of the LED produced by the board.

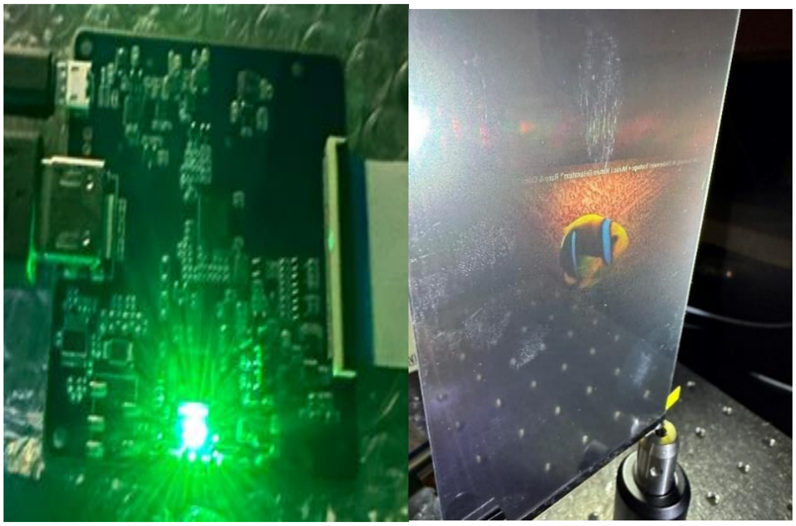


Figure 43. LCD Driver Board and Screen Test

Once the driver board is confirmed to be functioning properly, we can look at the display screen to see if the pixels are illuminating the images. If the pixels are illuminated with the image colors then we can confirm that the screen is transmissive using a flashlight and shining it through the screen. If the imaged light is received on the opposite side of the screen then we know that the liquid crystal display is functioning properly, and the backlight was removed correctly. This can be shown below in Figure 81 where the LCD screen was confirmed to be functioning properly displaying images and being able to transmit that imaged light.

6.3 Autofocus Design Testing

This section will discuss all the subsystems testing that went into making our autofocusing system. The most important subsystems being the LiDAR unit and the stepper motor, and ultimately have these two subsystems be able to communicate with each other. We also need to have this system be able to be integrated with the projection lens to make our project feasible.

The ultimate goal for this part of the design is to incorporate the LiDAR module and stepper motors in order to design a system which will be able to automatically focus our projection lens for a range of given distances. In order to do this, we first needed to test both our LiDAR module and stepper motors individually to ensure that they were working as expected.

Once we tested both the LiDAR module and stepper motors individually and confirmed that they were working as expected. The next step involved testing the integration between the two components. The goal of this test was in order to create software which moved the stepper motors such that it was correlated with the reading received from the LiDAR module. This would ultimately form the basis for our initial autofocusing system.

6.3.1 LiDAR Module test

The first step that we took for testing our autofocus system was to test our TF Mini-LiDAR module. In order to test the TF Mini-LiDAR module, the LiDAR module was first connected to a set of data wires, which was then connected to an Arduino Uno development board. Next, we connected the Arduino development board to a laptop via USB and then we ran our test code on the Arduino IDE software. Once we confirmed that the software was compiled without any errors, we finally uploaded the test software to our Arduino development board.

Initially it was difficult to confirm whether the TF Mini-LiDAR module was being powered on or not. This was because the wavelength of the VCSEL laser is at 850 nm, which is beginning to exit the visible range of light, it can be a bit difficult to determine if the device is on and working. Cameras are better at capturing infrared light than the human eye, hence we used our phone to capture an image to determine whether or not the laser was on. This image can be seen in the figure shown below.

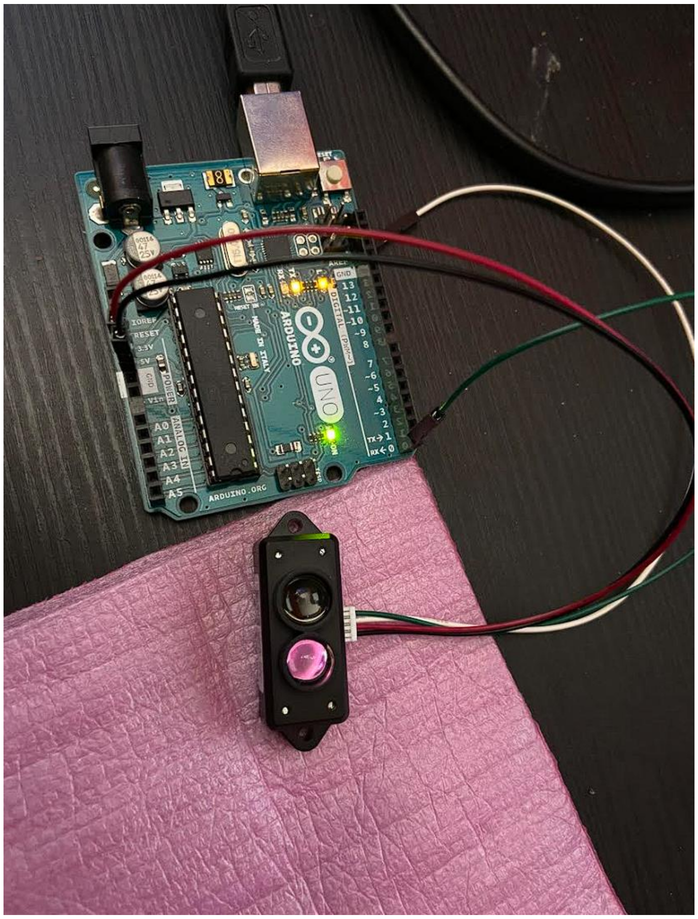


Figure 44. LiDAR Power On Test

For the following test setup an approach was used from GitHub published by the manufacturers of the product: Benewake. This approach was provided under the name “TFmini_Arduino_HardwareSerial_Polling”. Since the board that we selected for our initial testing was an Arduino Uno, the board only had one serial port, so the RX (white) was not used for this test. The following was the connection method used.

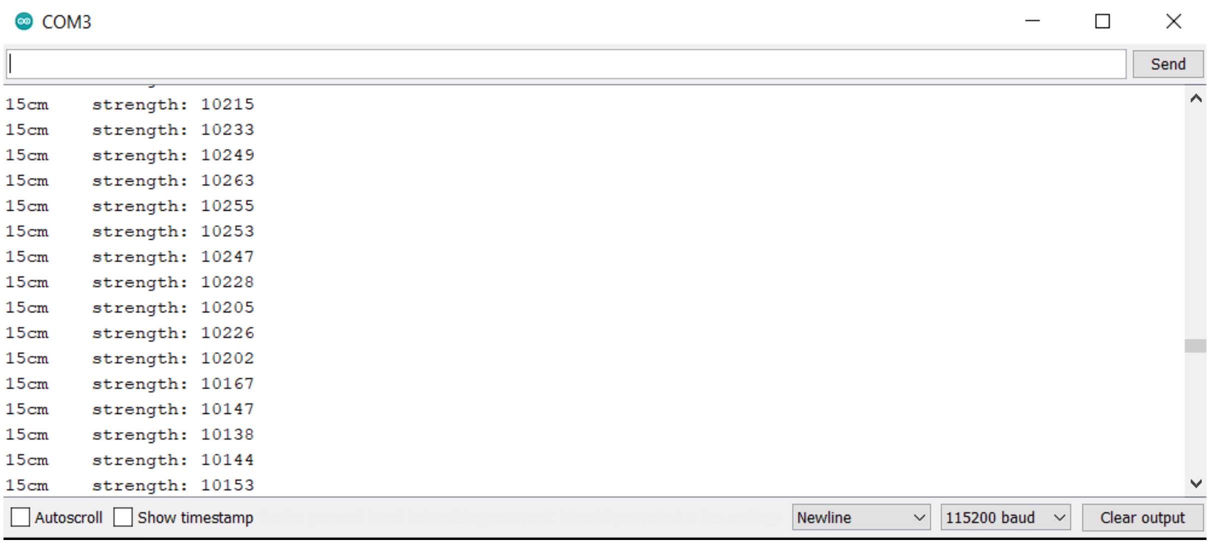
It is also important to note that for this method, the TX wire should only be plugged into the 0(RX) port after the test program has been downloaded, ran, and uploaded.

Table 32. LiDAR Power on Table

TFmini	Arduino
5V(RED)	5V
GND(BLACK)	GND
TX(GREEN)	0(RX)

To test the detection capabilities of the device, a simple experiment was setup, where an object was placed approximately six inches (15.24 centimeters) away from the module which was verified by the use of a ruler. Figure 36 shows the results from the serial monitor, which gives us our desired result of 15 centimeters.

Figure 45. LiDAR Experimental Setup



```
15cm    strength: 10215
15cm    strength: 10233
15cm    strength: 10249
15cm    strength: 10263
15cm    strength: 10255
15cm    strength: 10253
15cm    strength: 10247
15cm    strength: 10228
15cm    strength: 10205
15cm    strength: 10226
15cm    strength: 10202
15cm    strength: 10167
15cm    strength: 10147
15cm    strength: 10138
15cm    strength: 10144
15cm    strength: 10153
```

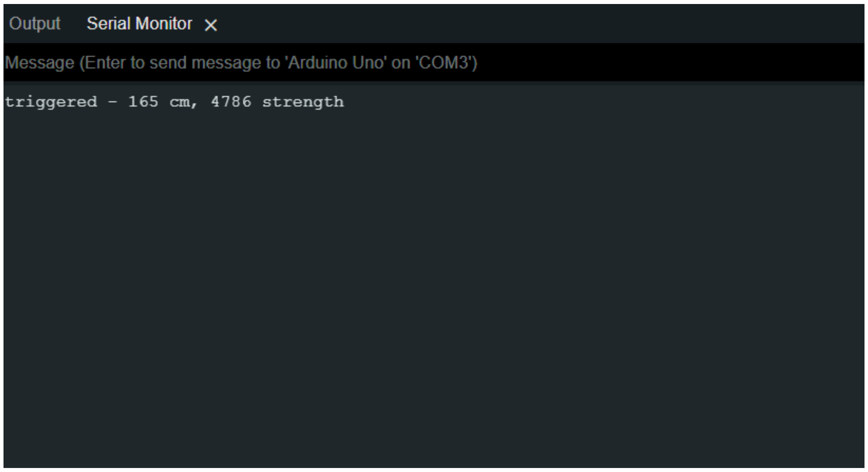
Figure 46. Serial Monitor Results

Another example that was attempted was one that was more applicable to our use case. The following table shows the pin layout, which now includes the RX(white) wire, this example is also beneficial because in the previous example, the TFmini’s TX wire needed to be unplugged when downloading the program, and then plugged in to the correct Arduino pin once downloaded, which also makes that approach not feasible moving forward.

Table 33. LiDAR Single Point Scan Pin Setup

TFmini	Arduino
5V(RED)	5V
GND(BLACK)	GND
TX(GREEN)	PIN 12
RX(WHITE)	PIN 13

This was an approach that used a single point scan to have the Lidar read the value once, and then repeating the process, instead of having continuous measurements updating multiple times a second, this example is helpful because it is from this one single point scan of the environment that will enable us to have that distance be communicated to the stepper motor, this design approach will be used later when integrating the TFmini-s LiDAR module and the 28BYJ-48 stepper motors. The following figure shows the single point scanned being triggered, which gives us the distance to the target as well as the strength of the signal.



```
triggered - 165 cm, 4786 strength
```

Figure 47. Single Point Scan Serial Monitor Results

6.3.2 Stepper motor test

This section will discuss the design configuration and testing of the stepper motor, since the ultimate is to integrate the TF mini-s LiDAR module, the same Arduino uno was used for testing, and this code will also be ran on the Arduino IDE software. The following image is the pin layout and wiring for the Arduino uno, Power supply, ULN 2003 motor driver, and 28 BYJ-48 stepper motor. There were two examples that were used to verify the use of the stepper motor, while a third example will be used later when integrating a second stepper motor to control the magnification on the projection lens, but the primary goal is to be able to control the focal length.

