UCF Senior Design II

Cell-Gazer - Portable Wide-Illuminating Microscope

120-page Final Document

Department of Electrical and Computer Engineering
and
The College of Optics and Photonics
University of Central Florida

Dr. Chung Yong Chan
Dr. Aravinda Kar

<u>Group 2</u>
Andres Parra: Computer Engineer
David Ponce: Computer Engineer
Jacob Roth: Electrical Engineer
Xuan Luo: CREOL

<u>Reviewers</u>
Qun Zhou Sun: ECE
Dr. Kyu Young Han: CREOL
Xun Gong: ECE

Table of Contents

Figure List

Table List

Appendices

Section 1: Executive Summary

Microscopes are a great tool that can be used by people of all ages and are made for learning and scientific discovery. Many high quality microscopes however, are bulky, heavy and hard to afford. Our group set out to create an affordable and portable microscope that also has all the marks of being high quality. What makes our microscope affordable is the cost of the individual parts. We chose parts that reach our standards and are still cost-effective. One way our group saves on cost is the use of 3D printing to create certain parts which are cheap, easy to make and hold their own against manufactured parts. Another way our group saves on cost is our part comparison in which we compare components used in our microscope based on their features, technical capabilities and of course cost.

One of the main design constraints of our project is the portability of the microscope. Most microscopes are meant to be fitted on a tabletop and rarely ever moved. Our design takes this portability constraint into consideration. We have designed our microscope to be lightweight weighing no more than 15 lbs, and to be easily carried by anyone. The body of the microscope is made from a 3D printer filament to reduce weight.

Our microscope is affordable but does not compromise on quality. Our group made sure to vet through components and their specifications in order to create a quality microscope. One of the ways we examined the quality of components is through our research and part selection. Looking at each component, we inspected the features and capabilities such as preciseness of the motors, image resolution of the camera module, or discharge time of the power supply.

As for additional features, our microscope will have certain capabilities that most microscopes in our budget range normally do not have. Our microscope will be able to detect and image not only visible light but also infrared and ultraviolet light as well. Our microscope will also feature a companion app to control the magnification and focus to give the observer more control over how they examine any specimen.

2.1 Project Description
The project is about a battery powered portable wide-spectrum illuminating microscope that can image biological specimens around 100 μm. This microscope consists of a designed LED light source, at least two objective lenses, one eyepiece lens, an iris, filters, a polarizer, and a diffraction-limited image sensor. Our microscope will have an image processing software to enhance the images captured by the image sensor. The microscope will be controlled by a mobile phone app to control the vertical axis and focus of the microscope with stepper motors. The mobile app will also feature software to capture the images given by the image sensor. It can be used by anyone and it is friendly for all ages. This is especially useful for teaching, observing, and exploring the smaller details of our world outside a laboratory.

2.2 Motivation
This project is a collaboration between students studying computer engineering, electrical engineering, and photonics in an effort to streamline and promote accessibility to biology. As a group we want to combine our knowledge to essentially automate microscopy by designing and building a portable microscope with a digital interface, where one or more users can easily take control of the microscope to observe small specimens on a display. We attempt to illuminate biological samples with a wide spectrum from ultraviolet to infrared, so it is easy to observe those biological specimens under different wavelengths. This project will bring microscopy to a mobile app. Through our own funding and research we will demonstrate how much more engaging, social, and accessible investigating the cellular world can be.

2.3 Project Goals and Objectives
This section describes our plan for developing the portable microscope containing three levels of goals: basic goals, advanced goals, and stretch goals. Our goals will be a list of what our microscope will be able to achieve.

Basic Goals
- Display a clear magnified image compared to commercial microscopes in the market.
- Our microscope will be able to change between at least two magnification levels with motor controls.
- The sample will be illuminated by a designed LED light source with a wide spectrum.
- Our microscope should be able to image biological specimens around 100 μm.
- Able to focus the image appropriately for each level of magnification through vertical axis control.
- The microscope will be small, portable, lightweight, and be easily carried having dimensions that do not exceed .
- The system will be powered via rechargeable batteries.
- A camera module controlled by a mobile app will be in place to capture the image displayed by the microscope.
- Images will be transmitted and displayed on a mobile app through the Raspberry pi.
- Axis controls with motors will be achieved through a mobile app.
- Store images using an image processing software app.

Advanced goals
Our second stage of development comprises some advanced goals that improve upon the completed prototype. In this stage we will improve already established systems while emphasizing the user experience and utility of the microscope.

- Images can be stored in a database with labels in real time
- Magnification and image resolution will be improved and balanced
- LED light source will be improved to view specimens in better lighting for all wavelengths (390 – 980 nm)
- Microscope will be improved to image biological samples around 80 μm.
- Motor system will be improved to make smoother and more accurate movements

Stretch goals
We have also defined a stretch goal to further improve the utility of the microscope if time permits.

- The microscope will have an "Educational mode" which will utilize machine learning to differentiate between plant and animal cells, and identify the different structures that make up a cell.
- Microscope will be able to image biological samples around 20 μm.

Objectives
The objective of this project is to develop a low weight and low cost portable battery-powered microscope that can be used for research in the field or for educational purposes in a classroom. Here's a list of optical objectives for our microscope in order to achieve our goals:

- UV, white, and IR LEDs will be used for LED light source design on PCB (390 – 980 nm spectrum)
- Small lenses will be used (small, portable, and lightweight)
- Two objective lenses will be used (magnifications of 40x and 100x)
- Image sensor will have high resolution and small pixel size (diffraction – limited)
- Doublet lenses will be used (achromatic)
- Iris for image size control
- Filter for wavelength control
- Polarizer for contrast control

List of electrical and computer engineering objectives:

- A PCB will be designed in order to deliver the types of wavelengths that the LEDs emit.
- Another PCB will be designed in order to regulate the voltage given to the raspberry pi, image sensor, motors, and LEDs.
- Rechargeable batteries will be used to achieve portable power to our microscope.
- The mobile app will use OpenCV to process the images to achieve good image quality.
- Two motor systems will be designed to achieve vertical control of our microscope, and rotational control of the objective lenses using the mobile app.

2.4 Functionalities

The Cell-Gazer will be a battery powered portable microscope meaning it will weigh less than 20 pounds and be compact enough to fit in a large book bag. The microscope will be able to see cells and appropriately focus depending on magnifications. The microscope will also have its own dedicated light source. . The portable microscope will be guided by several motors giving several functionalities such that the specimen can be spined 360 degrees, and the motors will control the magnification and focus. The motors and the magnification will be controlled by the mobile app. The microscope will also have a camera module being able to to capture images and send a live feed to the web app or phone app. There will be a database where one can store or search for videos or photos previously saved, this will be from a user created account in both the web and mobile application meaning they will share the database. Both of the Implementations will have their own front end meaning two different landing pages, but you will be able to create an account from both implementations. Both applications will be able to do image processing on saved videos or photos. The Image processing that our applications will have is Contrast adjustment, Conversion to B&W, Edge detection, Blur enhancing, Sharpening , Color balancing, Identification Labels, a stretch goal is Planet and Star identification.

2.5 Engineering Specifications

This section is dedicated to address the technical needs of the design. Below is a Table summarizing our engineering requirement specifications for the Cell-gazer microscope.

Table 1 - Engineering Specifications			
Component(s)	Parameter	Specification	Unit(s)
Camera Module	Image resolution	1920 x 1080	Pixels
Image Sensor	Pixel size	1.25 x 1.25	μm
Vertical Focusing motors	Latency	<100	ms
Objective lens motor	Latency	< 2	Seconds
Turntable for objective lens	Turn radius	360	Degrees
Objective Lens 1	Magnification	40x	Unitless
Objective Lens 1	Focal length	4	mm
Objective Lens 2	Magnification	100x	Unitless
Objective Lens 2	Focal length	1.6	mm
Tubular Lens	Focal length	75	mm
White LED	Wavelength	450 - 700	nm
850nm IR LED	Wavelength	850	nm
940nm IR LED	Wavelength	940	nm

UV LED	Wavelength	390 - 395	nm
Batteries	Discharge Time	≥1	Hour

2.6 Specification Improvements

This is a dedicated section that lists optical, electrical, and computer engineering improvements that we will make based on a previous group's project. This list is separated into those groups respectively.

Optical Improvements

- Our microscope will be able to clearly picture a human hair strand at about 80µm.
- Our microscope will have up to 2 magnification levels (40x and 100x) for the user.
- Three spectrums of the light source will be used instead of two. White, infrared, and violet LEDs will be used for a broad spectrum.

Electrical/Computer Engineering Improvements

- Motorized movement of the scope and specimen table.
- Mobile device controls
- Improved mobile device capabilities such as sharing and imaging options.

2.7 Software Details

Table 2 - Basic Software Details	
Basic Software Features	Description
Blur	Removes noise smoothens image
Sharpening	Enhances edges and smoothes
Motor controls	Spin objective lenses to control magnification
Database	Able to store photos and login information
Search saved photos or videos	Retrieve saved information from database
Camera controls	Make the camera start recording or flash a Picture
Wifi/Bluetooth module	Send and receive information from the Mcu to the web and phone app, possibly directly to the database via api

Table 3 - Advanced Software Details	
Advanced Software Features	Description
Contrast	Adjust the difference between the whites and blacks in an image
Convert to B&W	Convert an image to white and black
Edge Detection	Accentuates edges for images
Color balancing	Improve color composition of an image
Identification Labels	Identify specific features in an image
Make account	Create and account with password and login information
Mobile and Web implementation	Work in both Mobile and Web, meaning two separate front ends sharing one database
Api Implementation	Pull and Push requests to the database from the mobile and web app

2.8 House of Quality

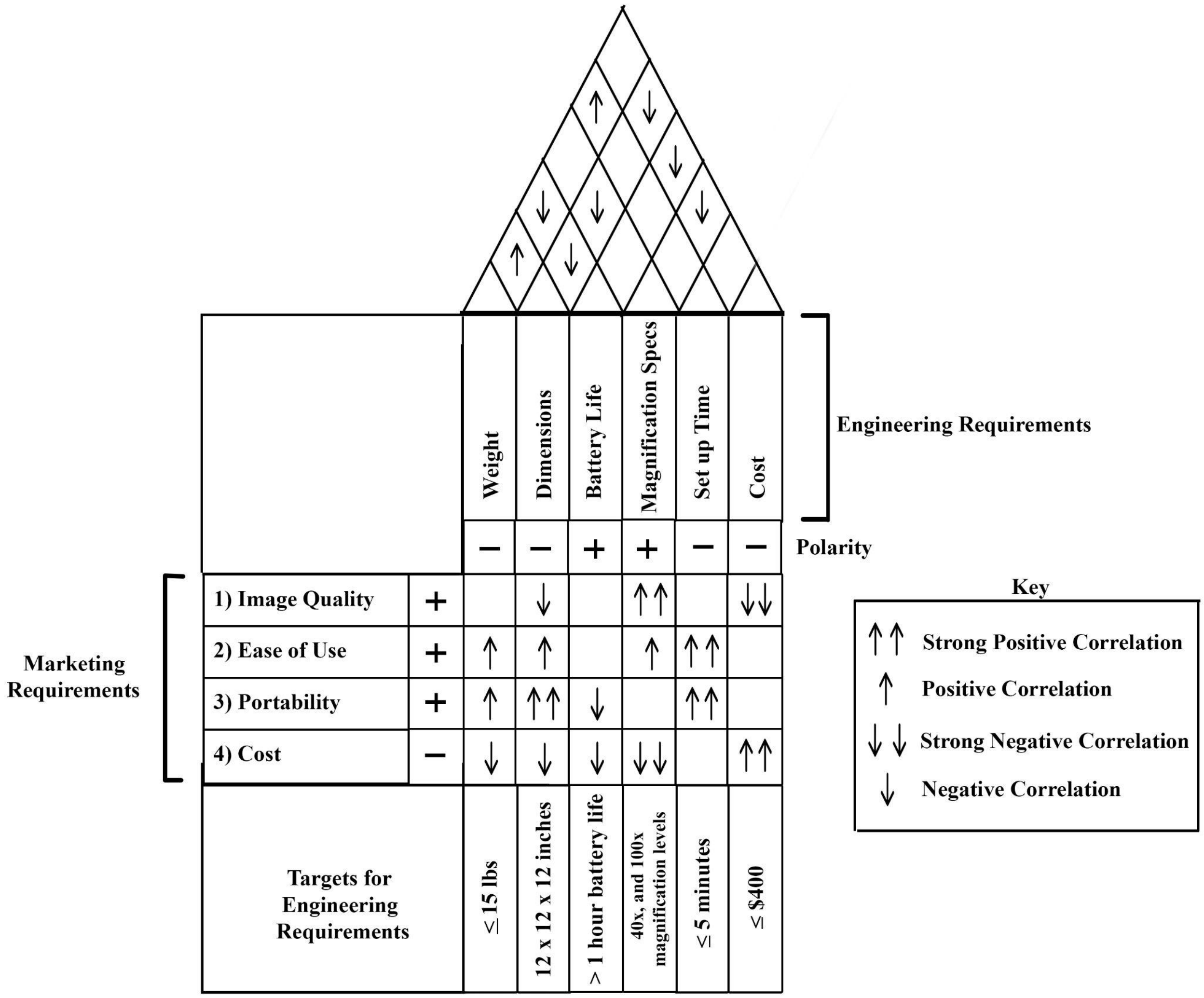


Figure 2.8 House of Quality

Figure 2.8 above shows the connection between marketing requirements and engineering requirements for the Cell-Gazer microscope project. For the engineering requirements we have listed weight, dimensions, battery life, magnification levels, set up time and cost. These requirements have either a positive or negative correlation with the marketing requirements we have listed such as image quality, ease-of-use, portability and cost.

2.9 Block Diagram in Hardware

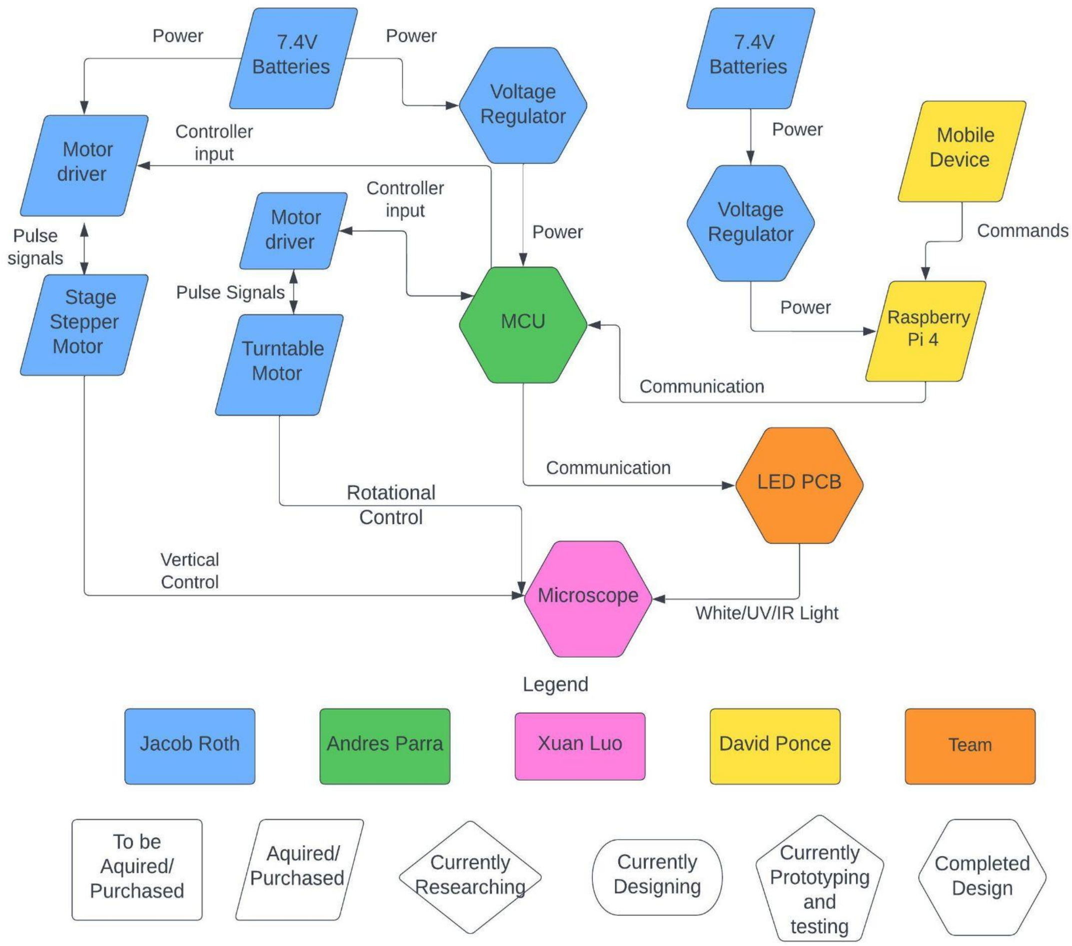


Figure 2.9 Hardware Block Diagram

2.10 Flowchart in Software

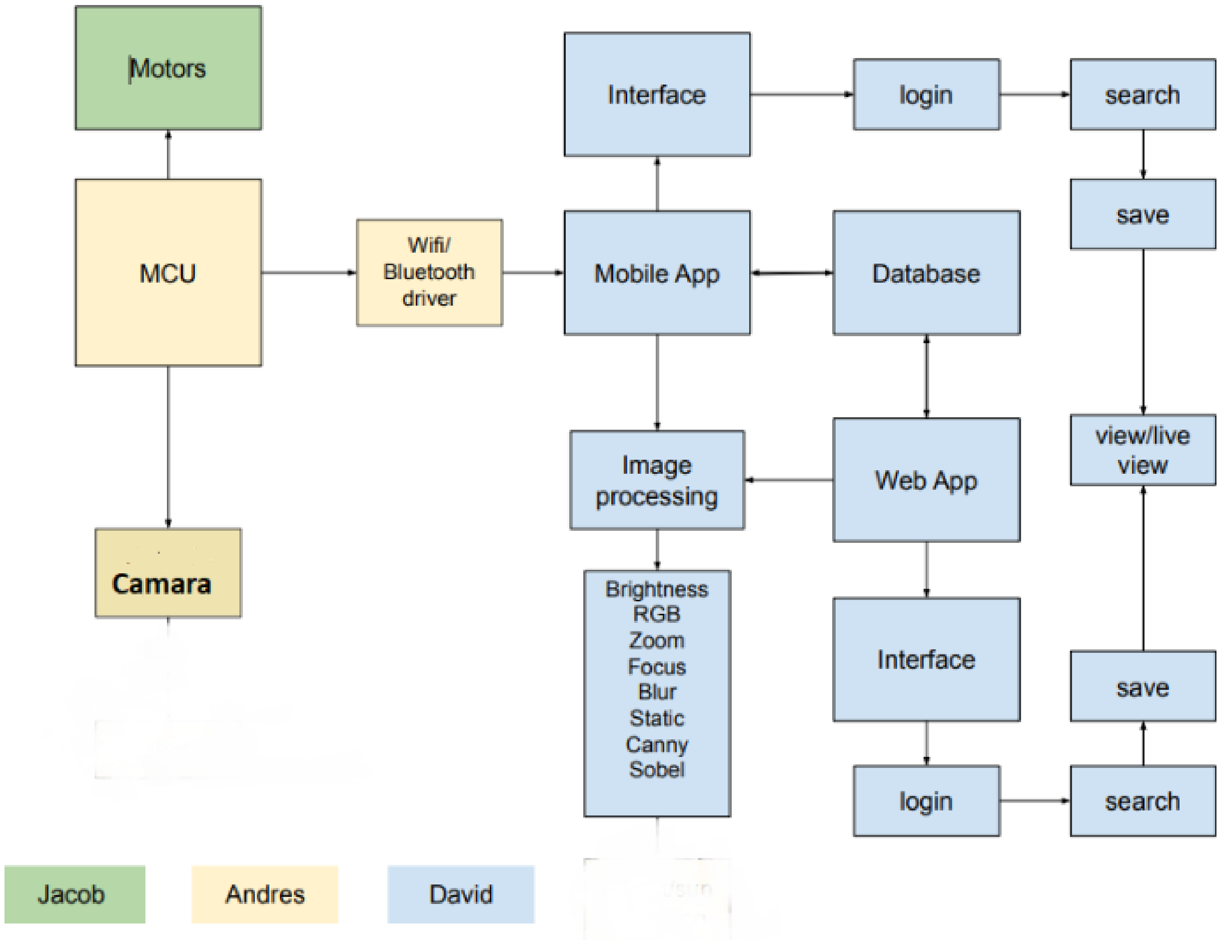


Figure 2.10 Flowchart in Software

2.11 Prototype Illustration

The following image below in figure 2.12.1 represents a prototype illustration of how the turntable design will look and how the turntable will be integrated into the microscope project. The stepper motor will be controlled by the mobile phone app which transmits inputs via WiFi or Bluetooth through the raspberry pi. The stepper motor will then spin the turntable disk to change from one objective lens to another. Figure 2.12.1 overall shows the integration of the turntable and how the magnification level can be wirelessly controlled in our project.

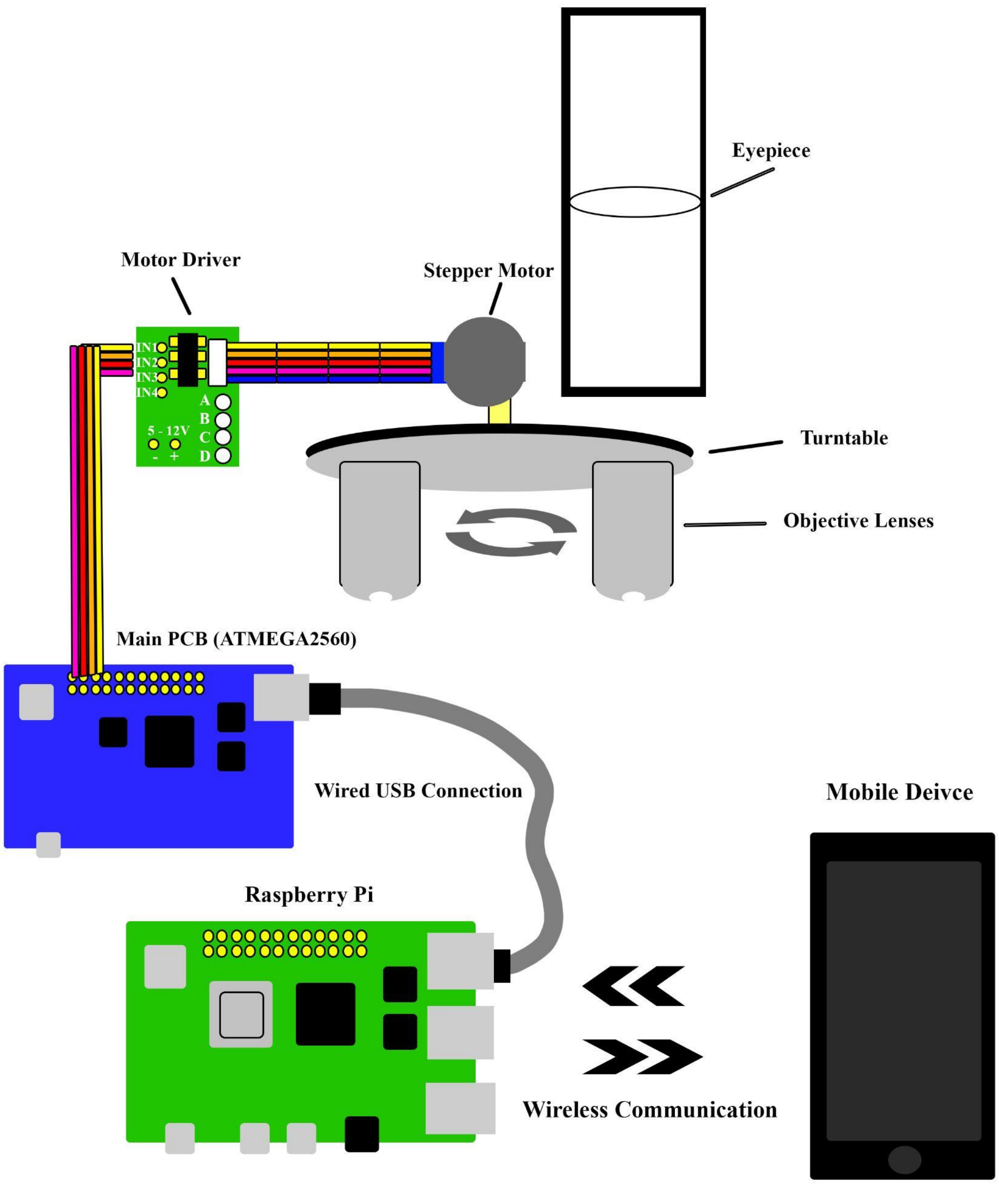


Figure 2.11.1 Turntable Design with Magnification level controlled with motors

Our group took inspiration from the previous portable microscope design and added a new electrical feature which automates the process of focusing the microscope. The following image below in figure 2.12.2 represents a prototype illustration of how the vertical lift design will look and how this will be integrated into the microscope project. The stepper motor will be controlled by the mobile phone app which transmits inputs via WiFi or Bluetooth through the raspberry pi. The stepper motor will then spin the gear system to rotate the screw which lifts or drops the flange nut and in turn lifts and drops the microscope. Figure 2.12.2 shows the integration of the vertical focusing system and how the focus can be controlled in our project.

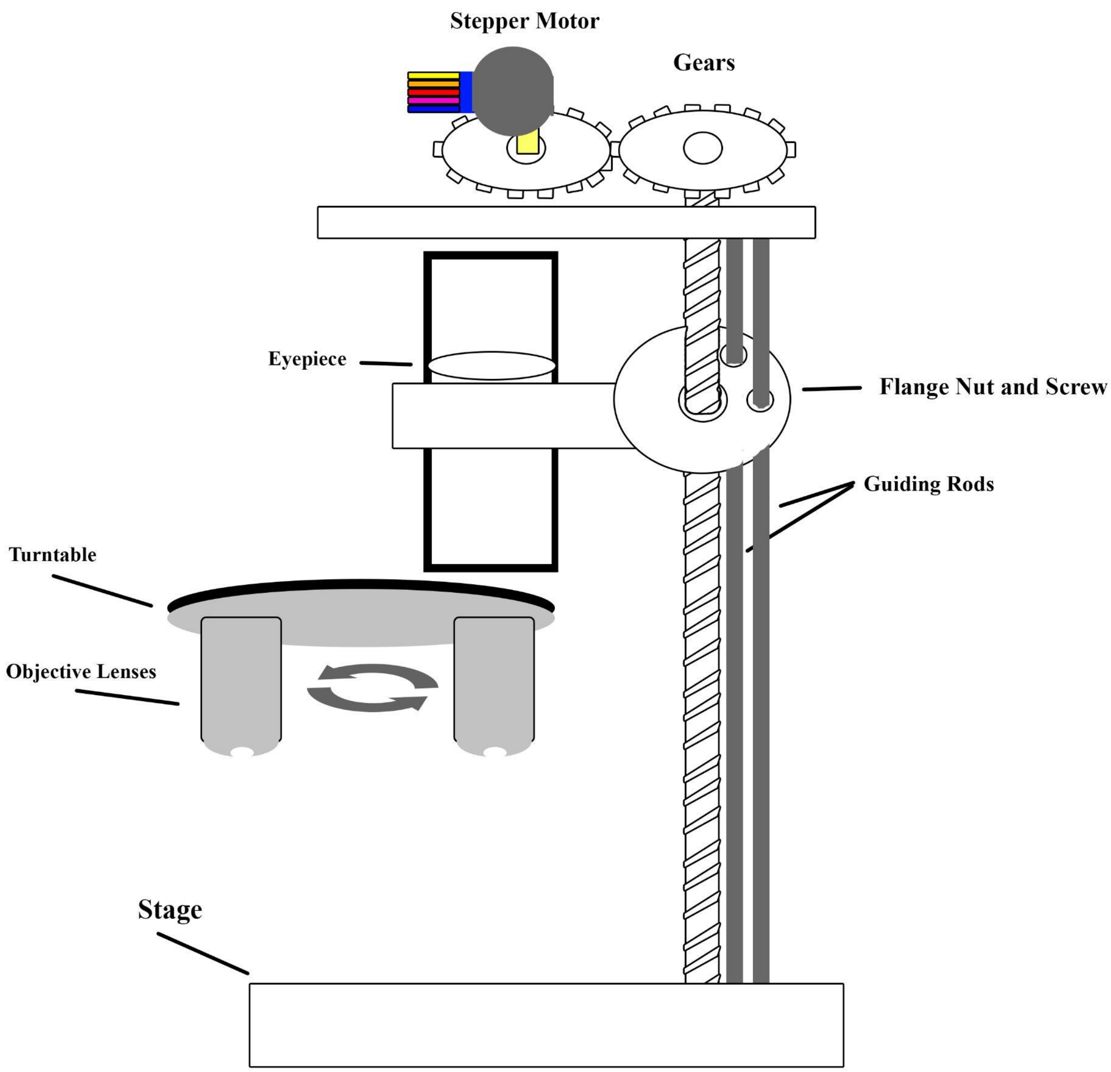


Figure 2.11.2 Vertical focusing design with the focus controlled with motors

Microscope design

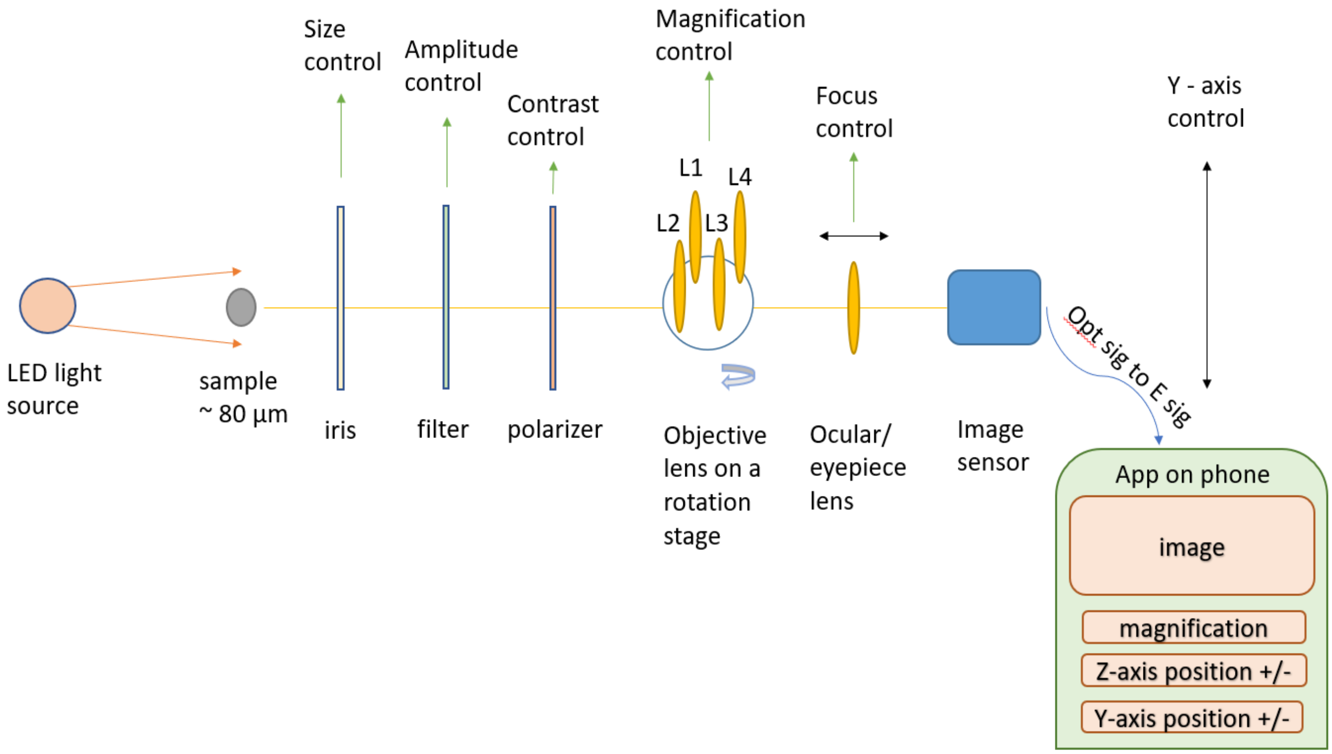


Figure 2.11.3 Optical system design

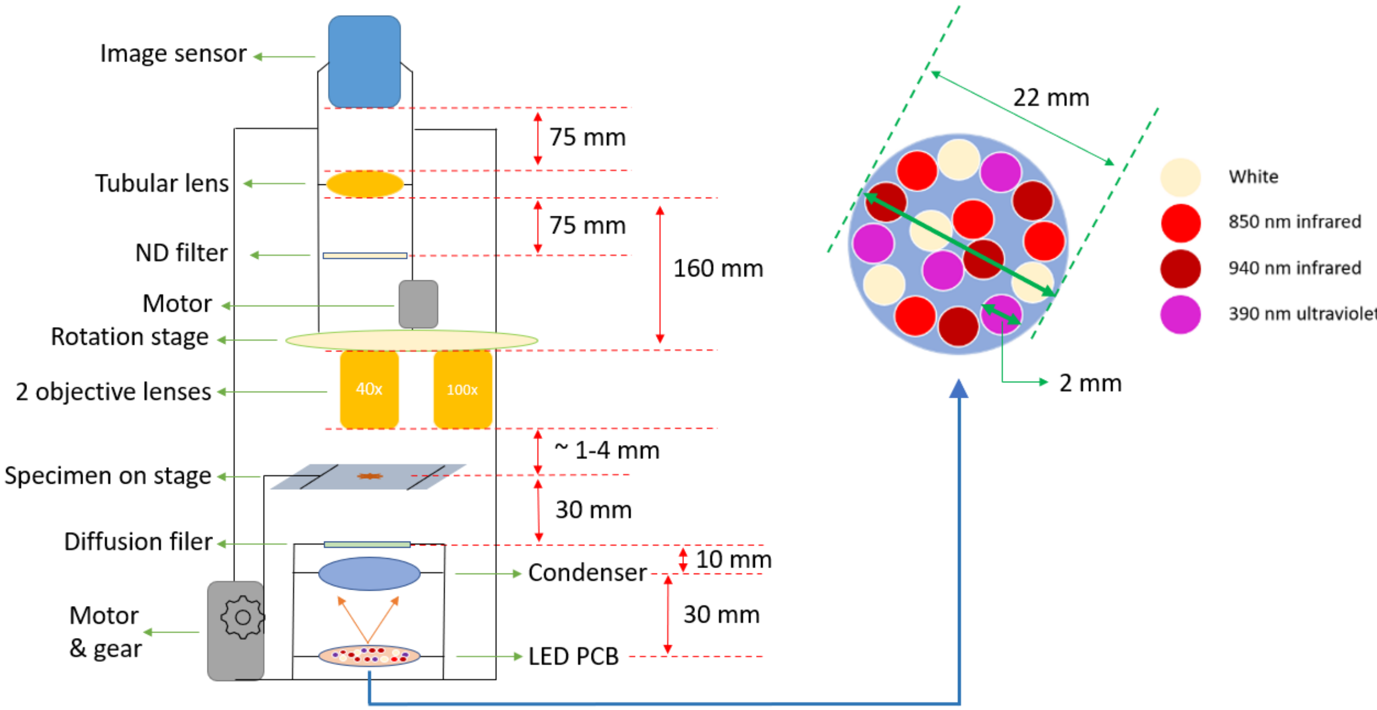


Figure 2.11.4 Microscope prototype design and LED layout design diagram

2.12 Decision Matrix

Table 4.1 - Decision Matrix		
Aspect/system	Telescope	Microscope
Sponsorship	Self - sponsor	Self - sponsor
Familiarity with the technology	Familiar	Familiar
Educational goal	Design a full optical system to image an object from a vast distance	Design a full optical system to image a tiny object (~100 μm) from a close distance
Motivation	Image the moon with axis control	Image a cell with axis and focus control
System complexity	Two - lens system (core)	Two - lens system (core)

Table 4.2 - Parameter Comparison		
parameter/system	Telescope	Microscope
Focal length	400 ~ 3000 mm	2 ~ 40 mm
Aperture	70 ~ 120 mm	0.25 (numerical)
Magnification	300x	10x ~ 100x
FOV	1.43 degrees	2 mm (100x)
Angular magnification	14.6x	30x
Depth of field	0.05 mm	3 ~ 5 μm
Image quality	Determined by optical aberrations and atmospheric seeing effects	Determined by the quality of the optics and light source
Angular resolution	$2.64 * 10^{-6}$	$3.23 * 10^{-5}$

Section 3: Research and technology comparison

The research conducted to design and build our microscope is contained in the following section. This section includes but is not limited to: research related to microscopes that are on the market versus our design, general microscopy practice, how lighting and magnification affect the quality of imaging, smartphones or electronics and microscopy, imaging and microscopy. What we learn from our research will help us design and build our own microscope.

3.0 Existing Microscopes

In order to study microscopy and the wider concept of designing and building a microscope of our own we researched and looked at some microscopes that are commonly sold online. We looked at what makes a good microscope in design and capability. We ended up purchasing a compact portable microscope to take apart, test, and add some capabilities to it. Many microscopes are available on Amazon, however we chose this one due to the cost and makeup of the design. We looked into the current capabilities of the purchased microscope and based on our knowledge, added more advanced features and functions.

3.1 Research

This section is to demonstrate how the decisions of choosing and designing a portable microscope are made through our research into the microscopy field. Researching microscopes for commercial and research use helped us to have references for critical optics parameters that are significant for optimal microscope imaging. It also helped us to design and make a portable microscope that is well suited for bio-imaging outside the lab environment. We investigated existing microscopes to have a comprehensive concept of building our own microscope and looked for minimal requirements of essential optics parameters. Magnification and resolution are two key parameters that determine the overall imaging outcome. The research we have done helped us to find a balance between magnification and resolution.

3.1.1 Existing Technologies

In order to make a proper microscope, we first searched several commercially used microscopes to get to know how microscopes work in general and found out some limitations of these microscopes that can be improved. We attempted to make a portable microscope that has an overall better imaging outcome than those commercial microscopes. We would also address the constraints that come with our design in the microscope.

3.1.2 Microscopes for Research

There are many different kinds of microscopes for all different purposes. In this project, we attempted to build a microscope that can be used outside of a laboratory, so the microscope needs to be easily carried out and moved around. Therefore, the microscopes that we chose to research are a pocket microscope, a digital USB microscope, and a portable microscope that was designed by a previous group in Senior Design in 2018.

3.1.2.1 Pocket Microscope

We investigated one cheap pocket microscope that is available on Amazon for twelve dollars. This microscope has a system of lenses, a light source, and variable focus. However, it does not have a high resolution at all and the magnification of it is only two. This microscope is not capable of viewing any actual biological samples such as cells and tissues. It was not even that much better than just one magnifying lens.

There is another pocket microscope showcasing the portability shown in figure 2.5.3 [3] [4]. This microscope can fit inside your pocket and still has a couple of interesting features such as an adjustable magnification and illumination. This is very lightweight and in such a small size that it is easily carried by antone. This product is a great example of what we would like to achieve in terms of portability.

Figure 3.1.2.1 Pocket microscope example [3] [4]

3.1.2.2 Digital USB Microscope

The other microscope that we investigated was a digital microscope that needed to be plugged into a computer using a USB drive. This microscope is lightweight and easy to use. It has a stand, a light source, a CMOS image sensor, and a focusing component. This microscope can image a sample with a high resolution but the magnification of it is around ten. There is a huge disadvantage of this digital microscope, which is that a laptop needs to be closely around the microscope for it to plug in. At some places, it is hard to put a laptop near the sample and the microscope at the same time due to the small space. This highly limits the movement and the portability of the microscope, and we do not want this in our product.

Many of the digital microscopes found in the market have built-in screens and lighting for the user to observe each specimen easily. An example that our group is researching is pictured below in figure 2.5.2 [2]. This on the market microscope is said to have up to 1200x magnification with a 7" LCD display. This example shows us how a digital interface can be integrated into a microscope design.

Figure 3.1.2.2 Digital Microscope example [2]

3.1.2.3 Portable Microscope

There was one Senior Design group that made a portable microscope in 2018. Their microscope has a multi-spectra light source, two objective lenses, and an image sensor. This microscope is able to provide the user with a clear image of a cluster of onion cells and distinguish the walls of the onion cells, approximately around 150 µm. There are two different levels of magnification, and they are four times and ten times.

Pictured below in figure 2.5.1 [1] is the portable microscope that has been designed by the previous senior design group. This particular project is called the "Portable Multi-Spectra Microscope" and credit appropriately goes to that team. This team gave us the inspiration to make a portable microscope, but to make it our own way and add our own improvements to the design.

Their project turned out to be something that we would like to build. We will improve the constraints in their design and make a better microscope. They only used visible and infrared rays to be the light source, so we would like to make a microscope that has a wider spectrum than theirs. We would like to use several magnifications above 10x in our project as well.

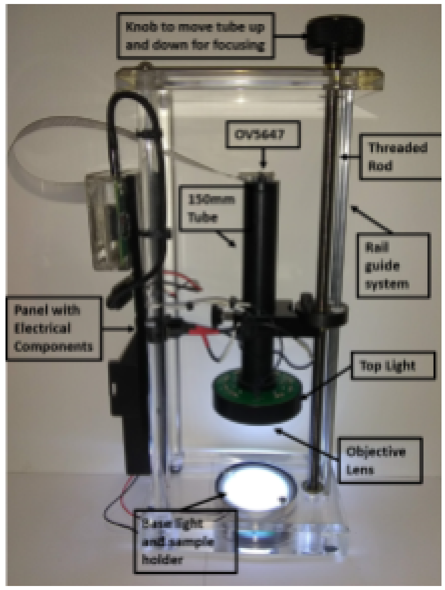


Figure 3.1.2.3 - Portable Microscope example [1]

3.1.3 Research Result

The design of the researched microscopes inspired us about our own microscope design. We attempted to build a portable microscope that is handful and light weight. A stand is not desired in our microscope, and we found that the stand used in a digital microscope can be replaced by a guard placed at the end. This guard can be put down on our microscope to keep it stable and steady in order to obtain an image. To easily switch between objective lenses, the guard will be built to have the same length as the objective lens focal length, so a user does not need to be worried about the varying focal lengths when switching one objective lens to another one. Also, a focusing stage commonly used in traditional microscopes will not be used in our microscope. A focusing stage is used to adjust the sample position for focus, and in our microscope, the guard will do this job.

The research done inspired us to use batteries instead of USB or wall plugged power support so that our microscope can be moved around more conveniently. The battery will be also rechargeable, and it can last for at least ten hours operating per charge.

The other thing we would like to improve is to make the light source with a wider spectrum. The light source of the microscope that the other senior design group built had two kinds of LED, white and IR. Some biological specimens react differently under different light wavelengths, so we would like to make our light source to have a wide spectrum in order to image the specimen at different wavelengths. We attempted to use UV, visible, and IR LEDs as our light source for the microscope. The other group's microscope is capable of imaging onion cells around 150 µm. We also attempted to improve it by using higher magnification to image samples below 150 µm. Our target sample size will be around 80 µm.

Table 5 - Existing microscope technology comparison			
-	Portable microscope (Senior design 2018)	Digital Microscope	Pocket microscope (Science Can microscope)
Dimensions	13.5 x 6 x 6 inches	4.7 x 7.9 x 14 inches	3.7 x 1.6 x 0.7 inches
Electrical Features	Battery powered, LEDs, microcontroller and camera module	7 inch LCD display, camera module, adjustable LEDs	White LED
Illumination spectrum	550 nm – 850 nm	450 nm – 600 nm	550 nm – 600 nm
Resolution in object plane	120 μm	180 μm	2 mm
Magnification levels	10x - 40x	3x - 1200x	60x - 100x
Camera module	OV5647, 5 megapixel HD camera	16 megapixel HD camera	none
Camera resolution	1920 x 1080 pixels	5376 x 3024 pixels	none
Portability	High	Low	High

3.2 Optical Part Selection & Design

In this section, we will go through our decisions about choosing optics components for our project. We completed many calculations about the required parameters of each optics component based on our design for this project, and investigated the common optics components that are available on the market and in CREOL undergraduate lab. For some components, we could not find a component that is a perfect fit for our design, so we had to make small compromises in order to achieve our designs.