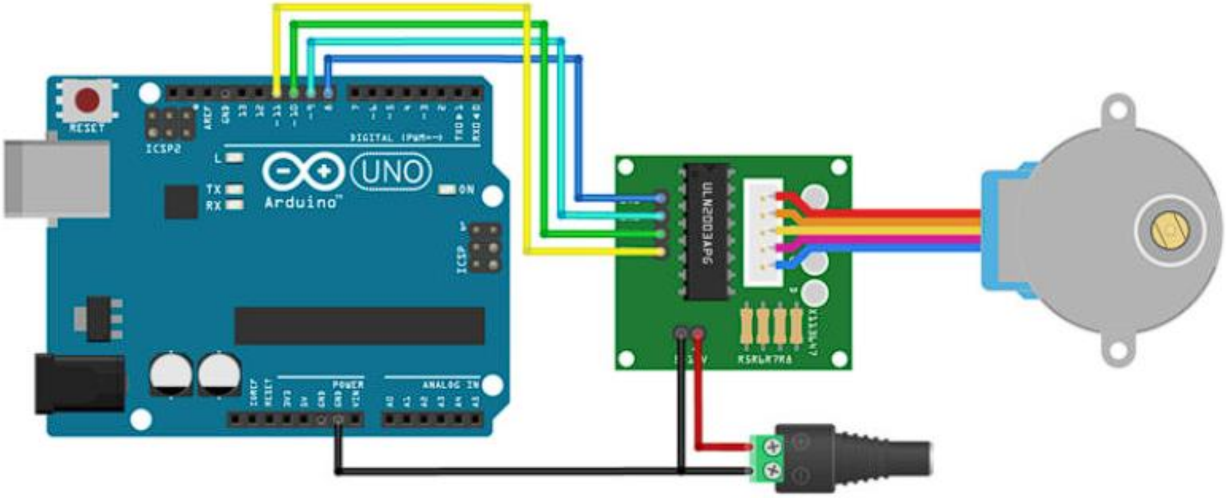


Figure 48. Wiring Diagram for ULN2003 Driver with 28BYJ-48 Stepper Motor

The first example is a simple one just to verify all of the systems work and will use a built-in stepper library “Stepper”. This example rotates the stepper motor slowly in the clockwise direction, and then rotates more quickly in the counterclockwise direction. Since no videos can be taken to show the motor moving, images are shown of the step indicator LEDs, which indicate activity on the four control input lines, these serve as a good visual indication while stepping, on the left image you can see all four of LEDs are lit up indicating motion, while on the right hand side you can see two of the four LEDs are off to indicate a pause and switch of direction from clockwise to counterclockwise or vice versa.

The second example will go over the use of a more extensive library “AccelStepper”, this is important to go over because the Arduino Stepper library can only be used for simple single motor applications, and with our design plan to control the focal length as well as the magnification, two stepper motors will be required to achieve that, so this library will be essential to achieve our ultimate goals. This example also shows some of the more sophisticated features such as acceleration and deceleration, while another feature of this library that is not shown is half step driving, which could also prove to be very helpful by increasing the precision by double and providing less vibration at low-speed operations. This example also creates the same type of behavior in the step indicator LEDs, which shows the example was working properly.

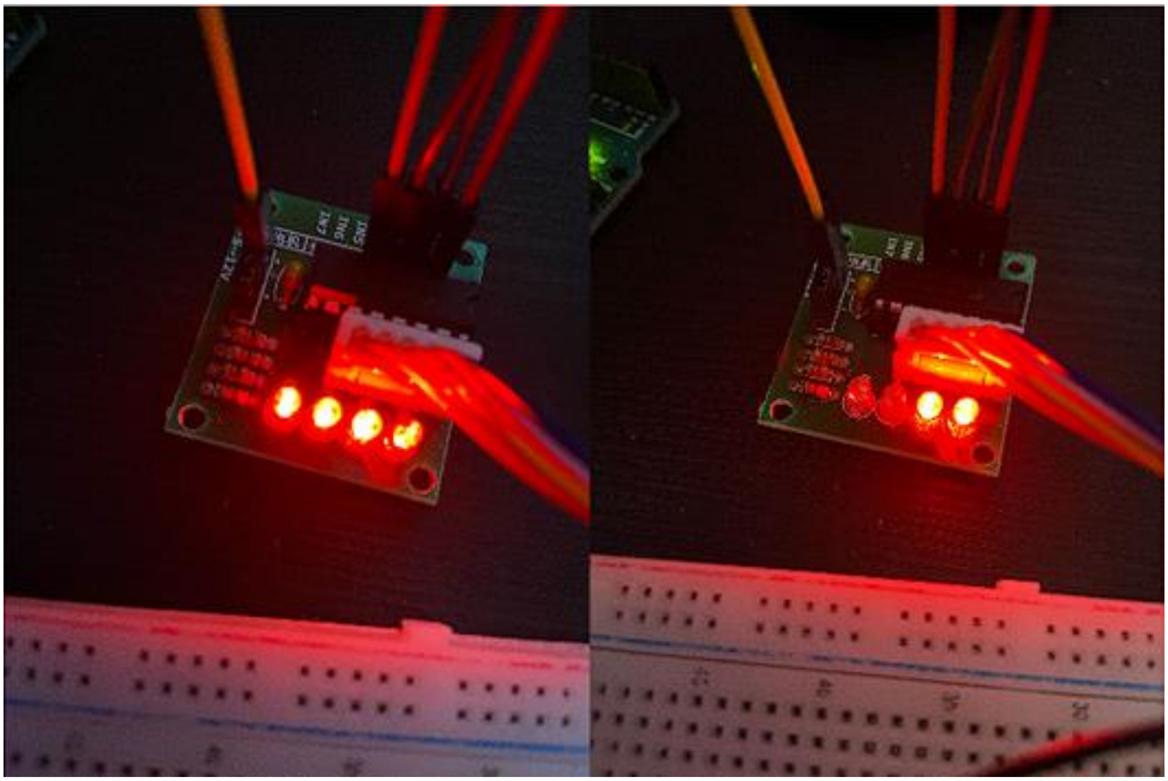


Figure 49. Step Indicator LEDs

The final stepper motor example that will be discussed is one that will incorporate two stepper motors. This is because our ultimate goal is to use two separate stepper motors in order to automate the movement of both the focus as well as the magnification of the projection lens. The following figure shows the pin layout for this example.

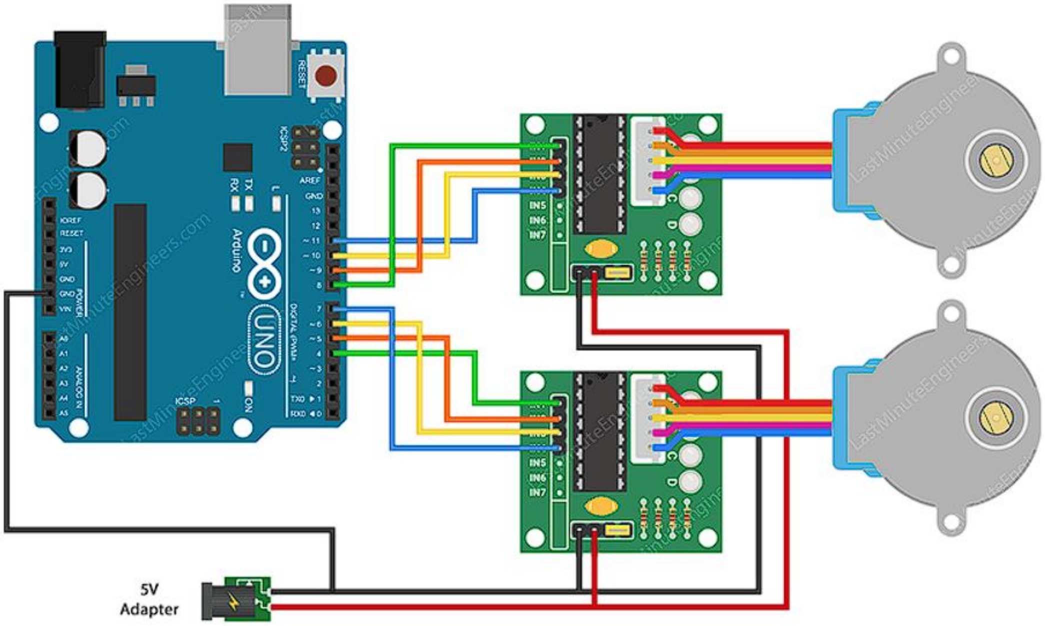


Figure 50. Two Stepper Motors Wiring Diagram

This example showcases the half step driving capabilities of the AccelStepper library which could be useful for us. The software drives one of the stepper motors in full step mode and the other stepper motor in half-step mode while accelerating and decelerating. After a singular revolution, the spinning direction of each stepper motor changes direction.

The following figure shows the initial position of the motors before running the code (left), as well as the motor position after running for some time (right), where the left motor is turning clockwise, and the right motor is turning counterclockwise.

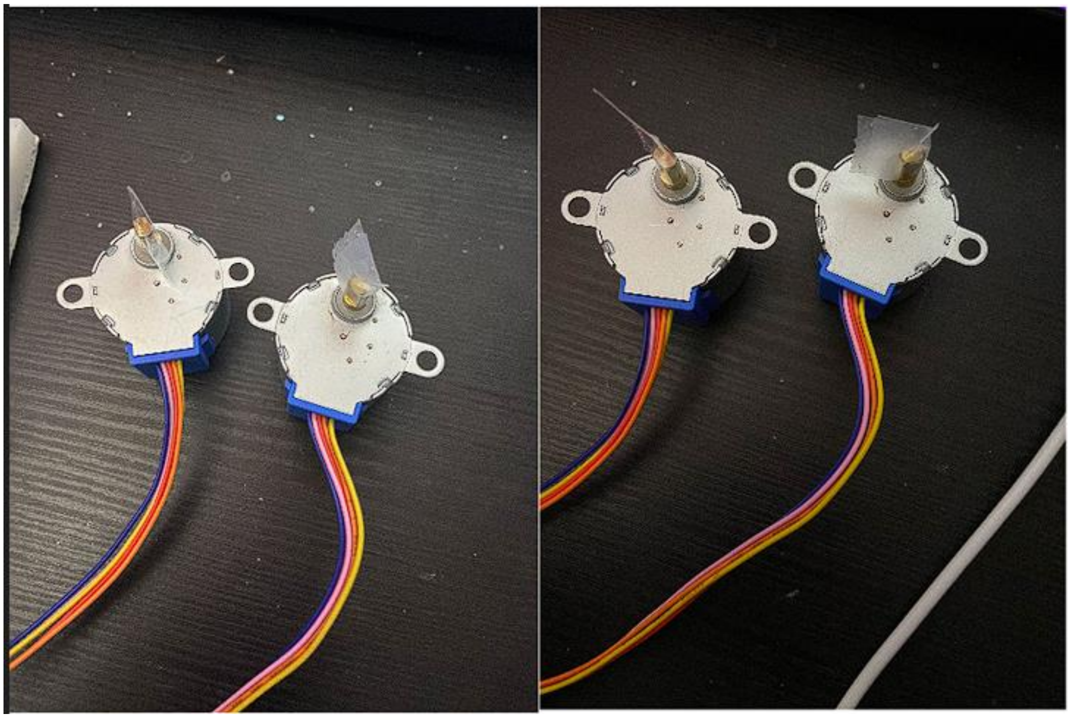


Figure 51. Stepper Motor Initial and Final Position

6.3.3 LiDAR/Stepper integration test

Now begins what will be the core of our autofocusing system, that is the rangefinder and stepper motor working in tandem to achieve our desired goal. Now that we have established that these systems are in working order, integrating them is the next step. For this example, our goal was to correlate rangefinder distance with the amount of stepper motor movement, so as the distance from the rangefinder increased, so did the amount of stepper motor movement. The following figure is the pin configuration for this example.