3.2.1 Achromatic Objective Lenses

There are generally two kinds of objective lenses that are available on the market. One is corrected for infinite long and the other one is corrected for 160 mm. Since the one for 160 mm can give a variety of magnification levels with a combination of eyepiece lens, we chose this kind of objective lens to be used in our project.

We picked two objective lenses corrected for 160 mm so far — one is 40x and the other one is 100x. For the 40x objective lens, its focal length is $160/40 = 4\ mm$. This focal length enables us to have enough room in front of the objective lens to place biological samples. For the 100x objective lens, its focal length is $160/100 = 1.6\,mm$. This focal length is long enough for us to place samples as well, but the position of the sample needs to be adjusted everytime we change the objective lens.

The objective lenses we picked are achromatic, and the manufacturer claims that they are corrected for three colors — red, green, and blue, but further testing will be performed. Those objective lenses are available on Amazon, and they fit common size (DIN/JIS standard) with 20 mm mounting thread in diameter. The aperture of the 100x objective lens is 1.25 and it is 0.65 for the 40x objective lens. Both objectives are made for imaging samples with a thickness of 0.17 mm of the glass cover slip for best performance.

Table 6 - Objective Lens Manufacture Comparison (United Scope LLC. Selected)				
	United Scope LLC.	Zeiss LD	Leica	Nikon
Magnification	40x	40x	40x	40x
Numerical Aperture	0.65	0.50	0.65	0.65
Cost	$ 21.99	$ 495	$ 260	$ 546
Focal Length	4 mm	∞	2 mm	∞

3.2.2 Tubular Lens

Technically speaking, we only need one objective lens to image. However, the magnification will change as the position of the sample changes for refocusing. Thus, we chose to use one tubular lens to fix the magnification for the entire microscope, no matter how we adjusted the sample position.

The resolution is $\Delta r = \lambda/2NA = 390\, nm/(2x0.65) = 300\, nm$. We picked UV light to calculate the resolution because it gives the highest resolution in our microscope. The pixel size of our image sensor is 1.12 μm (see image sensor section), and for optimal sampling, it satisfies the relationship $\Delta r > 5$ pixels. Hence, $\Delta r/5 = 300\, nm/5 = 60\, nm$. The magnification for the entire microscope should be $1.12\, \mu m/60\, nm = 18.67$x. The magnification equals the focal length of the tubular lens divided by the focal length of the objective lens. Therefore, the focal length of the tubular lens should be $18.67x4\, mm = 74.68\, mm \sim 75\, mm$.

We borrowed our tubular lens from CREOL undergraduate lab. It is a Thorlabs bi-convex lens with an effective focal length of 75 mm, and its diameter is 25.4 mm. It is applicable for a wavelength range from 350 nm to 2 μm. Our light source wavelength range is from 390 nm to 940 nm, so this tubular lens will not absorb our illuminating light. Therefore, it is a promising tubular lens for our project.

3.2.3 LED Light Source

We chose LED to be our light source in the imaging system because we would like to improve the technology the other senior design group achieved in 2018 and they used LED as their light source. Therefore, we picked our light source to be LED as well to be comparable. The other reason that we chose LED is that LED bulbs can provide a steady illuminating light for the imaging system with a low power consumption on DC basis. It is safe in general and it has a broad illuminating spectrum choice. Its life span is very long, which means that it can last for a really long time without replacement. After all, it is very cheap.

The other senior design group has used two kinds of LEDs to be their light source — white and IR, which provides two illuminating spectra for their microscope. We would like to improve it by using three kinds of LEDs — UV, white, and IR, which can provide three spectra to illuminate biological samples. It enables users to view their biological specimens not only under visible and IR light but UV light as well, as some biological specimens react differently under UV light.

We have chosen white LED, infrared LED emitting at 850 nm, infrared LED emitting at 940 nm, and ultraviolet LED emitting at 395 nm. We made this decision because these LEDs can provide stable light in three different spectra to image biological samples. The white LED does not require high power consumption and it allows us to view specimens in a broad visible spectrum. The infrared 850 nm and 940 nm LED are chosen for imaging the infrared region of the biological specimens and these two wavelengths are selected because they can be detected by our image sensor. The ultraviolet 395 nm LED is chosen to image the ultraviolet region of biological specimens and this specific wavelength is selected because light rays below this wavelength are easily absorbed by our objective and tubular lenses. With three different LED light sources, we are able to image biological samples in three individual spectrums.

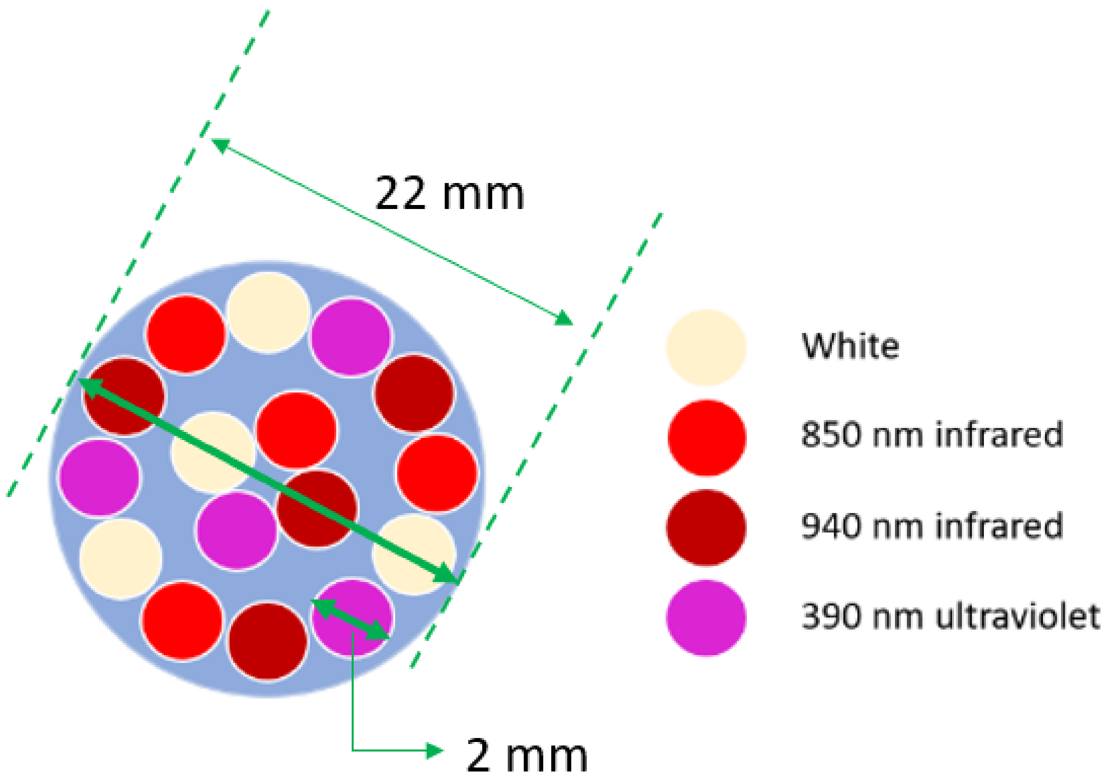


Figure 3.2.3.1 - LED layout design

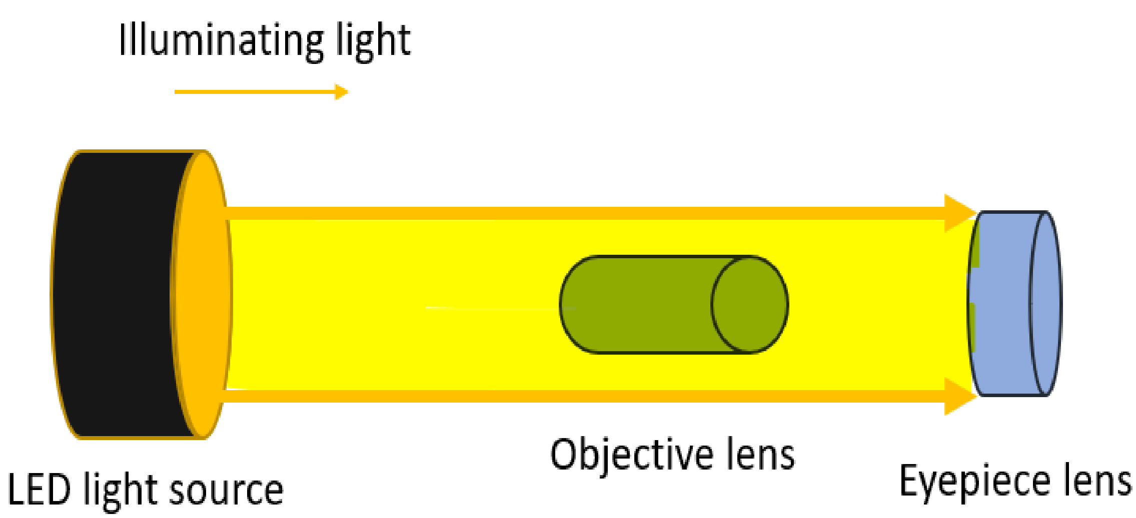


Figure 3.2.3.2 - LED illumination area

The layout design for our LED light source is shown in the figure. In order to get the promising diameter of each LED light bulb, some calculation needs to be done. We assumed the diameter of each LED light bulb is d, the diameter of the illuminating circle can be estimated as $4d$ (the green line in the figure 3.2.3.1), then the total illuminating area can be calculated as $\pi(2d)^2 = 4\pi d^2$. This illuminating area needs to at least cover the biggest lens in the imaging system (Fig. 3.2.3.2), so the diameter of the illuminating circle needs to be at least equal to the diameter of the eyepiece lens (25.4 mm). Therefore, we have $4d = 25.4\, mm$, $d = 6.35\, mm$, so the minimal diameter of each LED light bulb is 6.35 mm.

However, there are 8 mm white LED light bulbs on the market, but there are very limited diameter sizes to choose for IR and UV LED light bulbs. The most common diameter we can find for UV and IR LEDs is 5 mm, thus making us have to choose 5 mm as our LED light bulb size. Since it is smaller than the minimal diameter that we calculated, we need to insert another circle of LEDs into the illuminating circle to make up for it. Therefore, the actual LED layout will have three small circles of LEDs, and the actual diameter of the illuminating circle is $6d$. The actual illuminating area will be $\pi(3d)^2 = 9\pi d^2 = 225\pi$, and the area of the biggest lens in the system is $\pi r^2 = 161.29\pi$. The LED illuminating area can totally cover all the lenses in the imaging system.

3.2.4 Iris

In this project, spherical aberration will be introduced to our imaging system because of the use of a series of lenses. We plan to use an iris, which can be opened and closed, to block light going through the edge of the lenses. This will reduce the occurring spherical aberration and distortion of the images. Another reason that we would like to use an iris in the system is that an iris can be used for controlling the imaging area of our sample. The size of the iris will be chosen based on the diameter of our eyepiece lens (25.4 mm) to make sure it is capable of blocking light rays at the edge of the lens, since the eyepiece lens is bigger than our objective lens. The diameter of the iris needs to be at least 25.4 mm. We originally planned to borrow an iris that fits the requirement from CREOL undergraduate lab. However, after we built up our microscope, we found there is no need to add an iris to spot at a certain region on a specimen as the field of view is better as big as possible.

3.2.5 Filters

Filters will be used in our imaging system in order to achieve wavelength control. Since our objective lenses are achromatic only for three visible colors, existence of UV and IR light rays will introduce chromatic aberration on the images, which is unwanted. We plan to fix this problem by using UV, visible, and IR filters to filter out a certain wavelength. The lenses thus only need to focus one certain ray into the image sensor, and the position of the sample may need to be slightly adjusted for refocusing. Our filters will be placed in front of the light source. The filters will be purchased on Amazon as we basically finish the hard part of the design and set up.

However, in the actual set-up, of course we can put filters to control the wavelengths but the filters will occupy more space and make the microscope less compact. We would like to build a light-weight portable microscope with minimal size, so we chose not to use filters to achieve wavelength control. Instead, we will achieve wavelength control by controlling which LEDs get turned on. For each light mode, we will turn on the LEDs that are corresponding to only one single wavelength, so that the wavelength control is achieved.

3.2.6 Polarizer

A polarizer will be used in our imaging system in order to achieve contrast control. Since our light source is LED with an unknown polarization stage, a linear polarizer is useful to set the light source to have one specific polarization stage for better contrast in the image. The diameter of the polarizer needs to be equal or larger than the illuminating area that will be tested and determined later. We will borrow a linear polarizer that qualifies from CREOL undergraduate lab.

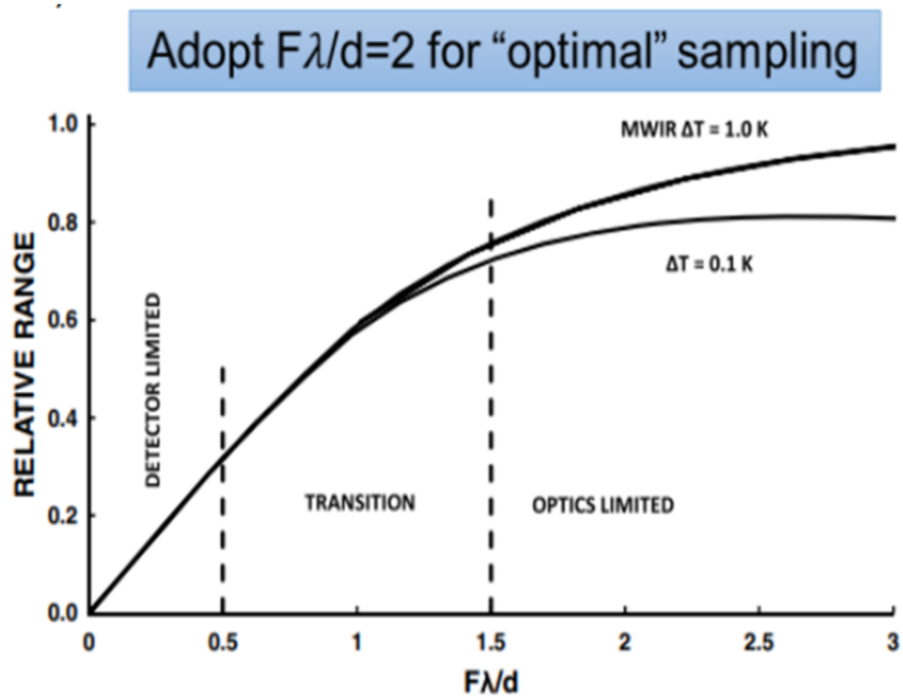
However, after testing out the result from our microscope with a linear polarizer, there were no significant improvements in terms of image contrast and the polarizer occupied quiet space in the microscope set-up, so we chose not to use a polarizer.

3.2.7 Image Sensor

One of the main functions of our microscope is to allow users to see through a microscope with a digital image for a more easily accessible view of specimens. Initially we decided that an image sensor would be the appropriate peripheral to use to achieve this functionality. However, upon further investigation, we found that there is a clear difference between an image sensor and a camera module. An image sensor uses photosensors that are sensitive to red, green, and blue light, and outputs these measurements as analog signals. A camera module includes an image sensor, but is also able to process these analog signals into digital signals that can be used by our MCU. Taking these factors into account, we can decide which camera module to use for our project while keeping in mind the kind of image sensor it uses as well as the preprocessing of the sensor's output to produce the best image possible.

Factors that we must take into account for the image sensor include its operational wavelengths, the pixel size, resolution, and the shutter. In terms of quality of the image produced, we want to find a sensor with smaller pixel sizes and a higher resolution. We also need a sensor with appropriate operational wavelengths so that it can detect an image within the visible light spectrum as well as the infrared and ultraviolet spectrums. For the purpose of our project we have considered an image sensor with a rolling shutter, as it is ideal for capturing still images, however this might cause problems later on when we try to capture videos, as a rolling shutter can produce a blurred image when capturing a moving object.

We chose our image sensor based on the resolution required by our stretch goal. Our stretch goal is being able to image around 20 μm, and we would like to pick a diffraction-limited image sensor for our project. This needs some calculations.



"Imaging system performance based upon Fλ/d," G. Holst, Opt. Eng. 46(10), 103204 (2007)
"Design considerations for advanced MWIR target acquisition systems," G. Holst, R. Driggers and O. Furxhi, Appl. Opt. 59(14), 4339 (2020)

Figure 3.2.7.1 - optimal sampling

The formula for diffraction blur is $2.44F\lambda$, where F is F-number and λ is wavelength. In Fig.3.2.7, it shows that when the ratio of $F\lambda$ to d (pixel size of image sensor) is equal to 2, optimal sampling in an imaging system is adopted. Then if we substitute $F\lambda = 2d$ to the diffraction blur formula, we have $2.44x2d = 4.88d$. Since our stretch goal is to resolute around 20 μm, the diffraction blur needs to be set as 20 μm. Therefore, we have $4.88d = 20$ μm, $d = 4.1$ μm. It means as long as the pixel size of our image sensor is equal to or smaller than 4.1 μm, the image sensor can achieve a diffraction-limited performance in our imaging system.

Based on our calculation, we originally chose an image sensor from CREOL undergraduate lab. Its model number is Thorlabs CS165CU and its pixel size is 3.45 μm. Then we tested this image sensor on our Raspberry Pi processor. Unfortunately, the driver of this image sensor is only for processors with an x86 architecture, while Raspberry Pi has an ARM architecture, so they are not compatible with each other. We went through all the image sensors that were available in the undergraduate lab but we found that none of them were compatible with the processor we have, so we had to order one image sensor that is specifically for the Raspberry Pi processor.

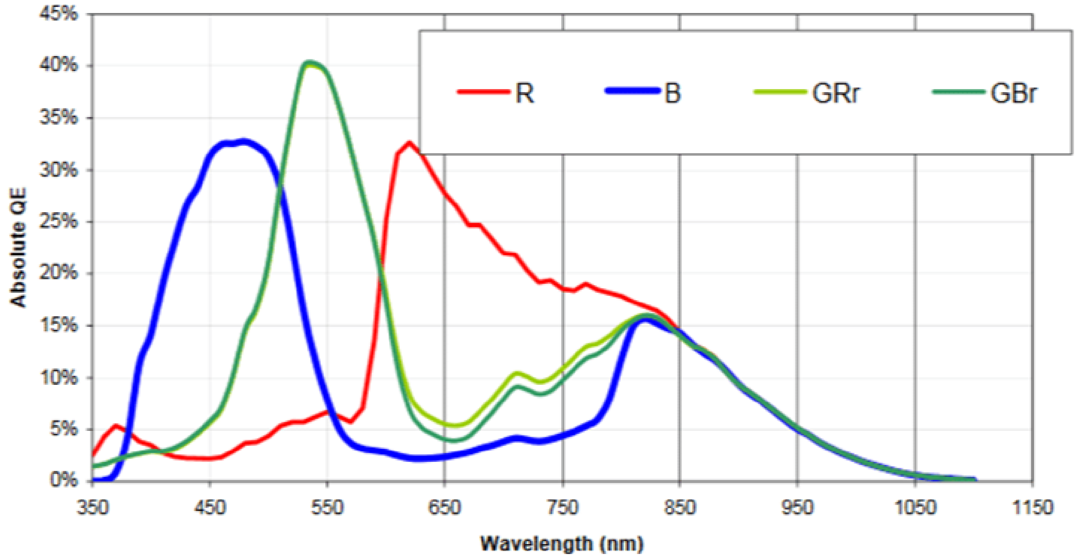


Figure 3.2.7.2 - wavelength response of the image sensor

We looked through all the image sensors provided by Raspberry Pi and we picked Camera Module v2 to be our new image sensor. Its pixel size is 1.12 μm, so that it can ensure a diffraction-limited performance for our imaging system. Its working wavelength is from 350 nm to 1100 nm, so it ensures that it is capable of capturing UV, visible, and IR light rays generated by our light source.

3.2.8 Camera Module

A camera module for a microcontroller unit (MCU) is a compact device that includes a camera sensor and supporting circuitry, designed to interface with an MCU. The camera module typically includes an image sensor, such as a charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS) sensor, along with a lens, image processing components, and interface circuitry.

The image sensor captures light and converts it into an electrical signal, which is processed by the camera's supporting circuitry. The lens on the camera module helps to focus the light onto the sensor and adjust the field of view. The image processing components include digital signal processors (DSPs), which are responsible for converting the analog signal from the sensor into a digital image that can be processed by the MCU. The interface circuitry is responsible for providing a communication interface between the camera module and the MCU, allowing the MCU to control the camera and receive the image data.

Some camera modules for MCUs also include additional features such as autofocus, image stabilization, or built-in flash. These features are typically implemented through additional circuitry or firmware, and can improve the quality and usability of the camera module.

Camera modules for MCUs are commonly used in a variety of applications, including security cameras, video conferencing systems, drones, and robotics. They can be designed to interface with a range of MCUs, from simple microcontrollers to more powerful embedded systems, depending on the specific application requirements.

Overall, a camera module for an MCU is an essential component for many applications that require image or video capture, and offers a compact and convenient solution for interfacing a camera with an MCU.

Table 7 - Image Sensor vs Camera Module Technology Comparison		
-	Image Sensor	Camera Module
Applications	Security cameras, drones, robotics	Security cameras, drones, robotics
Functionality	No on-board pre-processing	On-board pre-processing
Cost	Cheaper	More expensive
Ease of use	Harder to use	Easier to use
Size	Lighter weight	Heavier weight

Table 8 - Camera Module Part Comparison			
Name	IR-Cut Night Vision Camera Module	Raspberry Pi Camera Module V2-8 Megapixel,1080p (RPI-CAM-V2)	Raspberry Pi Camera Video Module 5 Megapixel 1080p Mini Webcam Sensor OV5647 for Raspberry Pi Model A/B/B+, RPi 2B Pi 3B 3B+ and Pi 4B
Aperture	1.8	1.2	1.6
Frame Rate	30 fps	30 fps	30 fps
Resolution	1080p	1080p	1080p
Power Needed	3.3 V	1.8 V	3.3 V
Field of View	75.5°	63°	54°
Pixels	5 MP	3 MP	5 MP
Focal length	2.8 mm	7.53 mm	5.1 mm

Costs	20-50 $	20-50 $	5-20 $

3.3 Motors

Microscopes require the ability to adjust its position over a specimen on a stage, so in order to control the microscope the use of motors is a must. The motors are going to be able to control the objective lenses in a turn-table like fashion, and the eyepiece with the objective lenses will move up and down giving the microscope vertical control as well as rotational control. The objective lenses will be able to rotate, and the microscope itself will be able to move vertically up and down. The motor will give the observer the control over how the user wants to view the specimen and how focused they want the microscope to be. Additionally, the mobile device application will communicate with the motors by giving the motors an input directed by the observer.

3.3.1 Stepper Motors

This section explains why stepper motors are in consideration for use in our microscope project and discusses the applications, advantages, disadvantages, capabilities and features of stepper motors. Stepper motors are used in applications in which position control is needed. Some examples include: CNC machines, 3D printers, automation machines, etc [5]. Some advantages that stepper motors have is the fact that they provide a constant holding torque without providing power to the motor [6]. Stepper motors can offer better low speed torque to drive various loads without using additional gears. Stepper motors also have a torque to speed inverse relation, meaning stepper motors reach their maximum torque at low speeds. This makes stepper motors a good choice for low speed and high precision applications. Some disadvantages that stepper motors have compared to servo motors is its low accuracy, low efficiency, and high noise. The low accuracy is due to the lack of an encoder to sense the position and give feedback to the microcontroller, this could cause missed steps [6.1]. The low efficiency is due to the amount of power that is needed for the motor no matter the load. Stepper motors can produce lots of noise at high speeds. Stepper motors do have some capabilities that can overcome its weakness of low accuracy such as microstepping or use of a different motor with more teeth.

3.3.2 Servo Motors

This section will discuss the applications, advantages, disadvantages, capabilities and features of servo motors. Servo motors can be used in many applications such as robotics, electronic manufacturing, CNC machines and more. Some advantages of servo motors compared to stepper motors include high accuracy, high efficiency, high speed and low noise. Servo motors use speed and position feedback devices and encoders to provide feedback to the microcontroller to correct missteps which increases accuracy. Servo motors have a higher torque performance compared to stepper motors at higher speeds (or RPM). Some disadvantages include tuning to stabilize feedback, peak torque limited to 1% of duty cycle and damage can be caused by continuous overload, Higher overall cost due to the extra feedback components.

Both types of motors could be applied to our microscope project and the research outlined above gives us a better scientific understanding of how they both work. In the end we will choose the best fitting and most capable motor based on a few factors: applications capabilities or features, noise, speed, torque, feedback and accuracy . The following table below shows the technology comparison between servo motors and stepper motors.

Table 9 - Motor Technology Comparison		
-	Servo Motors	Stepper Motors
Applications	Used for robotics, electronic manufacturing, CNC machines	3D-Printers, milling machines, automated machines
Capabilities/Features	Runs smoother than stepper motors	Can use microstepping to overcome misstepping issue
Noise	Quiet at high speeds	Lots of noise at high speed operation
Speed	Can provide 2-3 times the speed of stepper motors while maintaining the same torque	Inversely related to torque. Good for low speed and high torque applications
Torque	Constant torque at low and high speeds	Inversely related to speed. At low speeds, stepper motors provide higher torque compared to servo motors.
Feedback	Speed and positional feedback to monitor position. Misstep correction	No feedback to monitor position. Could result in missteps
Accuracy	High Accuracy. Continuously corrects positional errors using its encoder and use of feedback	Low accuracy. No feedback to monitor positional errors.
Efficiency	High efficiency	Low efficiency

3.3.3 Stepper Motor Part Comparison

In order to power and position our microscope in a precise manner, a stepper motor was the type of motor chosen. This section highlights the technical details and the use cases of a few stepper motors in consideration for our project. The technical details include rated voltage, pull-in torque, step angle, size, weight, and cost. The stepper motors our team researched is as follows: the 28BYJ-48 – 5V motor, the 42-23 Nema 17 motor from Iverntech, and the 28-28 Nema 11 stepper motor.

The first motor, the 28BYJ-48, was considered due to its popularity and availability. The 28BYJ-48 is typically used widely by beginners and first time learners as it usually comes in a kit for a good price. The price of this motor and its driver comes in at around $9.99. It is also one of the smallest and lightest stepper motors available measuring at 42 x 30 x 29 mm and weighing 40 grams. According to the datasheet, the rated voltage is 5V; the pull-in torque is 300 gf cm (gram force centimeters) or 0.0294 N m (newton meters). The step angle is 5.625°/64, meaning the motor moves 5.625° per step and has 64 steps. This motor is overall a good choice for the project due to the small size and weight which attributes to the portability aspect of our design.

The next motor in consideration was the 42-23 Nema 17 motor by Iverntech. This motor is slightly larger and heavier than the previous one at 42 x 42 x 23mm in dimensions and 132 grams in weight. Its rated voltage is 4.1V, lower than the 28BYJ-48 motor. Its holding torque is 0.13N m, and a step angle of 1.8°/200. Although the 42-23 Nema 17 motor is larger and heavier than the 28BYJ-48, it does have its advantages. These advantages include a smaller stepping angle allowing for more precise control, and a higher holding torque. This motor comes at the price of $8.99, only a dollar cheaper than the previous motor. This motor is primarily used for 3D printing, textile machining, or any automation equipment, but can be considered in our project build.

The last motor for our consideration is the 28-28 Nema 11 stepper motor, also by Iverntech. This motor does have its similarities with the Nema 17 in that the step angle is 1.8° and 200 steps. The holding torque is also much less than the Nema 17 at 0.065 N m, and its cost is higher at $17.99. The advantages that the 28-28 Nema 11 holds over the 42-23 Nema 17 is its small form factor. The 28-28 Nema 11 motor's dimensions are 28 x 28 x 28 mm and weighs only 80 grams. This motor is a sweet spot between the two motors previously mentioned and makes a good choice for our project build. Below is a table which summarizes the three stepper motors by their technical details.

Table 10 - Stepper Motor Part Comparison

-	28BYJ-48	42-23 Nema 17	28-28 Nema 11
Size	42 x 30 x 29 mm	42 x 42 x 23mm	28 x 28 x 28 mm
Weight	40 grams	132 grams	80 grams
Rated Voltage	5V	4.1V	3.8V
Step Angle	5.625°	1.8°	1.8°
Torque	Self-positioning torque: 0.0343 N x m	Holding torque: 0.13N x m	Holding torque: 0.065N x m
Cost	$9.99	$8.99	$17.99

3.3.4 Stepper Motor Drivers

As mentioned in previous sections stepper motors require a motor driver to drive the stepper, and to not cause damage to the motor itself [13]. This section is dedicated to the research on motor drivers and some examples that our group could use for our microscope. Motor drivers could be made with just some transistors, but for the purposes of our project we will be looking to purchase a number stepper motor drivers to suit our needs. A few of the possible motor drivers we looked at include: the ULN2003 which works well with the 28BYJ-48 motor, the A4988, and the DRV8825 the 2 latter of the choices both pair well with the Nema 11 and Nema 17 motors. The factors in consideration for the driver of choice are as follows: features, rated voltage or max voltage, price, advantages and disadvantages.

The 28BYJ-48 motor normally comes shipped with its own dedicated driver board called the "ULN2003". The ULN2003 has four input pins and a 4-phase LEDs called "STEP STATE LEDs" to indicate the status of the stepper motor state, and also has a 5-pin plug in for the 28BYJ-48. The supply voltage ranges from 5V to 12V so as not to damage the driver. This motor driver is the best option for the 28BYJ-48 due to its simplicity, easy setup, and compatibility with the 28BYJ-48 motor. One disadvantage to the ULN2003 driver is that it is only compatible with the 28BYJ-48 motor, so any other motors under consideration are not compatible.

For the Nema 17 or Nema 11 stepper motors, a different driver would be needed. One driver that is in consideration is the A4988 driver. The A4988 driver is designed for bipolar stepper motors and has 5 step resolutions listed as: full-step, half-step, quarter-step, eighth-step, and, sixteenth-step. Making this driver have 5 different levels of precision. The drive capacity maxes out at 35V and +/- 2A and offers over-temperature thermal shutdown as a protection feature. The A4988 also features a built-in translator for easier micro stepping applications. The last motor driver considered is the "DRV8825". The DRV8825 driver has 6 step resolutions including full-step all the way to 1/32-step. The DRV8825 has a maximum supply voltage of 45V and 2.5A maximum drive current with thermal shutdown protection. The DRV8825 also has a built-in micro stepping indexer to allow for various stepping modes. The main difference between the A4988 and the DRV8825 is the amount of stepping resolutions and the maximum voltage values. Below is a table to compare the three driver candidates in consideration.

Table 11 - Stepper Motor Driver Part Comparison

-	ULN2003	A4988	DRV8825
Features	4 phases, 4 step state LEDs	5 step revolutions up to 1/16-step	6 step resolutions up to 1/32-step
Rated Voltage or Max voltage	5V to 12V	Maximum voltage 35V	Maximum voltage 45V
Rated Current or Max Current	500mA	2A	2.5A

Advantages	Simple and ships with the 28BYJ-48	5 selectable step modes	6 selectable step modes
Disadvantages	Only compatible with the 28BYJ-48. Max current rating and voltage rating are low	Higher frequency noise. Less step modes than the DRV8825	Susceptible to voltage spikes due to its use of low-ESR ceramic capacitors
Cost	$1.32	$1.99	$3.99

3.4 Power Supply

In order to bring power to the electrical components of our microscope such as the motors microcontroller and lights, our research also includes a dive into a few power supply options. In our basic goals section we highlighted the main functionalities relating to the microscope. The microscope should be small, lightweight and portable. Therefore the power should come from a battery and not an AC adapter. Also the size and weight of the batteries are to be a considerable factor.

3.4.1 Rechargeable Batteries

This subsection is dedicated to researching the different types of rechargeable batteries that are available, and a technology comparison will be made between them. There are a few different types of rechargeable batteries that our group is considering for the project such as: Rechargeable Nickel-metal hydride batteries and rechargeable lithium-ion batteries. These batteries are the two main considerations due to our project goals, and the fact that both of these types are readily available.

The nickel-metal hydride (NiMH) battery is a rechargeable battery using nickel oxide hydroxide on the positive electrode and a hydrogen-absorbing alloy on the negative electrodes [7]. The NiMH battery was introduced to replace non-rechargeable alkaline batteries which are wasteful and do not serve a purpose to our project goals, however, NiMH batteries have a lower nominal voltage. The NiMH battery does boast two to three times the charge capacity compared to nickel-cadmium (NiCd) batteries, but still less than lithium-ion batteries. Looking at performance, NiMH batteries are still a good choice for any device that requires high-current-drain such as digital cameras and flashlights. This is due to the fact that NiMH cells supply a near constant voltage through its lifetime thanks to its low internal resistance.

The Lithium-ion (Li-ion) battery is a rechargeable battery using reversible reduction of lithium ions to store energy [8]. The anode is normally made up of graphite and the cathode is normally a metal oxide with the electrolyte being lithium salt. Li-ion batteries have a high energy density and low self-discharge. The Li-ion battery is commonly used in portable electronics making this another good choice for our project. The Li-ion cell also has a higher open-circuit voltage compared to the NiMH cells. In terms of performance, Li-ion cells also have a lower self-discharge rate as compared to NiMH cells, making them have a higher retention rate of their capacity after a certain period of storage.

Both of these types of batteries are useful and appropriate for our project. Based on the research conducted, the main difference between the two battery types is down to a few factors such as: self-discharge rate, nominal voltage rating, and recharge durability (or cycle durability). Below is a table summarizing the differences between the two considered types of batteries.

Table 12 - Battery Technology Comparison		
-	NiMH	Li-ion
Self-discharge rate	higher self-discharge rate	Lower self-discharge rate
Nominal Voltage	1.2 V. Lower than Li-ion	Varies (3.6V to 3.85V). Higher than NiMH
Cycle Durability	Estimated 180 to 2000	Estimated 400 to 1200

3.4.2 Rechargeable batteries on the market

From Table 10 it is clear to see that the Lithium-ion batteries have more advantages than disadvantages compared to the nickel-metal hydride batteries. The lithium-ion batteries offer a lower self-discharge rate and a higher voltage compared to NiMH batteries commonly used. Sourcing a single NiMH cell at 3.6V also is an issue since they are not as readily available as the Li-ion cells. These two factors play an important role in our battery of choice.

If a NiMH battery were chosen the high self-discharge rate would render the microscope less useful over long periods of time. This is the main reason why our group will choose to use Li-ion batteries for our project. In this section we outline some potential candidates of long-lasting, rechargeable Li-ion batteries found on the market for our project. Some important factors when looking for a battery are the size, weight, capacity, and nominal voltage.

3.4.3 Li-ion Rechargeable Batteries

The first cell our team looked at was a 7.4V 2600mAh rechargeable Li-ion battery from Vidar. As the name suggests, the operating voltage is 7.4V and has a nominal voltage of 8.4V. The size of the Vidar cell is 68 x 37 x 19mm which may seem large, but it fits for the operating voltage it boasts. The Vidar battery also comes with overcharge protection as well as overheating protection. The battery weighs 99 grams and comes with JST plug-in connectors for a price of $39.99. This battery is a good choice for our project because of the operating voltage it can support as well as the size and weight of the battery making it a good choice for any portable device.

The next battery our team looked into was the CBJJ 18650 battery. This cell is a 3200mAh battery and has an operating voltage of 3.7V. The size of each individual battery is 67 x 18 x 18mm. This battery comes with short-circuit protection as well as overcharge and discharge protection. The size and weight of the CBJJ batteries are much smaller than the previous Vidar battery discussed before, however, with only 3.7V our project would need to add multiple CBJJ cells in series in order to increase the voltage needed. Adding more batteries would add more weight and size to the overall design, so this factor is important to consider. The total cost of the CBJJ batteries in a pack of two comes to $24.99 making it much cheaper than the Vidar battery. The battery is a good candidate for our project due mostly to its cost and modularity of adding or subtracting batteries as needed.

The last battery considered for our project is the EBL 3.7V 3000mAh Li-ion rechargeable batteries. The dimensions of each battery are 70 x 18.5mm and has overcharge, short-circuit, and over discharge protection. The batteries also have micro-USB charging making the recharge process more convenient. Just like the CBJJ batteries, multiple EBL batteries will have to be connected in series in order to get the required voltage to power our microscope. Below is a table summarizing the properties and specification of each battery our team researched. The properties include any features associated with the battery, operating voltage for safe usage, cost, and the dimensions.

Table 13 - Battery Part Comparison

-	Vidar	CBJJ	EBL
Features	Over-charge, Over-discharge, Short-circuit protection	Over-charge, Over-discharge, Short-circuit protection	Over-charge, Over-discharge, Short-circuit protection, micro-USB charging
Operating voltage	7.4V operating, 8.4V nominal voltage	3.7V operating voltage	3.7V operating voltage
mAh (milliamp/ hour)	6600	3200mAh	3000
Cost	$39.99	$24.99	$24.99
Dimensions	68 x 37 x 19mm	67 x 18 x 18mm	70 x 18.5mm

3.5 Voltage Regulators

The purpose of a voltage regulator is to maintain the voltage of a power source to keep the voltage in a controlled range so as not to damage electrical equipment that it may be connected to. Voltage regulators are important in keeping sensitive electrical components from varying voltage levels [9]. There are many different types of voltage regulators available, and this section is dedicated to the research conducted on the two main classes. Those classes of voltage regulators being: Linear regulators and switching regulators. These types of regulators are applicable to our project as they can be used to regulate the input voltage into our system so as not to damage any components we may use.

3.5.1 Linear Regulators

This subsection dives into the applications, advantages, disadvantages, and properties of linear regulators. Linear regulators are in consideration for our microscope project because they can buck the input voltage down to a lower output voltage [12]. This is an important application of linear regulators for us because our microscope will operate at lower voltage levels. Linear regulators can be applied to low voltage projects such as our microscope.

Some advantages that linear regulators hold over switching regulators is the low complexity, low cost, slightly more portability, low noise, and less output voltage ripple [10]. Some disadvantages that linear regulators have compared to switching regulators are the voltage difference between the output and input. Linear regulators cannot have too much of a difference in voltage from the input to the output or else it can damage other components and overheat. Another disadvantage for the linear regulator is that the dropout voltages are typically much higher than switching regulators meaning that the system would have to supply more voltage in order to maintain its working conditions.

Some properties of linear regulators include its efficiency. As mentioned before there is waste in the form of heat which leads to power loss and inefficiency. One way to combat the heat is by installing a heat sink or using a switched-mode power supply.

3.5.2 Switching Regulators

This subsection dives into the applications, advantages, disadvantages, and properties of switching regulators. Switching regulators are in consideration for our microscope project because of their ability to buck the voltage down to the desired level. This is important so as not to damage other electrical parts of the project.

Some advantages that switching regulators hold over linear regulators is their high efficiency, low heat generation and less sensitivity to the input/output voltage difference. Some disadvantages of switching regulators compared to linear regulators are the noise levels, dropout voltage and cost. Switching regulators output voltage produce much more noise compared to linear regulators due to the behavior of switching regulators [11]. Switching regulators also produce some ripple voltage which can cause high noise while linear regulators do not produce such ripple. Switching regulators also cost more due to typical use of external components to control stability and these additional components will make the design more complex. Below is a table comparing these two classes of regulators.

Table 14 - Voltage Regulator Comparison		
-	Linear Regulator	Switching Regulator
Efficiency	Low efficiency due to waste heat. More sensitive to input/output voltage difference	Very high efficiency, and no heat waste. Deliver more on the desired current and voltage
Noise	Low noise	High noise

Dropout voltage	Higher dropout voltages	Lower dropout voltages
Ripple voltage	Lower ripple voltage	Higher ripple voltage
Cost	Cheap compared to standard switching regulators	More components leads to a higher cost
Simplicity	Linear regulators can be made with few parts. Less complex	More components than linear regulators. More complex

3.5.3 Voltage Regulator Part Comparison

From the previous section, it is clear that a switching regulator is more favorable than the linear regulator due to its higher efficiency, no waste heat, and better performance. In order to design our switching regulator some preliminary voltage measurements must be known. The operational voltage, as well as the maximum and minimum voltages of the microcontroller, image sensor, and stepper motors with motor drivers, must be known in order for the circuits to operate as intended.

Just like the previous senior design group has pointed out, one major flaw of the switching regulator that must be accounted for is the medium to high levels of noise. The noise is due to voltage and current ripple at the input and output filters generated by high-frequency operation [18]. The switching regulator must produce as little noise as possible because of the Wi-Fi chip. If there is some interference between the two, this could lead to either component to malfunction.

Texas Instruments WEBENCH Power Designer was used in order to compare a few switching regulator designs. From the previous senior design group, they had chosen the TPS561201 step-down converter based on cost, frequency, and efficiency [19]. Due to the additional stepper motors our design of the buck converter will need a higher output voltage. The first integrated circuit found was the LM2598, a simple switcher with either a 3.3V, 5V, 12V, or an adjustable output voltage and can drive a 1-amp load. The LM2598 operates at a switching frequency of 150kHz and can take input voltages from 4.5 volts to 40 volts.
Another Integrated circuit found by the group was the TPS54202 which can take a minimum voltage of 4.5V up to a maximum of 28V. The maximum and minimum output voltages are 0.6V and 26V respectively with a 2-amp continuous output current. The TPS54202 has a switching frequency of 500kHz making it much more noisy than the LM2598. This IC is still, however, a good choice for our project as it is more affordable and has a much smaller footprint.

The last IC that the team looked into was the TPS563300 which can take a slightly wider input voltage range from 3.8V to 28V. The maximum and minimum output voltage range is 0.8V to 22V respectively with 3-amp continuous output current. The switching frequency is 500kHz just like the TPS54202. What sets this IC apart is the efficiency. From the TI WEBENCH designs the TPS563300 consistently has a higher efficiency than the other ICs. In terms of cost, the TPS543300 has a cost between the other ICs. Below is a table comparing the three ICs in terms of their switching frequency, cost, and output voltage range.

Table 15 - Voltage Regulator Part Comparison				
-	LM2598	TPS54202	TPS563300	TPS564201DDCR
Output voltage Range	3.3V, 5V, 12V - fixed 1.2V to 37V - adjustable	0.6V to 26V	0.8V to 22V	0.76 V to 7 V
Input Voltage Range	Up to 40V	4.5 to 28V	3.8V to 28V	4.5 V to 17 V
Output Current	1A	2A	3A	4A
Switching Frequency	150kHz	500kHz	500kHz	560kHz
Cost	$3.33	$1.08	$0.31	$0.35

Below is an example of how we can use TI WEBENCH to design a voltage regulator for our microscope.

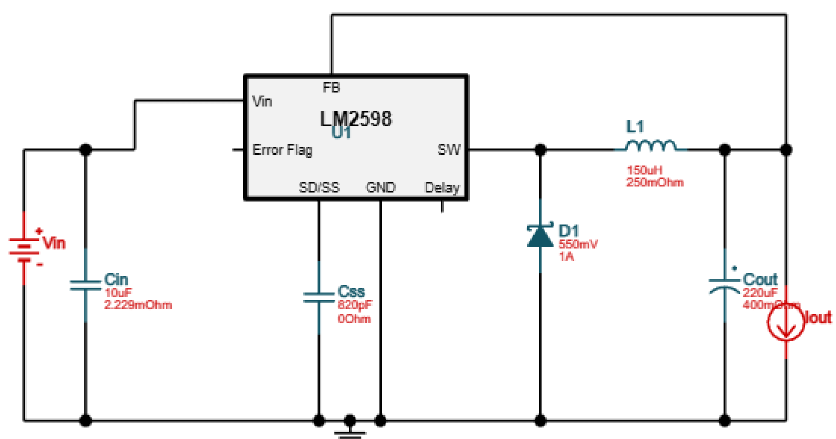


Figure 3.5.3 - LM2598 switching regulator design prototype

3.6 Microcontrollers

The microcontroller will be at the heart of most operations on the microscope, including enabling the motors, receiving data from the image sensor, and transmitting the data to an online database and any connected mobile device. The most limiting of these processes is the transmitting of information, as we plan on capturing a high quality image and transmitting it live to the mobile device with the minimum possible delay.