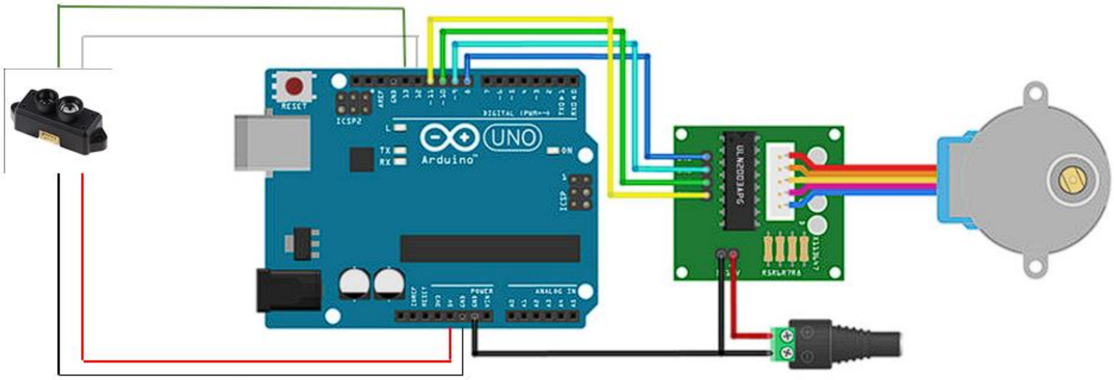
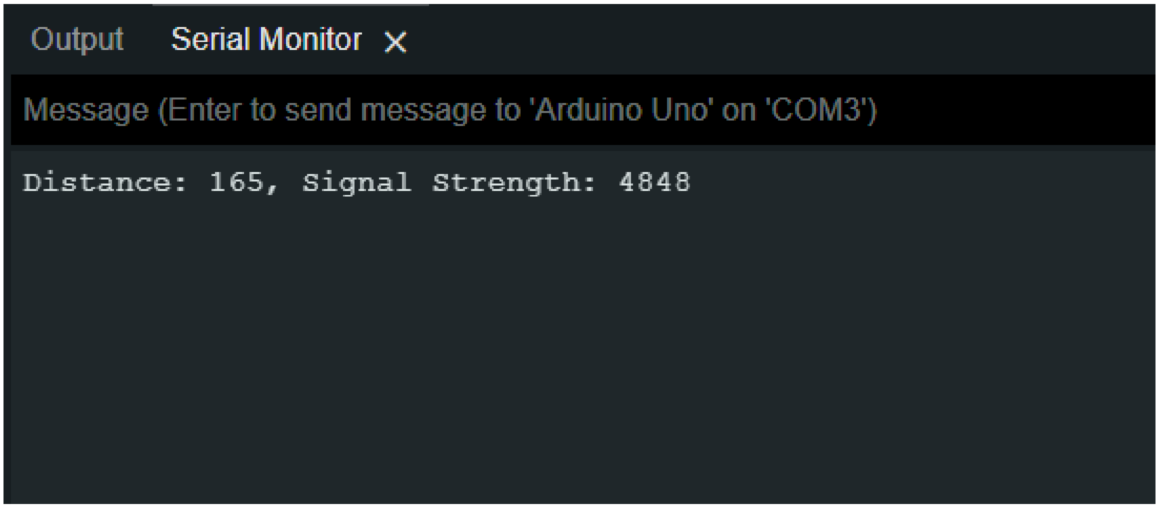


Figure 52. Rangefinder and Stepper Motor Wiring Diagram

In the first scenario, we are measuring from a relatively large distance of 1.65 meters, the rangefinder records that value which is shown in the figure below.



```
Distance: 165, Signal Strength: 4848
```

Figure 53. Long Distance Rangefinder Reading

Now, that distance is then communicated to the stepper motors, which results in a clockwise motion. As can be seen from the figure the initial start point of the motor position (left), and the end point of the motor position (right) the stepper motor moves by a large amount.

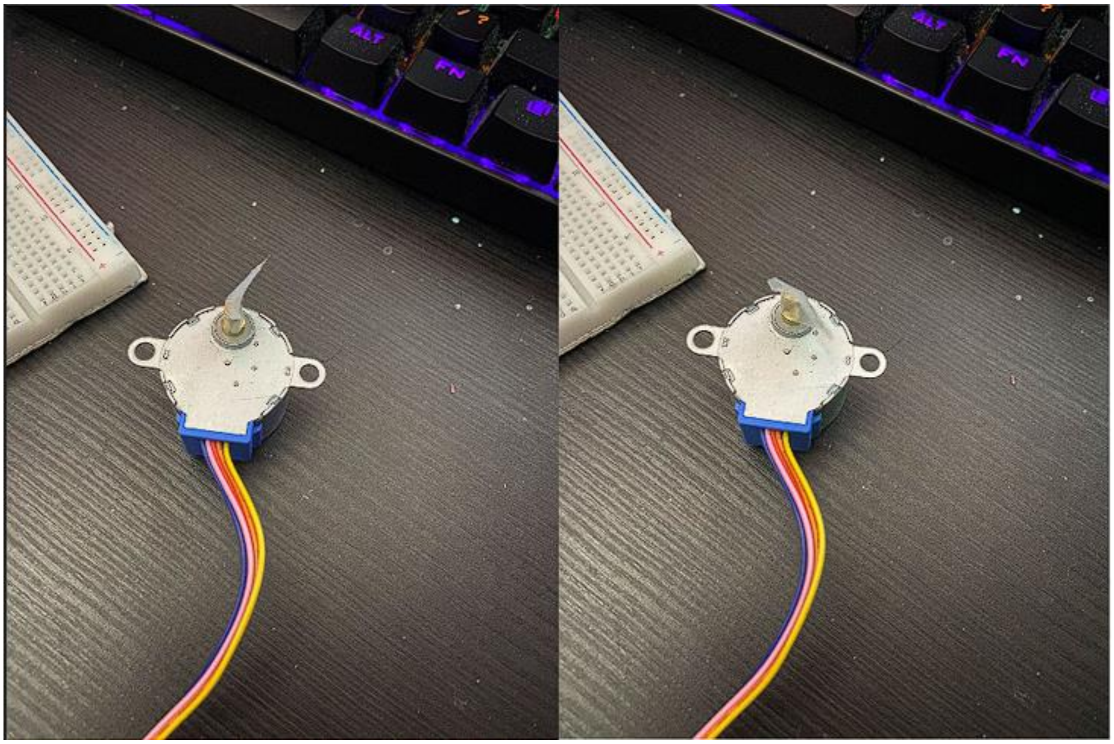
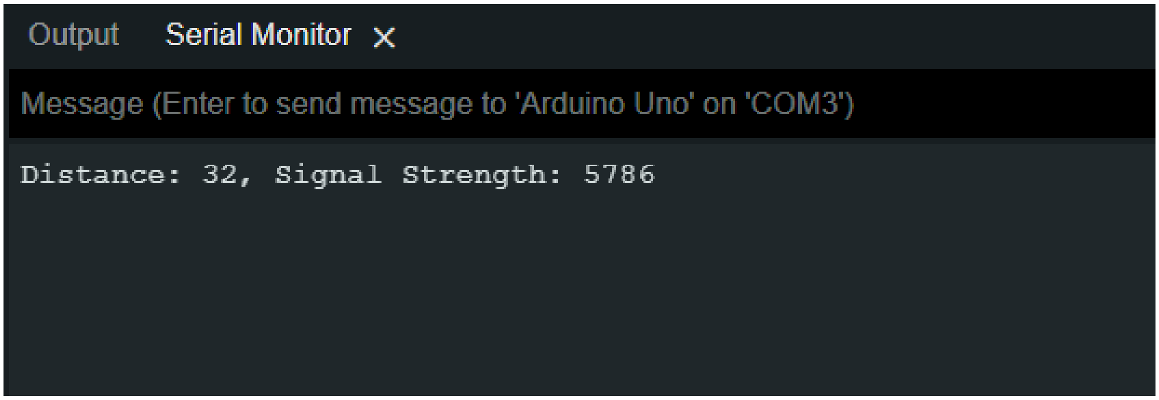


Figure 54. Long Distance Stepper Motor Rotation Before and After

The second scenario shows a much smaller distance of 0.32 meters, the rangefinder records that value and shows it below.



```
Distance: 32, Signal Strength: 5786
```

Figure 55. Short Distance Rangefinder Reading

This smaller distance is then communicated to the stepper motors, which also presents itself in a clockwise motion, and as can be seen, the stepper motor movement is significantly less than the previous scenario.

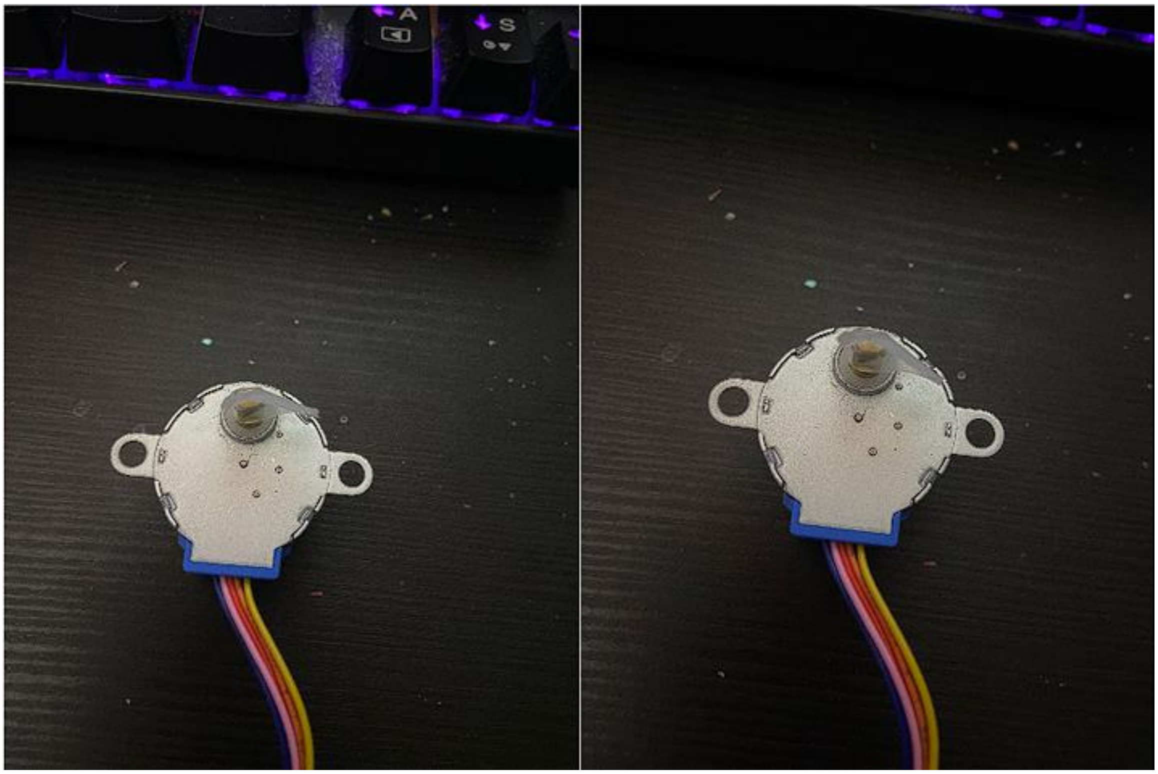


Figure 56. Short Distance Stepper Motor Rotation Before and After

This example shows that we have successfully created a system where these two subsystems are able to communicate with each other, where the output from the range finder becomes the input for the stepper motor, the next steps will involve integrating the stepper motor onto the projection lens, and then calibrating the motor to effectively adjust the projection lens to our liking.

6.3.4 Projection lens/Stepper gear integration test

This section will focus on the integration of our two-gear system, or gear train. In this case, the first gear is a drive gear attached to the motor shaft of the stepper motor, and the second gear is the driven gear which will be attached to the outer rim of the projection lens, we plan to attach the driven gear using a press fit, which means to design the gear slightly smaller than the diameter of the projection lens so it is a tight fit. To allow for the press fit attachment method, the projection lens needed to be slightly modified to accommodate this, as there was a piece of plastic sticking out from the magnification adjustment, which would get in the way of our driven gear. To solve this issue, a Dremel was used to remove and sand the piece down, so it is level with the rest of the projection lens. Below is the original and modified projection lens.

Figure 57. Projection lens modification

Now we must determine if the gears fit onto our desired components. To ensure proper fit, measurements were taken of the diameter of the projection lens, as well as the thickness of the focusing lens knob(silver). Measurements were also taken of the stepper motor shaft, such as the height, width, length, and the semicircles on the outer edges of the shaft. The following figure shows the gears being fitted onto the projection lens outer rim and the motor shaft of the stepper motor.

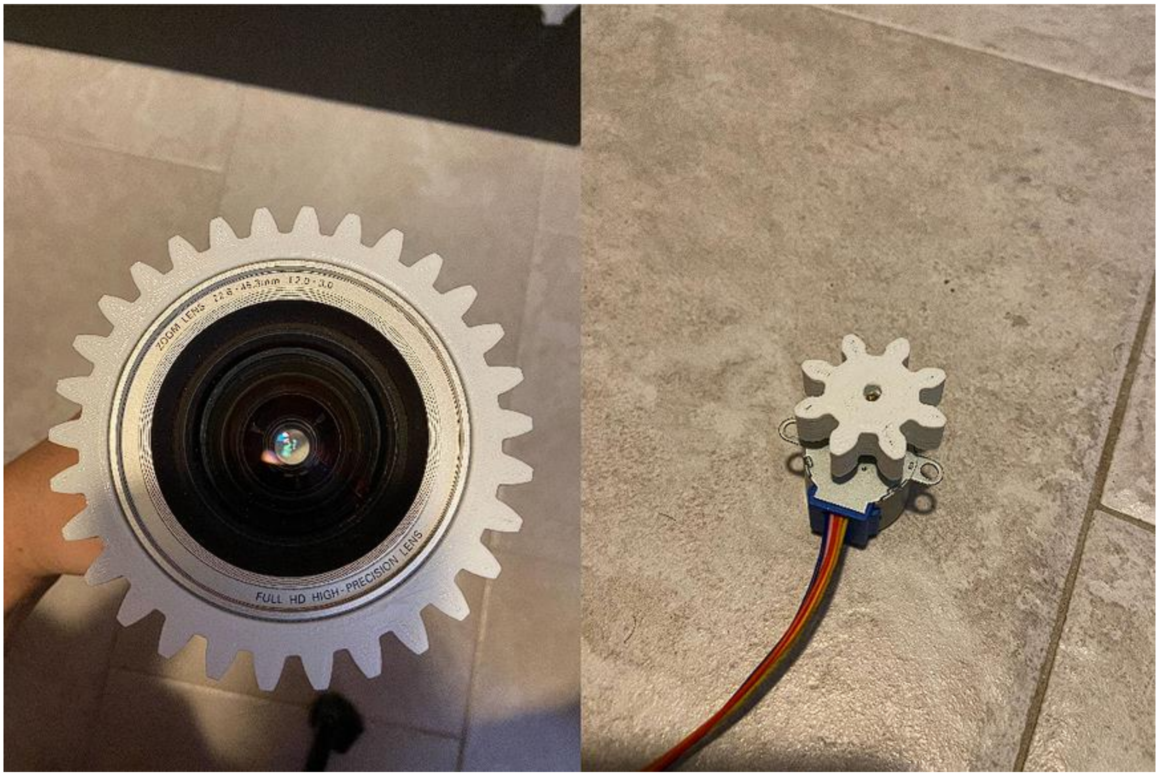


Figure 58. Gear System Integration

6.4 Voice Command Test

In this section we will discuss the means and methods by which we tested the voice commands system. The system after testing is expected to work as described in both Figure 2, the Software Flowchart, and Section 5.5, Voice Command Software Design Details.

6.4.1 Initial Testing

Once all of the code has been set up following the CMUSphinx guidelines, we first had to test whether or not it would function correctly. To ensure that there were no issues with our program's ability to recognize audio input, we first simply recorded audio using the Cheers.US K3 Omnidirectional microphone, and then played it back to hear what it sounded like. To some surprise, it was actually a much higher quality microphone than one would expect from an eleven-dollar purchase, and thus we moved forward confident with our selection.

Getting the code to run took more work than expected. Most of the documentation specifically states to put the referenced libraries in the Modulepath; however, after some research and testing we found that the program would only function as intended when the referenced libraries were added to the Classpath. The Modulepath is defined by a "module-info.java" file that the Eclipse IDE we were using automatically generates when creating a new Java project. This file helps direct which modules and packages interact with each other; however, this is mainly done to select which libraries to load when and to keep “public” classes from being exposed to classes outside the library, in case they were intended for internal use. None of this applies to our project, and manually adding to and defining the parameters of the “module-info.java” file was not a simple task, so by just deleting it and moving our referenced libraries to the Classpath we were finally able to run our program.

6.4.2 Audio Recognition Test

With our program running, we tried speaking simple words and phrases into the microphone. We had our program return whatever it heard as a string, and it was successfully able to recognize what we were saying with about 60% accuracy. While a great step in the right direction, this was far from ideal. The main issue was that it would attribute our phonemes to words that, while not our desired result, were just slightly off. “Projector” could be misheard as “protector”, “turn off” could be misheard as “term of”, and “focus” was constantly plagued with results such as “foe kiss”, “foe cuss”, “fork us”, “folk us” “folk cuss”, and so on. To remedy this issue, we added the aforementioned “grammar.gram” file, in which we were able to specify that we were only looking for the words/phrases “Hey projector”, “turn off”, and “focus”.

This essentially eliminated false negatives, leaving us with closer to 70~75% accuracy, but now there were times when we said one of the above words and it did not return anything, meaning that the program did not think we were saying one of the command words. This led us to more thoroughly research exactly how the audio inputs were being interpreted, leading to the discovery of the phonemes system and associated files detailed earlier. By defining the words we were looking for multiple times with different phonemes, we greatly increased our accuracy while only slightly increasing the risk of false positives. For example, “Projector” was specified as “P R AH JH EH K T ER”, but as can be seen in the table below, it now has 20 different phoneme combinations that it can be identified as.

Table 34. Voice Command Phonemes

“Hey”			
HH EY	HH AY	HH AA	HH EH
“Projector”			
P R AH JH EH K T ER	P R AH CH EH K T ER	P R AH CH EH K T OR	P R AH JH EH K T OR
P R OH JH EH K T ER	P R OH CH EH K T ER	P R OH CH EH K T OR	P R OH JH EH K T OR
P R AA JH EH K T ER	P R AA CH EH K T ER	P R AA CH EH K T OR	P R AA JH EH K T OR
P R AO JH EH K T ER	P R AO CH EH K T ER	P R AO CH EH K T OR	P R AO JH EH K T OR
P R OW JH EH K T ER	P R OW CH EH K T OR	P R OW CH EH K T OR	P R OW JH EH K T OR
“Turn”			
T ER N	T AR N	T UH R N	T AH R N
“Off”			
AO F	OW F	AH F	AA F
“Focus”			
F OW K AH S	F OW K IH S	F OW K EH S	F AH K AH S
F AH K IH S	F AH K EH S	F AO K AH S	F AO K IH S
F AO K EH S	F AA K AH S	F AA K IH S	F AA K EH S

While this does slightly increase the risk of false positives, we already have a few measures in place to mitigate that issue. Most notably, the two commands, “Turn Off” and “Focus”, are not able to be called unless “Hey Projector” has already been called within the last 10 seconds. The chance of the system misinterpreting audio input to be two named commands in both the correct order and timeframe is incredibly unlikely. Now our system rarely misses audio commands, and never once produced a false positive “Hey Projector”, although after that step we did have a few occurrences of false positives when saying things like “Foxes” or “ton of”, but this is a reasonable margin of error.

6.4.3 Integration Testing

CMUSphinx runs in Java, but Arduino code runs on what is essentially C++. Our original plan was to either use the Arduino PocketSphinx library or convert our existing Java code to C++. Unfortunately, there was practically no documentation on the Arduino PocketSphinx library, and much of CMUSphinx's functionality is tied up in JARs and configuration files, so it could not be easily translated to C++. These setbacks led us to move forward with our back-up option, the Voice Recognition V3 Module Compatible Board for Arduino. This module, specifically designed for use with Arduinos, can store 80 voice commands, although only 7 are available for quick access. This is not an issue, as the only commands it needs to listen for are "Hey Projector" and "Focus". We also found in this stage of testing that without heavy changes to the design, the "Turn Off" command wasn't feasible, as the microcontroller is not connected to the switch, and instead of wasting time and energy for one bonus feature, we decided to focus (no pun intended) on the autofocusing functionality. The Voice Recognition V3 Module Compatible Board for Arduino operates under a voltage of 5V with a current less than 40mA, so nothing about our battery or circuit needed to be altered to accommodate it. It operates by listening for a voice command and then storing it in one of its 80 slots. By loading that command into one of the 7 quick access slots, the module can compare newly inputted audio to its stored values, and determine whether or not they are a close enough match. This slightly decreased accuracy, as instead of comparing a sound to a library of sounds it is simply a one-to-one comparison, but the recognition itself was on par with CMUSphinx, although using the built-in microphone instead of the Cheers K3 Omnidirectional microphone did reduce the distance audio commands could be picked up from.

6.5 System Circuit Design

In section 6.5 we will go through the process of designing the schematic circuit diagram for the Autofocusing LED Projector which will be used to create the printed circuit board for our projector. This section will have four parts: System Power Flow, Microcontroller Connections, Schematic Diagram and Printed Circuit Board.

6.5.1 System Power Flow

One of the most important tasks for our projector project is making sure we can and are able to deliver power to all the devices within our projector. In order for us to do this we need to make an initial power flow design to map out how we plan to power the devices and what changes will need to be made to make everything work as expected. Before we do this, we must first account for all of the devices that are part of our projector system and list the devices voltage rating, how much current they draw and how much power they consume. We need this information to make sure we are delivering power to the devices in a safe and efficient way. With the voltage, current and power from all the devices we can also determine the total current draw and power consumption of the system. Below is a table with all the important listed information of each device:

Table 35. System Power Specifications

DEVICE	VOLTAGE RATING	CURRENT DRAW	POWER CONSUMPTION
STEPPER MOTOR DRIVER	5 Volts	1 Amp	5 Watts
LIQUID CRYSTAL DISPLAY	5 Volts	1 Amps	5 Watts
MICROPHONE	5 Volts	0.04 Amps	0.2 Watts
SPEAKER	5 Volts	1 Amp	5 Watts
LIDAR	5 Volts	0.18 Amps	0.9 Watts
LED	10 Volts	0.9 Amps	9 Watts
FAN	12 Volts	0.2 Amps	2.4 Watts
ARDUINO DEVELOPMENT BOARD	12 Volts	0.02 Amps	0.24 Watts

Now the first thing we will do is determine if the system falls within the specifications and requirements we listed in the beginning of the document. One of the requirements for the projector that we had was that it must consume under 50 watts of power. Adding the total power consumption of all devices, we get a total of 27.74 watts of power which is well below the 50-watt minimum we have chosen in our project requirement. With this information, below we made a hand drawn power flow chart for the projector. We start with the 12-volt lithium-ion rechargeable battery as the power supply. The power supply then goes to a switch (that will act as the on/off button for the projector) that can be flipped manually or through voice commands. While the switch is closed the 12 volts from the power supply will then go to two voltage regulators, a 5 volt and 12-volt regulator. The 5-volt (step down) regulator will take the 12-volt dc input voltage and convert it to a stabilized 5-volt dc voltage which will then be used to power the stepper motor, liquid crystal display, microphone, speaker, and the light detection and ranging system (LiDAR) by placing the devices in a parallel circuit. The 12-volt regulator will take the 12-volt dc input voltage and convert it to a stabilized 12-volt dc voltage which will then be used to power the light emitting diode (LED), fan and the Arduino Mega 2560 Rev 3 development board by, like the 5-volt regulator, putting the devices in a parallel circuit.