Initially we planned on transmitting the raw data captured by the image sensor directly to the mobile device because most phones have the computational power to be able to convert a raw

RGB image into JPEG format. However, we quickly realized this was an issue as a raw RGB image is larger than an encoded JPEG image. In order to save bandwidth and transmit more data, we decided it would be more efficient to do the JPEG encoding on the microcontroller side, however this requires us to use a microcontroller with the necessary processing power to be able to encode the images while running all of the other operations on the microscope.

JPEG encoding is the most computationally demanding process that will take place on the board. From the original RGB image received from the image sensor, the JPEG encoding of said image requires an additional color transform, multiple mathematical operations such as addition, multiplication, averaging, and a discrete cosine transform. Altogether, this process requires a large amount of CPU time compared to the other operations on the MCU. To make this process easier on the processor of the microcontroller, efficient use of memory can be implemented so that rather than repeating identical calculations various times, they might be stored and looked up in a lookup table.

Taking data transmission and JPEG encoding into consideration, this leaves memory as an important requirement for the microcontroller we choose to use. The microcontroller must have sufficient memory to store all the data used by the processor. Additionally it must implement efficient memory management to minimize the loss of data and prevent data corruption during image processing and transmission.

Another significant factor to take into account is the possibility of parallel computation. Some microcontrollers are built with a multi-core architecture that supports parallelism. This would make a very significant difference in the performance of the microscope overall. Having a microcontroller with a minimum of two cores, we could dedicate one core to performing the computations needed to operate the motors and other physical tasks as well as capturing images, while the other core(s) are dedicated to the JPEG encoding process, which could increase the throughput of the microprocessor overall several times. However, these advantages also come with significant drawbacks that can impact the design of our microscope significantly as well. Multiple core microcontrollers consume much more power than single core ones because of the increased potential throughput. For a system like the one on our microscope where we would be supplying a heavy load on multiple cores, the power consumption will be a significant consideration. Because batteries with longer lifetimes can be very heavy, we must find a balance to ensure performance and battery life of the microscope without sacrificing portability.

To summarize the requirements above, the selected microprocessor must be able to support efficient JPEG encoding, manage memory in a fault-efficient manner, and manage the large amount of information being transmitted to and from whatever mobile device used to operate the microscope. We have already identified three options to meet the stated processing requirements in the form of three embedded microcontroller packages, being Arduino Uno, the Texas Instruments MSP430fr6989, and the Raspberry Pi 4 model B. The table below compares the parameters of each board in terms of architecture, clock speed, memory, and power consumption.

Table 16 - Development Board Comparison

-	Arduino Uno	MSP4306968	Raspberry Pi 4 B
Microcontroller	ATMega328P 8-bit AVR RISC architecture (single core)	16 bit RISC architecture (single core)	Broadcom BCM2711, quad core Cortex-A72 64 bit, ARM v8 architecture (quad-core)
Clock speed	Up to 16-MHz	Up to 16-MHz	1.8-GHz
Memory	2KB SRAM 32KB FRAM	2KB SRAM 128KB FRAM	Up to 8GB SDRAM
Power consumption	Active mode: 6.9mA/MHz Sleep mode: 50µA/MHz	Active mode: 100µA/MHz Standby: 0.4µA/MHz	1280mA at 400% CPU load
Wifi Chip	802.11b/g/n Up to 150Mb/s 2.4GHz (Module sold separately)	802.11b/g/n Up to 150Mb/s 2.4GHz (Module sold separately)	802.11b/g/n Up to 150Mb/s 2.4GHz
Manufacturer	Adafruit Industries	Texas Instruments	Broadcom
Size	68.6x53.4mm	16x16mm	56.5x85.6mm
Price	$27.60 USD	$20.00 USD	$35.00 USD

3.6.1 BCM2711

After much consideration, an appropriate microcontroller was found for the task at hand, the BCM2711, the microprocessor on the Raspberry Pi 4 B. This line of microprocessors are quad core with a 64-bit bus width and a clock speed of 2GHz. At first glance, this chip meets the minimum requirements for the Cell-Gazer. A more in depth look gives us a more optimistic idea of the microprocessor's capabilities for this project.

The quad-core 64-bit 2GHz ARM® v8 Cortex®-A57 is a communication processor that targets a wide range of networking applications. This chip featured 10G service routers and gateways, control plane processing for ethernet, and network attached storage. The chip’s design revolving around networking applications bodes very well for its performance in the microscope, as a large portion of the systems are reliant on wireless communication between the microscope’s systems and the user interface on a separate device connected over a wireless network. Additionally, the microprocessor is stated to deliver 34,000 DMIPS under 10 watts by the manufacturer, which is exactly the solution we needed to our energy usage problem. Overall, this microprocessor’s architecture seems to be ideal for the applications in mind.

3.6.2 ATmega2560

In addition to the BCM2711 microcontroller on the raspberry pi, we will also be implementing the ATmega2560 microcontroller to our project. This decision was made as a result of discovering that the raspberry pi system is prone to overheating with the load that was being put on it. Therefore, to ease the load on our main microcontroller, we will be including a main PCB in our project containing the ATmega2560, for the purpose of adjusting the motors and LEDs on the microscope.

The ATmega2560 is a single core 8-bit microcontroller with a RISC based architecture. The ATmega2560 is designed for high performance with a low power consumption, which makes it ideal for the task at hand. Because this MCU will only be controlling the LEDs and motors, it does not require the computational power of the BCM2711. The ATmega2560 also has a byte oriented two wire serial interface, allowing it to send and receive information to and from the BCM2711 on the raspberry pi. Including this microcontroller to our project will ease the load on the raspberry pi, which will already be using a significant amount of CPU time on JPEG encoding as well as transmitting information to the database. The biggest drawback to using an additional microcontroller is the power consumption. As our system is battery powered and meant to be portable, another microcontroller will reduce the battery life between charging. However, because the ATmega2560 is a low power microcontroller, this should not pose too much of a problem.

3.7 Stack, Database & Image Processing

Our application has a wide range of capabilities that make it ideal for users who want to stream and process video data. Firstly, it can receive video data from MCU and stream it live, allowing users to share their video feed with others in real-time. Additionally, the app includes a feature that enables users to capture screenshots from the video stream. These screenshots can then undergo image processing, allowing users to enhance and refine their images in a variety of ways.

The application also allows users to save their processed images in a database, providing a convenient way to store and manage their media content. In order to take advantage of this feature, users can create an account and provide their information, which will be securely stored in the database along with their images. This will enable users to easily access and manage their images and account information from any device with internet access.

Overall, the application's ability to stream live video data from MCU, capture and process images, and store them in a database with user account information.

3.7.0.1 Stacks

Table 17 - Stack Comparison

Stack	Description	Pros	Cons
LAMP	Linux, Apache, MySQL, and PHP	• Open-source and free to use. • Stable, widely used, and has a large community. • Scalable and supports multiple programming languages. • Linux-based security, making it a secure option.	• Apache can be slow and consume high memory usage. • Code can become unmanageable as the codebase grows. • MySQL can be slow when handling a large amount of data
MEAN	MongoDB, Express.js, AngularJS, and Node.js	• Built entirely in JavaScript, which makes it easier for developers to work on both front-end and back-end development. • Scalable and supports real-time communication. • The single-page application is easy to build using AngularJS. • MongoDB is highly scalable and flexible in handling unstructured data	• Difficult to learn and maintain for developers with limited JavaScript knowledge. • Not suitable for complex web applications. • Lack of clear documentation can make development more challenging.
MERN	MongoDB, Express.js, React, and Node.js.	• Built entirely in JavaScript, which makes it easier for developers to work on both front-end and back-end development. • React allows developers to build highly interactive and dynamic UI components. • Express.js provides a range of built-in middleware for easier development. • MongoDB is highly scalable and flexible in handling unstructured data.	• Not suitable for large-scale enterprise applications. • Server-side rendering can be slow and result in poor SEO. • MongoDB is a document-based database, which can make it difficult to handle relationships between data.
Ruby on Rails	Ruby and follows the Model-View-Controlle	• Ruby on Rails is a highly productive framework and is easy to learn. • Supports the Agile	• Rails can be slow due to its dynamic nature. • Not suitable for CPU-intensive tasks.

	r (MVC) architectural pattern	methodology, which allows for fast prototyping. ● Built-in conventions and modular architecture make it easy to write clean code. ● High quality, extensive libraries and tools.	● Security vulnerabilities can arise from third-party libraries.
Django	Python and follows the Model-View-Template (MVT) architectural pattern	● Django is highly secure and has built-in security features. ● Built-in admin panel and authentication system. ● Suitable for large-scale, high-traffic websites. ● Highly scalable and flexible.	● Lack of flexibility in some cases. ● Steep learning curve for new developers. ● Limited support for NoSQL databases. ●

Image processing and live streaming have become essential components of modern applications, and building such an app requires careful consideration of the technology stack to be used. A tech stack is a set of technologies and tools that are used to build and deploy applications. For instance, suppose we are building an application that processes images and live stream. In that case, we need to carefully consider the tech stack to be used to ensure that the application is reliable, fast, and highly responsive.

Selecting the appropriate tech stack is crucial to ensure the success of the application. After careful consideration, we have decided to use AWS, Node.js, and React to build our application. AWS provides us with a highly scalable and secure cloud infrastructure that allows us to store and process large volumes of data efficiently. Node.js is being used as our back-end framework to handle image processing and live streaming, and React is being used as the front-end library to create a highly dynamic and interactive user interface.

One of the main challenges in building an image processing and live streaming application is ensuring that the application can handle high demands. The chosen tech stack must be highly scalable, reliable, and capable of handling a large number of users simultaneously. Using AWS as our cloud infrastructure ensures that we can scale the application as needed, and the use of Node.js provides a highly responsive and fast back-end framework to handle image processing and live streaming.

In addition to scalability and reliability, speed is also a crucial factor in the success of the application. The use of Node.js as the back-end framework provides a fast and responsive way of handling image processing and live streaming. The use of React as the front-end library further enhances the speed and responsiveness of the application, creating a highly dynamic and interactive user interface.

As we continue to develop our application, we are continuously testing and optimizing our tech stack to ensure that it meets our needs. By leveraging these technologies and tools, we are confident that we can build a highly successful and reliable image processing and live streaming application that meets our goals. The tech stack we have chosen provides many benefits, including faster development time, improved scalability, and enhanced performance, and we are excited to see the potential of our tech stack in creating an application that is efficient, fast, and highly responsive.

3.7.1 Storage

Data storage refers to the process of storing and preserving digital data in a safe and accessible manner. The importance of data storage has grown dramatically in recent years, as the amount of digital data being created and collected continues to increase exponentially. There are a wide range of data storage solutions available, including physical devices such as hard drives and flash drives, as well as cloud-based services that offer remote data storage and backup.

One of the key considerations when it comes to data storage is security. In today's digital landscape, the security of sensitive information is of utmost importance. There are various security measures that can be implemented to ensure that data is protected, including encryption, access controls, and firewalls. Additionally, data backups are essential to ensure that data can be restored in the event of a disaster or system failure.

Another important consideration in data storage is scalability. As organizations grow and data volumes increase, storage needs can quickly become overwhelming. Scalable storage solutions, such as cloud-based storage, allow for flexible and efficient expansion of storage capacity as needed. This not only provides greater flexibility, but also helps to reduce costs by allowing organizations to only pay for the storage they actually need at any given time. Overall, effective data storage solutions are essential for ensuring that data is accessible, secure, and available when needed.

3.7.1.1 Databases

Databases are collections of structured data that are organized and stored in a way that allows for efficient retrieval and manipulation of information. They are used by organizations of all sizes to store and manage various types of data, such as customer information, sales data, product inventory, and more. Databases are an essential component of modern information systems, allowing businesses and other entities to manage large amounts of data and to generate insights and reports that inform decision-making.

There are many different types of databases, each with its own unique features and advantages. Relational databases, which are the most commonly used type, organize data into tables with rows and columns, allowing for easy querying and manipulation of data. NoSQL databases, on the other hand, do not rely on a fixed schema and are designed to be more flexible and scalable. Both types of databases have their own strengths and weaknesses, and the choice of database type depends on the specific needs of the organization or application. Effective database design is critical to ensuring that data is stored and managed efficiently, and that the system is able to deliver the required performance and reliability.

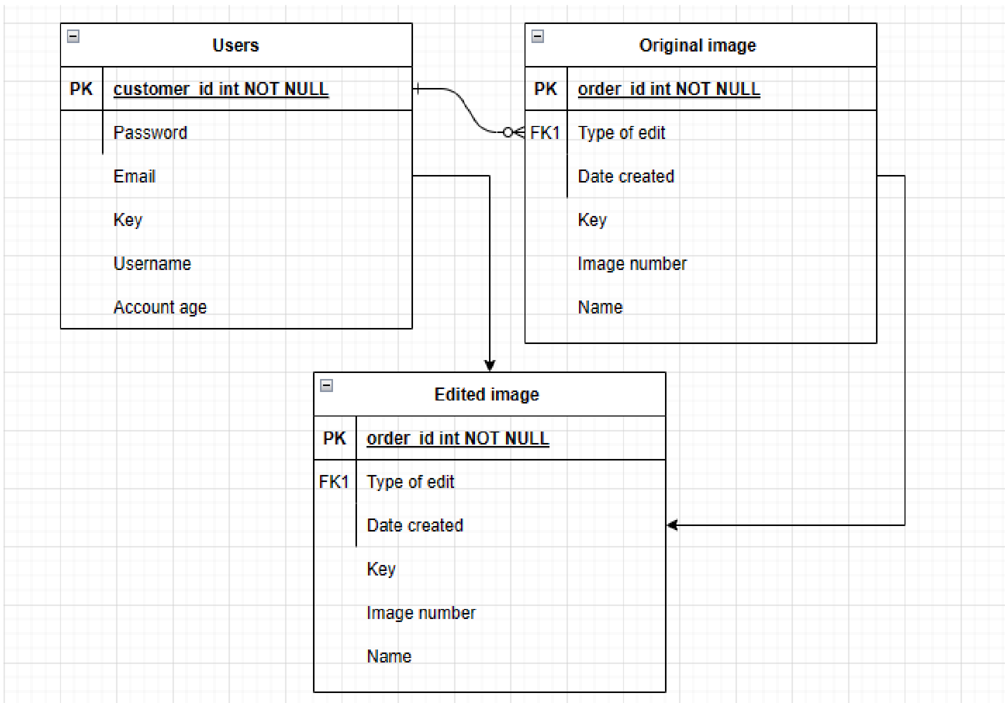


Figure 3.7.1.1 Sample ERD

3.7.1.2 Database Management Systems NoSQL vs SQL

SQL and NoSQL are two types of computer programs that help manage data. SQL databases organize data in a structured way like a table. Every piece of information has a specific spot in the table, like a row in a spreadsheet. SQL databases are best for things that have a clear structure, like lists or tables. NoSQL databases store data in a more flexible way. They can handle information that doesn't fit neatly into a table. NoSQL databases are good for things like social media, where people post all kinds of different things in different formats. When it comes to scaling up to handle more data, SQL databases add more resources like memory or storage, but can't easily add more computers. NoSQL databases can add more computers to handle more data, making them better at handling really big projects. So, if you have a project that has lots of structured data, like a list of names and addresses, you might use a SQL database. If you have a project that has more varied and unstructured data, like social media posts, you might use a NoSQL database. SQL (Structured Query Language) and NoSQL (Not Only SQL) are two types of database management systems that differ in their data storage models, query language, and scalability. Here's a brief comparison of SQL and NoSQL databases:

Data Storage Model:
SQL databases store data in tables with fixed schema, where each table represents a different entity and each row represents a single instance of that entity. SQL databases are relational, meaning that they establish relationships between tables using primary and foreign keys. NoSQL databases, on the other hand, store data in a variety of ways such as key-value pairs, document-oriented, column-family, and graph-based models. NoSQL databases are non-relational, meaning that they don't use fixed schemas and can handle unstructured data.

Query Language:
SQL databases use SQL, a standardized language for interacting with relational databases. SQL is used to define and manipulate data, perform queries, and modify the structure of tables. NoSQL databases use different query languages depending on the type of data model. For example, MongoDB uses a query language called MongoDB Query Language (MQL), and Cassandra uses a query language called Cassandra Query Language (CQL).

Scalability:
SQL databases are vertically scalable, meaning that they scale up by adding more hardware resources such as CPU, RAM, or storage. They're not as flexible when it comes to horizontal scaling, which involves distributing the data across multiple servers. NoSQL databases are horizontally scalable, meaning that they can handle large amounts of data by adding more servers to a cluster. They're designed to be highly scalable and fault-tolerant.

In summary, SQL databases are best suited for applications that require structured and relational data, while NoSQL databases are best suited for applications that require flexibility, scalability, and handling of unstructured data. Choosing between SQL and NoSQL databases depends on the specific needs of the application and the data being stored.

3.7.1.3 Cloud Storage

Cloud storage refers to a model of data storage where an organization or individual stores their data on remote servers that are maintained by a third-party provider. Cloud storage is increasingly popular as it provides easy access to data from any location with an internet connection. This means that data can be accessed and shared across multiple devices, making it easier to collaborate on projects or work remotely. Cloud storage providers offer a range of options from free to paid subscriptions, with varying levels of storage space, security, and additional features such as backup and file sharing.

One of the benefits of cloud storage is the ability to scale up or down as needed. Businesses and individuals can easily increase their storage capacity as their needs grow without having to purchase additional hardware or physical storage devices. This scalability also helps reduce costs associated with maintaining and upgrading physical storage infrastructure. Additionally, cloud storage providers typically offer advanced security features such as encryption, firewalls, and access controls, which can help protect data from unauthorized access or data breaches.

3.7.1.4 Types of Cloud Storage Products

Table 18 - Cloud Storage Comparison		
Name	Amazon S3	Google Cloud Storage
Features	● Storage Classes:Different storage classes to choose from based on the access patterns and frequency of data retrieval ● Object Versioning: S3 allows users to store multiple versions of an object ● Amazon S3 offers server-side encryption using customer-managed keys or AWS-managed keys, as well as client-side encryption ● Transfer Acceleration that enables faster uploads and downloads of large objects over the internet ● Amazon S3 can be queried using Amazon Athena, Redshift Spectrum, or Glue.	● Storage Classes:Different storage classes to choose from based on the access patterns and frequency of data retrieval ● Object Lifecycle Management that can be used to set rules for transitioning objects to different storage classes ● Google Cloud Storage provides server-side encryption using customer-supplied encryption keys or Google-managed keys. ● Google Cloud Storage provides a similar capability called Transfer Service. ● Google Cloud Storage provides a service called BigQuery, which enables users to query data stored in Google Cloud Storage directly
Pricing	Standard storage is the most popular option and is priced at $0.023 per GB per month, while infrequent access storage is priced at $0.0125 per GB per month. There are also options for Glacier storage, which is designed for long-term archival storage, and S3 Intelligent-Tiering,	Standard storage is priced at $0.020 per GB per month, while Nearline storage is priced at $0.010 per GB per month and Coldline storage is priced at $0.004 per GB per month.

	which automatically moves data to the most cost-effective storage tier based on access patterns.	
Scalability	Scale automatically to accommodate large volumes of data, and it can handle requests at any scale with no upfront costs or commitments. Additionally, Amazon offers a range of storage classes with varying levels of performance, durability, and availability, which can be easily switched as needed to optimize storage costs Transfer Acceleration, which can speed up data transfers by routing them over Amazon's optimized network.	Cloud Storage is designed to scale automatically to accommodate large volumes of data, and it can handle requests at any scale with no upfront costs or commitments. Object Versioning, which allows you to store multiple versions of an object
Integration	Amazon Web Services (AWS) offerings, including AWS Lambda, Amazon EC2, Amazon integration with other Amazon Web Services (AWS) offerings, including AWS Lambda, Amazon EC2, Amazon CloudFront, and Amazon Redshift. S3 also integrates with third-party tools and services through APIs and SDKs,	Google Cloud Platform services, including Google Cloud Functions, Google Compute Engine, Google BigQuery, and Google Cloud Pub/Sub. Google Cloud Storage also provides APIs and SDKs
Reliability	99.9% durability, which means that it is highly unlikely to lose data. It achieves this by storing data across multiple Availability Zones (AZs) within a region, providing automatic replication and failover capabilities.	99.9% annual durability rate. Google achieves this through its distributed architecture, which replicates data across multiple geographic locations

3.7.1.5 Cloud Storage vs Database and Results

Cloud storage and databases are both technologies that are used for storing and managing digital data, but they have some important differences. Cloud storage typically refers to the use of remote servers to store data, while databases are used to organize and manage data within a specific system. Cloud storage solutions are typically used to store unstructured data, such as files, documents, and multimedia content, while databases are used for structured data, such as customer information, inventory data, and transaction records.

One of the key advantages of cloud storage is the ease of use and accessibility. Cloud storage solutions allow users to access their data from anywhere with an internet connection, making it easier to collaborate and work remotely. On the other hand, databases are typically accessed through specific software applications and require some level of technical expertise to set up and maintain.

Another important difference between cloud storage and databases is in the type of data that they are designed to store. Cloud storage is typically used for storing files, documents, and other unstructured data that does not have a specific structure or format. Databases, on the other hand, are designed to store structured data in a specific format, such as tables and fields. Databases are essential for managing complex data sets and providing efficient access to that data, while cloud storage is often used for simpler data storage needs.

Results

To manage and store the large volume of data generated by the application, we have decided to use both a database and cloud storage. The database will be responsible for storing crucial information about the images being processed, including image metadata and processing results. Additionally, it will store user account information, such as login credentials and user settings. We will also use the database to store information about the streaming sessions, such as session start and end times, user information, and session data. For storing the actual image files and any processed data or results generated by the image processing algorithms, we have opted to use cloud storage. Cloud storage provides an excellent solution for storing large amounts of data while also offering easy access from anywhere. Additionally, it provides high levels of data redundancy and durability, ensuring that the data is always available when needed. By combining a database and cloud storage, we can ensure data integrity and security while providing fast and efficient access to the data. Moreover, the use of both technologies enables scalability and flexibility, allowing the application to adapt to changing requirements over time. As we continue building the application, we are testing and optimizing our use of both a database and cloud storage to ensure that they meet our needs. We are confident that by leveraging these technologies effectively, we can build a highly reliable and efficient image processing application that includes streaming capabilities from an MCU.

3.8 Image processing Libraries

An image processing library is a collection of software tools and functions that can be used to manipulate and analyze digital images. These libraries typically provide a wide range of

functions, such as image filtering, edge detection, segmentation, feature extraction, and image enhancement.
By using an image processing library, developers can save time and effort by relying on pre-built functions that have already been optimized and tested. These libraries also provide a common set of tools and functions that can be used across different platforms and programming languages.

Table 19 - Image Library Comparison

Name	Pros	Cons
OpenCv	• Powerful and flexible library for computer vision and image processing tasks • Supports a wide range of platforms, languages, and operating systems • Large community of developers and users, with extensive documentation and tutorials available • Includes many built-in algorithms and functions for common tasks	• Steep learning curve, particularly for beginners • Some functions can be slow and memory-intensive, particularly on large datasets • Documentation can be overwhelming and difficult to navigate
SimpleCV	• Easy-to-use framework for computer vision and image processing tasks, particularly for beginners • Python-based, with a simple and intuitive API • Includes many built-in algorithms and functions for common tasks • Active community of developers and users, with extensive documentation and tutorials available •	• Limited functionality compared to other libraries, particularly for more advanced tasks • May not be suitable for high-performance or large-scale applications •
Dlib	• Fast and efficient library for machine learning, computer vision, and image processing tasks • Written in modern C++, with support for multi-threading and GPU acceleration • Includes many built-in algorithms and functions for common tasks • Active community of developers and users, with extensive documentation and tutorials available •	• Steep learning curve, particularly for beginners • Limited functionality compared to other libraries, particularly for deep learning tasks • Requires C++ programming skills and knowledge of machine learning concepts •

scikit-image	• Comprehensive library for image processing tasks, particularly in scientific and medical domains • Python-based, with a simple and intuitive API • Includes many built-in algorithms and functions for common tasks • Active community of developers and users, with extensive documentation and tutorials available •	• Limited functionality compared to other libraries, particularly for computer vision and machine learning tasks • May not be suitable for high-performance or large-scale applications •
Caffe	• Powerful deep learning library for computer vision tasks, particularly for image classification and object detection • Written in C++, with support for multi-GPU training and inference • Includes many pre-trained models and tools for training and evaluation • Active community of developers and users, with extensive documentation and tutorials available •	• Limited functionality compared to other libraries, particularly for non-image data and tasks • Requires advanced knowledge of deep learning concepts and techniques • May not be suitable for beginners or small-scale applications •
TensorFlow	• One of the most popular and widely used deep learning libraries, with support for many platforms and languages Powerful and flexible, with support for a wide range of neural network architectures and models Includes many pre-trained models and tools for training and evaluation Active community of developers and users, with extensive documentation and tutorials available	• Steep learning curve, particularly for beginners Can be complex and difficult to use for certain tasks Requires advanced knowledge of deep learning concepts and techniques

3.8.1 Image processing(OpenCV)

We have decided to use OpenCV as the library for our image processing needs. There are several reasons why we have chosen OpenCV for our application.

First, OpenCV is a well-established and widely used library that is known for its reliability and stability. It is a mature library that has been around for many years and has a vast user base. This makes it a reliable choice for our application.

Second, OpenCV provides a rich set of functions and algorithms that we can use for our image processing tasks. We can perform basic image manipulation functions, feature detection, object recognition, and machine learning. Additionally, OpenCV is highly customizable, allowing us to add our own algorithms to the library.

Third, OpenCV is cross-platform, which means we can develop our application on multiple operating systems, including Windows, macOS, and Linux. This is important for us as we want our application to be accessible to a wide range of users.

Fourth, OpenCV is written in C++, which makes it highly performant and capable of handling large-scale image processing tasks. It also has bindings for popular programming languages such as Python and Java, which makes it accessible to developers who may not be familiar with C++.

Lastly, OpenCV has an active community of developers who contribute to the library by providing bug fixes, updates, and additional functionality. This community-driven approach has resulted in a highly collaborative environment that encourages sharing and collaboration among developers.

As we continue to develop our application, we are confident that using OpenCV as our image processing library will allow us to create a highly efficient and effective image processing application.

3.9 Construction of the microscope

The materials that make-up the microscope are important to our design. The goals and objectives of our project describe the microscope as small, lightweight and portable. Therefore, the materials chosen for each major component of the microscope need to be considered carefully so as not to make the microscope too large, heavy and cumbersome. This section will look at the properties of the materials to be considered for the body or tubing of the scope, the stage, the LED layout, and more.

3.9.1 Microscope body

The body of the microscope which houses the lenses needs to be made out of a lightweight material as it will be lifted by a stepper motor in order to zoom in and out on a specimen. The tubing of most microscopes are generally made with plastic, and the portable microscope example that we used is also made from plastic. The size of the lenses that are chosen have the biggest impact as to the size of our microscope, but this does not include compartments needed to house the stage, the microcontroller, batteries, LEDs, or image sensor. The size of the microscope will need to be larger than those found on the market or the one we used for research purposes. The tubing can be made from plastic, either 3D printed or cut from an already made piece of tubing. At the end of the tube there is often a guard piece to house the LEDs which is a clear plastic material which cannot be 3D printed and must be sourced from a manufacturer.

3.9.2 3D Printed parts

3D printing has its advantages and disadvantages compared to machined parts or injected molded plastic ones. The key advantages that 3D printed parts give us is the same-day availability, or the speed at which we can obtain a needed part. Customizability and ease of use are two more advantages that come with 3D printing, as well as the weight of the part. The main disadvantages of 3D printed parts is the fragility, as machined or metal parts are much sturdier than any filament could offer. These advantages and disadvantages will be highlighted in this section.

One of the key components that will be used in our project to control the microscope and zoom functions will be the gears. The gears will drive the vertical motion of the eyepiece as well as the rotational motion of the objective lenses. There are many choices in consideration as to the makeup of the material used in said gear. One of those choices this section aims to recognize is the 3D printer filaments that are in consideration.

Another key component of the microscope is the stage as previously mentioned in section 3.10.2. The stage holds the specimen in place while the user controls the microscope. 3D printing a stage has many benefits such as same day availability, prototyping, and testing until a final design is finalized and ready for use. One type of filament will be chosen from a selection of different filaments that are in consideration.

The first 3D printer filament our team researched was PLA filament. PLA stands for Polylactic acid and is a widely used material due to its low cost and ease of use. PLA is also made from renewable sources, more specifically, manufactured with raw material cornstarch [14]. PLA is also biodegradable making this material environmentally friendly. The 1kg PLA filament role available from MatterHackers has a density of 1.25g/cm^3 (or 1250 kg/m^3) with a heat deflection temperature (or HDT) of 56C. The heat deflection is an indicator of how well the polymer's resistance to alteration under a given load at an elevated temperature [15]. The flexural modulus is a measure of how a material resists bending under force, and the flexural modulus of the PLA is measured at 3600 MPa. The cost of 1kg PLA filament is $20.87 making this an affordable material that can be considered a good candidate for our project.

Another filament to consider is the BASF PRO1 tough PLA filament. The PRO1 PLA filament has similar material properties as the normal PLA such as density and flexural modulus but has its own advantages. PRO1 offers a faster printing speed from 30 to 80%[16] and boasts much better performance in terms of strength. In one experiment which tested how much torque a gear could handle, the PRO1 managed to handle 15 Nm of torque before failing [17]. This BASF PRO1 tough PLA is available from MatterHackers and is sold in 0.75kg spindles at $39.99

The last filament in consideration is the ABS fusion+ filament. ABS stands for Acrylonitrile butadiene styrene and is also very commonly used in 3D printing. The key difference between the PLA filament and the ABS filament is the greater resistance to temperature. The ABS fusion+ has a HDT of 71C at 1.8MPa which is much higher than the PLA's 56C. The ABS fusion+ is also less dense at 1075 kg/m^3, compared to the PLA's 1250 kg/m^3 , which makes for lighter weight parts. The ABS fusion+ is sold in spindles of 0.75kg at $39.99, the same price and quantity as the PRO1 PLA. ABS fusion+ is a good candidate for our project due to its lighter density, and HDT properties. The table below summarizes the differences between each filament in terms of their price, HDT, and density.

Table 20 - 3D filament Comparison			
-	PLA	BASF PRO1 PLA	ABS fusion+
Density	1250 kg/m3	1250 kg/m3	1075 kg/m3
Heat Deflection Temperature (HDT)	56C	-	71C
Cost	$20.87	$39.99	$39.99

3.10 Part Selection Summary

The following section is a summary of all components considered for our project. The parts are summarized including information on the manufacturer, size, price, quantity, and model number.

Table 21 - Part Selection Summary					
Components	Manufacturer	Size	Price	Quantity	Model Number
40x Objective Lens	United Scope LLC.	6 x 3 x 2 in	$ 21.99	1	A40x
100x Objective Lens	Hoopoocolor	6 x 3 x 2 in	$ 26.54	1	Hoopoocolor 5y43gdqbkc
Ultraviolet LED	CHANZON	5 mm	$ 7.99	1 (pack of 100)	100F5T-PT-WH-PU
940 nm Infrared LED	CHANZON	5 mm	$ 7.99	1 (pack of 100)	100F5T-IR-FS-940NM
850 nm Infrared LED	CHANZON	5 mm	$ 8.99	1 (pack of 100)	100F5T-IR-FS-850NM
White LED	CHANZON	5 mm	$ 6.99	1 (pack of 100)	100F5T-PT-WH-WH

Raspberry Pi Camera Module V2	KEYESTUDIO	141.9 x 71.88 x 45.97mm	$ 32.99	1	SMP0083
Stepper Motors	KOOKYE	42 x 30 x 29 mm	$9.00	1 (pack of 2)	28BYJ-48
Motor Drivers	KOOKYE	32 x 35 mm	$9.00	1 (pack of 2)	ULN2003
Battery	CBJJ	67 x 18 x 18mm	$24.99	1 (pack of 4)	CBJJ 18650
Filament	MatterHackers	1.75mm diameter. 1kg spool	$20.87	1	MH Build Series PLA
MCU	ATMEGA2560	14mm x 14mm	$17.79	1	Digi-key
Switching Regulator IC	Texas Instruments	14.986 mm × 10.16 mm (varies on package)	$3.33	1	LM2598
Image Processing Libraries	OpenCV	-	free	-	Version: 4.7.0
MongoDB	MongoDB Inc.	-	$57.00	-	
Total	$255.46				

Looking over all of our total parts, we can see that we haven't hit our maximum budget of $400 thus far. This total could change in the future, however this is so far what we have spent or plan to spend in the near future for the cellgazer microscope.

Section 4: Standards and Constraints

In this section our group defines two important terms that have some realistic effect on our portable microscope project - cell gazer. These two terms are standards and constraints. We aim to explain in detail various design constraints and how these constraints impact our design. We have also compiled and identified some relevant standards that apply to our project and have summarized them in the following sections.

4.1 Constraints

A design constraint is a limitation that is introduced to the design that affects the final outcome. Constraints can come from inside or outside factors ranging anywhere from economic constraints to manufacturability and sustainability constraints. An integral part of the design process is complying with certain standards to ensure a safe and functioning device, while being aware of the constraints that limit our design.

4.1.1 Economic Constraints

Objective lenses and image sensors are expensive in general, the prices of them can vary from a couple hundreds to several thousands based on different specifications required by microscopes for different purposes. In our project, since it is self-sponsored, we chose cheap objective lenses that correct chromatic aberration for only two colors. These objective lenses are expected to have defects such as color aberrations due to three different spectrums in use. If we have financial support for this project, more advanced and expensive objective lenses can be selected, and those objectives can correct chromatic aberrations for more colors (up to five). Chromatic aberrations will thus be reduced significantly. For CMOS image sensor, we had to borrow one form optics undergraduate lab at CREOL due to budget constraint, so our choices are limited by what types of image sensors CREOL has in the lab. Gladly, we were able to borrow one great CMOS image sensor that is sensitive within the three spectrums of our light source and can provide a high resolution.

Each hardware component researched in section 3 was compared to various likewise components in terms of their cost. The cost of this project as a whole is a main constraint on our portable microscope as we are not sponsored and will be paying for each component out of pocket. A verbal agreement was met among all team members that each would contribute up to $100 each if needed totaling up to $400. We believe that $400 is enough to design and build our portable microscope, however certain components are much more expensive than others. For example, the lenses for the microscope in particular are very expensive with some reaching in the hundreds of dollars.

Due to the cost constraint, our project will be limited in the amount of testing and prototyping we can perform. There are a limited amount of resources and therefore a limited number of tries when building a prototype. This cost constraint is what led the team to decide on rechargeable batteries as they don't have to be thrown out after they are fully depleted. Rechargeable batteries will make testing components much more affordable compared to disposable ones. Another decision made based on this cost constraint is the use of the 28BYJ-48 stepper motor with the ULN2003 motor driver. The combination of this stepper motor and motor driver is usually packaged together which saves on cost and shipping time too. The use of 3D printed gears gives us some freedom to prototype many different gear designs to ensure the most reliable design is used in the final product. 3D printed gears will save on cost even if we were to use the entire roll of filament because machined gears cost much more.

One final external economic constraint for our project is the availability of components. Whilst researching for parts, our team noticed that some components could not be purchased, as in, there wasn't any in stock while looking at the online shop's inventory. This lack of availability, albeit minimal, forced the group to look for other manufacturers that had the components in stock. Other manufacturers, however, can have different prices which has a direct effect on our budget. For example, when searching for an appropriate stepper motor online, the 42-23 Nema 17 stepper motor from Iverntech was out of stock until weeks later, so another component had to be considered for a slight increase in cost. This increase in cost is not much, however a completely different stepper motor in use drastically changes the final design.

4.1.2 Environmental Constraints

Optical light sources are potentially dangerous for an environment and people in an environment. Three level and four level lasers are generally considered hazards, even two level lasers are relatively weak, they are harmful if a user looks at the laser beam directly. In our project, we avoid using high power output lasers as our light source as they can cause damage to the user's eyes and skin, or to the people around the user in the environment. We also avoid using LEDs that are so bright that may cause eye damage as well.

One of the environmental constraints researched early on was the power supply choice of rechargeable batteries. Rechargeable batteries were chosen due to the known issue of potential risks involved with the disposal of depleted batteries. The risks include exposure to manufacturing waste and emissions from nickel, cadmium, cobalt, and other materials [21]. By today's standards there is little risk in exposure to these spent batteries, however, the available space in the landfills is quickly depleting. Therefore, it is best to always go with rechargeable power sources whenever possible.

Another environmental constraint imposed on the microscope itself is the amount of natural light being absorbed by the specimen on the stage. This natural light could throw off the image sensor's ability to capture a quality image using the on-board LEDs. This natural light has to be considered as the image sensor could be very light sensitive.

One of the deciding factors which was an environmental constraint that had a direct impact on the choice of voltage regulator components was temperature. Linear regulators differed from switching regulators not only in efficiency, but also had the effect of dispersing waste in the form of heat. This heat, if not mitigated, can cause damage to other electrical components of the design and result in a complete failure of the system. The decision was made to use a switching regulator to avoid the waste heat given off, thus potentially saving the rest of the system.

The final environmental constraint our team considered was the frequency response of the switching regulator. The frequency response of the switching regulator has an impact on the reaction time, precision, and stability of the voltage under load [22]. If the switching regulator were unstable, this could introduce noise, unstable voltage levels, and overheating. The decision to choose a switching regulator design with an IC that has a low switching frequency was chosen to help mitigate any potential issues with noise levels.

4.1.3 Social Constraints

By design, the microscope is meant to be used in a social environment like among colleagues for research or in a classroom for education. However, there are some social constraints that must be followed to allow the microscope to achieve its purpose effectively, without interference from anyone outside of the group that is using it. If it is too easy for an unauthorized person to connect to the microscope, it could result in a collection of arbitrary data and make it difficult for any relevant data to be processed by authorized users. To limit the risk of unauthorized persons connecting to the microscope, we will implement an account database within the application so that users may register their device with the microscope to enable remote operation.

4.1.4 Political Constraints

As a result of government regulation we recognize that data privacy and cybersecurity are ongoing concerns that require constant attention and vigilance. As such, we have implemented a number of measures to ensure that our microscope app is up to date and compliant with the latest privacy and cybersecurity standards.

In terms of privacy laws, we have made it a priority to stay informed of any changes or updates to privacy laws.. Additionally, we have implemented measures to ensure that user data is only collected and processed for legitimate purposes and is stored securely.

To address cybersecurity threats, we have taken a multi-layered approach to security. This includes using advanced encryption methods to protect user data, implementing secure authentication protocols to prevent unauthorized access.

In addition to complying with privacy and cybersecurity regulations, we also prioritize transparency and communication with our users. We provide clear and concise information about the data we collect and how it is used, as well as giving users control over their data.

Overall, we understand that privacy and cybersecurity are paramount concerns for our users, and we are committed to ensuring that our microscope app provides a secure and transparent user experience. By implementing robust privacy and cybersecurity measures and staying up to date with the latest regulations and best practices.

4.1.5 Ethical Constraints

Microscopes and microscopy apps have revolutionized scientific research, medical diagnosis, and treatment. These technologies have made it possible to visualize samples at the cellular and molecular level, providing unprecedented insights into the workings of the human body and other biological systems. However, with these advancements come ethical constraints that must be considered and addressed.

One of the primary ethical constraints related to microscopes and microscopy apps is data privacy. Many apps collect and store data on the user, such as images and videos of the samples being analyzed. This data must be stored securely and kept private to protect the user's privacy. This is particularly important when using microscopy apps on human or animal samples, as this data can contain sensitive information that could be used to identify individuals. It is therefore essential to implement appropriate security measures and protocols to ensure that this data is protected.

Another ethical constraint is informed consent. When using microscopy apps on human or animal samples, the user must obtain informed consent from the subjects or their owners. This ensures that the subjects are aware of how their samples will be used and that they have given their consent for their samples to be analyzed. Informed consent is essential to protect the rights of the subjects and to ensure that they are not exploited for research purposes.

Accuracy of results is another ethical constraint that must be considered. Microscopy apps must provide accurate and reliable results to ensure that decisions made based on the results are correct. This is especially important in medical diagnosis and treatment decisions, where inaccurate results could have serious consequences for the patient. It is therefore crucial to ensure that microscopy apps are rigorously tested and validated to ensure that they meet the required standards for accuracy and reliability.

Bias and fairness are also ethical constraints that must be addressed when developing and using microscopy apps. Microscopy apps must be designed and trained to avoid bias and ensure fairness. For example, if an app is used to analyze skin color, it must be trained on a diverse set of skin tones to avoid bias against certain groups. This is particularly important in medical applications, where bias and unfairness can result in misdiagnosis or unequal treatment.

Finally, safety and reliability are essential ethical constraints related to microscopes and microscopy apps. These technologies must be safe and reliable to use, as they can have serious consequences if they malfunction or fail. They must be designed and manufactured to meet safety standards and must be regularly maintained to ensure that they function properly.

In conclusion, the ethical constraints related to microscopes and microscopy apps are significant and must be carefully considered and addressed. It is essential to ensure that these technologies are used ethically and responsibly to protect user privacy, ensure accuracy and fairness, and maintain safety and reliability. By addressing these ethical constraints, we can ensure that microscopes and microscopy apps continue to advance scientific research and medical diagnosis and treatment in a responsible and ethical manner.

4.1.6 Health and Safety Constraints

The design of the microscope should not put any user in danger of using the microscope. One of the health constraints during the design process of making the 3D gears and stage could introduce certain toxic chemicals when the filament is melted together. These potential toxic fumes were a deciding factor in choosing a filament for the 3D printed parts. Another health and safety constraint that has an impact on the design is the brightness of the LEDs. The LEDs should not shine so bright as to damage any user’s eye, or else this could result in permanent damage to the retina. A careful design in the LED PCB layout should be considered due to this major safety concern. The last safety constraint falls into the security of the mobile app. The mobile app should not allow the user’s data to be stolen while using the mobile app. This could be a safety concern as many users have private data stored on their mobile devices, and thus our mobile app should respect user’s privacy and not risk their data from being stolen.

4.1.7 Manufacturability Constraints

As we begin the process of building our microscope and app within a $400 budget and 6-month timeline, we must carefully consider manufacturability constraints. These constraints will play a critical role in ensuring that our microscope and app are of high quality, user-friendly, and cost-effective.

First and foremost, we will prioritize cost in our design process. We will optimize our design to use affordable materials, components, and manufacturing processes, while also ensuring that the quality of the final product is not compromised.

Assembly is another important consideration, as we want to ensure that our microscope and app are easy to assemble, efficient, and require minimal time and effort. To achieve this, we will design our product with simplicity in mind, using components and manufacturing processes that facilitate easy assembly.

When it comes to the manufacturing process itself, we will focus on finishing the microscope and app within the given timeline and budget. We will choose manufacturing processes that are reliable, cost-effective, and readily available, while also prioritizing quality control measures to ensure that each microscope and app meets our required standards.

User-friendliness is a crucial aspect of our design process. We will ensure that our microscope and app are easy to use, even for individuals with little to no experience with microscopy. To achieve this, we will focus on an intuitive user interface and clear instructions.

Size and weight will also be taken into account in our design process, as we want to ensure that our microscope and app are easy to handle and transport. This will make it easier to use the microscope and app in various settings, including fieldwork.

Finally, we will prioritize compatibility, ensuring that our microscope and app are compatible with various operating systems and devices. This will help ensure broad accessibility and make it easier for users to access our product.

By carefully considering these manufacturability constraints, we are confident that we can build a high-quality microscope and app that meets the required standards within our given budget and timeline.