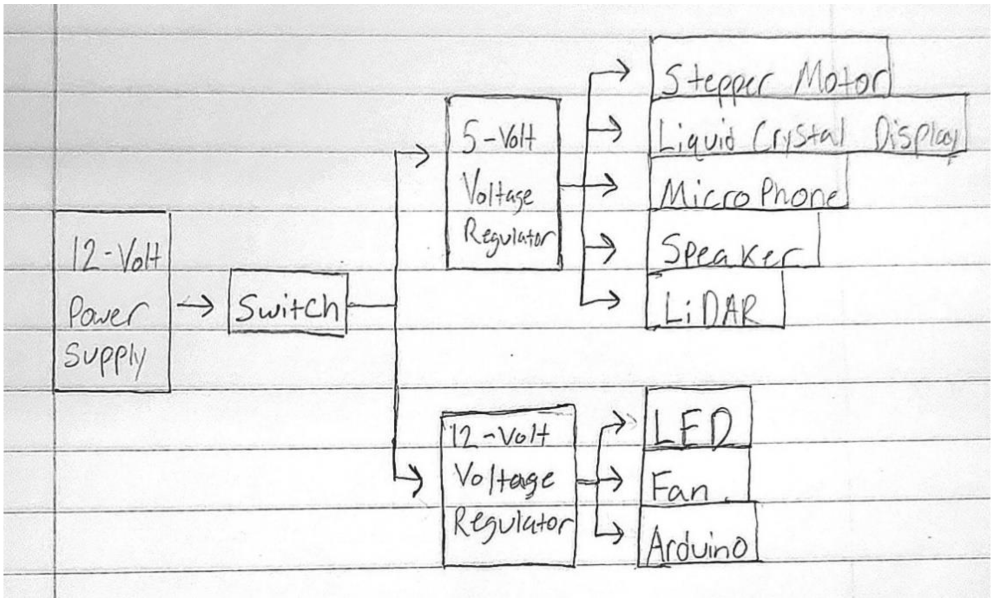


Figure 59. Initial Power Flowchart

After testing some of the projector's components and some circuit models of the power flow chart a few problems came to surface. One problem is that after we tested the LED, we noticed that the initial 10–15-volt LED does not properly illuminate the image on the LCD screen so we will need one that is brighter. This is not only a problem for the function of the projector but also for the power system because a brighter LED will require more voltage than our power supply can provide and require more power. The new LED that was chosen is a 30-volt LED and a solution to power this is by using a voltage boosting regulator (step up) that can increase the voltage to 30 volts. Regarding the power, the new 30-volt LED draws 0.5 amps of current which makes its power consumption 15 watts. Even with this large increase in power our overall power consumption for the projector is still only around 34 watts which is still under our 50-watt requirement.

Some problems with the design is that first although we are using the development board as of right now on the printed circuit board for the projector we will use just the ATMEGA 2560 microcontroller. The problem is that although the development board can handle 7 to12-volt vcc input voltage the ATMEGA 2560 will only need 4.5 to 5.5 volts maximum, so we have to move the microcontroller to the 5-volt regulator side of the flowchart. Another problem with the power flow chart is that if we have the devices in parallel with each other after each of the voltage regulators then the systems total current draw would be the summation of current draws from each device which would be a total of approximately 4 amps. This is problem because our power supply is rated to only handle a maximum of 2 amps. The solution we will use to avoid this is to add another power supply that can handle the rest of the 2 amps. The power supply we chose was the 12-volt Rechargeable Battery Pack from Sparkole which has a output voltage of 12 volts, current limit of 3 amps and a rated capacity of 5200 mAh. After adding the other power supply, we now have one circuit (Abenic battery circuit) for powering the Motor/Driver, LiDAR, and Microphone. While the other circuit (Sparkole battery circuit) will power the LED, ATMEGA, LCD and FAN.

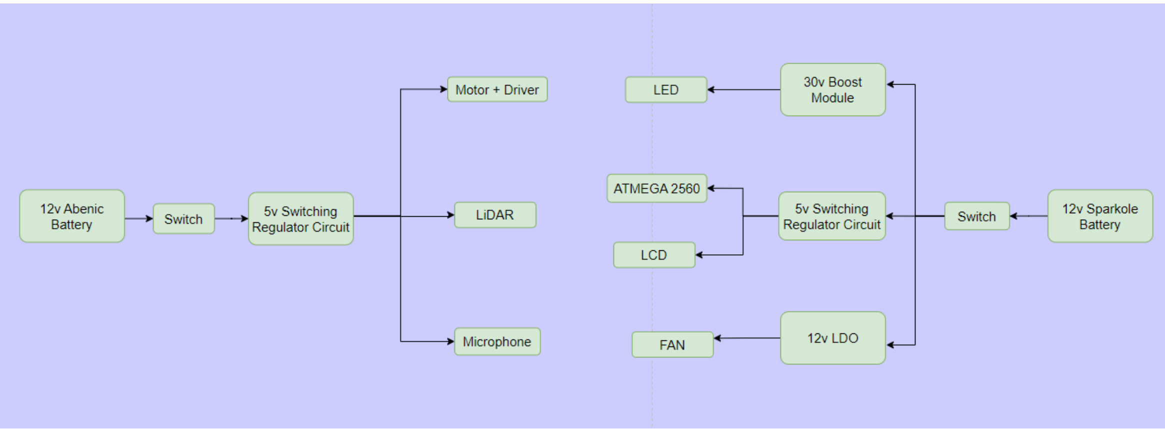


Figure 60. Projector Power Flowchart

For Abenic battery circuit we start similar to the original flowchart with the 12-volt lithium-ion rechargeable battery as the power supply. The power supply then goes to a switch to turn the projector on and off manually. Next the 12 volts from the power supply will then go to the 5-volt switching regulator circuit. The 5-volt switching regulator circuit will step down the 12 volts to 5 volts and will supply power to the stepper motor, motor driver circuit, microphone, and LiDAR with the devices in a parallel circuit. For the Sparkole battery circuit we start with the second power supply that supplies 12 volts to another switch. From the switch the 12 volts will go to the voltage boosting module, 12-volt LDO and the other 5 volt switching regulator circuit. The boost module will step up the 12 volts to 30 volts to power the LED. The 12-volt LDO will regulate the input voltage to supply a constant 12 volts to the fan. The other 5-volt switching regulator circuit will step down the 12 volts from the power supply to 5 volts to power the ATMEGA 2560 and the Liquid Crystal Display.

6.5.2 Microcontroller Connection

Arduino Mega 2560 Rev Development Board Pin Connections:

In this section we will be show how the devices, that we plan to program, will be connected to the Arduino Mega 2560 Rev 3 Development Board. The devices that will be programmed by the Arduino are the LiDAR, stepper motor and microphone. The Arduino will program the LiDAR to detect the distance the image is being projected. It will program the stepper motor to adjust the focus of the lens (by turning the gears on the lens) after determining the distance of projection. Lastly the Arduino will program the microphone to receive voice commands to focus the image (by using the LiDAR and stepper motor). To connect these devices to fulfill their purpose, on the Arduino development board we will use the digital pulse width modulation pins to connect the programmable devices to the microcontroller. The device descriptions below will give you a better understanding of the pin information and location from the image and how we plan and have used each device while testing it connected to the Arduino development board:

LiDAR – The TFmini-S LiDAR Module has two pins that connects to the microcontroller, RX and TX. RX is the receiver pin used to receive data and the TX is the transmitter pin used to transmit data. We will connect the receiver data pin to D12 and the transmitter data pin to D13 on the development board.

Stepper Motor – The ULN2003 stepper motor driver board has 4 pins (IN1, IN2, IN3, IN4) used for microcontroller connection and each pin corresponds with a coil in the 28byj-48 stepper motor. We will use pins D6 (for IN1), D7 (for IN2), D8 (for IN3) and D9 (for IN4) on the development board to program the motor.

Microphone - For the microphone, similar to the LiDAR setup, the two pins that are going to be connected to the microcontroller are the transmitter and the receiver pins. The pins on the development board that we will use for transmitting and receiving the audio signals are D10 and D11.

Below is a visual representation of how we connect the devices to the development board with the yellow dots on the development board image below indicating where the devices will be connected for programming:

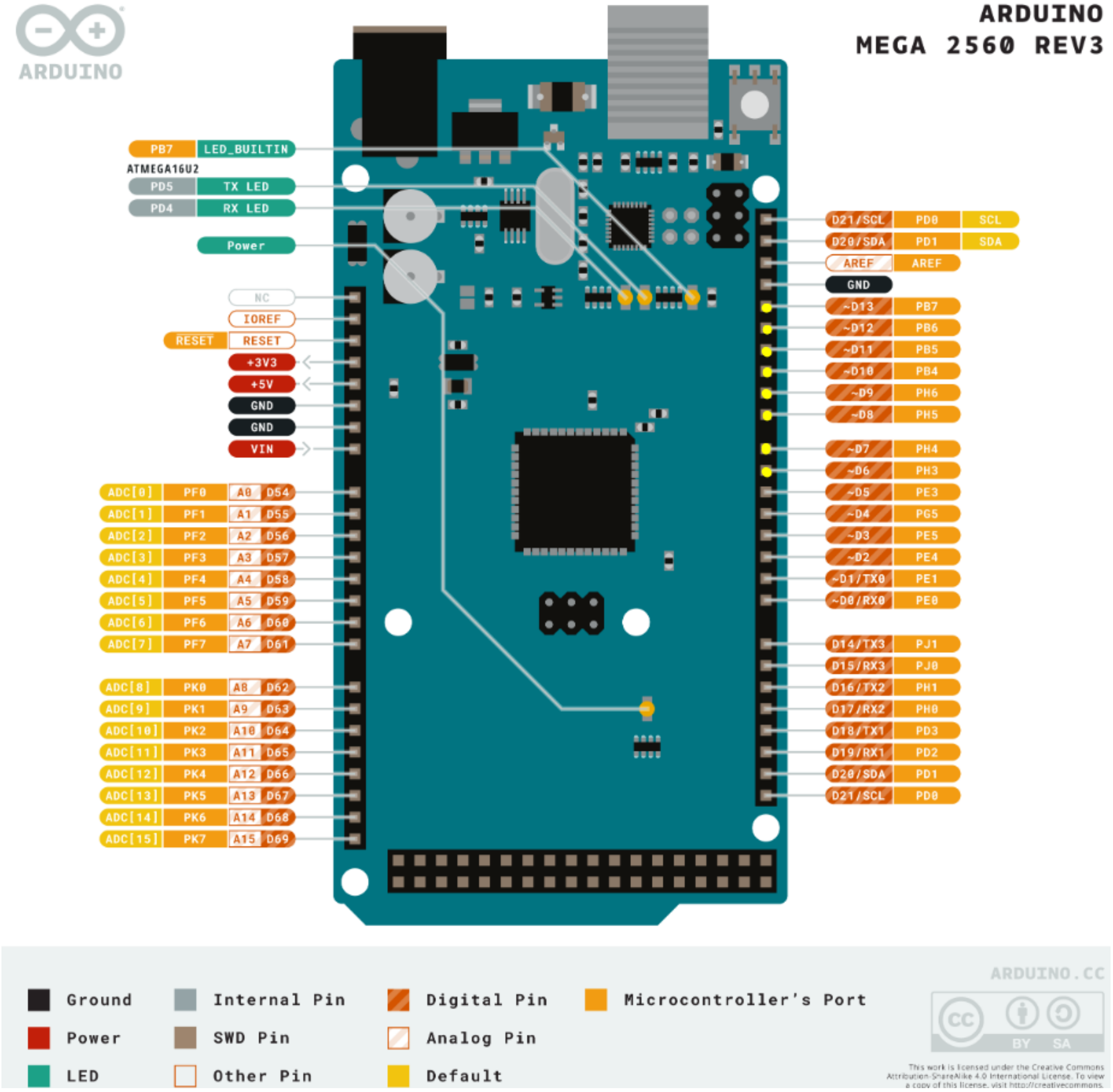


Figure 61. Arduino MEGA 2560 Development Board

<u>ATMEGA 2560 Microcontroller Pinout and Design:</u>

On the final PCB for the projector will be using the ATMEGA 2560 microcontroller to replace the Arduino Mega 2560 Rev3 Development board. Therefore, we must know where the female pin header locations on the development board are located with reference to the microcontroller. In figure 61, next to the pin numbers D# are the labels for the microcontroller ports. For the projector we will be using ports PB and PH to connect our programmable components. In addition to this we will also need to add a 6 pin In-circuit serial programming header on our PCB to be able to program the microcontroller. The function for each pin on the header is power (VCC), ground (GND), reset, master in slave out (MISO), master out slave in (MOSI), and serial clock (SCK). The VCC and GND pins will be connected to the system circuit, the reset pin will be connected to RESET on the ATMEGA and we will use port PB to connect to pins MISO, MOSI and SCK. The schematic symbol for the ATMEGA we are going to use for our schematic drawing is going to have all of the pins in numerical order from 1-100. So, we will use Figure 62, which also has all the pins placed in numerical order, to show all the pins we will use on the ATMEGA and where they are located. Below we list where the pins we are using on the development board are located on the microcontroller (pin numbers). These pins on the ATMEGA are all highlighted in the image below along with the location on the pin headers.