4.1.8 Sustainability

Sustainability is an important consideration for the development of a microscope with an image processing application. To ensure sustainability, we must carefully consider the materials and resources used in the construction and operation of the microscope. We will try the use of environmentally-friendly materials and minimize waste during the production process. Finally, we will consider the end-of-life of the microscope and ensure that it can be properly recycled or disposed of in an environmentally-friendly manner. By taking into account sustainability in our design and production process, we can reduce our environmental impact and contribute to a more sustainable future.

4.1.9 Time Constraints

The main time constraint our group has for our senior design project is the timeline in which we have to finish our final product. Since we started senior design in the spring of 2023 we have a total of 16 weeks for senior design 1 and roughly 12 weeks for senior design 2. This tight schedule makes our group work under a lot of stress to finish the project and have a working final model by the end of summer. Another time constraint for our group is how much lab time we use as a group. We all have different schedules, but we will overcome this obstacle by communicating to each other when we are available to work on the microscope.

A third time constraint put on our group are the external due dates for classes outside senior design. As a group we will work together to help one another when a fellow team member needs it the most. The final time constraint our group has is the shipping times for parts needed for the project. Each component will come from different manufacturers and each company may have different schedules that are more or less busy during certain times of the year. This time constraint has made the team pick and choose the more widely available parts that can be shipped in a timely manner compared to parts that may need to wait several weeks to be shipped.

4.1.10 Portability Constraints

The makeup of our project is a portable microscope, so therefore there are constraints set upon the dimensions and weight. The design has to be portable, meaning, one person should be easily able to carry the product, or store the product in a compact carrying case, backpack, or box. In the engineering specifications we have set out a goal to not go beyond the specified dimensions in order to keep the final product portable. The design's weight also has a direct impact on portability as anyone should be able to easily carry the microscope and move it without any trouble. The material used for the body of the microscope was carefully considered due to this constraint. The sizes of objective lenses and eyepiece lenses were carefully selected to be small. The final component that has a direct impact on portability is the power source. We chose rechargeable batteries instead of an AC adapter plugged into an outlet. The batteries allow the microscope to be taken to any location even without an outlet, which is an important factor in portability.

4.1.11 Construction Constraints

For the construction of the microscope we must take into account the structural standards of the device overall. The microscope must be light enough to be easily portable, while still be made out of a durable enough material to make it viable for field research use. Additionally the slots for the lenses must be snug enough to prevent the lenses from shifting and distorting the image.

4.2 Standards

A standard is a document that defines the characteristics of a product, process, or service, such as dimensions, safety aspects, and performance requirements [20]. Standards, much like constraints, have a direct impact on the final outcome of the design project and thus need to be carefully identified. Below is a list of standards pertaining to our project with a summary that defines each standard.

4.2.1 IEEE 802.11 Wireless LAN

The IEEE 802.11 Wireless LAN standards are relevant to a microcontroller like Raspberry Pi when it comes to implementing wireless connectivity. These standards define the protocols and specifications for wireless communication between devices, including the frequencies and data rates that can be used. The Raspberry Pi can be equipped with a wireless adapter that supports these standards, allowing it to connect to a wireless network and communicate with other devices that support the same standards. By adhering to these standards, the Raspberry Pi can ensure compatibility with a wide range of devices and networks, providing reliable wireless connectivity for various applications, including those involving microscopes with image processing capabilities.

IEEE 802.11 is a set of standards for wireless local area networks (WLANs) commonly known as Wi-Fi. These standards define the protocols and procedures for wireless communication in the 2.4 GHz and 5 GHz frequency bands. The 802.11 standards specify various physical and media access control (MAC) layer protocols that enable high-speed wireless communication between devices, such as laptops, smartphones, and routers. These standards have evolved over the years, with the latest one being 802.11ax, which provides higher throughput, improved efficiency, and better performance in dense environments. The 802.11 standards have an integral part of modern wireless communication technology, enabling ubiquitous wireless connectivity for various applications including this one.

4.2.2 Web Development Standards

Our web application for a microscope with an image processing application is built to adhere to several key standards to ensure that it is a user-friendly, accessible, and high-performing application. These standards have been implemented in every aspect of our application's design and development, ensuring that our users have the best possible experience.

Firstly, usability has been given the utmost importance in our application's design. The application has been designed to have a clear and intuitive interface, enabling users to easily navigate between different functions and features. The interface is uncluttered and easy-to-understand, with clear labeling of features and easily identifiable icons. Additionally, we have ensured that all actions within the application provide clear feedback, so users are always aware of what is happening.

We understand that creating an application that is user-friendly and easy to use is critical to the success of any project. We have taken great care to ensure that our application is accessible and easy to navigate for all users. Our design incorporates a clear and intuitive interface that allows for easy navigation between different functions and features. We provide clear feedback to users when actions are taken to ensure that they are always aware of what is happening within the application. Our goal is to create a welcoming and inclusive experience for all users, whether they are experienced or new to the application. We believe that by adhering to these standards, we have developed a high-quality, user-friendly web application for a microscope with an image processing application that will be well-received by users of all levels of experience.

To ensure that the application performs well, we have optimized it to handle large and complex images efficiently. We have implemented caching and other performance optimizations, and we pay careful attention to resource management to ensure that the application runs smoothly, even when dealing with large amounts of data.

Security is always a top priority in our application's development. We have designed the application with security in mind, protecting against attacks such as cross-site scripting and SQL injection. We use secure coding practices and encryption techniques, as well as regular security audits and testing to ensure that the application is as secure as possible.

Our application has been designed to work across a range of devices and browsers, including both desktop and mobile devices. We have used responsive design techniques and tested the application across different platforms to ensure that it works as expected on all devices. This ensures that users can access our application from any device they choose, without any loss of functionality.

The application adheres to relevant web standards, such as HTML, CSS, and JavaScript, ensuring that it is future-proof and can be easily maintained and updated over time. This ensures that the application remains relevant and useful for our users, even as technology advances and changes.

Finally, scalability is an important aspect that we have taken into consideration. We have designed our application to scale as needed, to accommodate increasing numbers of users and data. We use cloud-based infrastructure and other scalable technologies to ensure that the application can handle large amounts of traffic and data, without any impact on the user experience.

In conclusion, by implementing these standards, we have created a high-quality, user-friendly web application for a microscope with an image processing application that performs well, is secure, and can be easily maintained and updated over time. We take pride in delivering a top-quality application to our users that they can rely on for their research and imaging needs.

4.2.2.1 Coding Standards

Coding standards are essential to ensure that code is clean, organized, and easy to maintain. Here are some examples of standards that will be implemented:

Consistent formatting: All code should be formatted consistently. Indentation, spacing, and bracket placement should be consistent throughout the codebase.

Clear and descriptive variable and function names: Variable and function names should be clear, descriptive, and easy to understand. This makes the code easier to read and maintain.

Modularity: Code should be broken down into small, modular components that can be reused and tested independently.

Comments: Code should be thoroughly commented to explain the purpose and functionality of each section of code. This makes it easier for other developers to understand the code and for future developers to maintain it.

Error handling: Code should have proper error handling to handle unexpected events and exceptions. This helps prevent crashes and makes the code more robust.
Version control: Code should be managed using a version control system such as Git, which allows developers to collaborate, track changes, and roll back to previous versions if necessary.
Testing: Code should be tested thoroughly to ensure that it works as intended and to catch any bugs or issues before they cause problems in production.

4.2.2.2 Database Standards

Database standards are a set of guidelines and best practices that ensure the reliability, security, and efficiency of databases. Here are some important database standards that will be implemented:

Data integrity: Ensure that data stored in the database is accurate and consistent. This can be achieved through the use of constraints, such as primary keys, foreign keys, and unique constraints, as well as data validation checks.

Security: Protect the database from unauthorized access, modification, or deletion. This can be achieved through the use of access control mechanisms, such as user accounts and passwords, and encryption techniques, such as data encryption and secure network connections.

Performance: Optimize the database for efficient access and retrieval of data. This can be achieved through the use of indexing, normalization, and other database optimization techniques.

Backup and recovery: Develop and implement a backup and recovery strategy to ensure that data can be recovered in the event of a disaster or system failure.

Data retention: Establish policies for data retention and deletion to ensure that the database does not become cluttered with unnecessary data.

Documentation: Document the database schema, data dictionary, and other important aspects of the database design and implementation to facilitate maintenance and future development.

4.2.3 IPC 2221 Generic Standard on Printed Board Design

The IPC 2221 generic standard on printed board designs is intended to create design concepts and recommendations. These recommendations are to be used to produce comprehensive designs to mount and connect electrical components. The scope of IPC 2221 includes spacing between conductors, creepage, and insulation requirements [25]. The IPC 2221 standard highlights requirements for organic circuit board design and different forms of component mounting, and interconnecting structures.

This standard plays an important role in the PCB design of our microscope because our design includes the design and creation of our own PCB. The voltage regulator and the LED mounted to the microscope will have a PCB designed by the group and IPC 2221 will be referenced as a standard used in our design.

4.2.4 IEEE Std 1789 LED brightness

An important standard to follow is for the LED brightness for the backlight of the microscope. Improper implementation of the LEDs for the backlight can result in various risks for both health and data integrity. Studies have shown that office lighting modulating at improper frequencies can increase the risk of headaches, migraines, and even epileptic seizures in the worst cases. Looking directly at shining LEDs that are too bright is also potentially harmful to human eyes.

The main concern in the scope of this project is that these risks could transfer over the LED backlight used in the microscope given that users will be able to see an image from the microscope in real time. There is also an added risk of compromising data integrity, as the lighting of the image greatly affects the view a user has of the subject being viewed through the microscope. Also, light sources being too bright may also cause damages to certain biological specimens. In order to mitigate these risks, we will be referencing the IEEE Recommended Practices for Modulating Current in High Brightness LEDs for Mitigating Health Risks to Viewers.

4.2.5 IEC 60086-1 Primary Batteries

Since Primary batteries are designed to be used once and be thrown out, parts of this standard do not apply, however, There are safety and interchangeability standards that we will follow in our project. Our design for the microscope with rechargeable batteries will follow the safety standards outlined in IEC 60086 to ensure user safety and health whilst operating the microscope. This standard will be used in the design process and development in order to create the best possible experience for our end user.

IEC 60086-1 standardizes many details relating to primary batteries such as dimensions, terminal configurations, test methods, performance, safety, and environmental specifications [23]. The intention of IEC 60086-1 is to provide many benefits to users such as interchangeability among different batteries from different manufacturers. This standard also highlights test methods provided for the primary batteries to ensure compliance with the specifications defined in the document.

4.2.6 IEEE Std 1679.1 Guide for Lithium-Based Batteries in Stationary Applications

Our portable microscope will have rechargeable Lithium-ion batteries and because of this we will follow the standards put in place before us as described in IEEE Std 1679.1 guide for lithium-based batteries. The scope of this standard document includes technology descriptions, information on aging and failure modes, safety problems, testing methods, and regulatory problems.

IEEE Std 1679.1 defines a Lithium-ion (Li-ion) cell as: "A rechargeable cell in which lithium ions move via an electrolyte from the negative electrode to the positive electrode during discharge and in reverse when charging, and in which the negative electrode is an intercalated lithium compound, rather than metallic lithium" [24]. The intended applications as highlighted in IEEE Std 1679.1 range from high-power applications to long-duration discharge applications and are typically used for their smaller and lighter design making them a good fit for lightweight projects.

Li-ion batteries can be used for high-power projects where the discharge rate is very fast and discharges within minutes, or for medium-power projects which are designed for longer use cases. These two systems are categorized by power rating vs. discharge time, and energy rating vs. discharge time. These ratings give our team a good indication as to what is expected of the cells. The manufacturer commonly includes duration of discharge and temperature, which makes an impact on our project directly and this was considered when deciding on the power supply for the microscope.

The final impact that this standard has on our project is the disposability and cycling aging of lithium-based batteries. According to IEEE Std 1679.1 "lithium-based batteries cannot be disposed of in household waste because of the organic chemicals in the electrolyte and, in some cases, because of the metals used as active materials" [24]. Since the lithium-ion batteries cannot be disposed of conveniently, we have chosen to pick rechargeable cells so as not to create an environmental burden. This standard also describes the number of cycles as an important consideration to make by the end user because this will have an effect on the application. The manufacturer should publish the end-of-life cell capacity in order for our team to make a decision on the sustainability of the battery.

In summary, IEEE Std. 1679.1 has several impacts on our design in terms of safety, discharge time, cycle aging, and disposability. These four main guidelines have given our team a good indication as to which type of power supply to use in our design project.

Section 5 Hardware Design

5.0 Power Calculation

In order to design the PCBs for the voltage regulator connected to the raspberry pi and the microcontroller we will need a complete look at the voltage and current needs of each electrical component. Below is a table showing the minimum and maximum voltages and currents of the 28BYJ-48 motor, its driver, the raspberry pi 4 model B, the raspberry pi camera module V2, the ATMEGA2560 mcu, the TLC5940 LED driver.

Table 22 - Power Calculation Table

Component	Minimum Voltage input	Maximum Voltage input	Minimum input Current	Maximum input Current
28BYJ-48 Stepper Motor	5V	5V	0.16A	0.16A
ULN2003A Stepper Motor Driver chip	3.85V	12V	0.93mA	1.35mA
Raspberry Pi 4 Model B	5V	6V	2.5A	3A
Raspberry Pi Camera Module V2	-0.3V	3.3V	38mA	160mA
White LEDs	3V	3.2V	20mA	20mA
IR LEDs	1.2V	1.5V	20mA	20mA
UV LEDs	3V	3.4V	20mA	20mA
ATMEGA2560	1.8V (or 2.7V if using 16MHz clock)	5.5V	40mA (DC current per I/O pin)	200mA (DC current VCC and GND pins)
TLC5940PWP	3V	5.5V	0mA	60mA (if VCC < 3.6V) 120mA (if VCC > 3.6V)
Total Current			2.54A	4.001A

In our current setup, we use 13 I/O pins at 40mA maximum current rating plus the VCC and GND pins have a maximum current rating of 200mA. Adding these together nets us 720mA. All together, we summed together the currents of the motor driver, the raspberry pi, the raspberry pi camera module, the ATMEGA2560 VCC and GND pins with 13 I/O pins, and the TLC5940PWP. A total of 4.001A was found which brings our total power to roughly 20W total.

5.1 Power Flowchart

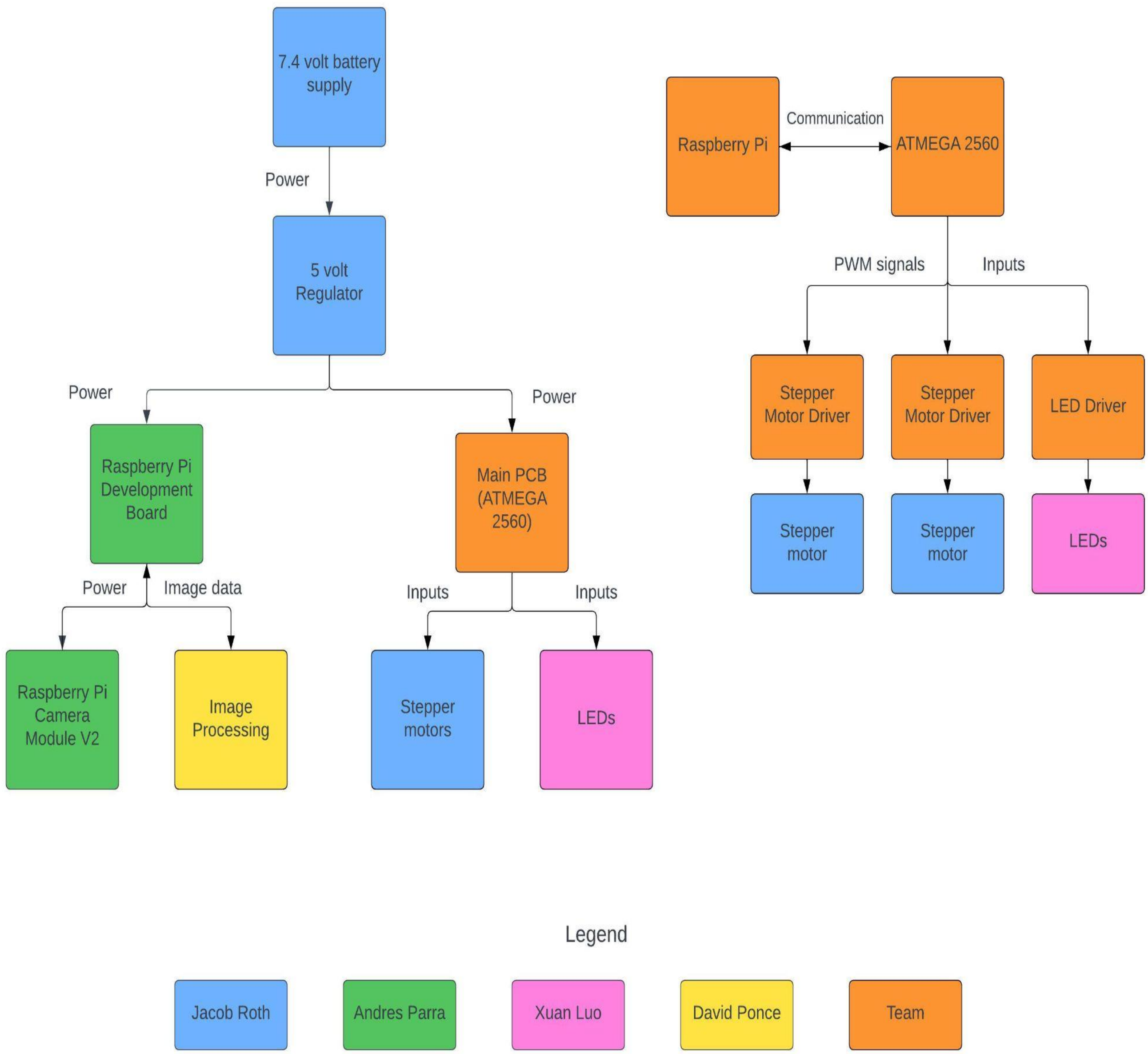


Figure 5.1.1 Power Flowchart

Figure 5.1.1 shows how the raspberry will be powered using batteries that sum to 7.4 volts. This 7.4 input voltage will be regulated down to 5 volts to power the Raspberry Pi 4 development board which then controls the camera module, image processing, and communicates with the main PCB. In the main PCB the LEDs will be controlled using an LED driver to power each type of LED from white, to infrared, to ultraviolet. The main PCB will also feature stepper motor drivers to drive the two motors that control the microscope. The main PCB's microchip will be the ATMEGA2560 16AU. The main PCB will be powered via the batteries as well and will be stepped down to 5V. The datasheet provided a safe operating voltage range for the 16MHz clock version of the microcontroller at 4.5 volts to 5.5 volts.

On our main PCB, we have the two ULN2003AID stepper motor drivers which drive the motors. The main PCB also has the TLC5940PWP LED driver to control the four kinds of LEDs. The four kinds of LEDs are white, ultraviolet, 850nm infrared, and 940nm infrared LEDs. The main PCB will connect to the PCB made for the LEDs to send signals to that board. For the stepper motors, there will be a 5-pin connector directly on the main PCB so that plugging in the motors are easy and seamless.

5.1.1 ATMEGA 2560 Power Schematic

Using the schematics and datasheet provided for the ATMEGA 2560 microcontroller and the Arduino mega 2560 development board, the connections between a 5 volt source and ground were made with the appropriate pins. The reference schematic can be found in appendix B. The appropriate decoupling capacitor values found on the schematics were all 100 nF. These decoupling capacitors are important because they prevent undesired energy transfer between two subsystems [29]. The capacitor shunts the noise created by other elements of the circuit reducing their effects. According to the datasheet the AVCC and GND_5 pins had to be connected to VCC even if the ADC is not used. The rest of the four VCC and GND pins were connected to a 5 volt external voltage with the 100 nF decoupling capacitors connected to them. Below is the EasyEDA schematic showing how the external power will be connected to the ATMEGA 2560 microcontroller.

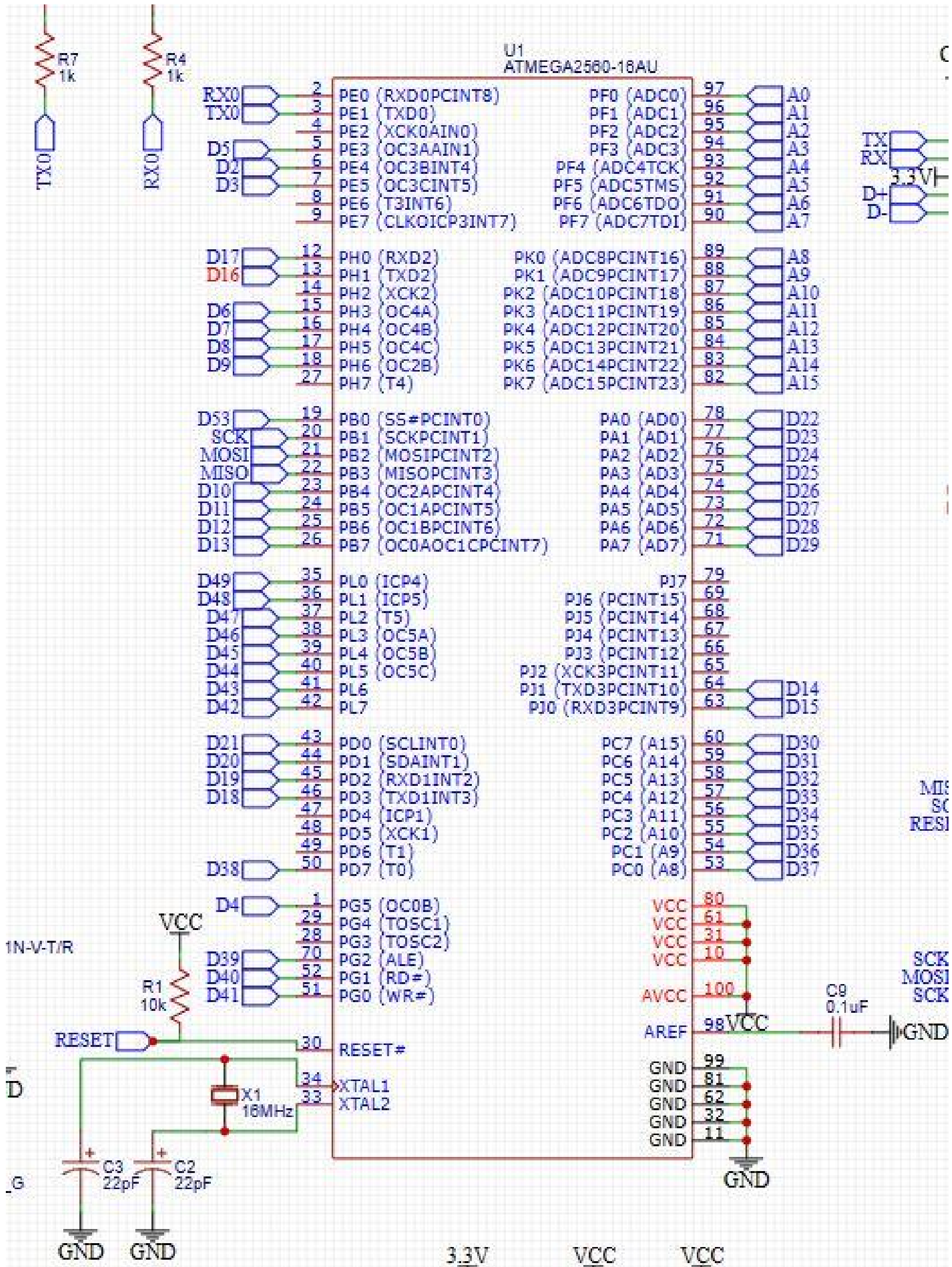


Figure 5.1.1.2 Power Schematic

5.1.2 ULN 2003AID Stepper Motor Driver Schematic

Using schematics and the datasheet provided for the ATMEGA2560 and the ULN2003AID we made the pin connections between the two chips. The reference schematic for the ULN2003 can be found in appendix B. The capacitor value of 10 nF was found in the schematic and connected to the COM and E pins. The E pin was then set to ground and the COM pin was set to 5 volts. We then used a 5-pin XH connector to connect the output pins, these 5 output pins are to be connected to the 28BYJ-48 stepper motors.

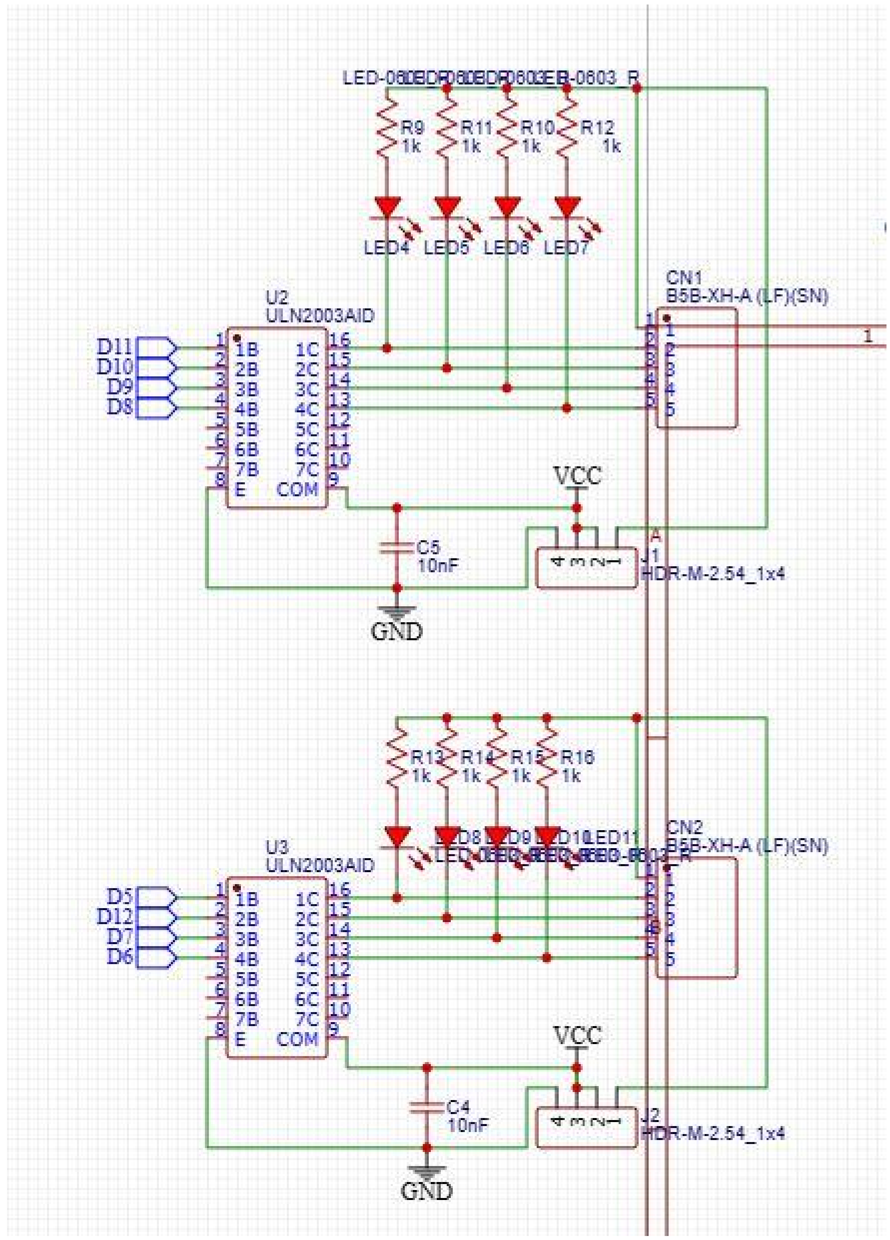


Figure 5.1.2 Stepper Motor Driver Schematic

5.1.3 CH340C Driver, ICSP, and Crystal Schematics

Using the schematics of the ATMEGA2560 microcontroller and CH340C driver we made the pin connections in EasyEDA. Firstly, the VCC and GND were set to VCC and ground. Next the TX and RX pins from the CH340C were connected to the RX and TX pins on the ATMEGA2560. Next, the DTR pin from the driver was connected to a 0.1uF capacitor, then to the RESET pin on the microcontroller. The D+ and D- pin on the driver was connected to the D+and D- pins on the Micro-usb port for data in and data out. VCC and GND were also set on the micro-usb port via the VBUS and GND pins. SH1, SH2, SH3, and SH4 are all set to GND on the micro-usb port.

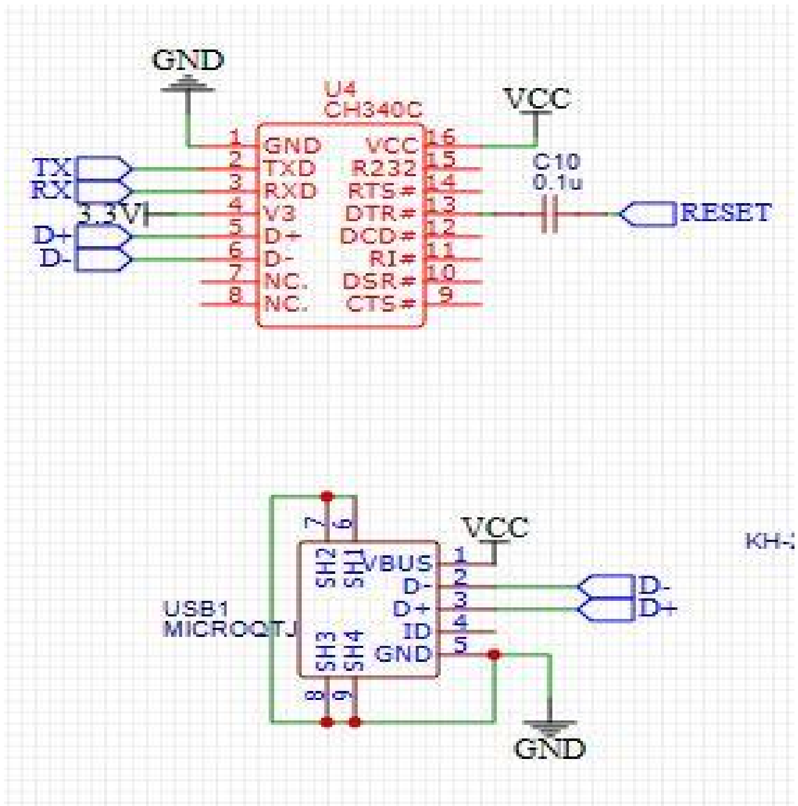


Figure 5.1.3.1 CH340C Driver Schematic with Micro-usb

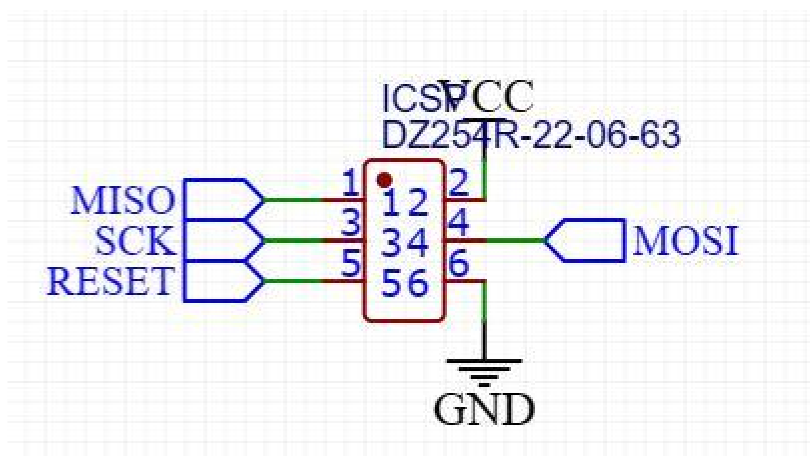


Figure 5.1.3.2 ICSP pins connected to MISO, MOSI, SCK, RESET, VCC and GND

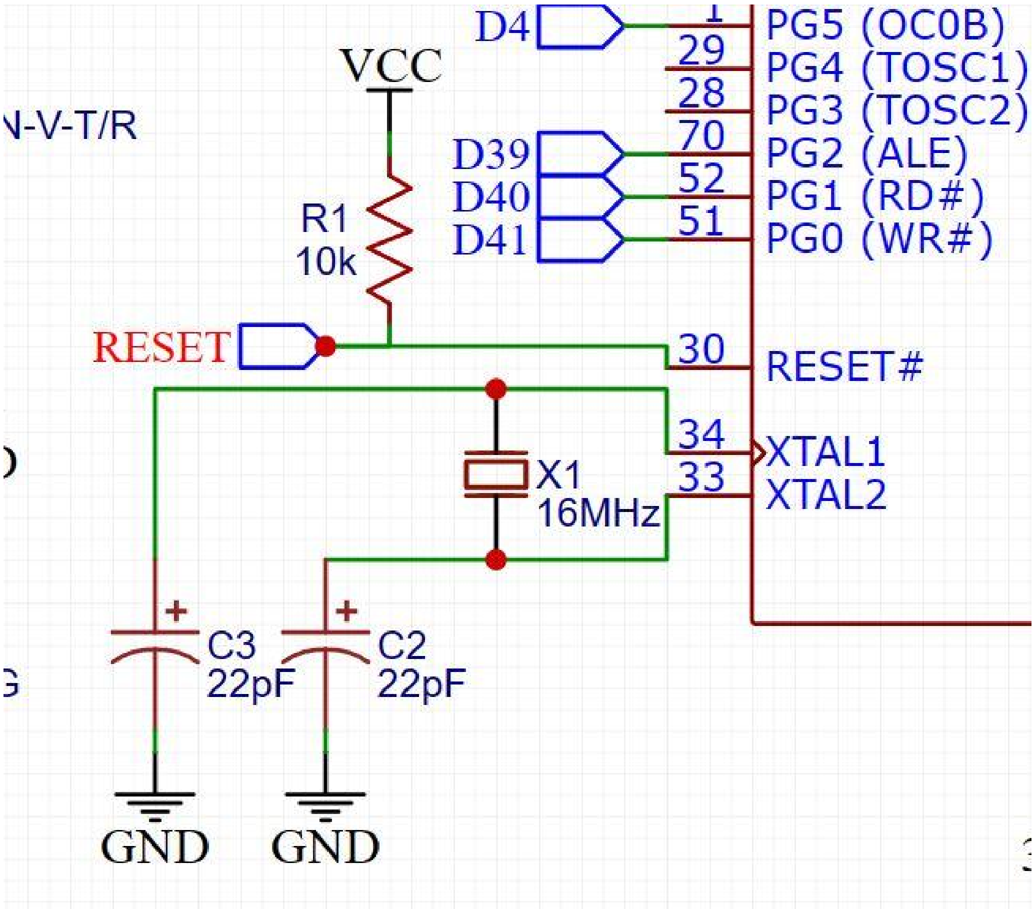


Figure 5.1.3.3 16MHz Crystal connected to the ATMEGA2560 MCU

5.1.4 LED Schematics

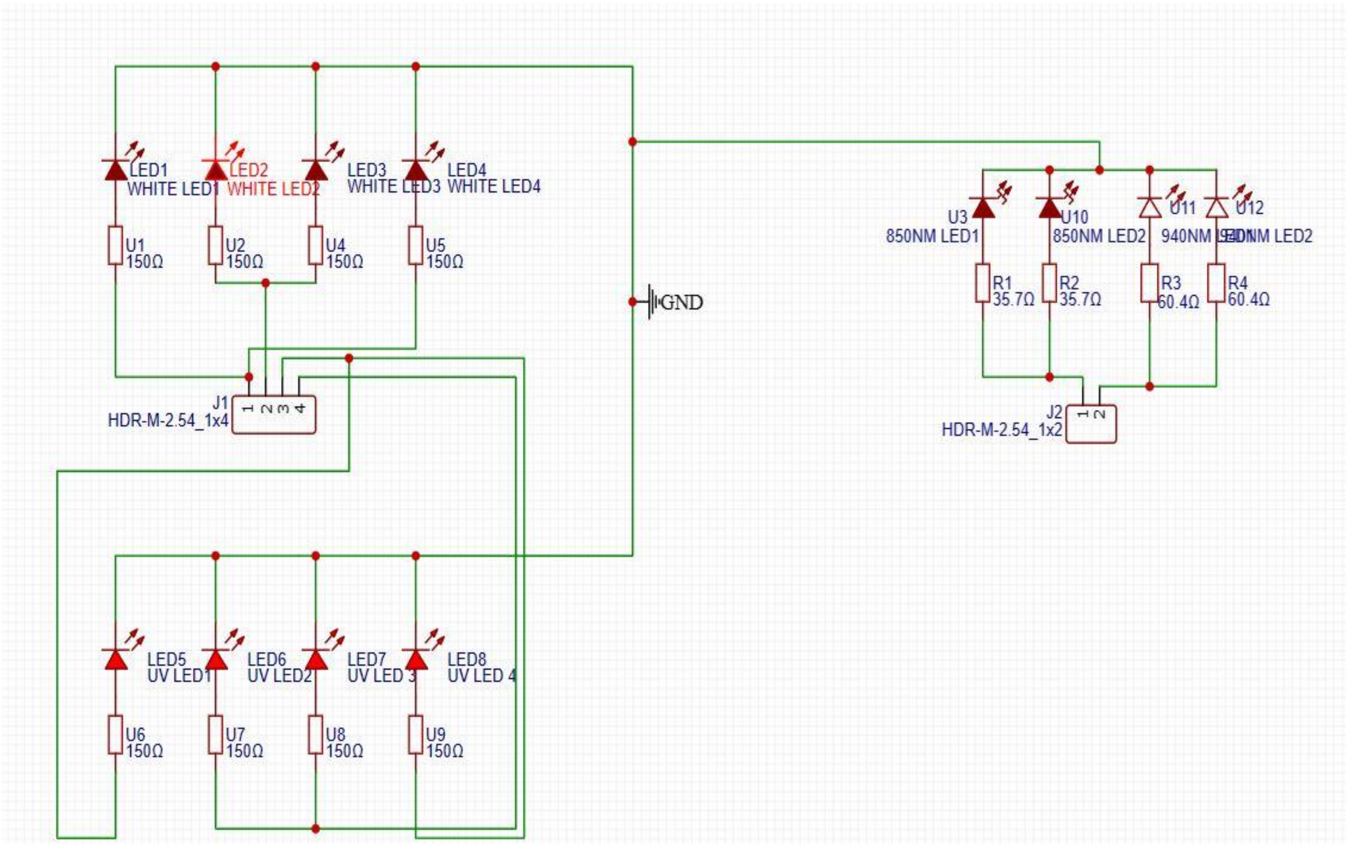


Figure 5.1.4 LEDs connected to pin headers for the LED PCB

5.1.5 Overall Schematics

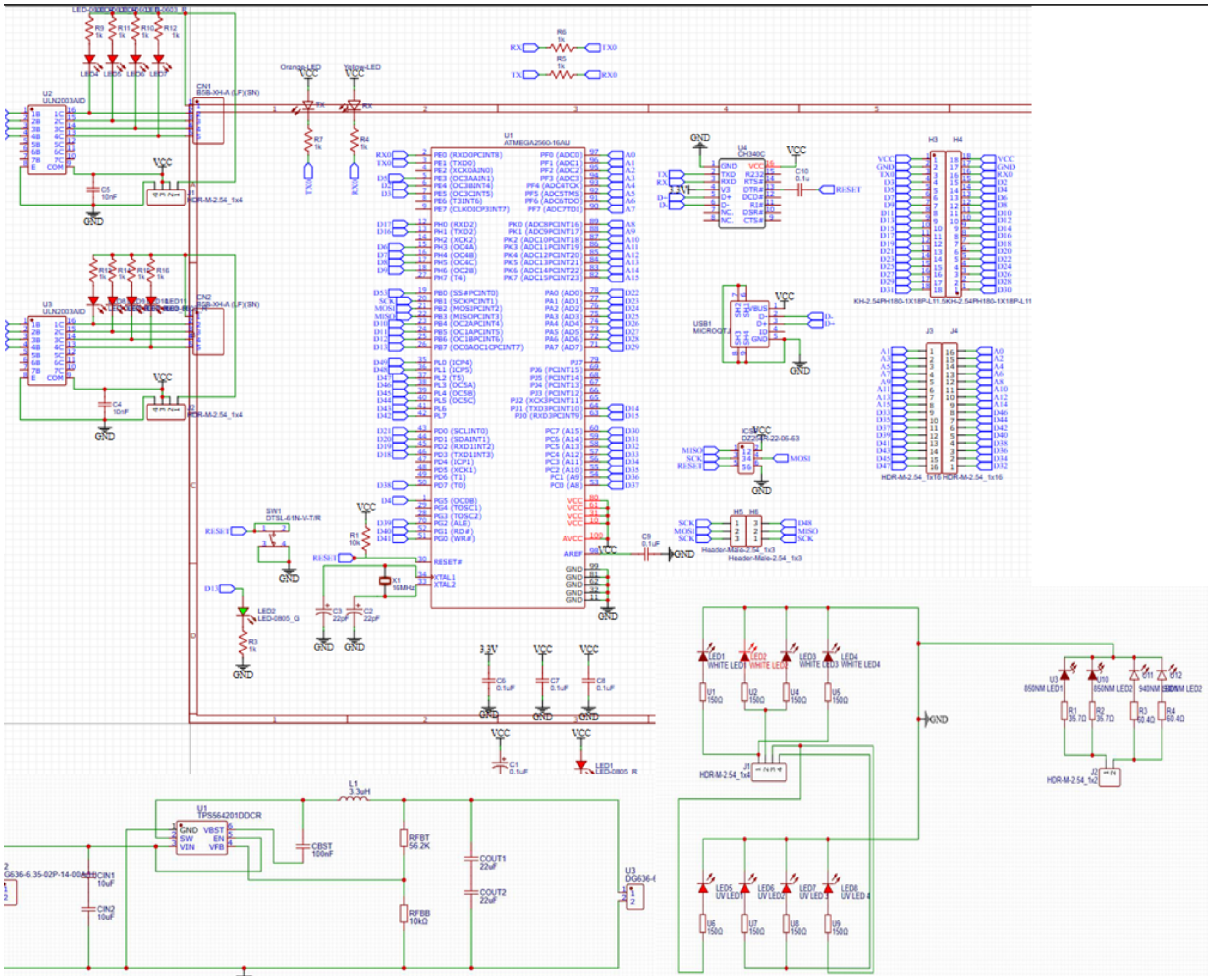


Figure 5.1.5 Schematics for LEDs, voltage regulator, and main PCB components

5.2 Switching Regulator Design

Based on the power table shown in section 5.0 we need a regulator that can take 7.4V or more at the input and buck that voltage down to 5V at the output. The input currents of each component were obtained from the data sheets provided for each part. We summed the current we needed for the motor drivers, LED driver, ATMEGA2560, and the raspberry pi. The total current came out to be 4.001A. The voltage regulator can output a total of 20W. Below in figure 5.2.1 is a design of such a regulator capable of taking 7.4V input and giving 5V and 4A at the output using TI Webench first. In figure 5.2.2 the voltage regulator design is shown using EasyEDA. The voltage regulator used in this case was the TPS5662242DRL.

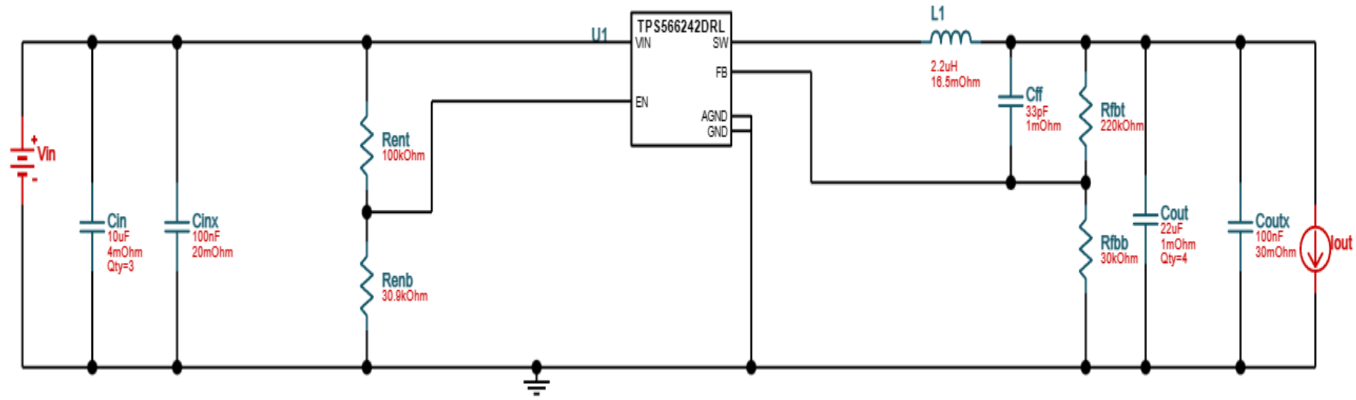


Figure 5.2.1 5 voltage regulator Design made in TI Webench

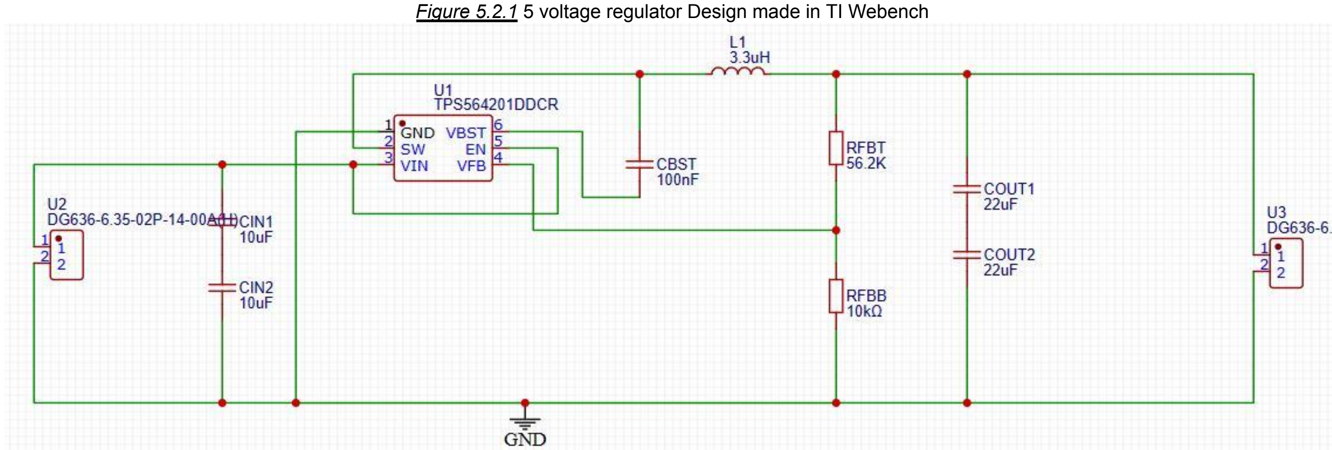


Figure 5.2.2 5 voltage regulator schematic made in EasyEDA

5.3 Microscope Design

In this section, we will go into details to demonstrate how we designed our microscope and how we made our design decisions. Optical design for each optical component in the microscope will be discussed fully, and we will explain thoroughly how our designs compromise and integrate with each other. Microscope body design will be demonstrated as well.

5.3.1 Microscope Optical Design

All the optical components of the portable wide-illuminating microscope will be discussed from a perspective of design. We will discuss all the designs about the objective lenses, the tubular lens, our LED layout, the illuminating system, overall resolution, and two modes of our microscope.

5.3.1.1 Two – Lens Imaging System

We will use one objective lens and one tubular lens to magnify biological samples and focus the image into our image sensor. Technically speaking, only using one objective lens can totally achieve what we attempt to do; however, everytime the sample position changes, the magnification of the entire imaging system will change correspondingly. In bio-imaging systems, it is common to add an extra lens, called tubular lens, to avoid the change of magnification. With a tubular lens, we can fix the overall magnification of our system, no matter how we adjust our sample position. This is why we chose to build an objective-tubular (two-lens) system for imaging.

The tubular lens will be placed 160 mm after the objective lens since the objective lenses we are going to use are corrected for a tube length of 160 mm. As stated in the previous part selection section, our tubular lens is a Thorlabs 25.4 mm BK-7 imaging lens with a focal length of 75 mm. We entered the parameters of this tubular lens in Zemax and simulated the performance of this tubular lens with parallel incoming light rays. The wavelengths are set to be white (486 nm, 587 nm, and 656 nm), UV (390 nm), and IR (850 nm and 940 nm). With the field editor, we used four fields in total, which are 0, 0.5, 1.0, and 1.5 degrees in the object plane. This procedure helps us to estimate the aberrations occurring within the full field.

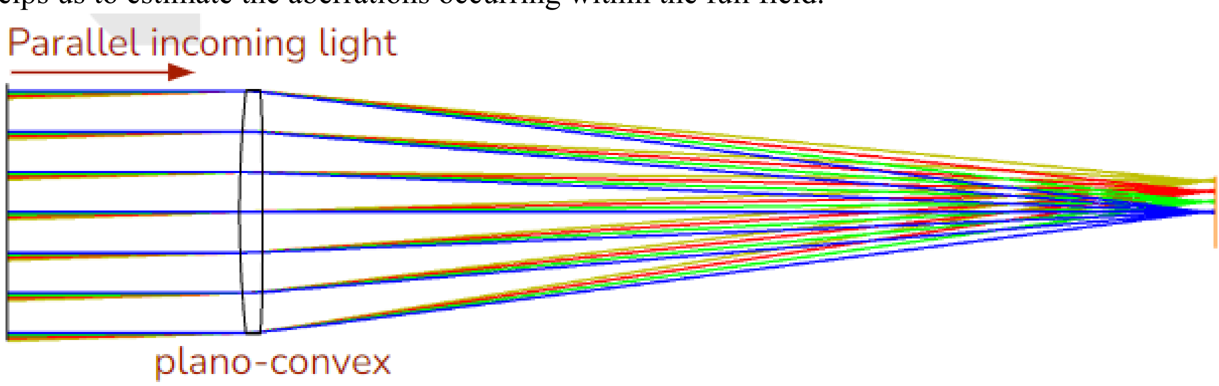


Figure 5.3.1.1.2 tubular lens Design

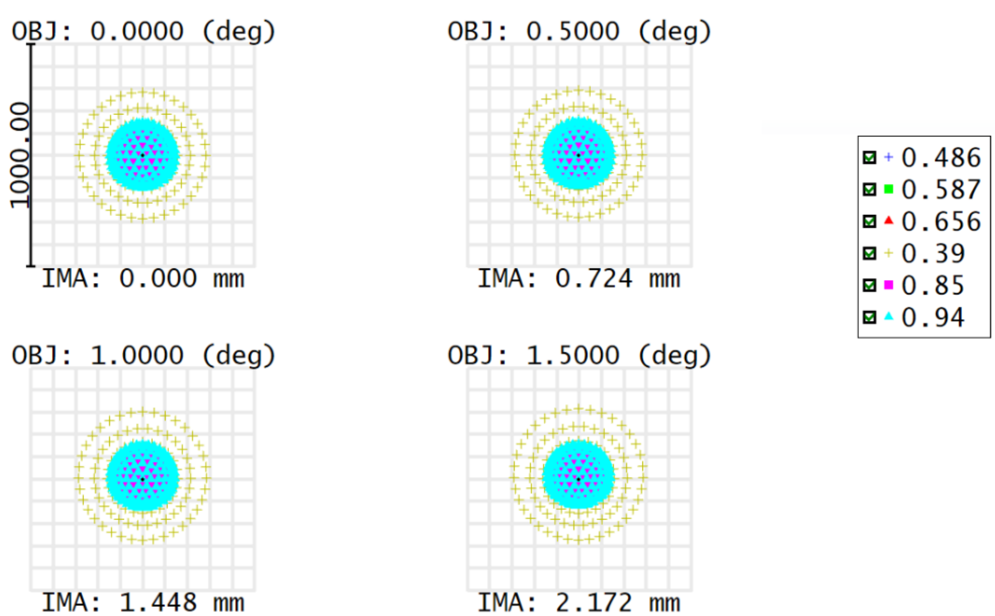


Figure 5.3.1.1.3 tubular lens spot diagram at all wavelengths

In the spot diagram of the tubular lens (Fig. 5.3.1.1.3), it is clear that the light rays at different wavelengths do not "merge" into one perfect spot. This brings chromatic aberration to the resulting image. Therefore, we will need to come up with one way to filter out one certain wavelength for imaging. In the same figure, it is also obvious that all the light rays form an exactly same pattern even in four different fields. This means that the tubular lens we chose introduces very small distortion to the resulting image.

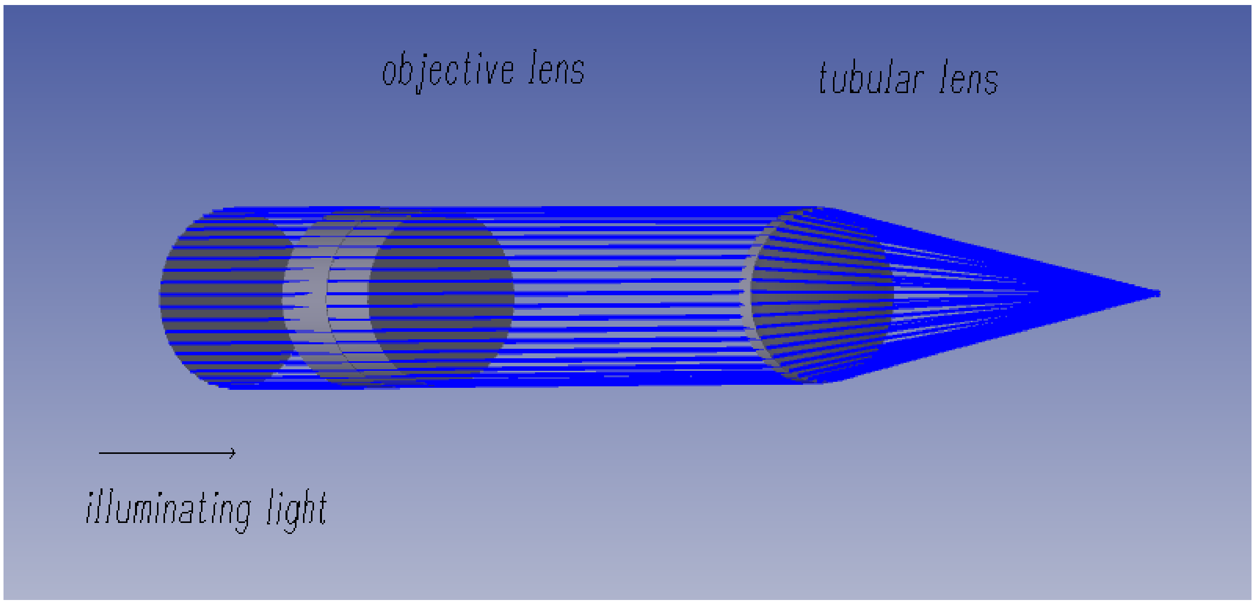


Figure 5.3.1.1.4 objective-tubular imaging system

In Fig. 5.3.1.1.4, it shows a 3D model of our two-lens imaging system. The LED illuminating light comes from the left and passes through the objective lens. Then, the tubular lens, which is at a position of 160 mm after the objective lens, focuses the light into our image sensor that is 75 mm after the tubular lens.

5.3.1.2 Resolution

The resolution in the image plane is determined by the wavelength of the illuminating light and the numerical aperture of the objective lens, which can be calculated by $\Delta r = \lambda/2NA$. Since our illuminating spectrum is from 390 nm to 940 nm, the resolution is going to change when different wavelengths are used. For calculating the resolution, we are going to use wavelengths of white (486 nm, 587 nm, and 656 nm), UV (390 nm), and IR (850 nm and 940 nm) as the same values also used for calculation in the last section.

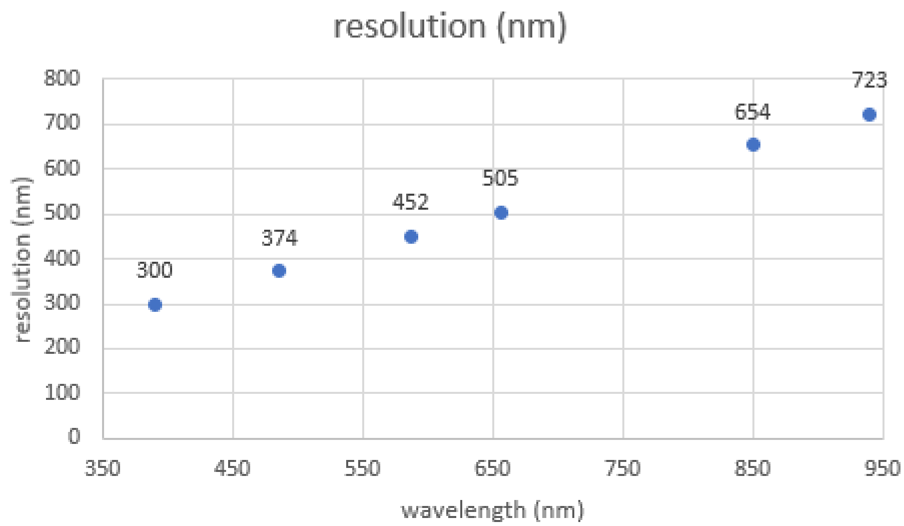


Figure 5.3.1.2.1 resolution vs. wavelength

In Fig. 5.3.1.2.1, it is clear that when UV light is used, the resolution is 300 nm, which is the highest resolution among all the wavelengths; when 940 nm IR light is used, the resolution reaches the lowest, which is 723 nm.

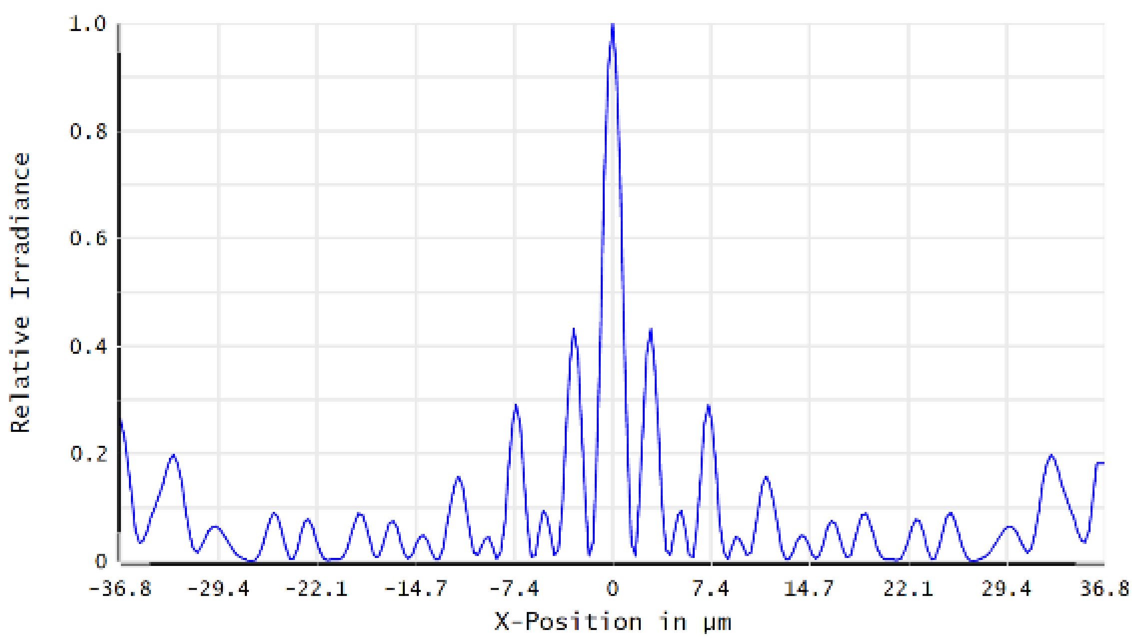


Figure 5.3.1.2.2 Point spread function of the system at all wavelengths

We extracted out the point spread function of our two-lens imaging system and it indicates that our imaging system has a diffraction limit around 0.5 μm at all wavelengths (Fig. 5.3.1.2.2). This resolution is relatively close to the resolution calculated using wavelengths, and having a diffraction limit at 0.5 μm is more than enough to obtain a good image of around 20 μm (our stretch goal).

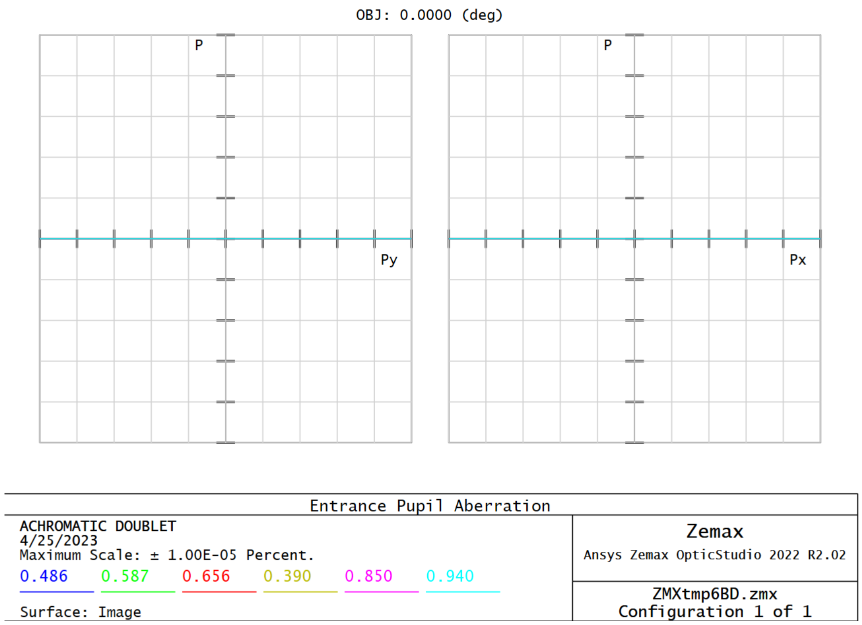


Figure 5.3.1.2.3 pupil aberration

We extracted the information about the pupil aberration occurring in the system and kept modifying the parameters until we obtained minimal aberration at all wavelengths (Fig. 5.3.1.2.3). As shown in the figure, the pupil aberration is zero along the x-axis and the y-axis under all wavelengths, which is a very good result.

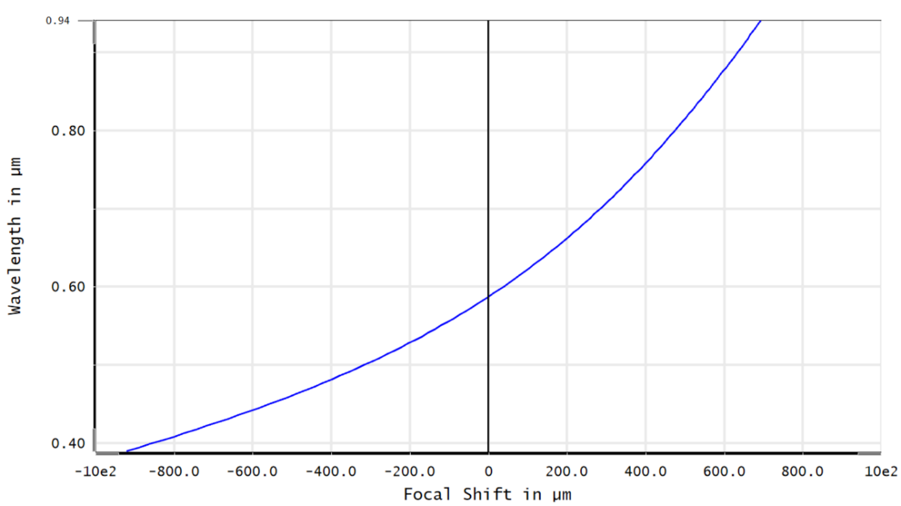


Figure 5.3.1.2.4 chromatic focal shift

Another critical aberration in the system is chromatic aberration. To reduce the chromatic aberration, we will either use filters to filter out one certain wavelength for imaging or control which color LEDs get turned on on the PCB to achieve wavelength control. Every time we switch the wavelength for imaging, we will need to adjust the position of the sample to refocus. Therefore, we extracted the information about the focal shift at all wavelengths for future refocusing reference (Fig. 5.3.1.2.4). The average chromatic focal shift is around 0.3 mm per 100 nm.

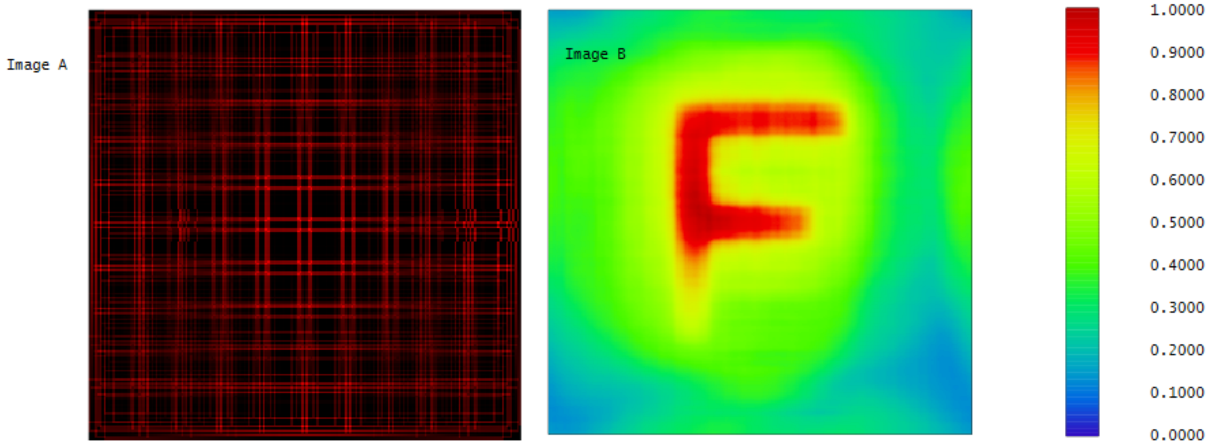


Figure 5.3.1.2.5 image simulation. A is a grid of lines with a size of 0.001 mm (W) x 0.001 mm (H). B is an extended diffraction image.

We ran two simple image simulations to test the overall image quality. In Fig. 5.3.1.2.5, image A is the simulation of a test image with a grid of lines that is 0.001 mm both horizontal and vertical. The center of the image is clear with high contrast, minimal aberrations, and minimal distortion. The central image is satisfactory but the image around the edge experiences more aberration and distortion. Therefore, when we use the microscope, it is better if we image our samples at the center of the lenses. Image B is a diffraction image obtained by simulating the performance of our imaging system with a letter 'F'. This also shows which part of the sample gets the better imaging result by the system.

5.3.1.3 Magnification

As we discussed in the part selection section earlier in this paper, we will use a tubular lens with a focal length of 75 mm. Let us start from the 40x objective lens. The 40x objective lens we are using has a magnification of 40 when it is used with a 160 mm focal length lens. This gives us its focal length, which can be calculated by $160\ mm/40\ =\ 4\ mm$. With our tubular lens with a focal length of 75 mm, we can obtain the overall magnification of the entire imaging system by calculating $75\ mm/4\ mm\ =\ 18.5$x, so our microscope has a fixed magnification of 18.5 with the 40x objective lens.

We can do the same calculation for the 100x objective lens. The 100x objective lens has a magnification of 100x when it is used with a 160 mm focal length lens, so its focal length is $160\ mm/100\ =\ 1.6\ mm$. With the same tubular lens, we can obtain the overall magnification as $75\ mm/1.6\ mm\ =\ 46.875$x ~ 47x. Therefore, our microscope has a fixed magnification around 47 with the 100x objective lens.

5.3.1.4 Field of View

As mentioned in earlier sections, the pixel size of the image sensor we are using is 1.12 µm x 1.12 µm, so using 40x objective lens, in the sample plane, one pixel is $1.12\ \mu m/18.5\ =\ 60.5\ nm$. The sensor has 3280(H) × 2464(V) pixels. Hence, the horizontal field of view is

$3280x60.5\ nm = 198\ \mu m$ in the sample plane; the vertical field of view is $2464x60.5\ nm = 149\ \mu m$ in the sample plane.
For 100x objective lens, one pixel is $1.12\ \mu m/47 = 24\ nm$. Thus, the horizontal field of view is $3280x24\ nm = 79\ \mu m$ in the sample plane; the vertical field of view is $2464x24\ nm = 59$ μm in the sample plane.

5.3.1.5 LED Design

In Fig. 5.3.1.5.1, we show an overall layout design about our LED light source besides the PCB part. As stated in the previous sections, we are going to use four types of LEDs for illuminating the system, which are white, UV at 390 nm, IR at 850 nm, and IR at 940 nm. With calculation, we found we need 16 LEDs in total for lighting up the microscope, so we will use four of each type of the LEDs we have.
All the LEDs should be placed symmetrically in order to be equally distributed when they are used for illuminating biological samples. We chose a single symmetrical pattern of four LEDs of one kind, and then just simply rotated this pattern for the other three kinds of LED. We ended up with 16 equally distributed LEDs (Fig. 5.3.1.5.1).

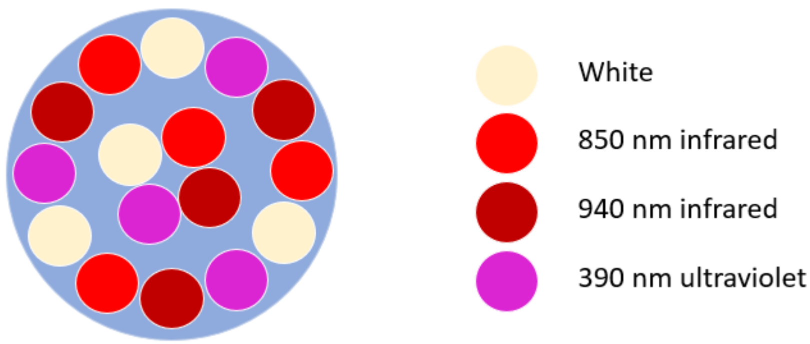


Figure 5.3.1.5.1 LED layout design

The spectrum of our LED light source is illustrated in Fig. 5.3.1.2.2. Please note that this is just an illustration chart and it does not represent the actual spectrum correctly. Firstly, we used three typical wavelengths at 486 nm, 587 nm, and 656 nm to represent the white LED because the manufacturer did not specify the wavelengths for the white LED. We need to use a spectrometer to obtain the wavelength information of the white LED. Secondly, the spectrum of LEDs is supposed to have a bandwidth, but this image does not show that. Thirdly, in reality, even though we distributed our LEDs equally, the optical power of each type of LED may still differ from each other per unit area. This issue may not be necessary to solve because it does not affect the resulting image that much, but in principle, the weights of each wavelength may not be exactly equal per unit area. Again, this picture is only an illustration as the actual spectrum will have bandwidth.. A more accurate spectrum figure will be done with testing.

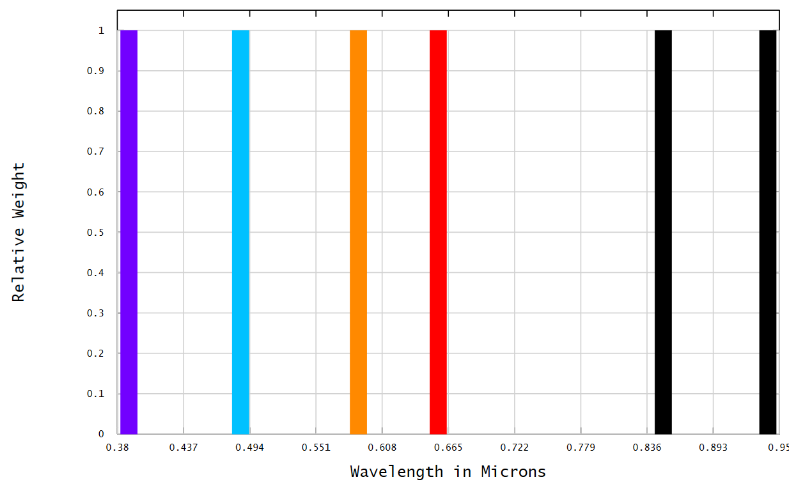


Figure 5.3.1.2.2 illuminating spectrum (only illustration)

5.3.1.6 Illumination System

There is a potential issue with our LED light source. When only one LED is used for illuminating, it will cause either a very bright spot at the center of the image or not enough light illuminating the edge of the image. It is common to use an illumination system to solve this problem, as the illumination system can distribute all the LED lights equally and convert it into a uniform light source.
However, we are using 16 LEDs for our light source, so the light source we have may not cause the problem that one LED will cause. Besides, right now we do not have our LED light source ready, so we cannot test to see whether it causes this problem or not.
Still, we designed two different illumination systems just in case our LED has this problem. The first illumination system is a classical Kohler illumination system. As shown in Fig. 5.3.1.6.1, it consists of one collector lens, one field lens, and one condenser. Normally, an aperture is placed between the collector and the field lens. This system will convert the original light source to a uniform light source. This illumination system is kind of long and has many lenses.

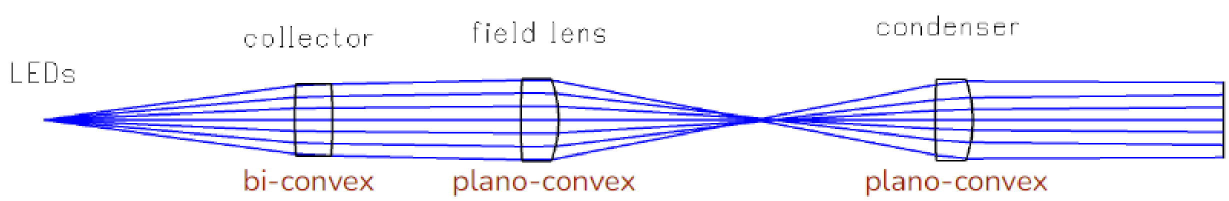


Figure 5.3.1.6.1 Kohler illumination system

Another illumination system is shown in Fig. 5.3.1.6.2. This illumination system consists of only one lens and one diffusion filter. Then the condenser will first convert the original light beams into parallel beams, and then the diffusion filter will scatter and ‘mix’ all the light beams. Thus, the original light source can be turned into a uniform light source. This system has less lens and is easier to implement.

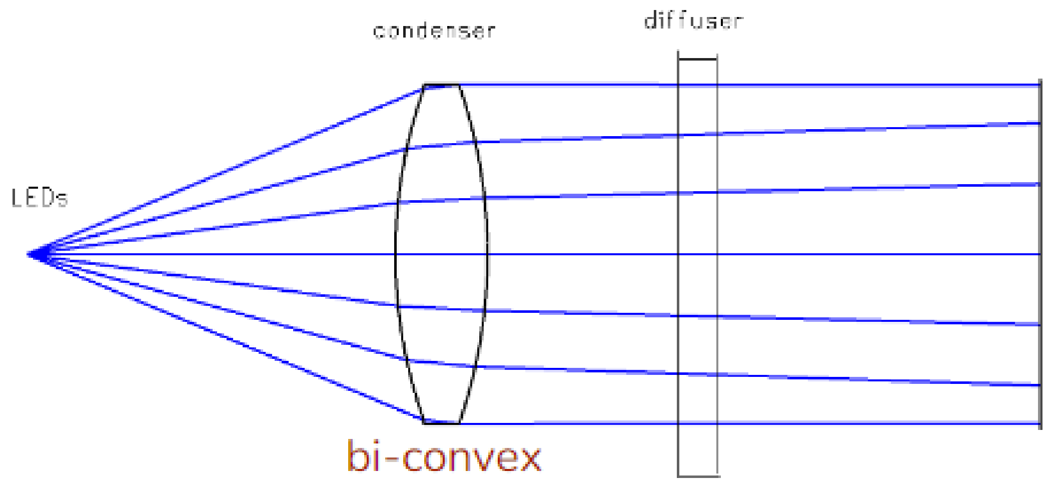


Figure 5.3.1.6.2 Lambertian diffuser illumination system

We chose to use Lambertian illumination as our illumination system because this is more compact. The focal length of the condenser is 30 mm and the diffusion filter is purchased on Amazon.

5.3.1.7 Bright Mode and Dark Mode

In order to make our microscope more competitive, we would like to have two different modes for our microscope – bright mode and dark mode.

Every objective lens has a maximum acceptance angle that is determined by the numerical aperture (NA). An objective lens can only captures the light incoming at an angle that is smaller than the maximum acceptance angle; if a beam of light is propagating at an angle bigger than the maximum acceptance angle, it cannot be captured by the objective lens. Our objective lens has an NA of 0.65, so the maximum acceptance angle is arcsin(0.65), which is 40°. Based on this fact, bright-mode and dark-mode are designed as follows.

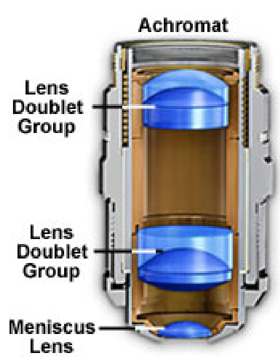


Figure 5.3.1.7.1 Achromatic objective lens cross-section

The bright mode stands for bright-field microscopy. When bright mode is on, both the central and the outer circles of LEDs will be turned on. The LED light beams will first illuminate the sample and then get captured by the objective lens for imaging (Fig. 5.3.1.7.2, A).

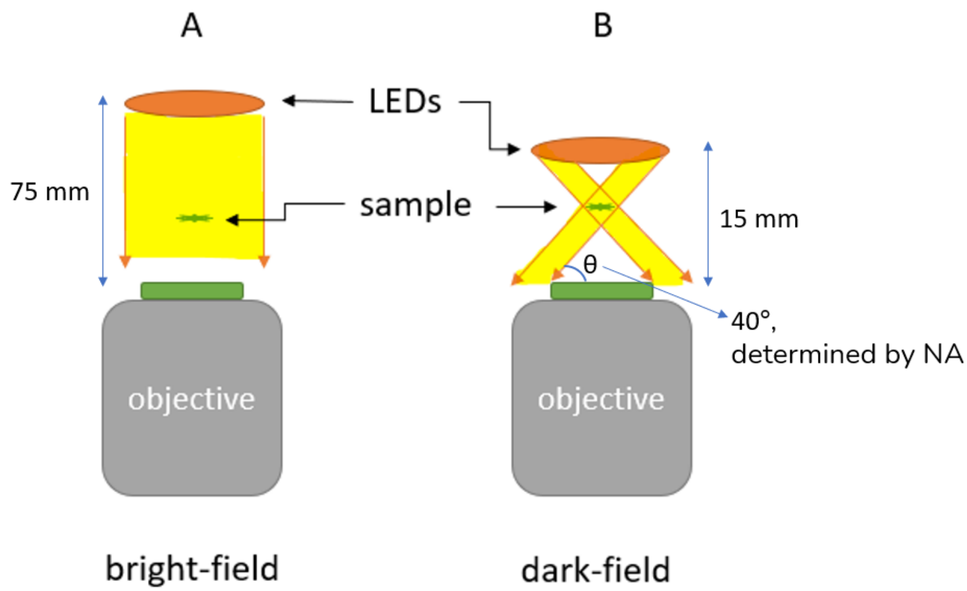


Figure 5.3.1.7.2 two modes of the microscope. A is the bright mode for bright-field microscopy. B is dark mode for dark-field microscopy.

The dark mode stands for dark-field microscopy. When dark mode is on, the central circle of LEDs will be turned off and only two LEDs on the outer circle will be turned on. The two LED light beams will illuminate the sample, but they will not be captured by the objective lens as they both propagate at an angle that is bigger than the maximum acceptable angle of the objective lens (Fig. 5.3.1.7.2, B). The objective lens, thus, only captures the light that is scattered by the sample.
The switch between the bright mode and the dark mode will be done by controlling which LED gets turned on on the PCB. A detailed explanation of how we achieve controlling LEDs will be given in the PCB design section.

5.3.2 Microscope Body Design

The primary considerations we've taken in designing the body of the microscope are the size and weight of all the combined systems. In order to maximize the portability of the microscope we need to contain all of its systems in a body that is light enough to carry and small enough to easily transport. The entire body of the microscope will be made up of two main components, which is the base and the optical train, connected by a support. The optical train is where all of the lenses will be encased in the microscope. The base is where the backlights and specimen will be held for viewing.

The basic design of the optical train is made of the lenses held in place by four rails that keep them aligned. In order to minimize the total weight of the casing for the optical train, we have decided to work around its basic design by 3D printing a box design that uses the same rails to hold it in place around the gaps between the lenses. The modularity of this design also allows for easy implementation of the objective lens mechanism to adjust the zoom of the microscope.

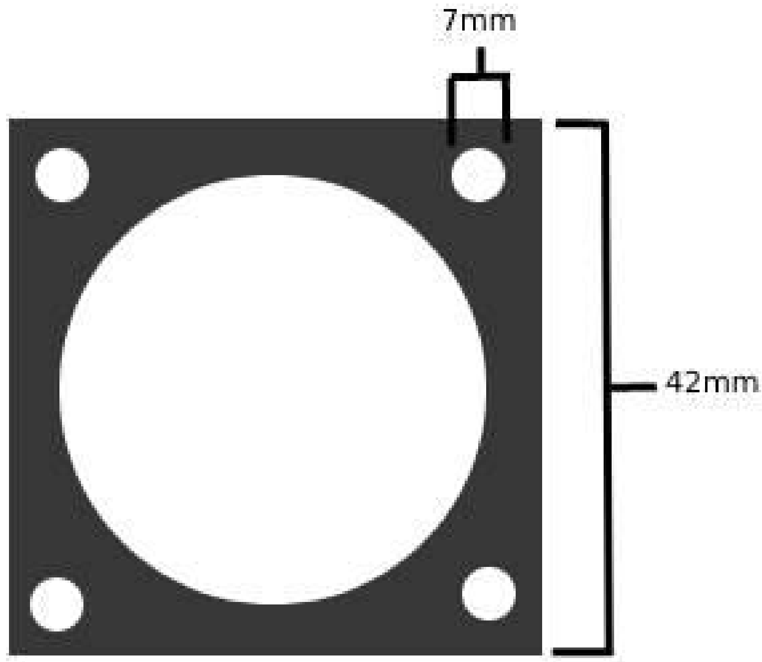


Figure 5.3.2.1 Optical Train Casing Measurements

Figure 5.3.2.2 Final Optical Train assembly

Section 6 Application Software Design Overview

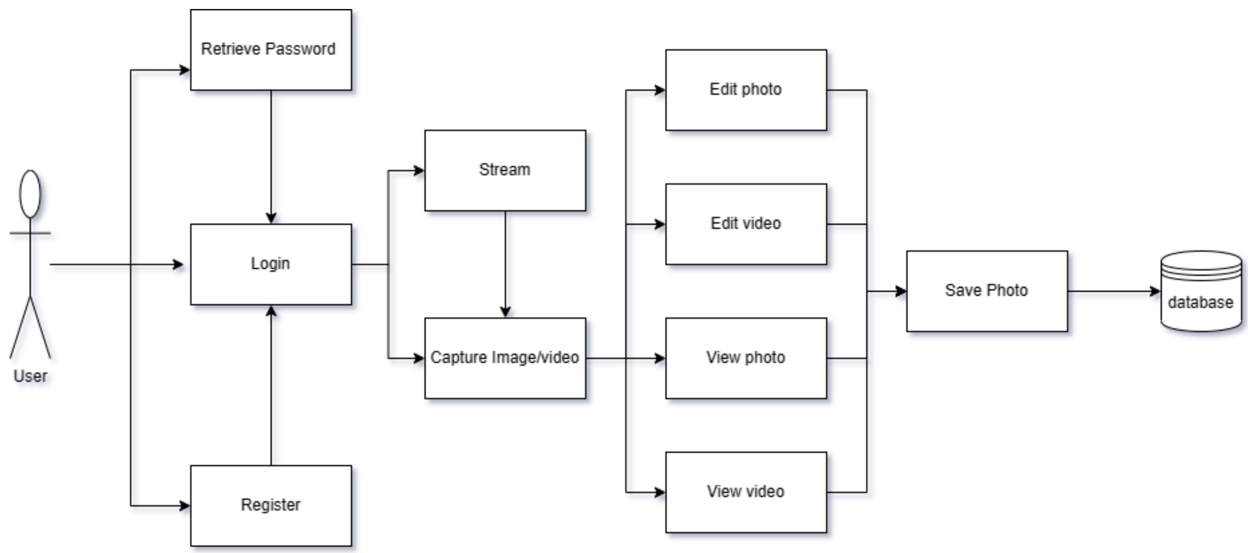


Figure 6.0.1 Use Case Diagram

Registration and Login: The registration and login feature ensures that only authorized users can access the app's features. Users can register by providing their email address and creating a password. Once registered, they can log in to the app and access its features. The app may also ask users to verify their email address before allowing them to log in.

Password Retrieval: It is common for users to forget their passwords, especially if they do not use the app frequently. To address this issue, the app provides an option to reset passwords by entering the user's registered email address. Once the email address is verified, the app sends an email with instructions on how to reset the password.
Streaming Video from Microscope: One of the most important features of the app is the ability to stream live video from a microscope to a smartphone or tablet. This feature enables remote collaboration, allowing users to share their samples with others, even if they are not in the same location.

Saving Video to a Database: The app allows users to save videos recorded from the microscope to a cloud database. This feature enables users to store and organize their recorded videos and analyze them later for research or educational purposes. Users can also delete videos they no longer need, freeing up storage space on their devices.

Saving Photos to a Database: In addition to videos, the app also allows users to capture still images from the microscope video and save them to the same cloud database for later use. This feature enables users to capture high-quality images of their samples and share them with others or analyze them further. The app may also support different file formats to ensure compatibility with other software and platforms.

Image Processing: The app uses image processing algorithms to enhance the quality of microscope images and videos. It can adjust brightness, contrast, and color and apply various filters. Image processing can help users to identify details in their samples that would be hard to see otherwise, making the app more useful for scientific research. The app may also provide advanced image processing features, such as image segmentation, object recognition, and 3D reconstruction.

Backend motor controls allow users to control the movement of the microscope stage remotely through the app. This feature can be particularly useful for remote collaboration, allowing users to adjust the position of their samples in real-time, even if they are not in the same location. Backend LED controls enable users to adjust the intensity and color temperature of the microscope's LED lighting through the app. This feature can help users to optimize their lighting settings for their samples, improving the quality of their images and videos.
In conclusion, a microscope photo editing phone/web app with features such as registration and login, password retrieval, streaming video from a microscope, saving videos and photos to a cloud database, and image processing can be a valuable tool for scientific research, education, and hobbyists. With the ability to capture and process high-quality images and videos, users can analyze their samples more effectively, share their results with others, and collaborate remotely. The app's features should be designed with user convenience and compatibility in mind, ensuring that it is easy to use.