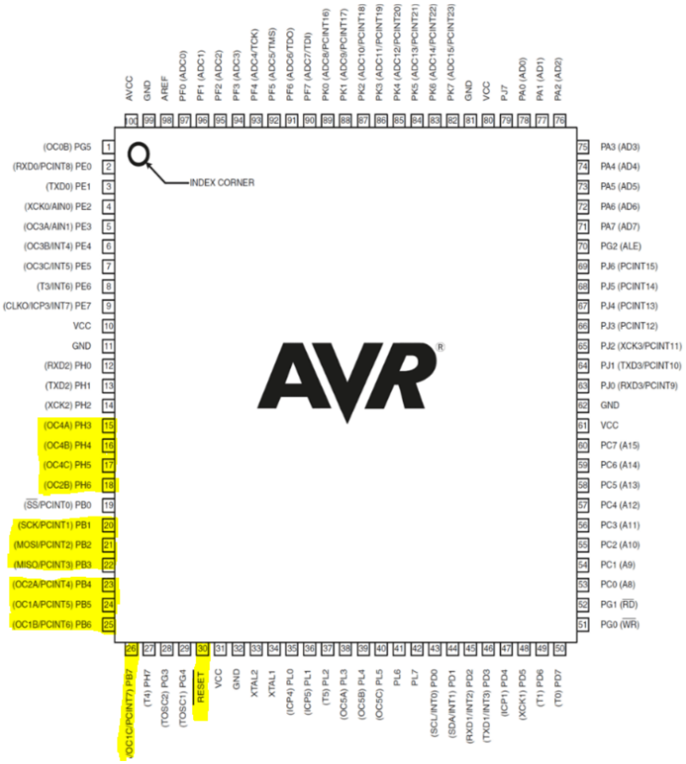


Figure 62. ATMEGA 2560 Microcontroller Pinout

On the ATMEGA 2560
Stepper Motor: PH6 - PH3 (D9 to D6) is located on pins 18 to 16.
Microphone: PB5 - PB4 (D11 and D10) is located on pins 24 and 23.
LiDAR: PB5 - PB4 (D12 and D13) is located on pins 26 and 25.
ICSP: PB1 - PB3 is located on pins 20 to 22

With all the pin numbers found for our device connections we can get a better understanding of where the connection for our devices will be located on the ATMEGA in our schematic. In the image below of the ATMEGA pinout we can see that all of our pin connections are on pins 1 – 50. The schematic symbol will not look like the image above, it will be a long rectangle that has 50 pins on each side. Therefore, when creating the schematic, we only have to use one side of the microcontroller to connect all the devices.

6.5.3 Schematic Diagram

Using all the previous design knowledge we have gained from the microcontroller connection and system power flow sections we have made a schematic diagram for our projector. In the system circuit schematic image below the left side of the ATMEAG2560 corresponds to the left side of the power flowchart (Abenic battery circuit) and the right side corresponds to the right side of the power flowchart (Sparkole battery circuit). The PCB design tool we used to design the schematic for the Autofocusing LED projector is Eagle. Eagle is a EAGLE is electronic design automation (EDA) software

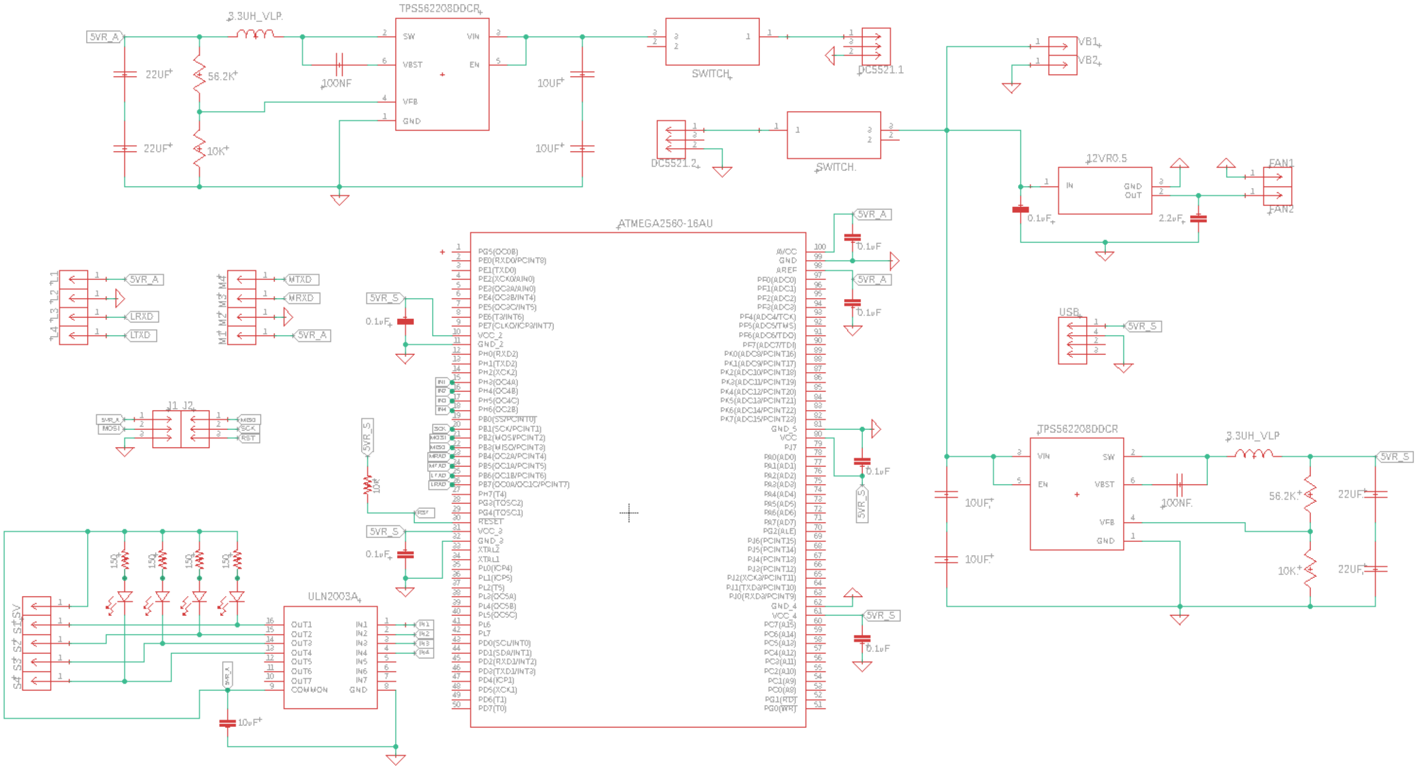


Figure 63. System Circuit Schematic

For the Abenic battery circuit we will start by using a DC5521 barrel jack to connect to the 12-volt lithium-ion battery. The barrel jack in the schematic has 3 pins: positive lead, negative lead, and a switching pin. The positive lead delivers the 12 volts to the circuit, the negative lead is connected to ground, and the switching pin is either grounded with the negative pin when there is no connection or disconnected when the power cord is plugged into the barrel jack. The 12 volts is then connected to a slide switch. The slide switch has 3 pins with pin one and two connected to each side of the circuit and pin 3 left unconnected. When the switch is flipped to the side with contact to pins 1 and 2 the circuit will be turned on and when the switch is flipped to the side with contact on pins 2 and 3 the projector will be turned on. When the projector is on the 12 volts will then go to the 5-volt TPS562208DDCR step down switching regulator circuit. The 5-volt voltage regulator circuit steps down the 12-volt input and provides a safe 5-volt output to power the vcc pin headers for the Lidar, Microphone and the ULN2003 stepper motor driver circuit (bottom left of figure 63). The vcc pin connections to the 5-volt regulator circuit are shown by the net label 5VR_A which is the net connected to the output of the regulator circuit. Designing it this way will cause less confusion by minimizing potential crossing of wires that are not connected to each other.

For the Sparkole battery circuit, we start again by using a DC5521 barrel jack to connect the Sparkole 12-volt lithium-ion battery pack to the circuit with the same pin connections as the Abenic battery circuit. The 12 volts from the barrel jack again goes to another slide switch that is used to turn the power to the circuit off and on. From the switch 12 volts go to the vcc pin header for the voltage booster module, the voltage input pin on the LDO and to the other 5 volt switching regulator circuit. The vcc and ground pin headers connects to the V+ and V- pins on the boost module. Then the module connects the output ports of the module to the LED and the module steps up the voltage to 30 volts to power the LED. Regarding the LDO, it outputs a steady and 12 volts to the fan vcc pin header and the other pin header is connected to ground. From the pin headers we connect female header 1 on the fan to the ground pin header on the circuit and connect header 2 (the middle one) on the fan to the vcc pin header on the circuit.

Lastly in the other switching regulator circuit it will step down the 12 volts from the lithium-Ion battery and convert it to 5 volts which will then go to the USB port and the ATMEGA 2560. Pin 1 on the USB port is connected to the 5-volt output of the regulator circuit and pin 4 is connected to ground while pin 2 and 3 (receive and transmit pins) are left unconnected. The USB port is used to power the LCD and the speaker. This may not initially seem like the case because in the image of the schematic there is only one USB jack, and we need to power two devices. However, we used a Male to Dual USB Female Jack Y Splitter Hub Power Cord Extension Adapter Cable, from amazon, to power both devices using the single USB port. For the microcontroller, in the branches used to power the ATMEGA we connect the VCC pin on the microcontroller to the circuit output of the 5-volt regulator circuit in parallel with a 100 nano-farad decoupling capacitor between the VCC and ground. We use these capacitors to wires to filter out additional noise and voltage irregularities.

6.5.4 Printed Circuit Board

After creating the system schematic, we made the printed circuit board (PCB) shown in Figure 64. Our PCB is a two-layer board with a ground plane on both the top and bottom of the board. The red traces indicate the traces on the top layer while the blue traces show the traces on the bottom of the board. To ensure proper connection of the traces on both sides of the board we have placed 14 vias. We also have four 70 mm holes at each corner of the board for mounting the PCB. On the right side of the PCB DC5521.1 (Abenic) and DC5521.2 (Sparkole) are the two barrel jack ports for the batteries. Above them we have pin headers FAN1 and FAN2 with 1 being the ground pin and 2 being the vcc pin.

Below the Barrel jack ports, labeled USB, is the USBA port for the LCD and speaker with pin 1 (vcc) being the one at the top and pin 4 (ground) being the one at the bottom. On the top left, the pin headers labeled VB1 (vcc) and VB2 (ground) are the pins for the DZS voltage boost module. Below the ATMEGA (to the left of the resistor) is the ICSP header with the top three pins being VCC, MOSI, GND and the bottom three being MISO, SCK and RESET respectively.