6.1 UI Design- Phone app/Web app

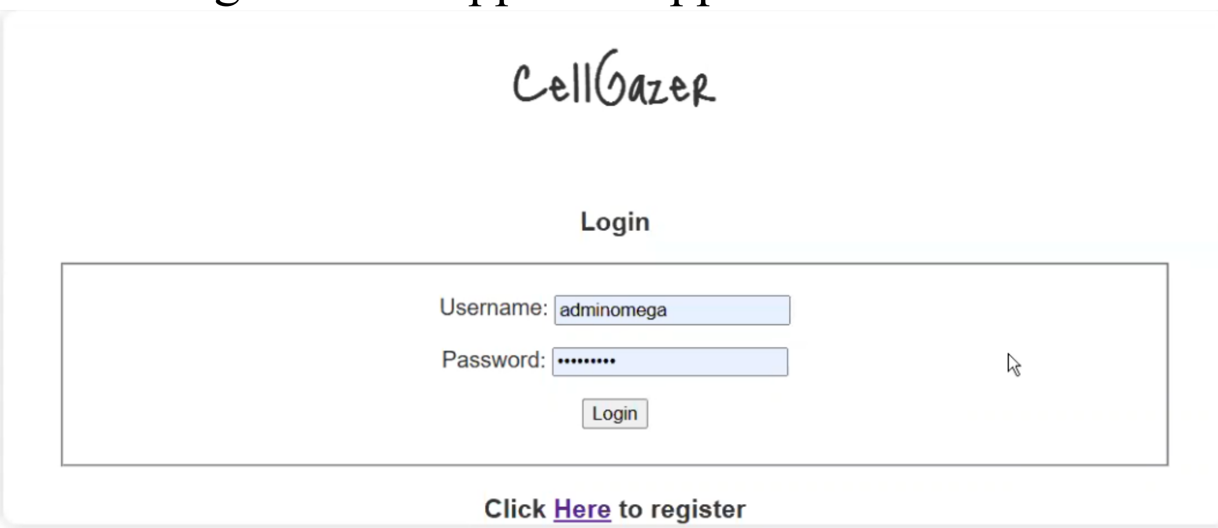


Figure 6.1.1 UI Design 1

Figure 6.1.2 UI Design 2

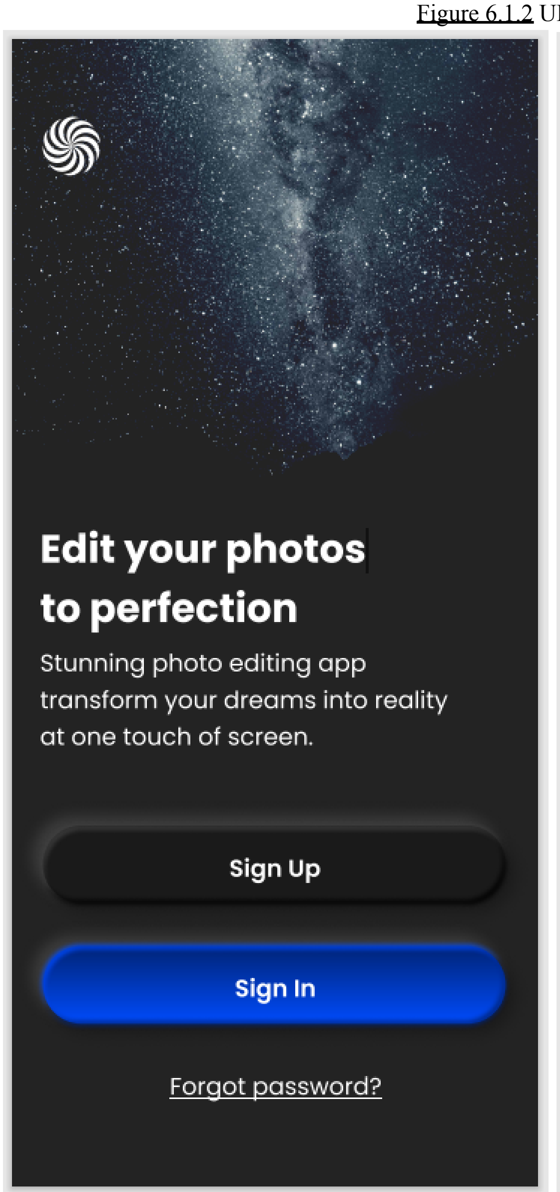


Figure 6.1.3.1 Login UI 1

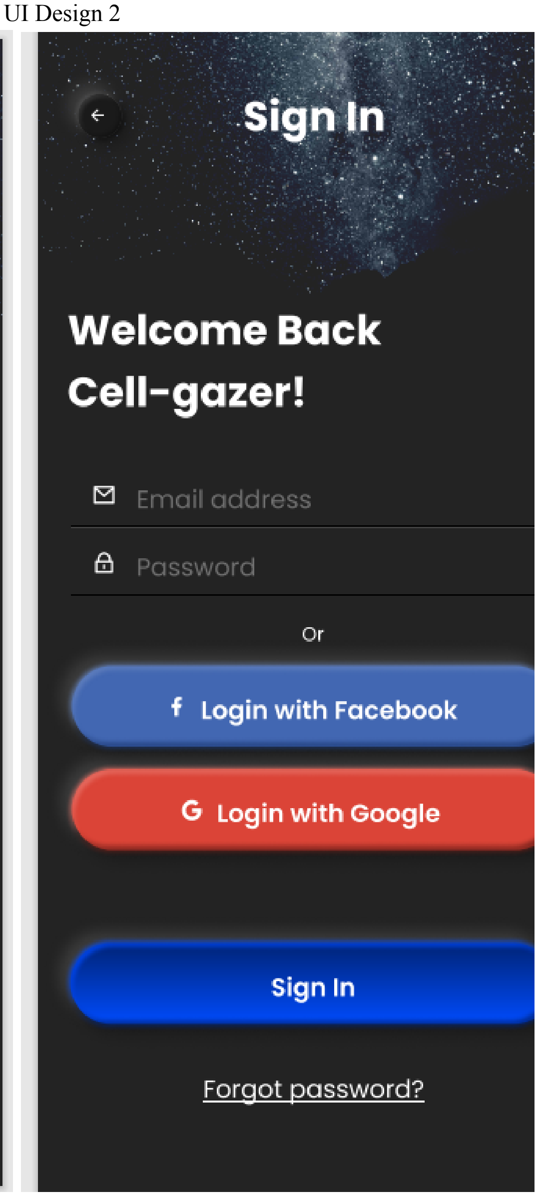


Figure 6.1.3.2 Login UI 2

In the above Image, The registration and login UI shows the features ensures that only authorized users can access the app's features. Users can register by providing their email address and creating a password, as shown in the image above. Once registered, they can log in to the app and access its features. In case users forget their passwords, the app provides an option to reset passwords by entering the user's registered email address. Once the email address is verified, the app sends an email with instructions on how to reset the password, as demonstrated in the image below. This feature ensures that users can quickly regain access to their accounts without having to create a new account.

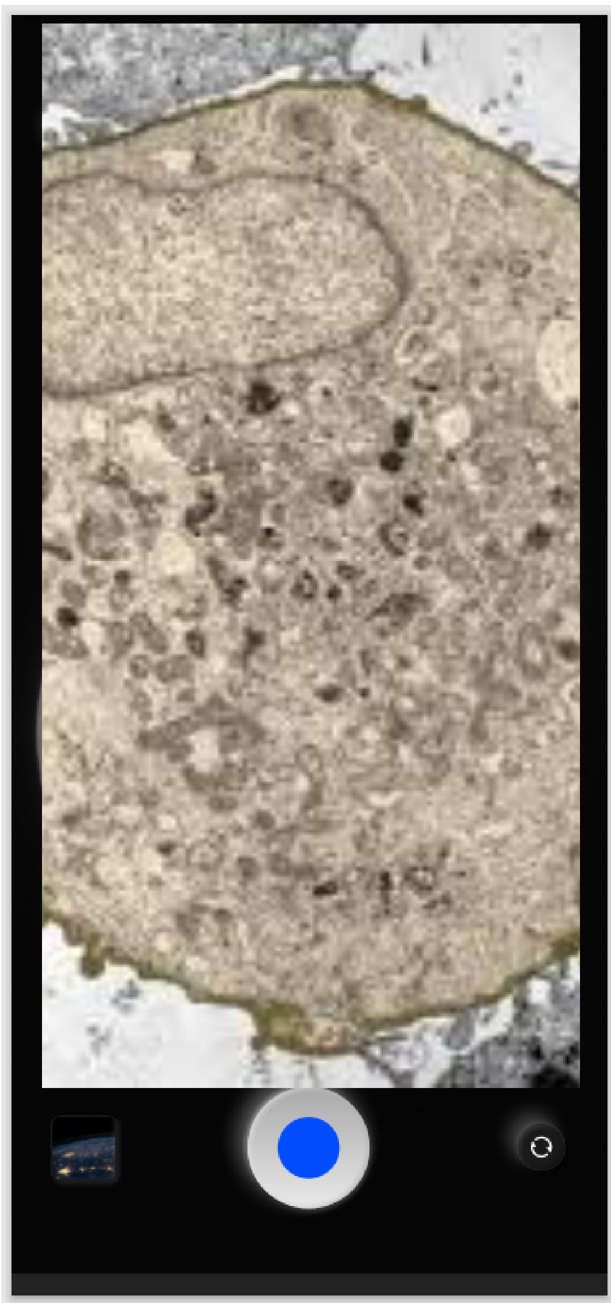


Figure 6.1.4.1 “My Gallery” Page Diagram 1

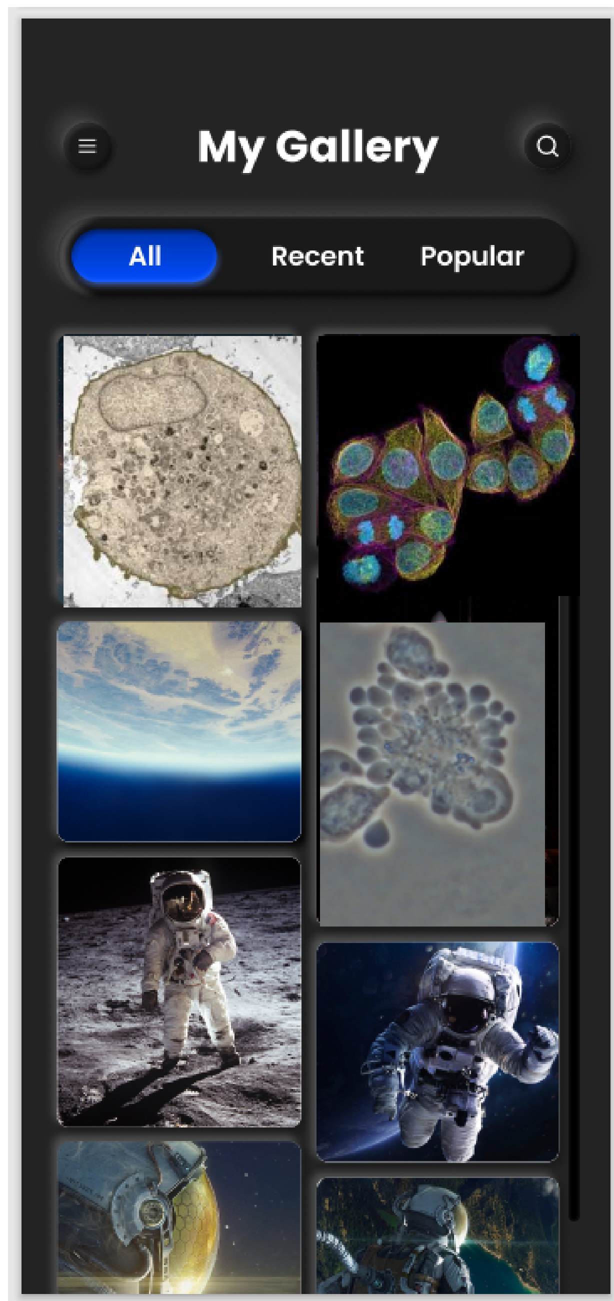
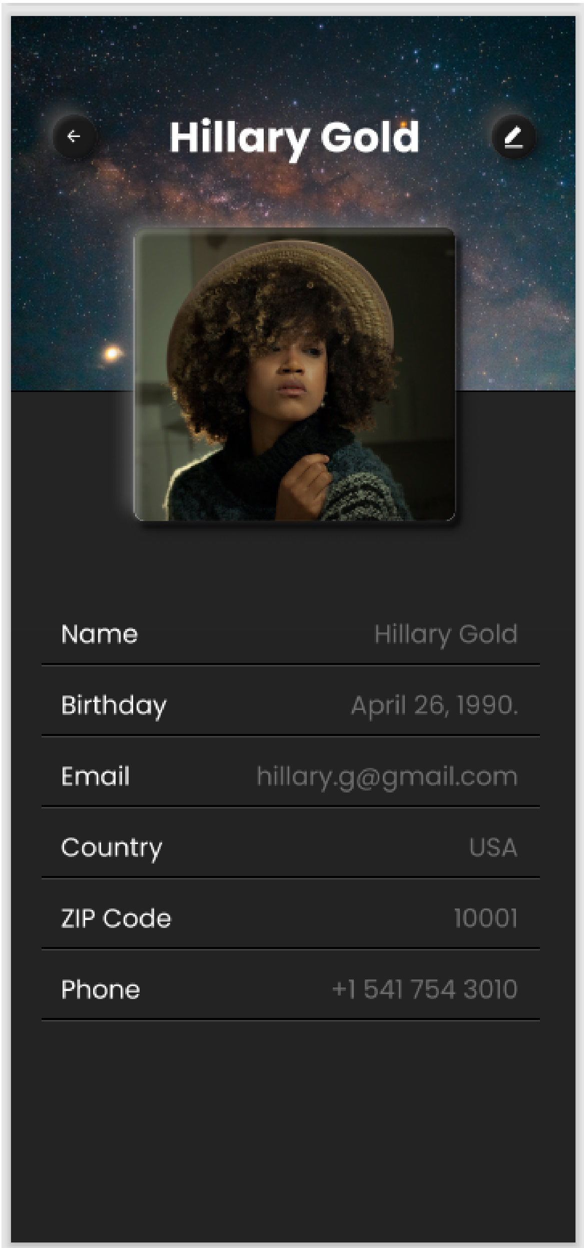


Figure 6.1.4.2 “My Gallery” Page Diagram 2

The database also enables users to save still images captured from the microscope video. These photos can be accessed through the "My Galley" option in the app's user interface, as demonstrated in the image Above. Users can save and organize their microscope images for later use, share them with others, or analyze them further.



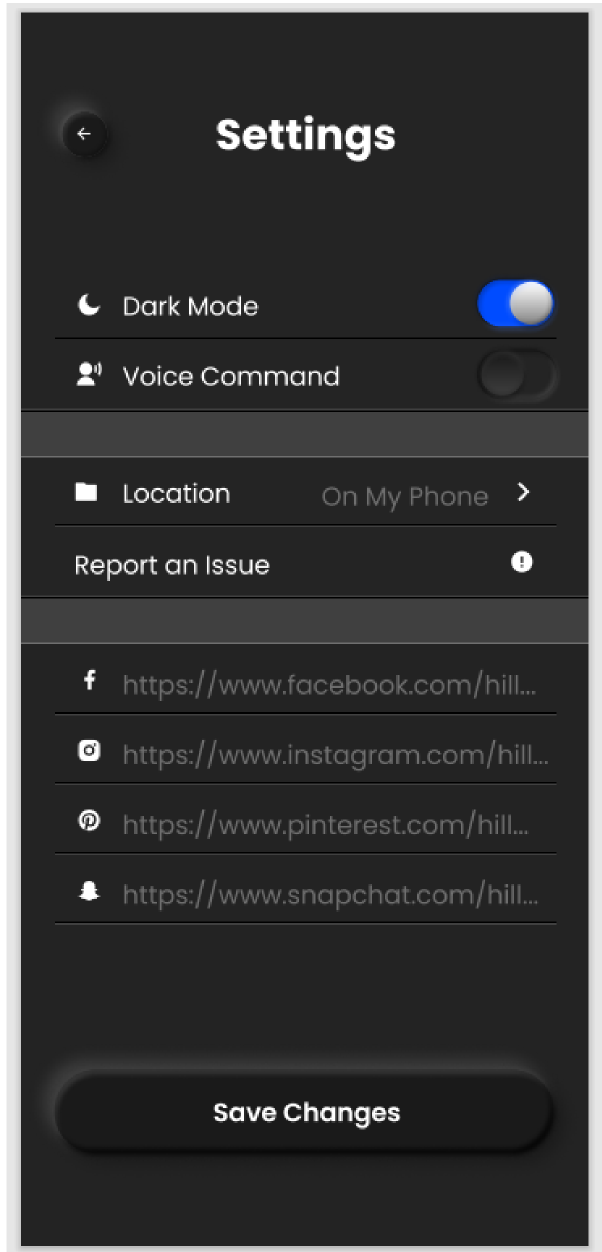


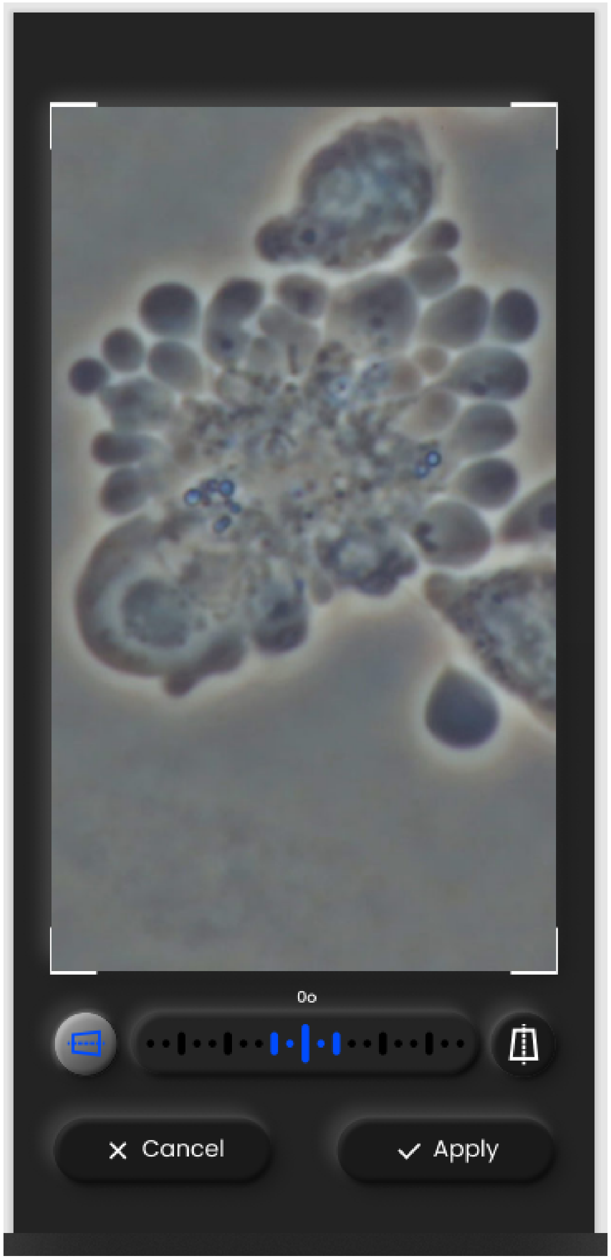
Figure 6.1.5.1 Profile and settings UI 1

Figure 6.1.5.2 Profile and settings UI 2

The above images displays the user profile section of the app's user interface. This section allows users to view their personal information, such as their name and email address, as well as their saved videos and photos. Users can access this section by clicking on their profile icon, as shown in the image. The user profile section also enables users to customize their app settings. By selecting the "Settings" option, users can adjust various app features, such as the app's color scheme, font size, and notification settings, as shown in the image above. This customization allows users to personalize the app to their liking and optimize their user experience

Figure 6.1.6.1 Image editing UI design 1

Figure 6.1.6.2 Image editing UI design 2



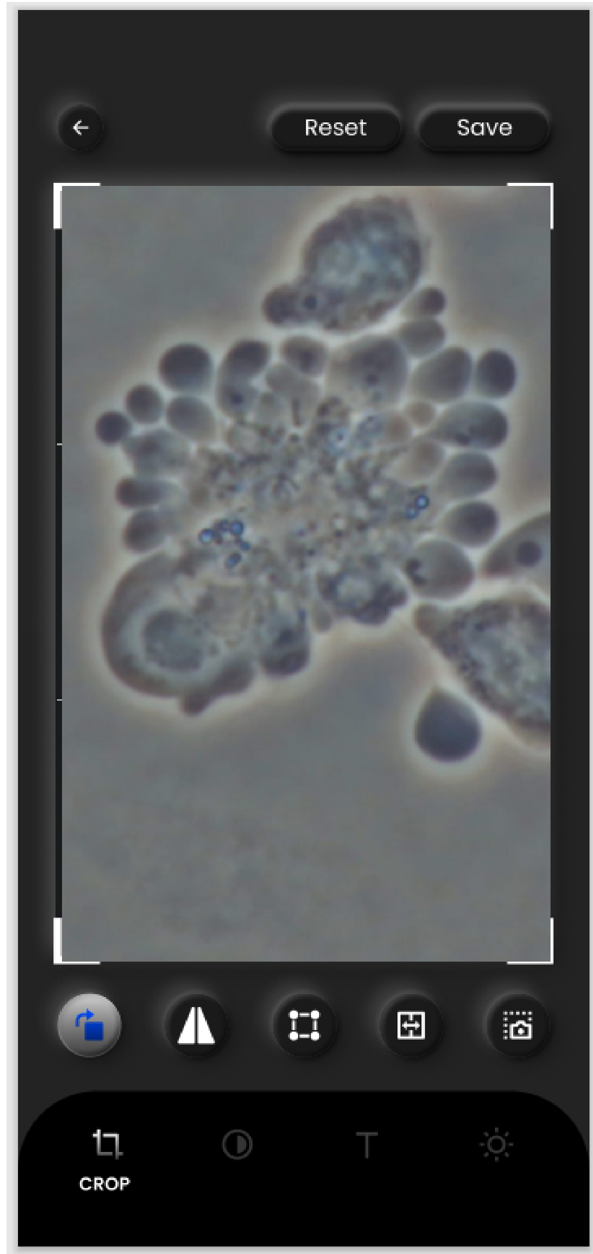


Figure 6.1.7.1 Image editing UI design 3 Figure 6.1.7.2 Image editing UI design 4

The above images show the user interface for editing microscope images within the app. Users can access this feature by selecting a saved image from their database, as shown in the image. The image editing interface provides users with a variety of editing tools to enhance their microscope images. These tools include the ability to adjust the image's brightness, contrast, and saturation, as well as apply various filters and effects. Users can also crop and resize their images to focus on specific areas of interest. Once users are satisfied with their edited image, they can save it back to the database or share it with others directly from the app. This feature allows users to easily edit and enhance their microscope images without having to transfer them to a separate editing software.

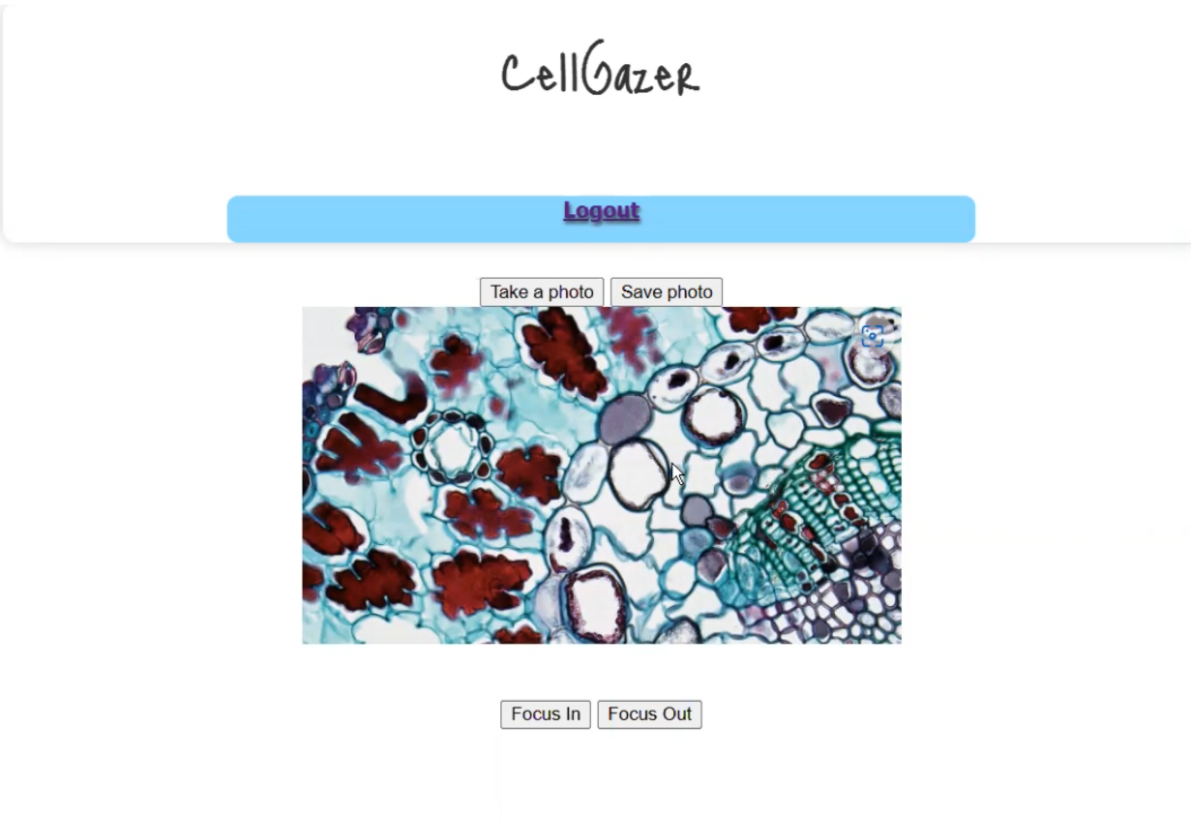


Figure 6.1.8 Log out page

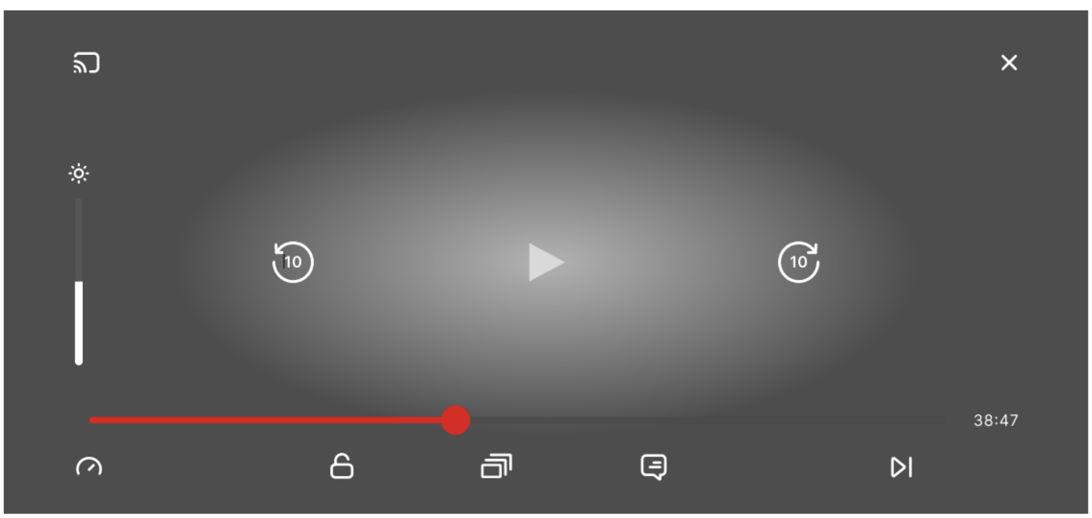


Figure 6.1.9 Video Playback Design Interface 1

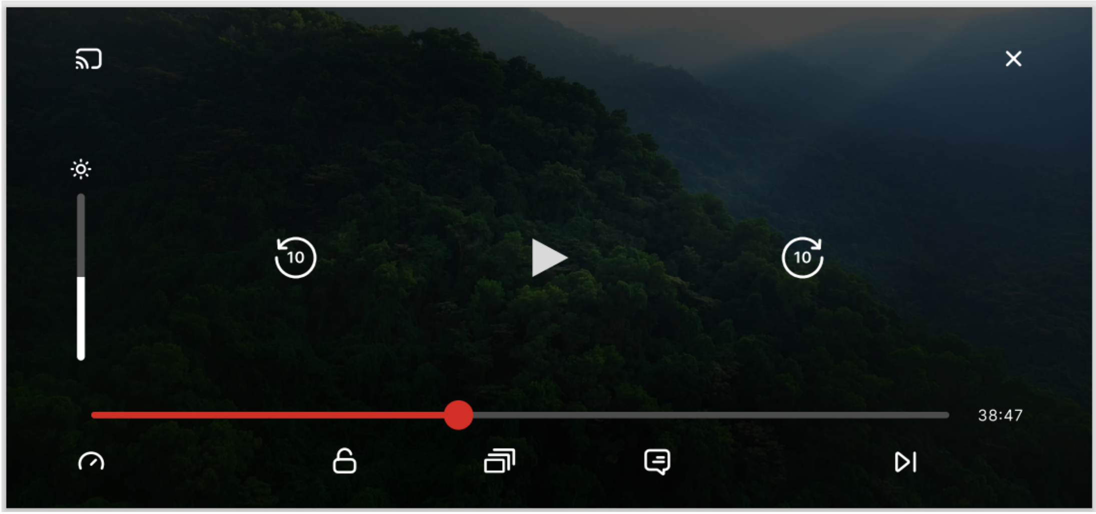
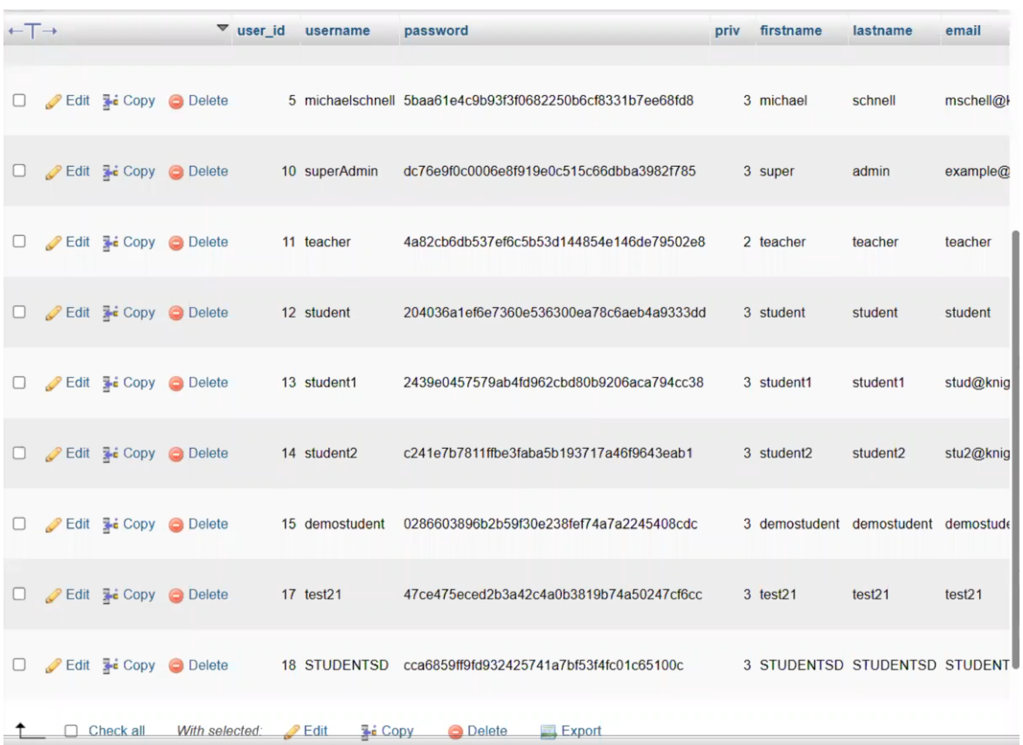


Figure 6.1.10 Video Playback Design Interface 2

The above images show the user interface for streaming live microscope video within the app. Users can access this feature by connecting their smartphone or tablet to a microscope camera and selecting the "Live Video" option within the app, as shown in the image. The live video interface provides users with a clear and detailed view of the microscope's current field of view. Users can adjust the zoom and focus of the microscope camera directly within the app, as well as record the live video stream for later analysis.

6.2 Database Architecture



←T→	user_id	username	password	priv	firstname	lastname	email
Edit Copy Delete	5	michaelschnell	5baa61e4c9b93f3f0682250b6cf8331b7ee68fd8	3	michael	schnell	mschell@l
Edit Copy Delete	10	superAdmin	dc76e9f0c0006e8f919e0c515c66dbba3982f785	3	super	admin	example@
Edit Copy Delete	11	teacher	4a82cb6db537ef6c5b53d144854e146de79502e8	2	teacher	teacher	teacher
Edit Copy Delete	12	student	204036a1ef6e7360e536300ea78c6aeb4a9333dd	3	student	student	student
Edit Copy Delete	13	student1	2439e0457579ab4fd962cbd80b9206aca794cc38	3	student1	student1	stud@knig
Edit Copy Delete	14	student2	c241e7b7811ffbe3faba5b193717a46f9643eab1	3	student2	student2	stu2@knig
Edit Copy Delete	15	demostudent	0286603896b2b59f30e238fef74a7a2245408cdc	3	demostudent	demostudent	demostude
Edit Copy Delete	17	test21	47ce475eced2b3a42c4a0b3819b74a50247cf6cc	3	test21	test21	test21
Edit Copy Delete	18	STUDENTSD	cca6859ff9fd932425741a7bf53f4fc01c65100c	3	STUDENTSD	STUDENTSD	STUDENT

Check all With selected: Edit Copy Delete Export

Figure 6.2.1 Database Architecture

The Cell-Gazer app will have a backend database to store information about registered users, their uploaded photos, and videos. The database is designed to be relational with four tables: "users", "photos", "videos", and "editedvideos". The "users" table will store user information, such as name, email, password, account ID, account level, profile photo, and account creation date. This table will be used to authenticate users and connect them to their uploaded content.

The "photos" table will store information about photos uploaded by users. This includes metadata such as the photo ID, email of the user who uploaded the photo, account ID, date the photo was taken, location where the photo was taken, photo number, editing type, and the ID of the original photo. The "videos" table will store information about videos uploaded by users. This includes metadata such as the video ID, email of the user who uploaded the video, account ID, date the video was taken, location where the video was taken, and video number. The "editedvideos" table will store information about edited versions of videos uploaded by users. This includes metadata such as the video ID, email of the user who uploaded the edited video, account ID, date the edited video was created, location where the edited video was created, video number, editing type, and the ID of the original video. The database will be implemented with MySQL, and queries will be made using SQL. The Cell-Gazer app will use the database to provide a seamless and secure user experience, allowing users to upload, share, and edit photos and videos with ease. The app will be designed to interact with the database to retrieve and display user data, making it simple for users to manage their content. Below is the Entity Relationship (ER) Diagram describing the database.

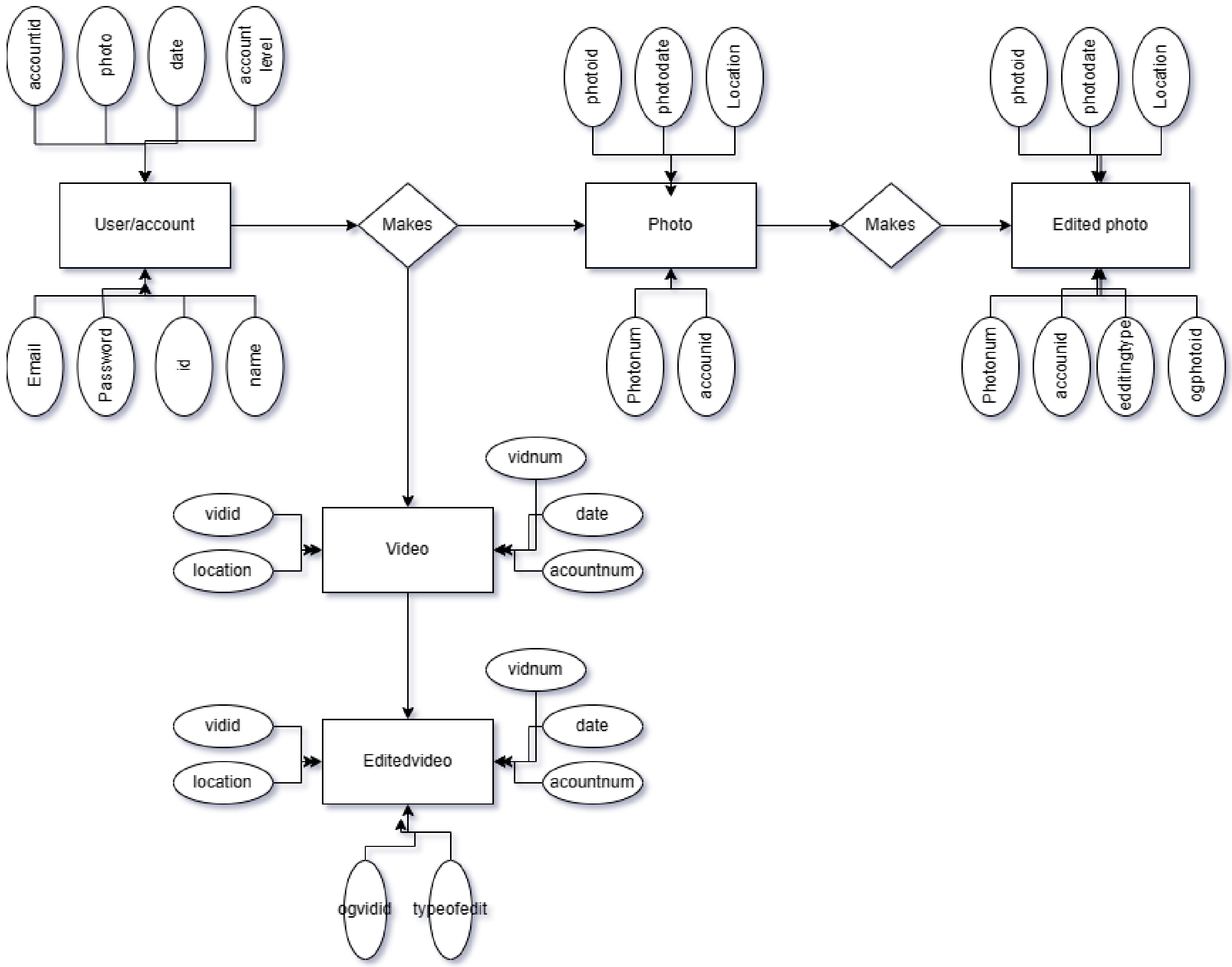


Figure 6.2.2 Entity Relationship Diagram describing the database

The below ERD shows the relationship between the four main entities in the "cell-gazer" app. The "users" entity represents the users of the app who can upload and edit their photos and videos. The "photos" entity represents the photos uploaded by the users, and the "videos" entity represents the videos uploaded by the users. The "edited videos" entity represents the videos that have been edited by users, including the edited version and the original video.

The "users" entity has several attributes such as ID, name, email, password, account ID, account level, photo, and date. The "ID" attribute is the primary key for the entity, and is automatically incremented. The "name" attribute stores the user's name, while the "email" attribute stores the user's email address. The "password" attribute stores the user's password in a hashed format to ensure security. The "account ID" attribute stores a unique identifier for the user's account, and the "account level" attribute stores the user's level of access to the app. The "photo" attribute stores a link to the user's profile photo, and the "date" attribute stores the date the user created their account.

The "photos" entity has attributes such as photo ID, email, account ID, photo date, location, photonum, editingtype, and OG photo ID. The "photo ID" attribute is the primary key for the entity, and is automatically incremented. The "email" attribute stores the email address of the user who uploaded the photo, and the "account ID" attribute stores the unique identifier for the user's account. The "photo date" attribute stores the date the photo was uploaded, while the "location" attribute stores the location where the photo was taken. The "photonum" attribute stores a unique identifier for the photo. The "editingtype" attribute stores the type of editing that has been applied to the photo, such as filters or cropping. The "OG photo ID" attribute stores the photo ID of the original photo if this photo was edited from an existing photo.

The "videos" entity has attributes such as video ID, email, account ID, video date, location, and vidnum. The "video ID" attribute is the primary key for the entity, and is automatically incremented. The "email" attribute stores the email address of the user who uploaded the video, and the "account ID" attribute stores the unique identifier for the user's account. The "video date" attribute stores the date the video was uploaded, while the "location" attribute stores the location where the video was taken. The "vidnum" attribute stores a unique identifier for the video.
The "edited videos" entity has attributes such as video ID, email, account ID, video date, location, vidnum, editingtype, and OG video ID. The "video ID" attribute is the primary key for the entity, and is automatically incremented. The "email" attribute stores the email address of the user who edited the video, and the "account ID" attribute stores the unique identifier for the user's account. The "video date" attribute stores the date the edited video was created, while the "location" attribute stores the location where the video was created. The "vidnum" attribute stores a unique identifier for the edited video. The "editingtype" attribute stores the type of editing that has been applied to the video, such as trimming or adding filters. The "OG video ID" attribute stores the video ID of the original video if this edited video was created from an existing video.

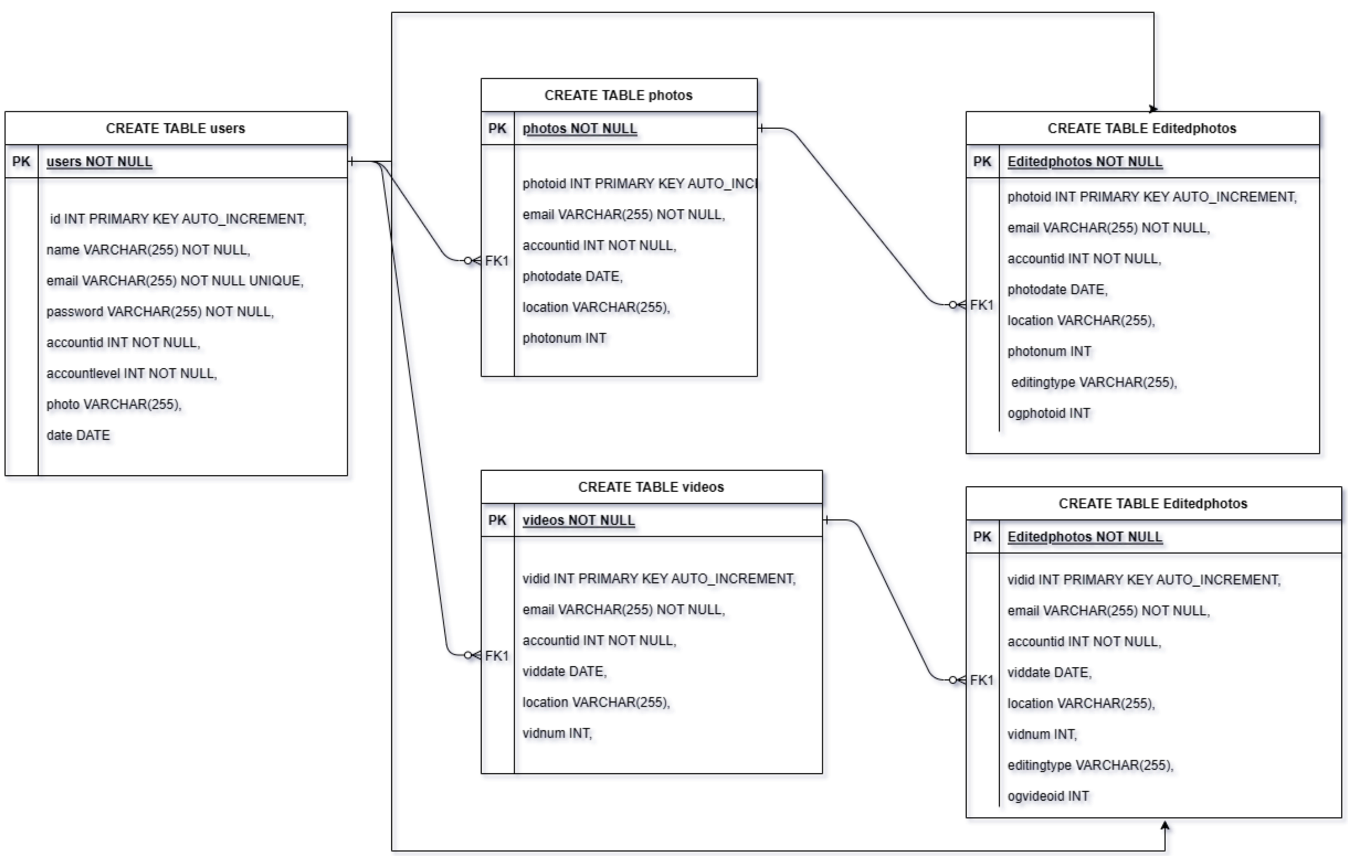


Figure 6.2.3 Entity Relationship Diagram

6.3 LED Control Backend Design
The code to control the LED PCB is part of an overall serial driver code that controls the lights and motors on the microscope. The code on the AtMega2560 takes in a string from the raspberry pi that dictated the command for each operation to complete. The commands for the LEDs are “White_HIGH”, “White_LOW”, “UV_HIGH”, “UV_LOW”, “IR850”, “IR940”, and “LEDOFF”, which are transmitted over UART. The White_HIGH command turns on all four white LEDs on the board, while the White_LOW command only turns on two of the LEDs on the board and turns off two of them if all four of the lights are already on. The UV_HIGH and the UV_LOW commands work the same with the UV lights on the board. The IR850 command turns on the 850nm IR lights, and the IR940 turns on the 940nm IR lights.

6.4 Motor Control Backend Design
The code for controlling the motors on the microscope includes four pole arrays and a stepper driver function for each motor. Each also has a goToAngle variable and a correction variable to precisely control the positioning of each motor. The goToAngle and correction are used to calculate the number of steps that the motor has to take. When the appropriate command is passed to move one of the motors, the code initiates a loop that cycles through the pole arrays and passes them to the stepper driver functions, which in turn tells the motors which steps to take and how many steps to take. The motors also take in a delay value, which dictates the speed at which the motors rotates. The delay value can be either 3, 2 or 1, where 1 is the fastest speed setting.

The various commands to move the motors are “OBJ40”, OBJ100”, “STGUP”, and “STGDOWN”. The OBJ40 commands checks for a variable called “activelens” which tells the code which objective lens is actively being used. If activelens is set to 40, that means that the 40x objective lens is currently in use and the turntable motor will not move. However, if the activelens variable is not set to 40, then the motor will turn 180 degrees, aligning the 40x objective lens to the optical train. The OBJ100 command works in the same way, and checks if the activelens is set to 100. The STGUP and STGDOWN commands are used to move the specimen stage of the microscope up and down. The goToAngle of this motor is set to 5 degrees, which moves the stage about half a millimeter up or down. It also checks a variable named “level” which stops the stage from moving too high or too low. Everytime the stage is moved up the level variable is incremented by one, and every time it is moved down the level is decremented by 1. The level ranges from 0 to 15, meaning that the stage can make 15 steps up, half a millimeter each, before it is forced to stop.

6.4.1 MCU & Raspberry pi 4 Communication
In order to control the LED and motor systems, we will use a Mega2560 MCU in addition to our primary Raspberry pi 4 development board in order to reduce the load on the raspberry pi. To achieve this, we will set up a bidirectional serial communication connection between the Raspberry Pi and the MCU. This is done via the USB port present on the Raspberry Pi and the serial port on the Mega2560.

On the Mega2560's end, we make use of the arduino IDE to easily write and upload our C++ code to the MCU. Serial communication on the Mega2560 can be easily initiated with the Serial.begin() function, which takes in an argument of the baud rate of the communication. In this case we used a baud rate of 9600 on both the MCU and the raspberry pi. To send information from the MCU to the raspberry pi, we made use of the Serial.println() which takes in a variable that is then sent to the raspberry pi. To read a signal coming from the raspberry pi, the function Serial.readStringUntil('\n') can be used to return the value being transmitted from the raspberry pi and assign it to a variable in the C++ code. Taking the available functions into account, we can initialize the serial communication within the setup function of our C++ code. This is then followed by the main loop of the code, which will send a signal from the Mega2560 containing the active LED mode in use or current positions of the motors. Following this command the code then awaits the response from the Raspberry pi, assigning it to a variable on the Mega2560 which can then be processed and control either the LEDs or the motors.

On the Raspberry Pi's side, we use the Thonny python IDE to write the python code to receive and send signals to and from the Mega2560. Upon importing the necessary libraries, specifically the serial library for serial communication, we initialize the serial communication with the serial.Serial() function, in which we assign the USB port of the MCU, the baud rate, and the timeout. Next, in the while loop, we use the ser.readline().decode('utf-8').rstrip function to read, decode, and trim the variable received from the Mega2560, which is then assigned to a variable in the python code. Using this variable, we define the logic that will decide what action needs to be taken for the LEDs and motors, then use the ser.write() function to send the necessary information to the Mega2560.
Using this basic software architecture for bidirectional serial communication between the Raspberry Pi and the Mega2560, we can design the basic framework of our application to control the microscope's onboard systems. However, we must take into account the limitations of serial communication, as the process of sending and receiving signals requires both systems to be perfectly synchronized. Failing to take this into account can result in the wrong information being received and sent. Specifically, the information received on one end of the serial communication might be outdated if the two systems are out of synch, and the resulting action might compromise the microscope's user interface functionality, or even damage the microscope's mechanical systems.

6.5 Raspberry pi 4 and Application Communication

The Raspberry Pi will be both sending and receiving information from the application. On a very basic level, the Mega2560 will get information from the motors and LEDs, such as the position of the motors and which LEDs are active, and send this information to the raspberry pi. From the raspberry pi, this information will then be sent to the database, which will contain a table storing all the most recent information provided of the microscope's systems. The application will then be able to pull this information from the database and display it to users via the application. Once the user inputs a command from the application, such as changing the LED mode or taking a picture, the application will update the information in the database. On the raspberry pi, the php script used to interact with the database will be able to pull this updated information from the database and pass it on the Mega2560 to make any adjustments. If the user is capturing an image or video with the camera module, the Mega2560 will not receive any new information as the camera is on the raspberry pi. Once the user's action has been executed on the microscope, the raspberry pi will receive this updated information from the Mega2560, or as an image from the camera module. The information regarding the microscope's systems will be sent to the database via the PHP script and update the information on the table storing the microscope's systems information. Pictures and videos will also be sent to the database, and will be added to the image or video database associated with the user's account.

Section 7 Integration testing and PCB

7.0 Integrated testing

The microscope, raspberry pi 4, raspberry pi camera module version 2, and LEDs were set up and tested together. First the microscope was set up as before with the objective lens on one end and the eyepiece lens on the other. On the back of the eyepiece lens we attached the raspberry pi camera module v2 to stream and take pictures of two samples. We used a streaming mode of the raspberry pi camera module to set up clear images. Behind each sample were the four types of LEDs we had tested before, white, ultraviolet, infrared at 850 nm, and infrared at 940 nm. For the two samples, we chose grid paper for sample one and tissue paper for sample two. Found below are some figures that show the whole setup and some samples being lit up using different LEDs.

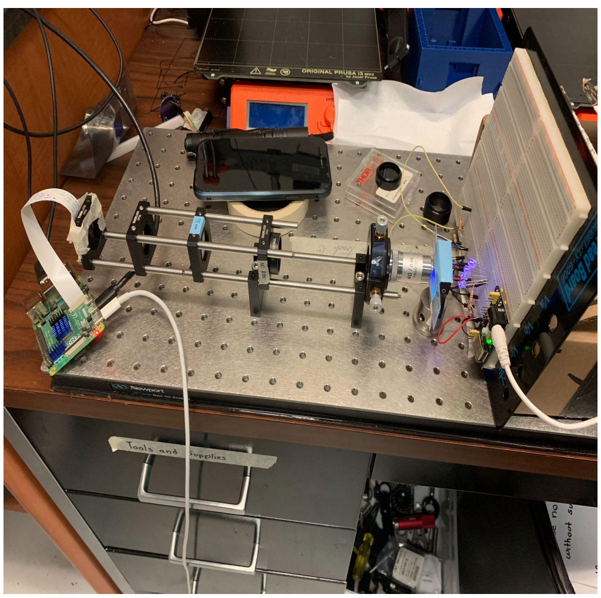


Figure 7.0.1 Integrated Microscope Setup

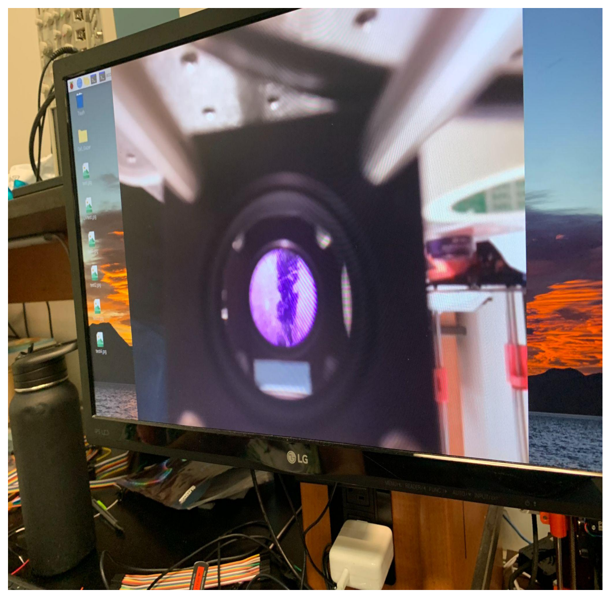


Figure 7.0.3 Grid paper sample with UV LEDs

The grid paper sample was chosen because of its small intricate details that could be shown with our microscope setup. The sample could be clearly seen on the monitor from the raspberry pi camera module. Each line drawn on the grid paper was roughly 1 mm apart and the microscope could see the small imperfections on the printed line. The grid paper sample shows how powerful the eyepiece and objective lenses are. The different LEDs gave a slightly different perspective on the sample as shown in the figures above.

Below are the figures we captured for the second sample using the raspberry pi camera module. The second sample was tissue paper and with our microscope we can see some of the individual fibers that make up the tissue. We used four different LEDs just like before, white, ultraviolet, 840 nm, and 950 nm LEDs. Each type of LED was set up in parallel and in groups of four because this will mimic our final design, and mimics the initial design found in figure 3.2.3.1. The raspberry pi 4 was hooked up to a monitor so we could see the images in real time and adjust the space between the samples and objective lens until we were able to get clear images. The figures below were then captured with a mobile phone camera.

Figure 7.0.5 Tissue paper sample with white LEDs

Figure 7.0.6 Tissue paper sample with UV LEDs

7.1 Results from integrated Testing

Together we tested the raspberry pi, the raspberry pi camera module v2, our microscope lenses, objective lenses, and finally the four types of LEDs. From these parts being tested in one system we found that the image quality of the camera is very good. The magnification of the lenses is also allowing us to see the fibers in the tissue paper as well as the little imperfections in the grid paper. The LEDs we used are also very bright and can light up the samples very well even with ambient light around the microscope.

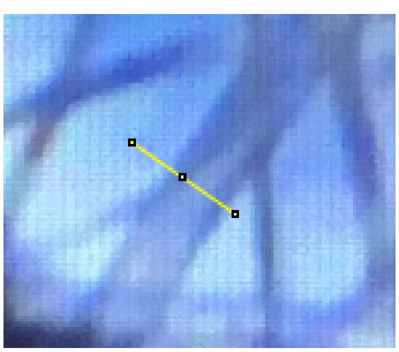


Figure 7.1.1 cropped paper tissue

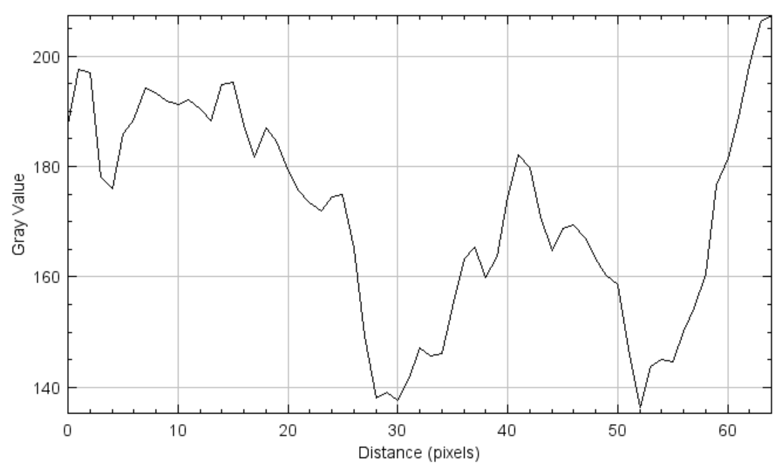


Figure 7.1.2 gray value profile of the selected line

The place where the line marks in Fig. 7.1.1 can be viewed clearly by the microscope, so we chose this line to plot an intensity profile (Fig. 7.1.2). The width of one fiber of the paper tissue takes up 20 pixels in the image plane. One pixel size is 1.12 μm. Thus, the width of the fiber of the paper tissue can be calculated as $20x1.12\ \mu m = 22.4\ \ \mu m$. This is a very successful image testing.

There are, however, some things which need some improvement such as camera field of view, focusing and the crashing issues we encountered with the raspberry pi. Since the camera module has a wide field of view, it also captures the microscope setup itself as well as the background. This can be seen in figure 7.0.5 and figure 7.0.6. To rectify this, we plan on closing off or blocking out the background so the camera can capture just the sample itself. Another option we could explore here could be a command we give to the raspberry pi camera module to zoom into the image that it receives. The other issue we had while integrating the camera with the microscope was the focus. It took a while to have a clear image and we had to move the sample back and forth in order for the camera to focus in on the sample. This focus time creates a time waste for the user, so to rectify this we plan on building the vertical focusing system over the two week break.

The last issue we ran into while running the raspberry pi 4 with the camera module was streaming time. We were able to stream the live feed to a desktop monitor for around 10 minutes before the raspberry pi 4 would crash and had to be rebooted. To rectify this, we have tried applying heatsinks to the appropriate chips and monitoring temperature. To further cool the system we are looking into a cooling fan as well. This crashing issue could be further fixed with a limited streaming mode where you may use the streaming mode for a maximum of 10 minutes at a time. Another mode we can add is an image capture-only mode to help with the overuse of the raspberry pi. Capturing images alone is very easy and a lot less demanding on the raspberry pi.

7.2 Main PCB

The main PCB onboard our microscope will be responsible for receiving and sending information to and from the Raspberry Pi in order to properly adjust the LEDs and motors. The main pcb design takes into account the power needs of the Mega2560 MCU to avoid damaging the hardware, as well as the communication needs between the MCU and the Raspberry Pi. Below are the figures illustrating our design on a PCB.

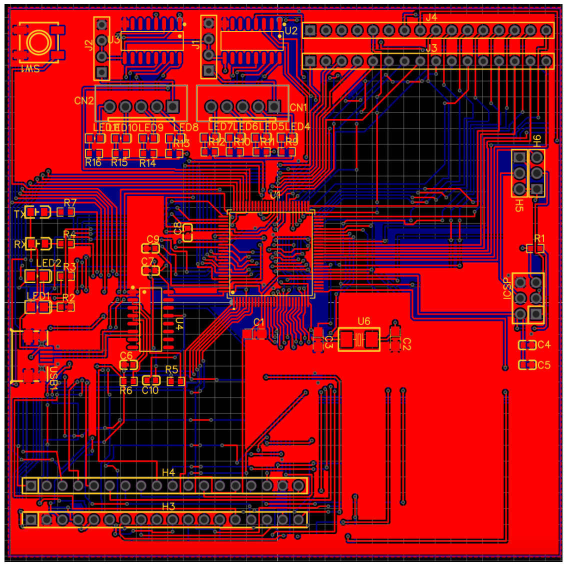


Figure 7.2.1 Final draft main PCB design.

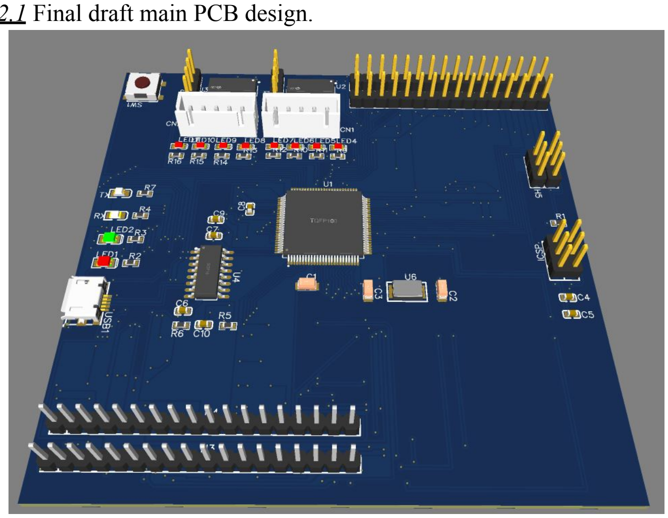


Figure 7.2.2 Top view of final draft of main PCB design.

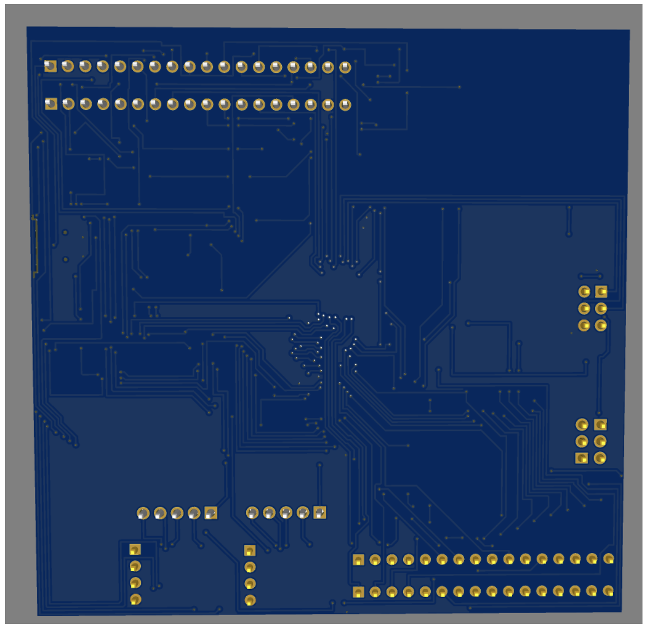


Figure 7.2.3 Bottom view of final draft of main PCB design

7.3 LED PCB

The PCB we designed for housing the LEDs on the base of the microscope will be responsible for providing lighting to the specimen being viewed through the microscope. The LEDs on the board are of three different varieties: white light, infrared light, and ultraviolet light. With these LEDs oriented in a circular shape, the subject of the microscope can be observed in three different spectrums of observable light. The figures below illustrate our design on the board.

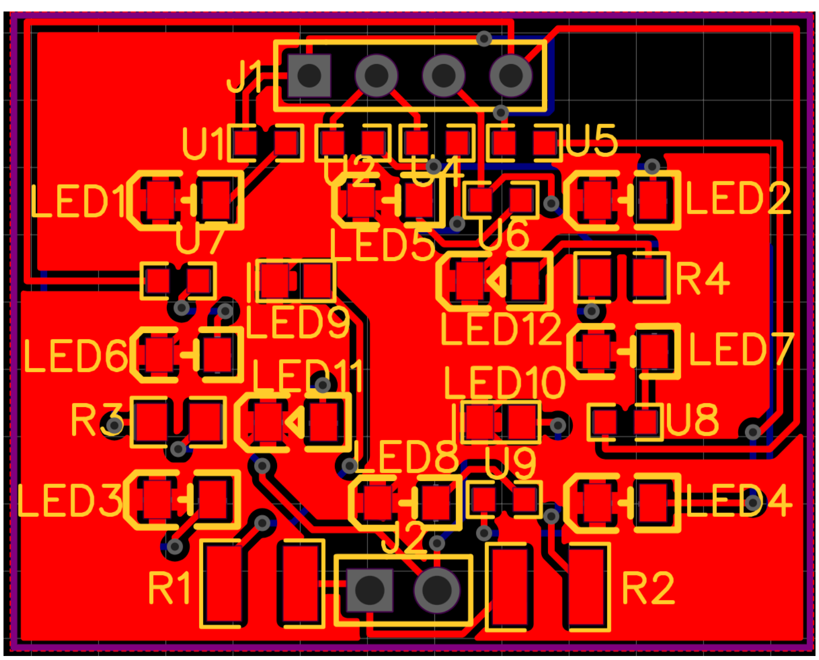


Figure 7.3.1 LED PCB final draft.

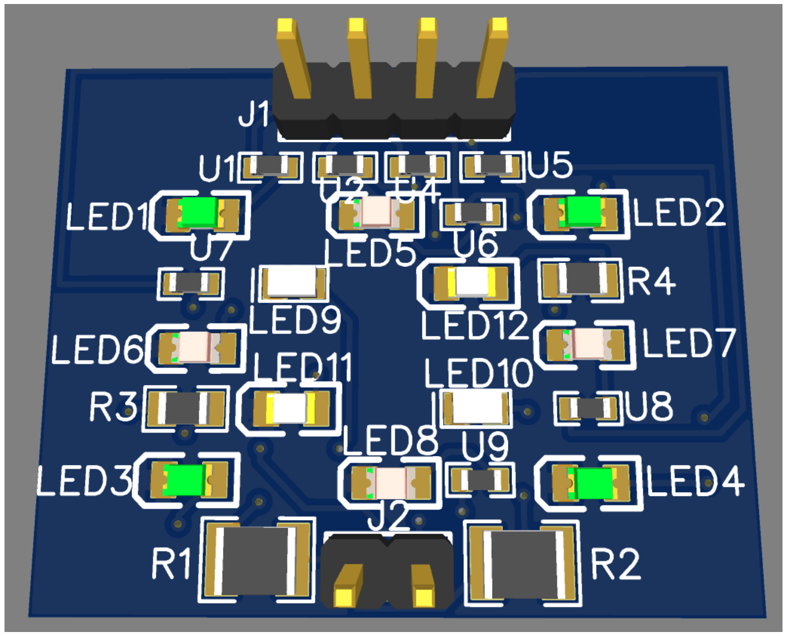


Figure 7.3.2 Top view of the LED PCB final draft.

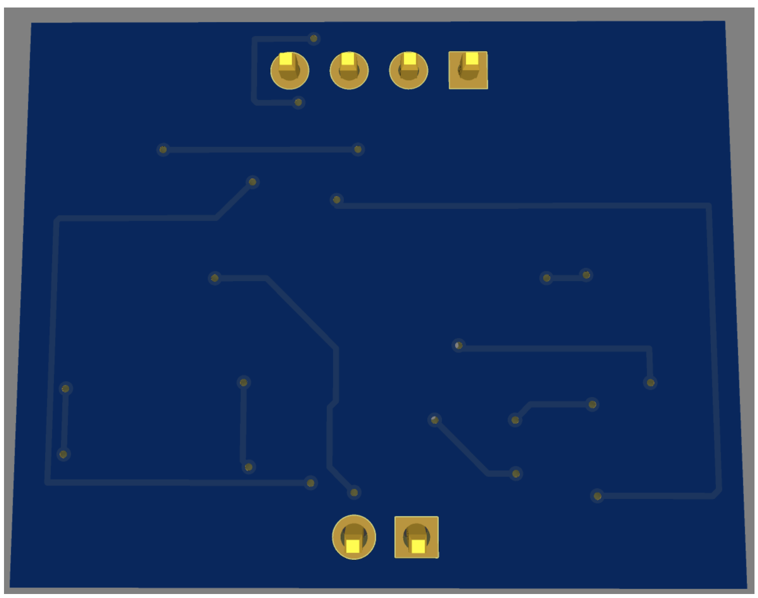


Figure 7.3.3 Bottom view of the LED PCB final draft.

7.4 Voltage Regulator PCB

The first regulator we have designed is a simple 7.4 volt input to 5 volt output buck converter which also delivers 4 amps to the raspberry pi and main PCB. The PCB was designed in such a way that the input and output loops were minimized to reduce the chance of parasitic inductance. Below are the figures. This is a rough draft of what we plan on implementing in senior design 2.

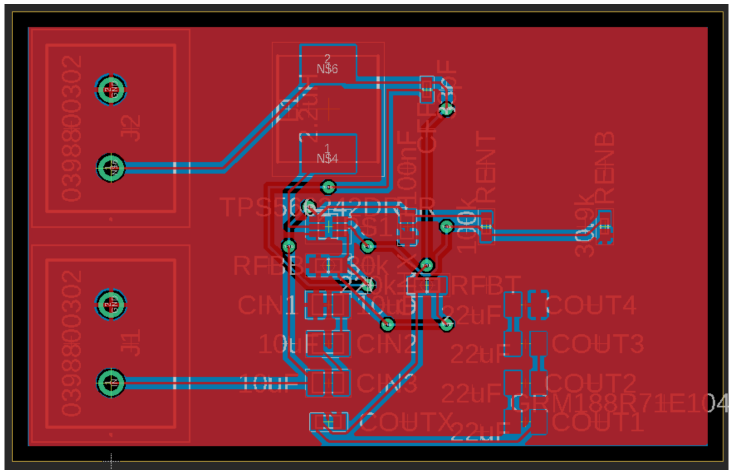


Figure 7.4.1 Rough draft PCB design of the voltage regulator as of senior design 1

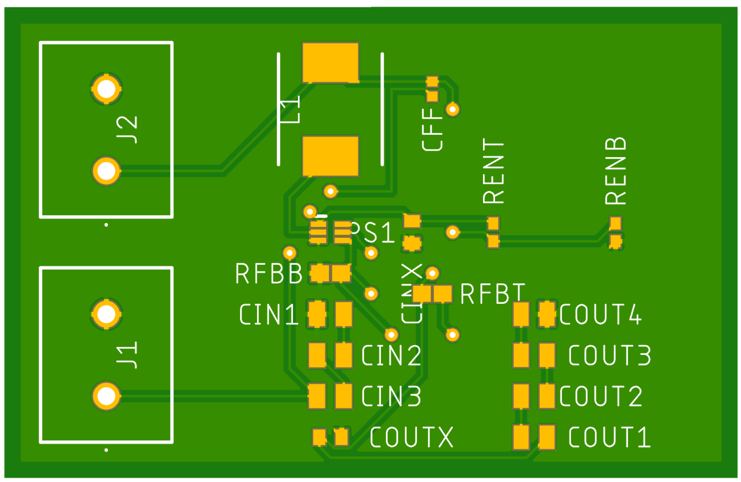


Figure 7.4.2 Top view of Rough draft PCB design of the voltage regulator as of senior design 1

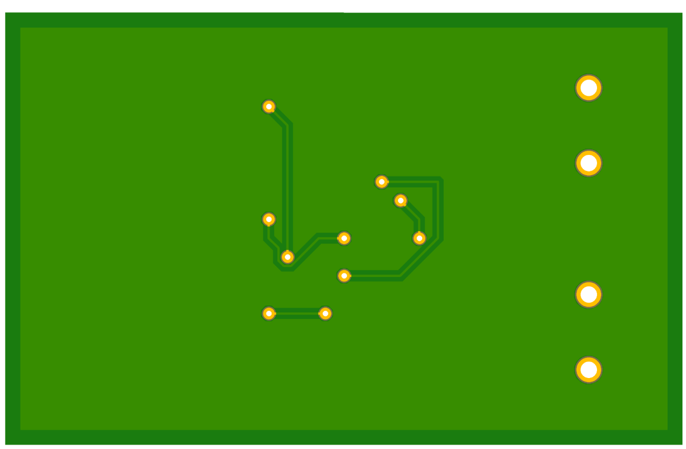


Figure 7.4.3 Bottom view of Rough draft PCB design of the voltage regulator as of senior design 1

Section 8 Testing

8.0 Breadboard Testing

All electrical components used in our design have been tested on a breadboard to measure the desired voltage and current levels. Testing all these components also allows us to troubleshoot any issues the part has before moving on to the final stage of development. In the following section our team has conducted tests on the 28BYJ-48 stepper motor, the Raspberry Pi Camera module V2, white LEDs, infrared LEDs, and UV LEDs.

8.1 Stepper Motor Testing

The 28BYJ-48 Stepper motor and driver were set up on a breadboard to measure the voltage level and current. The circuit contained a development board, three buttons, the motor driver and the stepper motor itself. The development board was connected to a computer to compile the code and the power supply module was connected to an AC adapter to provide power to the rail on the breadboard. 5 volts was supplied to the breadboard through the power supply module. No resistors were needed for the buttons as in the code they were defined as “pullup” to access internal resistors of the development board. The input voltage and current were measured using a multimeter and are shown below.

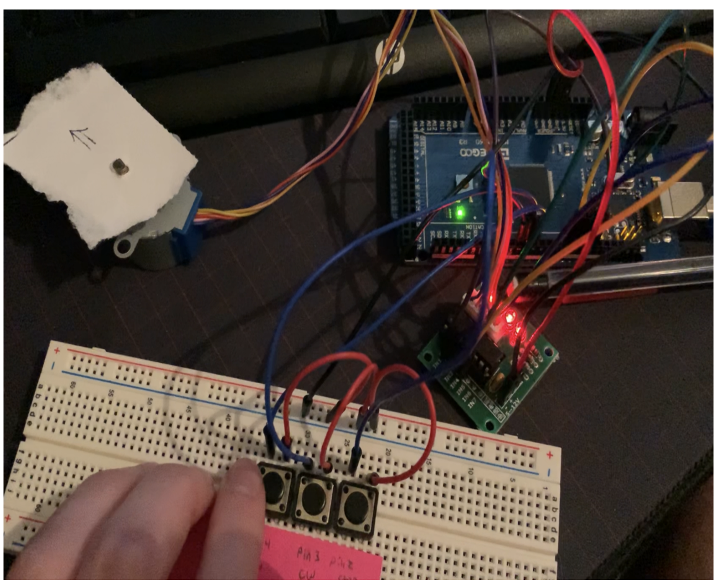


Figure 8.1.1 Breadboard test stepper motor

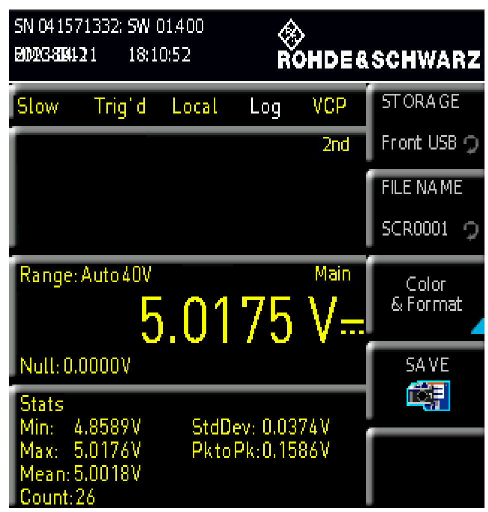


Figure 8.1.2 Breadboard testing voltage

The voltage came out to 5V as expected and the current was measured as 0.16A. Given these values our design requires a 5V power supply that can sustain 0.16A to the motors. This should be kept in mind when designing the voltage regulator, as it will need to supply not only the stepper motor but also the raspberry pi development board. The buttons on the breadboard were also programmed to turn the stepper motor to turn 180 degrees either clockwise or counter clockwise. This is setup in a way such that the code can be reused as we transfer our analog button controls into digital mobile phone controls.

8.2 LED Testing

Each type of LED was tested on a breadboard to check the minimum and maximum rated voltages and to measure their currents. We used a 100Ω resistor for all four kinds of LEDs. Testing the white LEDs we found the minimum voltage and current to be 2.5V and 0.06mA, while the maximum voltage and current was found to be 5.19V and 19.9mA. Putting four white LEDs in parallel we found that the maximum voltage was 5V at 19.7mA. For the ultraviolet LEDs we measured a maximum voltage and current at 5V and 15mA. With four ultraviolet LEDs in parallel we measured 5.4V at 19.7mA. For the 850 nanometer infrared LEDs the maximum voltage and current was found to be 3.5V at 18.7mA. Lastly the 950 nanometer LEDs maximum voltage and current was measured out to be 3.4V at 19.2mA. The images below show the working circuits of the LEDs on a phone camera. Further testing with the raspberry pi camera module will be done in the integration section. The table below summarizes the testing results.

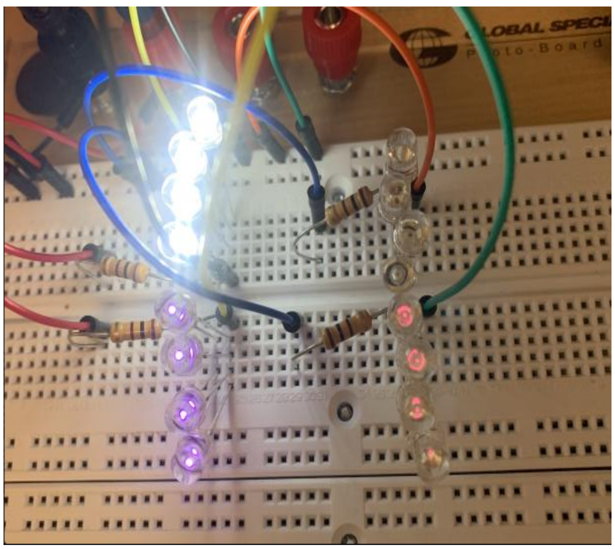


Figure 8.2.1 Breadboard testing all LEDs

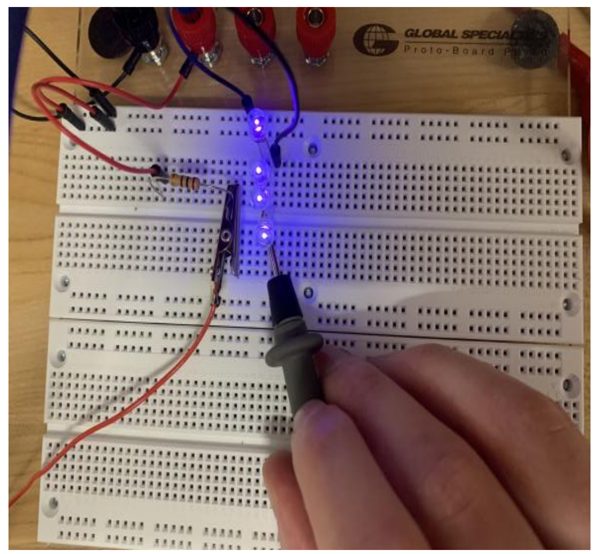


Figure 8.2.3 Breadboard testing ultraviolet LEDs

Table 23 - LED Testing Results Summarized

-	White LEDs	UV LEDs	IR LEDs (850 nm)	IR LEDs (950 nm)
Minimum Voltage	2.5V	2.4V	1.2V	1.2V
Maximum Voltage	5.19V	5V	3.5V	3.4V
Minimum Current	0.06mA	10mA	9.2mA	9.1mA

Maximum Current	19.9mA	19.7mA	18.7mA	19.2mA

8.3 Wavelength Testing

We tested the spectra for white, UV, and IR LEDs using Stellar Net spectrometer.

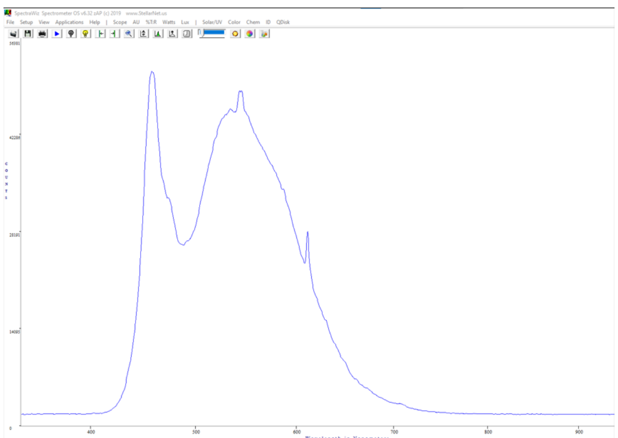


Figure 8.3.1 White LED spectrum

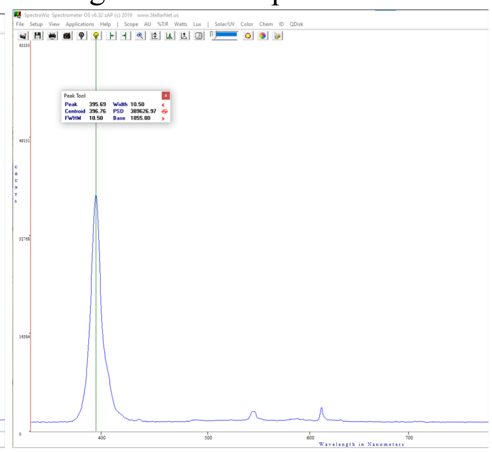


Figure 8.3.2 UV LED spectrum

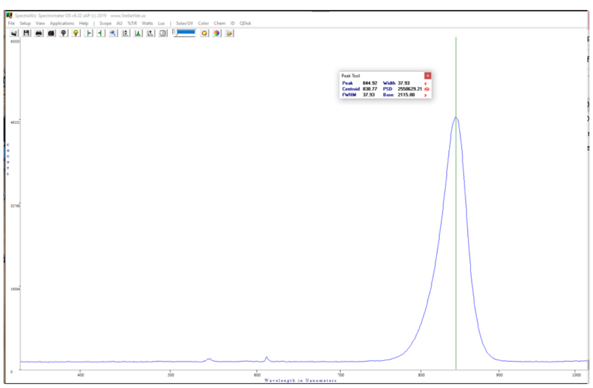


Figure 8.3.3 850 nm IR LED spectrum

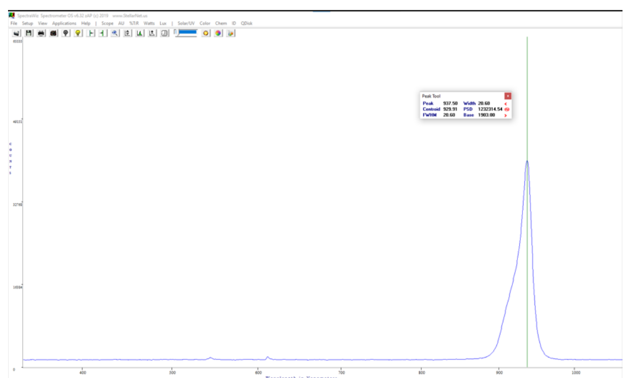


Figure 8.3.4 940 nm IR LED spectrum

The white LED spectrum is from 450 nm to 630 nm (Fig. 8.3.1). The UV LED emits at 390 nm with bandwidth of 10.5 nm (Fig. 8.3.2). 850 nm IR LED emits at 845 nm with a bandwidth of 38 nm (Fig. 8.3.3). 940 nm IR LED emits at 937.5 nm with a bandwidth of 20.6 nm (Fig. 8.3.4).

8.4 Camera Module Testing

The camera module was tested directly on the raspberry pi development board to verify its integrity and functionality on arrival. Installing the hardware was very straightforward, plugging it into the designated slot on the board. Following this I enabled the camera interface through the Raspbian operating system that is native to the board. To perform a thorough test of the camera module's functionality, I issued various commands through the terminal to enable the camera to capture a still image as well as a video. Upon inspection of the images captured, we were able to verify that the camera worked as advertised, producing infrared images in both pictures and video.

8.5 Software Testing

During the software development process, we conducted several types of testing to ensure the database, input and motor functions, and security features of the software were functioning properly. To test the database, we created a registration and login system to ensure that users' data was being stored and retrieved accurately. For the unit testing, we tested the input and motor functions to ensure that they were working as expected and without errors. Finally, we conducted security testing by implementing regular expressions to verify password strength and email verification. Through this thorough testing process, we were able to ensure that the software was reliable,

8.5.1 Database

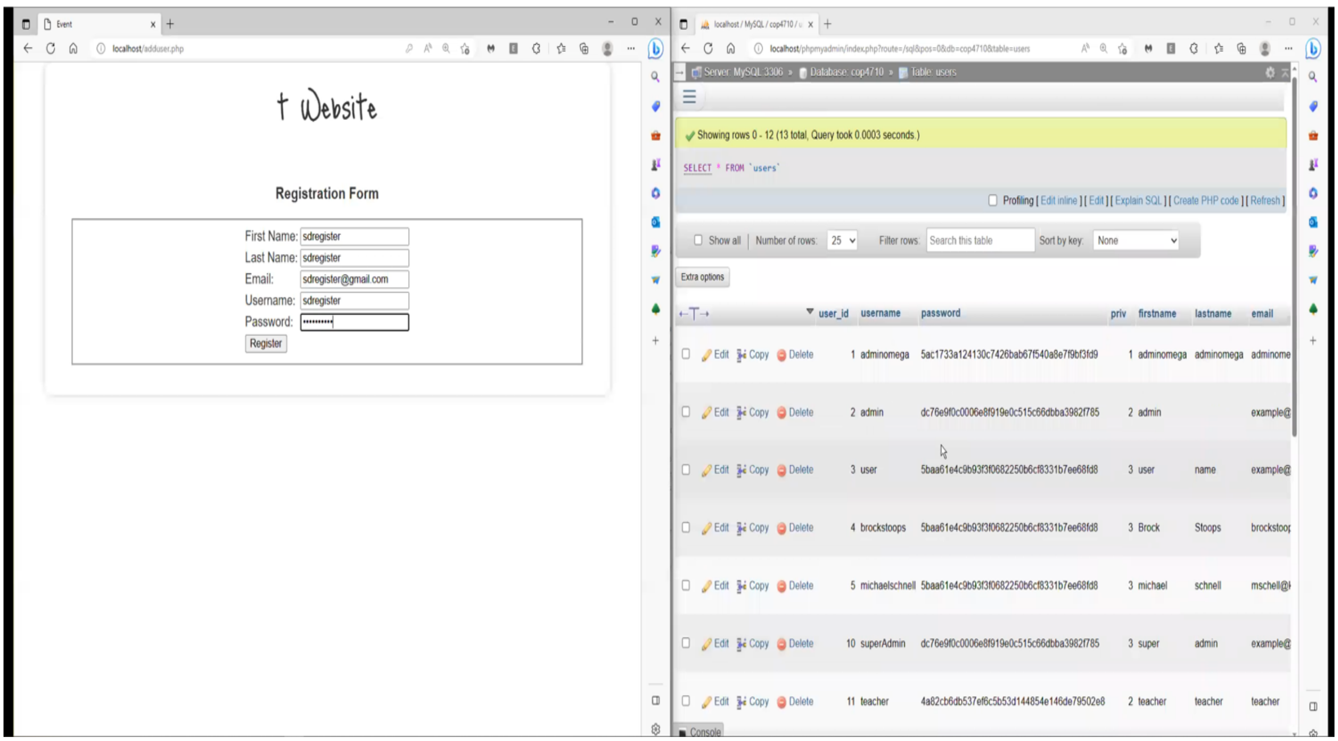


Figure 8.5.1 Database

To test the database for the entity users with the given schema, we would first create test cases for the registration and login system. For the registration system, we would test to ensure that when a user inputs their name, email, password, account level, and photo, the data is being stored accurately in the database. We would check that the id is being generated correctly, and the date is recorded correctly in the format specified in the schema.
Next, we would test the login system to ensure that the user's data is being retrieved accurately from the database. We would check that when the user inputs their email and password, the correct data is being retrieved from the database, and the user is successfully logged in. We would also verify that the accountid and accountlevel are being stored and retrieved accurately. Throughout these tests, we would ensure that the database is functioning correctly by checking that data is being stored and retrieved accurately and that the schema is being followed correctly. We would also check for any errors or exceptions that may arise during the testing process and

make sure that they are handled appropriately. By conducting these tests, we can ensure that the database is functioning correctly and that the users' data is being stored and retrieved accurately.

8.5.2 Unit Testing

As part of our software development process, we conducted unit testing on the input and motor functions of our software to ensure that they were working as expected and without errors. For the input functions, we created test cases to verify that the software was correctly handling user input. We tested different scenarios, including empty input, incorrect input formats, and input values that exceeded the software's limitations. By doing so, we were able to identify and fix any errors or issues with the input functions before deploying the software.

Similarly, for the motor functions, we created test cases to verify that the software was functioning correctly and providing the expected output. We tested different scenarios, including edge cases and situations where the input values were unexpected. By doing so, we were able to identify and fix any issues with the motor functions before deploying the software.

In addition to the input and motor function tests, we also conducted LED testing to verify the functionality of the software. This involved creating test cases for each feature of the software and verifying that each one was working as expected. We also checked for any errors or exceptions that may have been thrown during the testing process and made sure that they were handled appropriately.

Through this unit testing process, we were able to identify and fix any issues with the input and motor functions, ensuring that the software was functioning as expected and without errors. The LED testing also allowed us to verify that each feature of the software was working as intended, ensuring that our users would have a reliable and error-free experience when using our software. We also conducted unit testing on the API functions for the earlier mentioned schema of the entity users. This involved testing the API functions for each CRUD operation, including Create, Read, Update, and Delete.