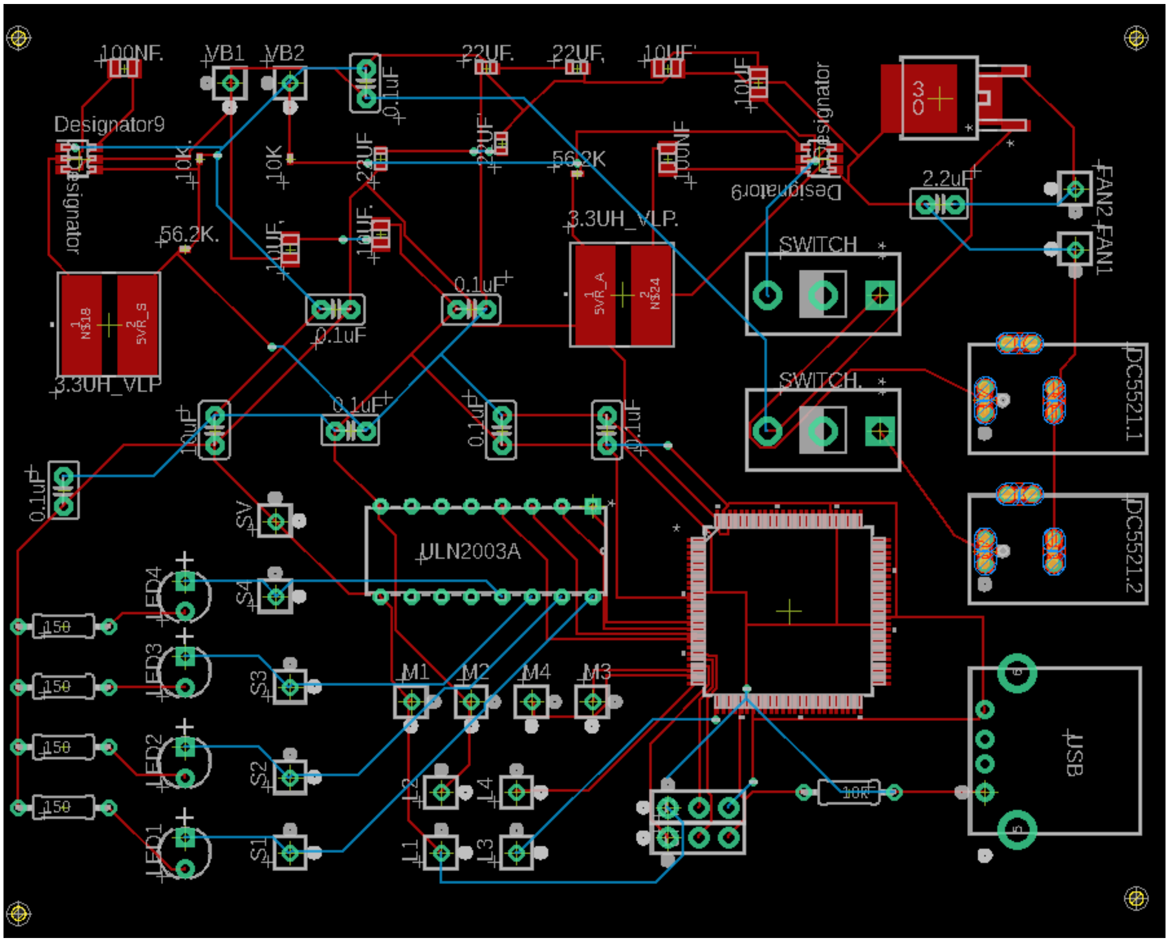


Figure 64. Printed Circuit Board Layout

At the bottom of the PCB pin headers L1 through L4 are the LiDAR pins and pin headers M1 through M4 are the Microphone pins. The functions for the pins on each device is the same with pin 1 being vcc, pin 2 being ground, pin 3 being receiving data pin and pin 4 being the transmitting data pin. Pin headers SV and S1 to S4 are the stepper motor pins. SV is the 5-volt pin used to power the motor and pins 1 through 4 are the microcontroller/driver input pins used to power the coils in the stepper motor.

7 Administrative Content

Throughout this section we will recap and discuss the milestones, budget & finance, and distribution of work for our senior design project the Autofocusing LED Projector. The content in this section is very important as it briefly summarizes the responsibilities completed and not completed by each team member and how their impact affects the overall project.

7.1 Milestone Discussion

Entering into our final course sequence of senior design in the spring of 2023 we first formed our group the first week of class. From there we brainstormed project ideas that everyone was interested in and could see themselves working on. Project section occurred the second week of class where each team member was able to divide the work and roles of each person depending on their corresponding major. The first major milestone for our team was the divide and conquer assignment where we were given the task of completing a ten-page summary document on the outlook of our project. From defining the project motivation, engineering specifications, block diagram, flowchart, house of quality diagram, and project illustration. Along with rough estimates for milestone completion and budget constraints. After receiving feedback for our first divide and conquer submission our team worked endlessly to fix and correct mistakes to begin working on the 75-page draft document.

The 75-page draft document was a major deadline for our team because it included the design constraints, industry standards, and part selection along with the content previously discussed in the original divide and conquer document. Furthermore, the team was able to conduct technological investigation into similar projects and projectors on the market today. Seeing what is out there already enabled the team to come up with more innovative methods to engineering and designing the next generation Autofocusing LED Projector. During that time the initial website design was established and created for our team and project. Ordering parts was another priority for the group to be able to get ahead and begin working on the project.

The final major milestones for senior design 1 were the three-minute video demonstration of our project and the 150-page final document. The 150-page final document includes everything that you would need to know about our project from beginning to end. The three-minute video demonstration was conducted in the final month of the semester to start showing off the progress we made on our project and the fundamental design of it. Including the optical path, range finder. Stepper motor, and voice commands. The end goal of senior design 1 was to establish a foundation on which our team can easily build on heading into senior design 2 so that project integration can be completed successfully in the short time frame.

Table 36. Senior Design 1 Milestones

Milestone	Progress	Assigned To	Start Date	End Date
Form Group	Completed	All	01/09/2023	01/13/2023
Gather Ideas	Completed	All	01/09/2023	01/13/2023
Project Selection	Completed	All	01/13/2023	01/17/202
Divide and Conquer	Completed	All	01/17/2023	02/03/2023
75 Page Draft	Completed	All	02/03/2023	03/24/2023
150 Page Final Document	Completed	All	03/24/2023	04/25/2023
Initial Website Creation	Completed	Corey	01/17/2023	02/10/2023
Order Parts for Initial Design	Completed	All	02/01/2023	02/28/2023
Light/Image Source Configuration	Completed	Daniel	02/03/2023	04/11/2023
Optical Path Build	Completed	Daniel	02/03/2023	04/11/2023
Wooden Box Build	Completed	All	2/03/2023	04/11/2023

Voice Recognition Functionality	Completed	Alex	02/03/2023	04/11/2023
LiDAR Module Test	Completed	Corey	04/01/2023	04/05/2023
Stepper Motor Test	Completed	Gabriel	04/01/2023	04/08/2023
Initial Autofocusing System Design	Completed	Gabriel / Corey	2/03/2023	04/11/2023
Improved Website Design	Completed	Corey	02/10/2023	04/11/2023
Initial PCB Schematic Design	Completed	Tyler	2/03/2023	04/11/2023
3 Minute Demonstration Video	Completed	All	04/13/2023	04/14/2023

Succeeding senior design 1 and entering senior design 2, the group planned to start working on the project a lot sooner. This is due to the fact that the majority of the optical setup needed to be close to being finished if not finished before other systems could be implemented. The fast-paced desire from the entire group helped alleviate stress due to taking other classes or work outside of academia. However, the team was able to have more excess time during senior design 2 to finish the project. As a result, the team was able to build a prototype of our projector system along with testing and troubleshooting such a design.

The goal in senior design 1 was to finalize the design, prototype, and build prior to peer presentations, final report, and final presentations, whereas the goal for senior design 2 was to create a successful project and compete for first-place prize amongst other senior design teams. The milestones that our senior design followed for successfully completing the project in senior design 2 is shown in the table below.

Table 37. Senior Design 2 Milestones

Milestone	Progress	Assigned To	Start Date	End Date
Build Prototype	Completed	All	05/15/2023	06/01/2023
Testing and Troubleshooting	Completed	All	05/15/2023	07/15/2023
Finalize Design	Completed	All	06/23/2023	07/01/2023
Build Finalized Design / Modify Prototype	Completed	All	07/02/2023	07/08/2023
Peer Presentation	Completed	All	05/30/2023	06/09/2023
Final Report	Completed	All	05/15/2023	07/22/2023
Final Presentation	Completed	All	07/10/2023	07/16/2023
In-Person CREOL Demo	Completed	All	06/01/2023	08/05/2023

7.2 Budget and Finance Discussion

This chapter will cover the final project budget and provide a table that is categorized by optical, electrical, general, miscellaneous, and building materials. One of the primary goals of our project was to design a projector system that is affordable for everyone and therefore we allowed ourselves a budget of five hundred dollars. Keeping the costs low not only enabled a more competitive product but also kept stress levels low for the college students in our team. The components that are marked with the label N/A were able to be implemented into our group at no costs and therefore enabled our budget constraints to be followed. The execution of our project was expected to have problems and therefore we had roughly $190 left over in the case that we need replacement components or further materials needed to be added to our system. With the estimated costs of our project, the Autofocusing LED Projector, being roughly $308.67, our budget falls almost two-hundred dollars shy of our goal resulting in successful finance predictions. The final project budget table below shows the material name, unit costs, quantity, and total cost for each component in our projector system laid out in an easy-to-read format. The team was able to keep the financial wiggle room for the project, so that if during senior design 2 further components were necessary to be added or hardware component malfunctions and a replacement needed to be ordered, we would have been able to afford it.

Table 28. Final Project Budget

Material	Unit Cost	Quantity	Total Cost
Optical Components			
Chip on Board Light Emitting Diode	$8.51	1	$8.51
Ground Glass Diffuser	$56.50	1	$56.50
Liquid Crystal Display	$56.55	1	$56.55
Projection Lens	N/A	1	N/A
Micro LiDAR module	$40.00	1	$40.00
Electrical Components			
28BYJ-48 Stepper motor	$5.00	2	$10.00
12-volt Lithium Ion Battery	$40.00	2	$80.00
ULN2003 motor driver	$5.00	2	$10.00
DZS Elec DC-DC Buck Boost Converter Module	$12.00	1	$12.00

General Components			
Pure Wings 2 Cooling Fan	$11.66	1	$11.66
Arduino Mega R3 Development Board	N/A	1	N/A
Cheers.US K3 Omnidirectional Microphone	$10.99	1	$10.99
Voice Recognition V3 Module Compatible Board for Arduino	$18.53	1	$18.53
Amazon Basics A100 USB Powered Computer Speakers	$13.69	1	$13.69
Miscellaneous			
HDMI Cable	$15.93	1	$15.93
Aluminum Heat Sink	$15.43	1	$15.43
USB 2.0 A Male Dual USB Female Jack Y Splitter Hub Power Cord	$6.88	1	$6.88
Building Materials			
Wood	$4.07	6	$24.42
Epoxy Glue	$8.48	1	$8.48
Thermal Paste	$7.98	1	$7.98
Total Cost Estimate			$308.67

7.3 Distribution of Work

Distribution of work was an important aspect of our senior design team. Distributing the workload based on each group member's strengths gave the project a higher chance for a successful outcome. Furthermore, it gave each student leadership and ownership of their work. That way they were given the opportunity to lead their design and contribution. Additionally, it kept everyone on track with their weekly and monthly goals to ensure the project did eventually get completed. Below is a brief paragraph from each team member of their contributions.

7.3.1 Daniel

I collaborated with the team weekly in our meetings on the short-, mid-, and long-term goals of our project in senior design 1. My main objective was to get the optical path up and running so that we could begin project integration in senior design 2. This included the tasks described in the project block diagram such as the light source, collimating lens, image source, and projection lens. I tested each component to ensure their functionality along with beginning to 3D print their corresponding optical mounts. I worked with Gabriel in our weekly discussion class for optics students where we presented PowerPoints of our progress throughout the semester. Including working together on the optical design details of the optical path and how that would interact with a range finder. I worked with Tyler on how the optical components will receive their necessary power. Corey and I brainstormed on how the cooling of the LED will be initiated. Alex and I discussed how the audio signal from the LCD driver board can be sent to speakers for the projector system.

7.3.2 Gabriel

I worked with the team in weekly meetings to discuss individual and group goals, as well as brainstorming ideas to better improve our project. My main objective was to come up with the approach for the autofocusing system, which is where the idea for a rangefinder/stepper motor came to be. As well as working with Daniel in our discussion section discussing progress and design details, we also collaborated on how to modify the projection lens to accommodate our design. I worked with Corey on how to achieve our goal of autofocusing, and to get the LiDAR system working properly.

7.3.3 Tyler

I worked with the team to delegate and complete tasks during our weekly meetings to help progress with completing this document and designing our projector. Regarding my contributions to the design of the projector my main task was to design the printed circuit board we will use to power all the devices within the projector. This process is thoroughly laid out in the system circuit design section and in order to effectively do this task I worked with each member of the group to understand the power requirements and microcontroller connections for the devices they worked on. Other parts of the document I helped contribute towards are in the project description section I worked on the requirement and specifications section and also the marketing requirements. In the technology comparison and part selection I wrote about the battery and motor. Lastly in the standards and constraints section I wrote about the power supply and printed circuit board standards.

7.3.4 Corey

I collaborated with the team on a weekly basis in order to discuss all of our individual goals, as well as the team goals. This helped the team greatly overall because it ensured everyone was making steady progress in order to complete all of the tasks on time. My largest main personal objective was working on the software design using the Arduino development board with the LiDAR module and stepper motors. During this process, I collaborated with Gabriel a lot in order to get the initial autofocusing system working. In addition to this, I also created and have maintained our team's website where I have uploaded all the needed documents and videos. In addition to these objectives, my contributions to this document include the HDMI connection, development board, and fan part selection sections. I also worked on a few of the standards sections, as well as the software design process section, and the LiDAR and stepper motor design details section. Additionally, I worked with Daniel in order to create the 3D printed components design detail section, and with Gabriel in order to create the autofocusing system test section.

7.3.5 Alex

I consistently worked with my team members in weekly meetings on the large-scale picture of how our project would be designed and how each system would interact with each other, but outside of our collaborative endeavors I essentially operated by myself in the world of voice commands until it was time to integrate our systems together. I made sure to contribute to team efforts such as creating the Project Illustration and editing the 3-Minute Demonstration Video, and many aspects of this document that weren't attributed to one person, like adding to the Designs and Constraints section. Aside from that, my main responsibilities were learning the ins and outs of how voice recognition works, all the way from the hardware in the microphones to the software in CMUSphinx, which also led me to also make the speaker selection. After CMUSphinx was found to be an unviable option, I researched and wrote the necessary code for the Voice Recognition V3 Module Compatible Board for Arduino to ensure voice commands worked as intended.

8 Conclusion

The development of a cost-friendly, user-friendly, Autofocusing LED Projector that is battery-powered and can be controlled by voice commands could be seen to represent a significant innovation in portable projection technology. The design and creation of such a system was a complex engineering process that required a combination of knowledge and skills in different fields, including optical engineering, electronics engineering, software engineering, and a bit of mechanical engineering. The mechanical engineering portion of our project is 3D printing mounts for the hardware components, along with constructing the frame and box that the projector system resides in. Through senior design our team developed a new product that is applicable to everyone with the vast diversity of capabilities that it enables.

The project involved designing, constructing, and fabricating a projector system that could automatically adjust the focus of the projected image based on the distance between the projector and the screen. The autofocus feature was critical in ensuring that the projected image is clear and sharp regardless of the distance, angle, or size of the screen. Additionally, the functionality of voice commands added an extra layer of complexity to the overall software design of the project. Through the use of voice commands, the auto focusing capabilities of our projector give it an advantage in the market today.

The design of the autofocusing LED projector started with the selection of suitable components, including the LED light source, the lens, the range finding module, the microphone, and the development board amongst the various other needed components discussed in the first half of this document. After acquiring all of the components, the next step was to start assembling initial designs of the major systems needed for the project. This included the projector system, the autofocusing system, and the voice command system. In addition to the physical assembly of these systems, initial software designs were created. Once these initial designs were created, we proceeded to test these systems before integrating them into the final Autofocusing LED Projector.

The design and creation of the Autofocusing LED Projector was a challenging and rewarding project that could have many practical applications in various fields, including education, entertainment, and business. The resulting product offers numerous benefits, including portability, autofocusing capabilities, and the ability to control it through voice commands. These features make it ideal for outdoor use, presentations, events, and other settings that require a high-quality and convenient projection system. With Orlando being one of the tourist capitals of the world, tons of business and entertainment is done in surrounding areas. Therefore, our Autofocusing LED Projector is not only University affiliated with Orlando but has the potential to be a local product that consumers can choose to support over the large corporate companies.

The project's successful completion depended on effective collaboration and communication among team members with different areas of expertise. This involved effective planning and execution on the part of all of the team members. Additionally, the project required rigorous testing, refinement, and optimization to achieve a final product that meets the project's goals. This involved a great amount of testing and measuring the performance of the projector under a variety of different conditions.

Overall, the design and creation of the Autofocusing LED Projector was a complex process that requires knowledge in a variety of different fields, including optical engineering, electronics engineering, software engineering, as well as some mechanical engineering. This project represents a significant contribution to the advancement of portable projection technology, with potential applications in education, entertainment, and business settings. The autofocusing and voice command features can enhance the overall user experience, as well as improve the quality of the projected image, making it more enjoyable for the audience. The project also provides plenty of opportunity for advancement and innovation, as new designs and features can be added to the projector to make it more versatile.

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Appendix B Copyright Permissions

Figure 6

Created: October 2001
Last modified: 15 January 2012
Source: http://www.techmind.org/

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andrew@techmind.org

Figure 8, 10

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
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Figure 14

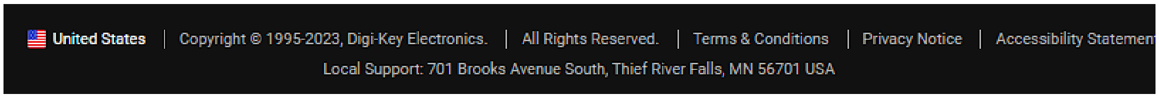

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Figure 15

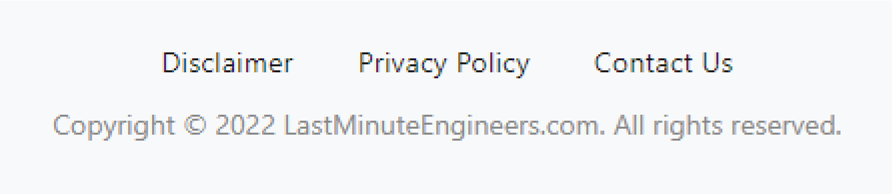

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Figure 16

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Figure 17

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Figures 18, 37

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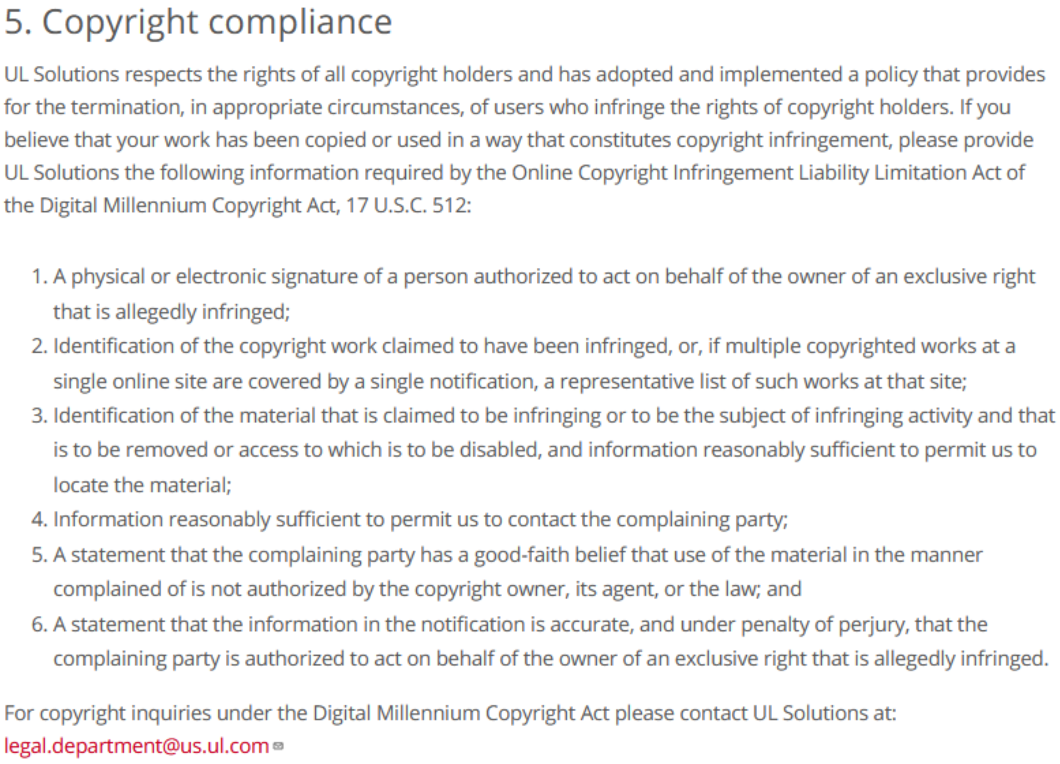
Figure 19, 20 ,21, 22



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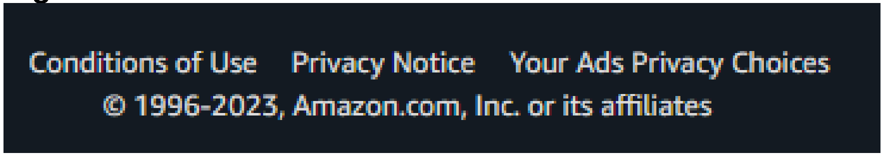

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Figure 24

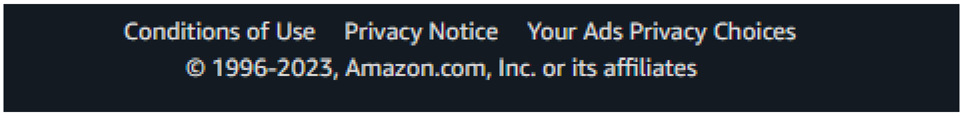
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Figure 26


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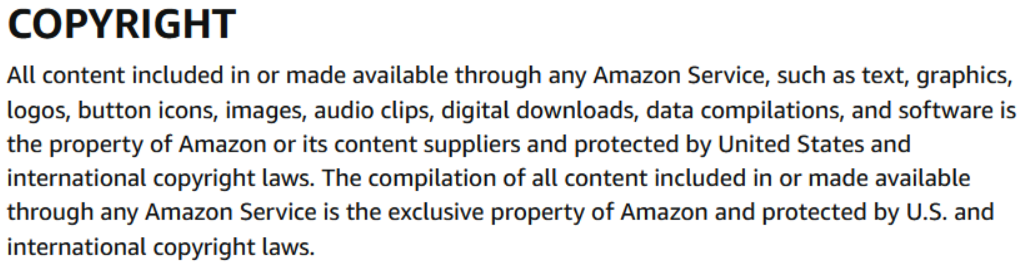
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Figure 62, 63

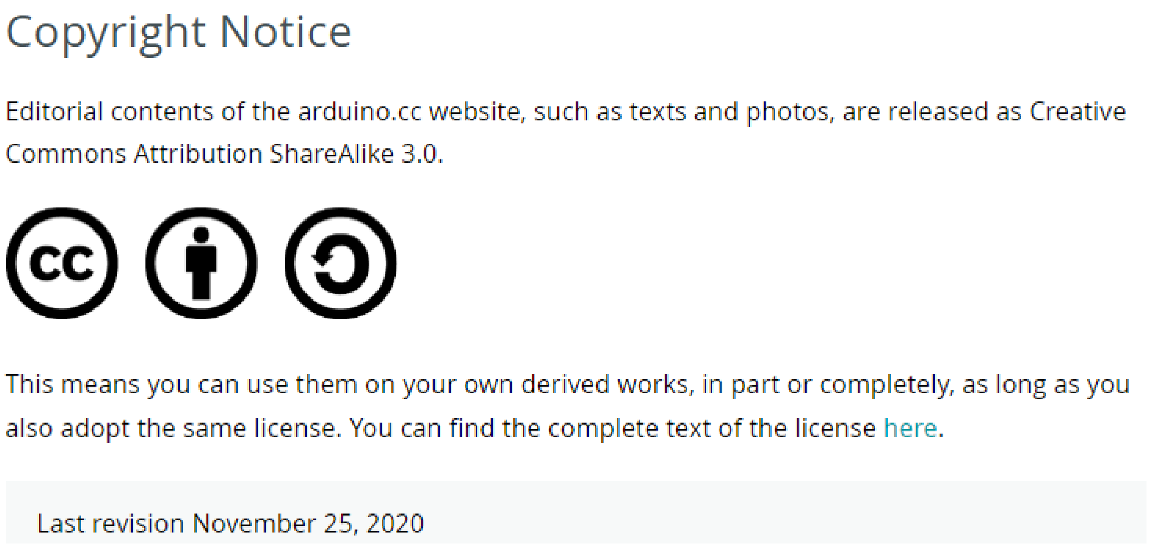
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Figure 64

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