For the Create operation, we created test cases to ensure that when the API receives a request to create a new user, the data is being stored accurately in the database, and the API is returning the correct response. We would also verify that the API is correctly handling any errors or exceptions that may arise during the process. For the Read operation, we created test cases to verify that the API is correctly retrieving the user's data from the database and returning it in the correct format. We would also test different scenarios, including retrieving data for a single user or multiple users, to ensure that the API is working as expected in all scenarios. For the Update operation, we created test cases to ensure that the API is correctly updating the user's data in the database and returning the correct response. We would test different scenarios, including updating a single field or multiple fields, to ensure that the API is handling all scenarios correctly. For the Delete operation, we created test cases to verify that the API is correctly deleting the user's data from the database and returning the correct response. We would also test different scenarios, including deleting a single user or multiple users, to ensure that the API is working as expected in all scenarios.

8.6 Software Testing Environment

I used AWS, Wampserver64, VSCode, and MyPHPAdmin as testing environments for the Cell Gazer application. By using these tools together, I was able to test the application in a range of scenarios and ensure that it performs well under different conditions. With AWS, I was able to create a distributed testing environment by spinning up multiple virtual machines or containers to test the application. This allowed me to monitor the application's performance in real-time and identify any potential performance issues.

Using Wampserver64, I set up a local testing environment for Cell Gazer on my Windows machine. This enabled me to debug and test new features before deploying them to a production environment. I was able to configure PHP settings and create test databases for the application with ease. VSCode was my primary code editor, and it provided me with a range of useful features for developing and testing the Cell Gazer application. It included built-in debugging tools, support for multiple programming languages, and a range of extensions that helped to customize the development environment. With VSCode, I was able to write and test code for Cell Gazer in a single integrated environment.

Finally, MyPHPAdmin was my go-to tool for managing MySQL databases. It provided me with a graphical user interface for creating and modifying database tables, and executing SQL queries. With MyPHPAdmin, I was able to create test databases for Cell Gazer and test queries to ensure that the application was able to access and manipulate data as expected. Overall, by utilizing AWS, Wampserver64, VSCode, and MyPHPAdmin as testing environments for Cell Gazer, I was able to thoroughly test the application and identify and fix any issues that arose.

9.0 Miscellaneous

9.1 Users Manual

The Cellgazer is a high-tech quad-spectrum microscope that can be controlled by a web or phone application. This innovative device allows users to easily adjust the focus of the lenses using the focus and defocus buttons located on the app. The app also offers a convenient feature that allows the user to switch between different fields of view, such as infrared, ultraviolet, and white light, with just the press of a button.

One of the standout features of the Cellgazer is its live view capability. This means that the user can stream live videos directly from the microscope's view using the app. Additionally, the app allows the user to save recordings or snapshots of what they are viewing.

Another useful feature of the app is the gallery function, which allows the user to access previously saved photos and edit them as needed. This is a convenient way to organize and manage data collected from the microscope.In addition to its many other features, the Cellgazer microscope app also allows users to edit photos directly within the app. The app includes a range of editing tools that enable users to enhance their images, adjust colors, add filters, crop and resize photos, and more.

Once the user has selected a photo from their gallery, they can begin editing by selecting the "edit" button. This opens up a range of options for modifying the image. For example, users can adjust brightness, contrast, saturation, and hue to create the desired effect. They can also add filters, such as black and white, sepia, or vintage, to give the image a unique look.
One of the most useful editing tools in the Cellgazer app is the crop and resize feature. This enables users to crop their photos to remove unwanted areas or to focus on a specific part of the image.

9.2 Predictions for Senior Design 2
This section was dedicated for senior design 2 predictions as to what the microscope project needed. The needs of Cellgazer range from hardware needs such as power consumption and software needs such as the link between the microcontroller and raspberry pi 4 are to be found out in senior design 2.

9.2.1 Predictions for Microscope
One of the predictions we have for the microscope itself is that as of now, the overall weight and size of the microscope could change. As we do more system testing we have started to build our prototype with all components working together. So far, we have tested the microscope lenses, the raspberry pi 4, the camera module and the four kinds of LEDs. We have tested out the motors and see how the vertical focusing system worked in the final version. We have two motors, one controlling the vertical focus and the other motor controlling the objective lenses. We have also tested the maximum torque we can implement in the motors to see if they produce the amount of torque that we need to control both of those systems for the microscope. Multiple biological specimens have been viewed by the microscope to determine the resolution. Implementation of two objective lenses have been done, and two modes of the microscope have been tested and modified.

9.2.2 Predictions for Hardware
All of the individual parts of the microscope's hardware are soon to be completed and testing some of these parts together has yielded promising results. We suspected that integrating the PCBs with the raspberry pi, the LEDs, and the motors have not given us too much trouble. However we predicted that the motors are the most difficult component to implement as this requires further investigation into mechanical principles that none of the members of our group is familiar with from our studies. Taking into account the progress we've made so far, assembling a working prototype of our project should not take us much time, and we suspected that a majority of our time spent in senior design 2 would be improving the prototype's portability and efficiency emphasized in our initial design, with minimal changes to electrical designs we've made thus far.

9.2.3 Predictions for Software
Both the phone and web app interfaces have been fully completed, along with the back-end development of the software. This means that all the necessary database entities have been in place, and the software has been able to store and retrieve user data as needed.

In addition to that, we also predicted that the link between the MCU and the Raspberry Pi would be established soon. This allows us to integrate the hardware components of the system with the software, making it possible to control the microscope remotely from the app.
Furthermore, the live streaming functionality from the Raspberry Pi camera module has been linked to the application. This means that users are able to view live images from the microscope on their mobile devices or desktop computers.
With the addition of these functionalities, our software became even more powerful and versatile. The LEDs control the lights in the microscope, while the motors control the focus and table.

Section 10 Results

10.0 Microscope prototype

In this section, we are going to show the actual microscope we built with labels.

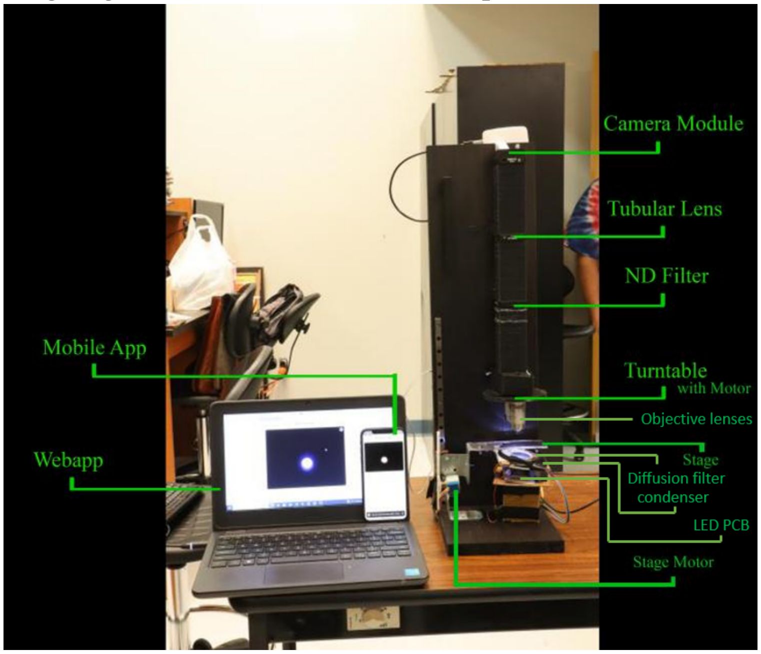


Figure 10.0.1 Front view of the microscope

As shown in Fig. 10.0.1, this is the front view of our microscope. We basically built our microscope exactly as our prototype design.

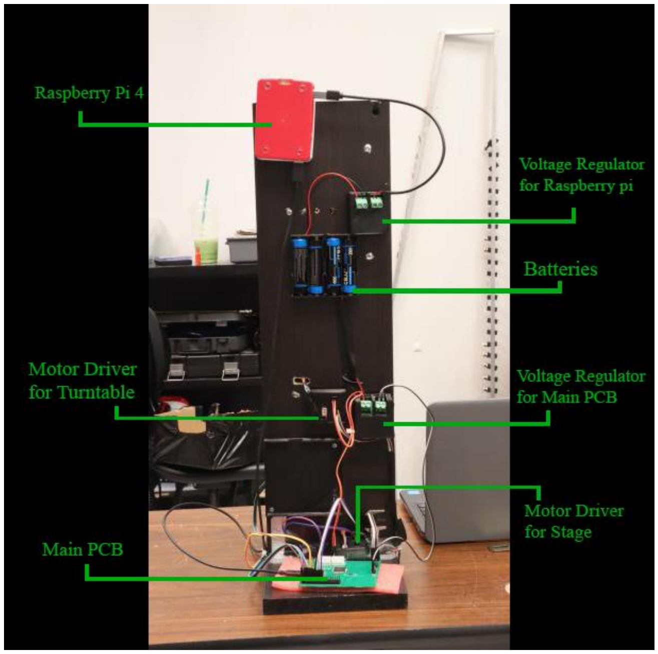


Figure 10.0.2 Back view of the microscope

As shown in Fig. 10.0.2, this is the back view of our microscope. This is how we mounted the batteries, motors, and our main PCB.

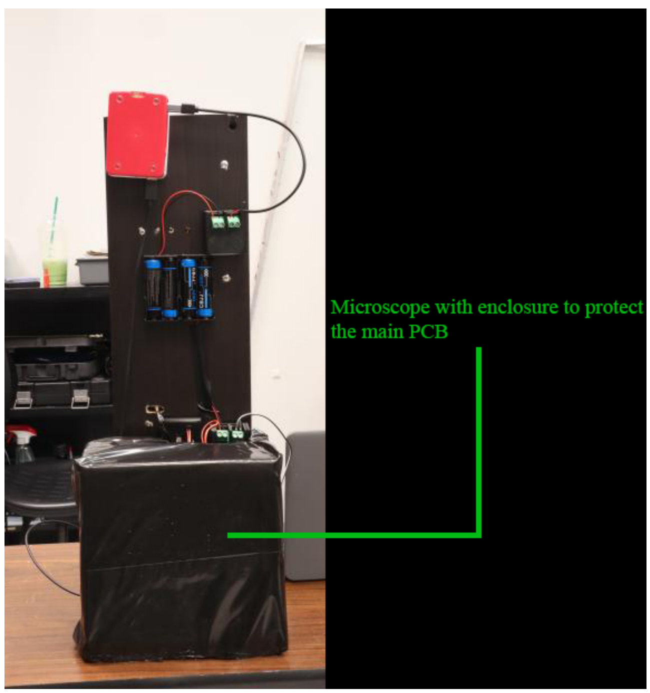


Figure 10.0.3 PCB protector

As shown in Fig. 10.0.3, we added a PCB protector to enclose the bottom of the back of our microscope to protect our main PCB.

10.1 Image results

In this section, we are going to present the results of many specimens imaged by our microscope. Based on the image results, we will discuss the advantages of using three spectra, the difference between the image results imaged with 40x and 100x objective lens, and the difference between the bright-mode and the dark-mode.

10.2 Overall performance

We purchased 50 prepared specimen kits for microscope on Amazon. It contains plants, insects, fish, animals, human tissue cell samples. Multiple specimens are tested under UV, white, IR spectra. This demonstrates the overall imaging results of our microscope under three spectra. As shown in the figure (Fig. 10.1.0.1), images of the specimens are clearly imaged by our microscope under three spectra.

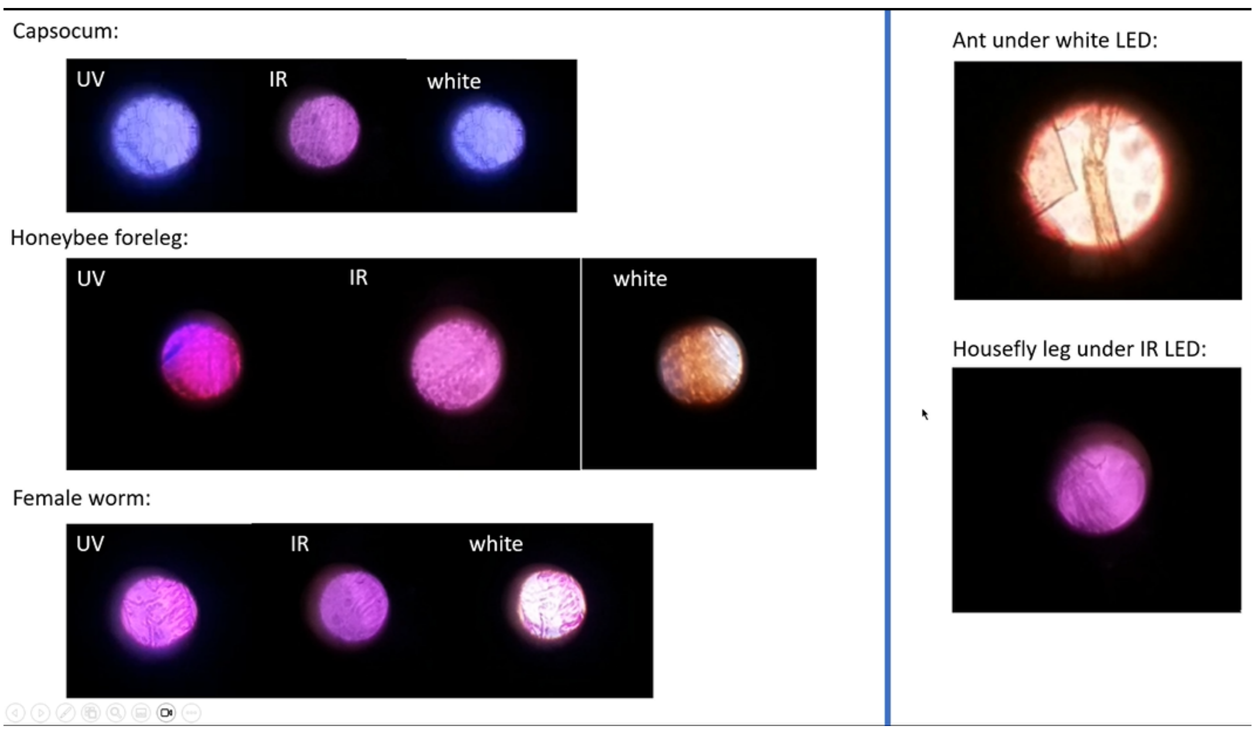


Figure 10.1.0.1 Multiple specimens under three spectra

10.3 UV vs. white vs. IR

We used three spectra to illuminate samples and compared the results according to each spectrum.

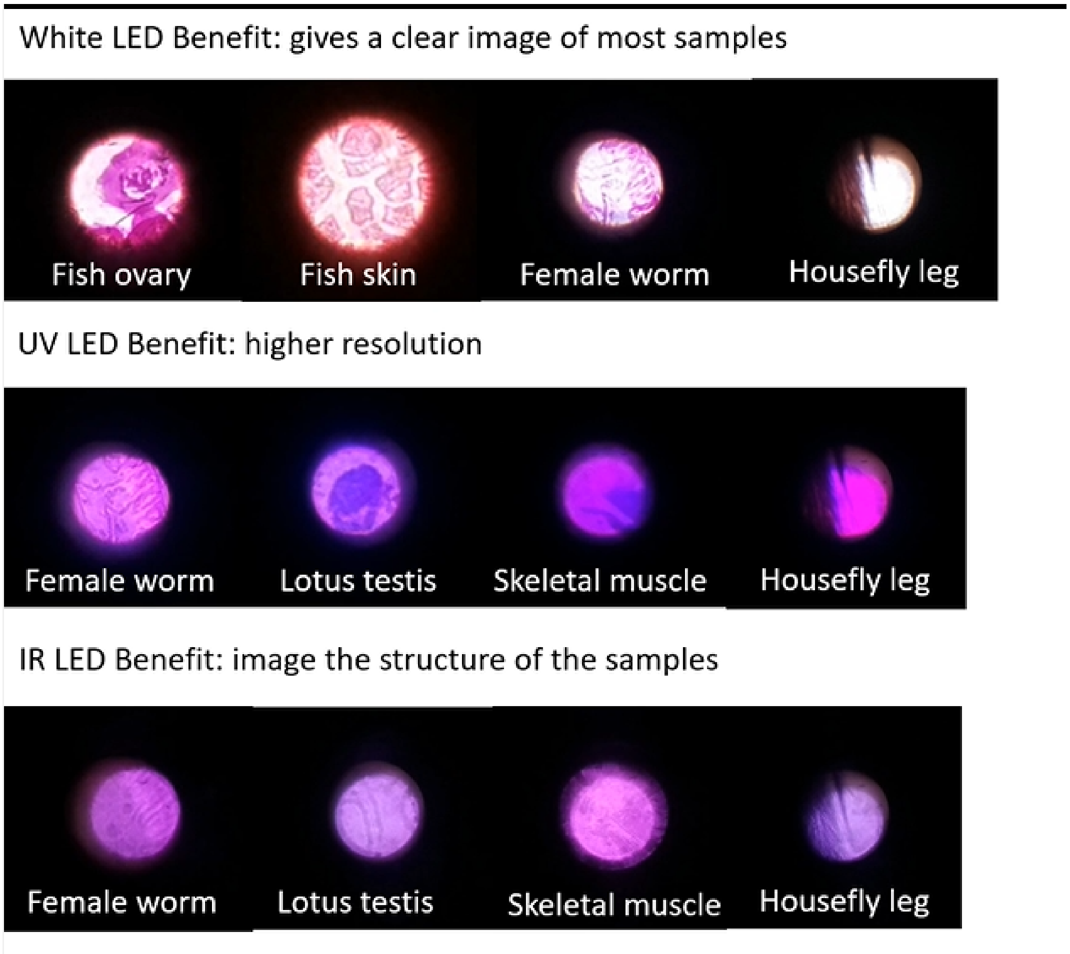


Figure 10.1.1.1 Same specimens under three spectra

As shown in the figure (Fig. 10.1.1.1), the advantage of using white LED is that it always provides enough brightness to illuminate the specimens and it is satisfactory for imaging colorful specimens; the advantage of using UV LED is that it gives a better resolution. The shorter the wavelength of the light source is, the higher the resolution can get; the advantage of using IR LED is that it is suitable for imaging the detailed structure of the specimens. However, IR LED cannot image the color of the specimens if it is used for imaging colorful specimens. We chose to use three spectra so that the user of this microscope can choose to use each spectrum depending on his/her imaging interests.

10.4 40x vs. 100x

We used the same specimens to be illuminated under the same spectrum but different magnification.

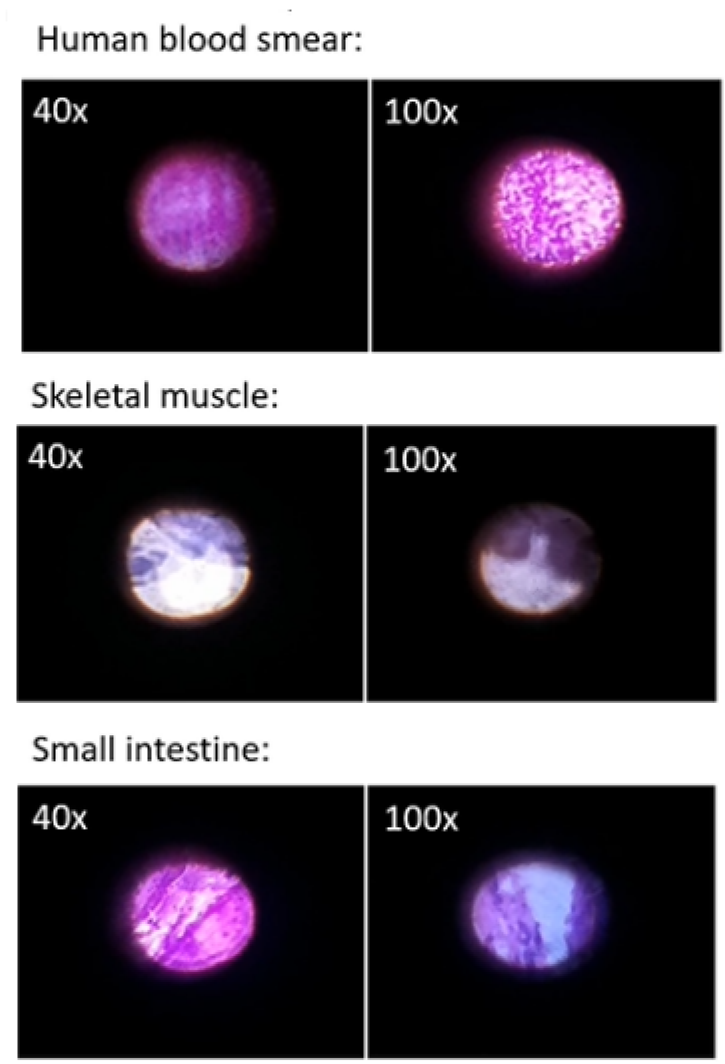


Figure 10.1.2.1 Same specimens with 40x and 100x objective lens

As shown in the figure (Fig. 10.1.2.1), the first specimen is human blood smear. With 40x objective lens, the image looks kind of blurry and with 100x objective lens, the image is much more clear; the second specimen is skeletal muscle. With 40x objective lens, the image is fine, and with 100x objective lens, the image is zoomed in and more clear; the third specimen is small intestine. With 40x objective lens, the image is very clear, and with 100x objective lens, the image is zoomed in to show more details. The user of our microscope can choose to use the 40x objective lens or the 100x objective lens based on his/her interests for the image to be zoomed in or not.

10.5 Bright-mode vs. Dark-mode Resolution

We imaged a specimen of bird feather under bright-mode and dark-mode.

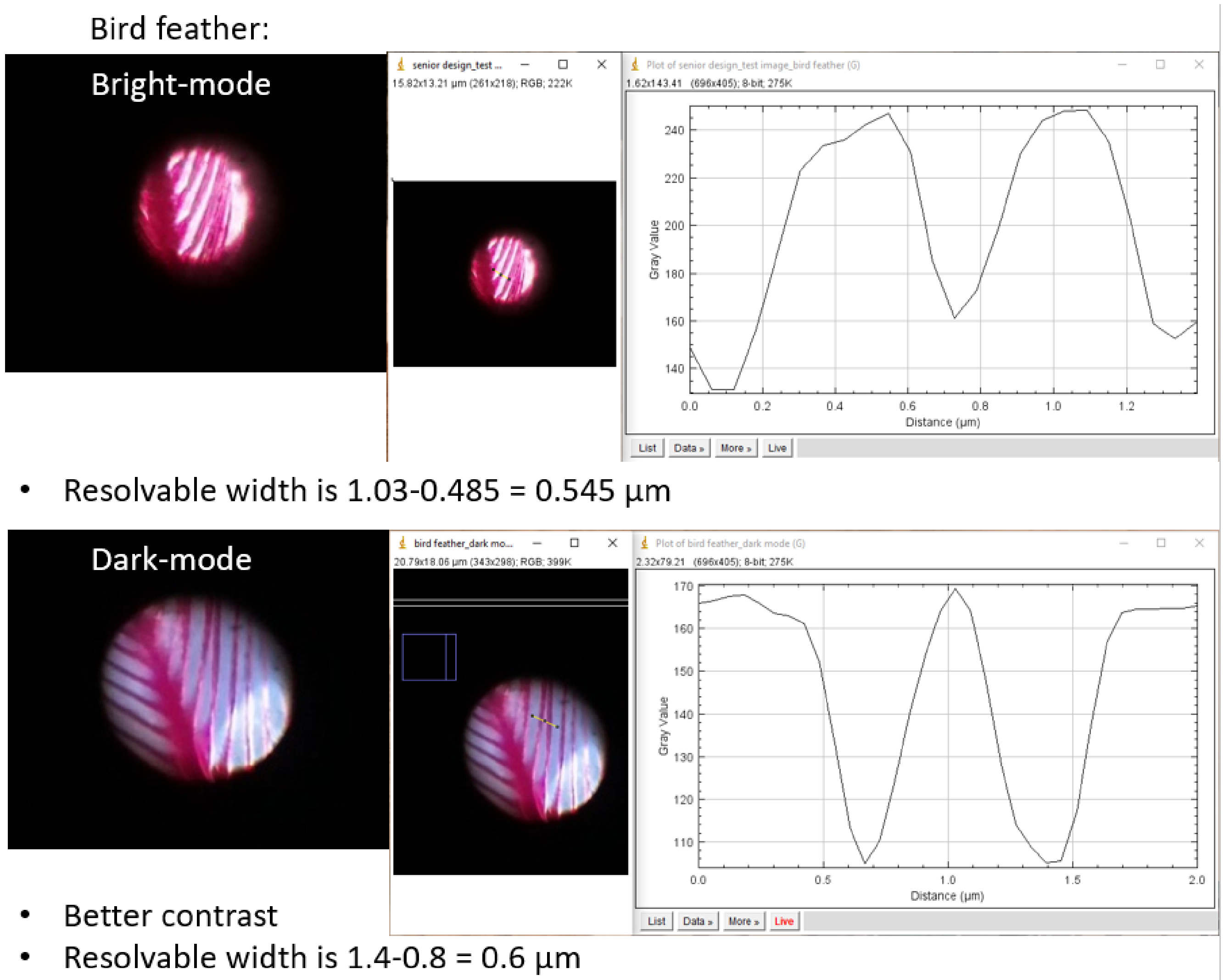


Figure 10.1.3.1 Bird feather specimen under bright-mode and dark-mode with intensity-distance plot

As shown in the figure (Fig. 10.1.3.1), the background of the image under bright-mode is brighter than that under dark-mode, and the image under dark-mode has a better contrast. The background under bright-mode is around 30% of the highest brightness while the background under dark-mode is almost 0% of the highest brightness. Therefore, the contrast under dark-mode is better, but the contrast under bright-mode is good enough for imaging most specimens.

Both images are captured using the 40x objective with a total magnification of 18.5x (Fig.). We used ImageJ to measure the width of the chosen fiber that is able to be resolved. Pixel size in image plane is obtained by 1.12 μm/18.5x = 0.0605 μm, so for 1 μm, there are 1μm/0.0605μm = 16.5 pixels. Therefore, 16.5 pixels/1μm is the scale to measure the width in the picture of the bird feather specimen.

The width of the chosen distances are calculated by the difference between two peaks in the intensity-distance plot. The resolvable distance under bright-mode is thus 1.03 μm - 0.485 μm = 0.545 μm, so the resolution under bright-mode is around 0.55 μm. The resolvable distance under dark-mode is 1.4 μm - 0.8 μm = 0.6 μm, so the resolution under dark-mode is 0.6 μm.

Section 11 Administration
11.0 Budget estimate
This project will be self-funded by all group members and an agreed upon maximum budget of 400 dollars was reached. Each team member has agreed, if needed, to spend up to $100 each to purchase all related parts for our project. In Table 23 shown below, the estimated group budget is tabulated. As the project progresses, the budget may vary.

Table 24 - Project Budget/Financing Early Estimate				
Item	Quantity	Per Unit Cost ($)	Total ($)	Extra
Objective Lens	2	34	34	2 lenses
Tubular Lens	1	70	70	
Flange Nut	1	0.99	0.99	
Silicone Sealant	1	6.28	6.28	(optional) For setting the lenses
Printer Filament	1	19.59	19.59	For use in the 3D printer
ATMEGA2560	1	21	21	
Stepper Motor	2	7.99 - 20.99	7.99 - 20.99	2-piece set
Stepper Motor Driver	1	10.79	10.79	2-Piece set
Batteries for motors	1	20.00	20.00	Set of four
Battery holders	1	10.00	10.00	Set of ten
Camera Module	1	20.00-25.00	20.00-25.00	
Main PCB	2	45.00	90.00	Set of two
Voltage Reg. PCB	5	12.47	62.34	Set of five
LED PCB	2	25.54	51.08	Set of two
Estimated Total	$424.06 - 442.06			

11.1 Bill of materials (BOM)

So far we have a bill of materials accounting for the voltage regulator, and main PCB. Below are the figures showing our bill of materials for both. The bill of materials

	A	B	C	D	E	F	G
1	Part	Manufacturer	Part Number	Quantity	Price ($)	Footprint	Description
2	Cff	MuRata	GRM1555C1E330JA01D	1	0.01	3	Cap: 33 pF Total Derated Cap: 33 pF VDC: 25 V ESR: 1 mΩ Package: 0402
3	Rfbb	Yageo	RC0603FR-0730KL	1	0.01	4.68	Resistance: 30 kΩ Tolerance: 1.0% Power: 100 mW
4	Rfbt	Yageo	RC0603FR-07220KL	1	0.01	4.68	Resistance: 220 kΩ Tolerance: 1.0% Power: 100 mW
5	Coutx	MuRata	GRM188R71E104KA01D	1	0.01	4.68	Cap: 100 nF Total Derated Cap: 99 nF VDC: 25 V ESR: 30 mΩ Package: 0603
6	Cin	MuRata	GRM21BR61E106MA73L	3	0.04	6.75	Cap: 10 µF Total Derated Cap: 9.5 µF VDC: 25 V ESR: 4 mΩ Package: 0805
7	L1	Vishay-Dale	IHLP2525CZER2R2M11	1	0.55	75.04	L: 2.2 µH DCR: 16.5 mΩ IDC: 7 A
8	Cout	Taiyo Yuden	LMK212BJ226MG-T	4	0.09	6.75	Cap: 22 µF Total Derated Cap: 44 µF VDC: 10 V ESR: 1 mΩ Package: 0805
9	U1	Texas Instruments	TPS566242DRLR	1	0.638	6.76	
10	Cinx	MuRata	GRM188R71H104KA93D	1	0.02	4.68	Cap: 100 nF Total Derated Cap: 99 nF VDC: 50 V ESR: 20 mΩ Package: 0603
11	Renb	Vishay-Dale	CRCW040230K9FKED	1	0.01	3	Resistance: 30.9 kΩ Tolerance: 1.0% Power: 63 mW
12	Rent	Vishay-Dale	CRCW0402100KFKED	1	0.01	3	Resistance: 100 kΩ Tolerance: 1.0% Power: 63 mW

Figure 11.1.1 Bill of Materials for the voltage regulator

3	Part	Value	Device	Package	Description
4	C1	10nF	C-EUC0603	C0603	CAPACITOR, European symbol
5	C2	10nF	C-EUC0603	C0603	CAPACITOR, European symbol
6	C4	100nF	C-EUC0603	C0603	CAPACITOR, European symbol
7	C5	100nF	C-EUC0603	C0603	CAPACITOR, European symbol
8	C6	100nF	C-EUC0603	C0603	CAPACITOR, European symbol
9	IC1	ULN2003AID	ULN2003AID	SOIC127P600X175-16N	Texas Instruments ULN2003AID, 7-element NPN Darlington Pair, 500 mA 50 V, 16-Pin SOIC
10	IC2	ULN2003AID	ULN2003AID	SOIC127P600X175-16N	Texas Instruments ULN2003AID, 7-element NPN Darlington Pair, 500 mA 50 V, 16-Pin SOIC
11	IC3	ATMEGA2560-16AU	ATMEGA2560-16AU	QFP50P1600X1600X120-100N	ATMEGA2560-16AU, 8 bit AVR Microcontroller 16MHz 4, 256kb Flash, 8kb RAM, I2C SPI 100-Pin TQFP
12	IC4	TLC5940PWP	TLC5940PWP	SOP65P640X120-29N	LED Driver IC 16 Output Linear Shift Register Dimming 120mA 28-HTSSOP
13	J1	B5B-XH-A_LF__SN_	B5B-XH-A_LF__SN_	SHDR5W64P0X250_1X5_1490X575X70	XH connector, 5 way
14	J2	B5B-XH-A_LF__SN_	B5B-XH-A_LF__SN_	SHDR5W64P0X250_1X5_1490X575X70	XH connector, 5 way
15	JP1		PINHD-1X8	1X08	PIN HEADER
16	JP2		PINHD-1X8	1X08	PIN HEADER
17	R1	2k	R-US_R0603	R0603	RESISTOR, American symbol
18	R2	10k	R-US_R0603	R0603	RESISTOR, American symbol

Figure 11.1.2 Bill of Materials for the Main PCB

11.2 Project Milestones

It is important for any team to keep the end goals in mind when creating a project. The goals for senior design 1 are seen below in table 25 starting with the initial design document, a revised initial document, then a 60-page draft design, a revised 60-page design, and finally the 120-page final documentation. Each document is important for the project as it lays out the plans we have to create a working microscope. The revision dates are important to have in a project because many things could need a second version or a second look as some details may not have been known at the time of writing the original document.

For senior design 2, we have finished implementing all of the milestones we have made for our project. We completed these milestones as early as possible to create a working prototype as soon as the spring 2023 semester ended. To create our prototype, we met up and put all of the parts we had together to ensure a more cohesive working project.

We utilized the 2 week window we have between the spring and summer semesters. Even with the summer semester only having 12 weeks, we have completed our goal of a working prototype.

Table 25 - Senior Design 1 Documentation Milestones			
Assignment	Start Date	Planned Goal Date	Due Date
Initial Project Document	1/10/2023	2/2/2023	2/3/2023
Initial Project Document ver. 2	2/3/2023	2/9/2023	2/10/2023
New Assignment on Standards	2/20/2023	3/3/2023	3/3/2023
60-page Draft Senior Design 1 Documentation	2/13/2023	3/17/2023	3/24/2023
120-page Final Document	3/25/2023	4/18/2023	4/25/2023
3D printed designs	4/22/2023	5/6/2023	N/A
Construction of Vertical design	5/1/2023	5/15/2023	N/A

Table 26 - Senior Design 2 Documentation Milestones			
Assignment	Start Date	Planned Goal Date	Due Date
Create Prototype	5/1/2023	5/24/2023	6/28/2023
Testing and documentation	5/24/2023	5/25/2023	6/28/2023
Finish Prototype	6/1/2023	7/14/2023	7/18/2023
Report	7/18/2023	7/23/2023	7/25/2023
Final Documentation	7/18/2023	7/23/2023	7/25/2023
Final Presentation	6/30/2023	7/16/2023	7/18/2023

11.3.1 Work Delegation for Senior Design 1

Table 27 - Hardware SENIOR DESIGN 1 Work Delegation		
Hardware		
Microscope		
	Design	Xuan
	Testing	Xuan
Power		
	Design	Jacob
	Testing	Jacob
LED		
	Design	Jacob/Xuan/Andres
	Testing	Jacob/Xuan/Andres
Breadboard		
	Design	Jacob
	Testing	Jacob
Motors		
	Design	Jacob/Andres
	Testing	Jacob/Andres
PCB		
	Design	Jacob/David/Andres
3d printed designs		
	Design	Andres
Camera module		
	Testing	Andres

Table 28 - Software SENIOR DESIGN 1 Work Delegation

Software		
Database		
	Design	David
	Testing	David
Phone app Front end		
	Design	David
	Testing	David
Web app Front end		
	Design	David
	Testing	David
OpenCv		
	Design	David
	Testing	David
Motor controls		
	Design	Jacob
LED controls		
	Design	Jacob
Mega 2560 connections to PI4		
	Design	Andres

11.3.2 Work Delegation for Senior Design 2

Table 29 - Hardware SENIOR DESIGN 2 Work Delegation
Hardware

Microscope Assembly with 3d parts		
	Design	Xuan/Andres
	Testing	Xuan/Andres
Power Supply/Voltage regulators		
	Design	Jacob
	Testing	Jacob
PCB with MCU		
	Design	Andres/Jacob
	Testing	Andres/Jacob
LED/Implementation with microscope		
	Design	Jacob/Xuan
	Testing	Jacob/Xuan
Motors/implementation with microscope		
	Design	Jacob/Xuan
	Testing	Jacob/Xuan
PCB/integrations with pi		
	Design	Jacob/David/Andres
Camera module/ implementation with app		
	Testing	Andres/David

Table 30 - Software SENIOR DESIGN 2 Work Delegation
Software

Database		
	Design	David
	Testing	David
Phone app Front end		
	Design	David/Andres
	Testing	David/Andres
Web app Front end		
	Design	David
	Testing	David
OpenCv/ Implementation with camera module		
	Design	David/Andres
	Testing	David/Andres
Motor controls/With Application		
	Design	Jacob/David
LED controls/With Application		
	Design	Jacob/Xuan/David
Mega 2560 connections to PI4 to Application		
	Design	Andres/David/Jacob

Section 12 Conclusion

In conclusion, by combining a custom-built microscope with sophisticated image processing software, the application enables researchers to study cellular structures. The use of advanced hardware and software, along with a user-friendly interface, makes the cell gazer application an invaluable tool for biological research.

One of the key features of the cell gazer application is the custom-built microscope.

To control the microscope, the cell gazer application uses a custom-designed PCB with motor and LED drivers. This PCB serves as the central processing unit for the system. The application also runs the image processing software, which is capable of identifying and analyzing cellular structures automatically. This integration of hardware and software creates a seamless user experience, allowing researchers to focus on the analysis and interpretation of the data rather than on technical details.

Another notable feature of the cell gazer application is the use of machine learning algorithms for image analysis.
The user interface for the cell gazer application is designed to be intuitive and user-friendly, even for users without extensive experience in microscopy or image analysis. The software includes tools for adjusting the imaging settings, capturing images and videos, and performing real-time image processing. The software also includes a database for storing and organizing the images.

During the development of the cell gazer application, it was a unique opportunity for the team members to learn about each other's areas of expertise. The team consisted of individuals with different engineering backgrounds, including electrical engineering, computer engineering, and photonics engineering. Through this project, the team members had the opportunity to collaborate and combine their skills to build a comprehensive system.

The electrical engineering team members were responsible for designing and building the custom PCB that controlled the motors and LEDs in the microscope. They were also responsible for ensuring that the system had the necessary power supplies and was wired correctly.

The computer engineering team members were responsible for developing the software that controlled the microscope and performed the image processing. They had expertise in programming languages, algorithms, and machine learning, which was critical for the development of the image analysis tools, and Web and Phone applications.

The photonics engineering team members were responsible for designing and implementing the optical components of the microscope, including the lenses and filters. They had expertise in the physics of light and optics, which was critical for optimizing the imaging performance of the microscope.

Throughout the project, the team members had to work closely together and communicate effectively to ensure that all aspects of the system were integrated correctly. They also had to learn about each other's areas of expertise to understand the overall system requirements.

As a result of this collaboration, the team members gained a deeper understanding of each other's disciplines and the ways in which they could work together to build a comprehensive system.

This cross-disciplinary collaboration was essential for the success of the project and is a testament to the value of diverse perspectives and skill sets in engineering projects.

Overall, the experience of working together on the cell gazer application was a valuable learning opportunity for the team members. They were able to develop a deeper understanding of each other's areas of expertise and the ways in which they could collaborate to build a complex system. This collaboration was critical for the success of the project and demonstrates the importance of cross-disciplinary teamwork in engineering projects. In conclusion, there were many lessons learned along the way.

Appendix A - References

[1] Bush, A., Bryant, A., Gill, C., & Pierson, H. (2019). (rep.). *Portable Multi-Spectra Microscope*. University of Central Florida. Retrieved February 10, 2023, from Portable Microscope - Group 27 (ucf.edu).

[2] TOMLOV. (n.d.). *TOMLOV DM201 Pro HDMI Digital Microscope 1200X,10 Inch Stand Included, 7" LCD Digital Microscope,16MP Coin Micro Soldering Microscope with Screen, Windows/Mac OS/TV Compatible,32GB*. amazon. Retrieved February 10, 2023, from https://www.amazon.com/TOMLOV-DM201-Pro-Microscope-Compatible/dp/B09SF414XK

[3] SCIENCE CAN. (n.d.). *Science can microscope for kids,led Lighted Pocket Microscope for kids ...* amazon. Retrieved April 6, 2023, from https://www.amazon.com/SCIENCE-Microscope-Lighted-Pocket-Portable/dp/B09CSXD1M8

[4] SCIENCE CAN. (n.d.). *Science can microscope for kids,led Lighted Pocket Microscope for kids ...* amazon. Retrieved April 6, 2023, from https://www.amazon.com/SCIENCE-Microscope-Lighted-Pocket-Portable/dp/B09CSXD1M8

[5] YouTube. (2022). *Stepper Motors and Arduino - The Ultimate Guide*. *YouTube/Stepper Motors and Arduino - The Ultimate Guide*. Retrieved March 23, 2023, from https://www.youtube.com/watch?v=7spK_BkMJys&list=WL&index=2&t=342s.

[6] Gastreich, W. (2022, October 19). *Stepper Motors Advantages and disadvantages - realpars*. The Easiest Way to Learn Industrial Automation. Retrieved April 8, 2023, from https://realpars.com/stepper-motors-advantages/

[6.1] Texas Instruments. (n.d.). *Application design guidelines for LM339, LM393, TL331 family ...* Texas Instruments. Retrieved April 8, 2023, from https://www.ti.com/lit/ml/snoaa35b/snoaa35b.pdf?ts=1680107989081&ref_url=https%253A%252F%252Fe2e.ti.com%252F

[7] Wikimedia Foundation. (2022, December 13). *Nickel–metal hydride battery*. Wikipedia. Retrieved March 23, 2023, from https://en.wikipedia.org/wiki/Nickel%E2%80%93metal_hydride_battery

[8] Wikimedia Foundation. (2023, March 21). *Lithium-Ion Battery*. Wikipedia. Retrieved March 23, 2023, from https://en.wikipedia.org/wiki/Lithium-ion_battery

[9]Encyclopædia Britannica, inc. (n.d.). *Voltage regulator*. Encyclopædia Britannica. Retrieved March 23, 2023, from https://www.britannica.com/technology/voltage-regulator

[10] Hasan, W. by: M. (2023, January 21). *Difference between linear and switching regulators: A simple guide?* BDelectricity.Com. Retrieved April 8, 2023, from https://bdelectricity.com/difference-between-linear-and-switching-regulators/

[11] YouTube. (2023). *What is difference between switching and linear regulators? YouTube*. Retrieved April 8, 2023, from https://www.youtube.com/watch?v=abaTptF4LD0.

[12] Wikimedia Foundation. (2023, March 4). *Buck Converter*. Wikipedia. Retrieved March 23, 2023, from https://en.wikipedia.org/wiki/Buck_converter

[13] Jeewoonarain, R. (2021, June 13). *Stepper Motor Drivers: A step-by-step guide*. Leading Edge Industrial. Retrieved March 23, 2023, from https://leadingedgeindustrial.com/stepper-motor-drivers-step-guide/#:~:text=A%20Stepper%20Motor%20Driver%20is%20the%20driver%20circuit,considered%20more%20advanced%20than%20the%20typical%20DC%20motor

[14] Stone, W. (2023, January 26). *What does PLA stand for?: 3D printing spot*. RSS. Retrieved March 23, 2023, from https://www.3dprintingspot.com/post/what-does-pla-stand-for

[15] *Understanding heat deflection temperature (HDT) of plastics*. AIP Precision Machining. (2021, June 8). Retrieved March 23, 2023, from https://aipprecision.com/understanding-heat-deflection-temperature-plastics/

[16] MatterHackers. (n.d.). *BASF natural ultrafuse Pro1 tough pla filament - 2.85mm (0.75kg)*. MatterHackers. Retrieved March 23, 2023, from https://www.matterhackers.com/store/l/basf-pro1-pla-3d-printer-filament-075kg/sk/MXKWUA54?rcode=BING_SHOP&msclkid=25e3733337ce13dd90e91727804cf427

[17] YouTube. (2021). *Which 3D Printed Gear is Best? YouTube*. Retrieved March 23, 2023, from https://www.youtube.com/watch?v=UtRJ4lnNAXY&t=2s.

[18] Schweber, B. (2017, September 20). *Understanding the advantages and disadvantages of linear regulators*. Digi. Retrieved March 23, 2023, from https://www.digikey.com/en/articles/understanding-the-advantages-and-disadvantages-of-linear-regulators#:~:text=Switching%20regulators%20are%20highly%20efficient%20and%20able%20to,switching%20regulators%20also%20have%20some%20weaknesses%20%28Table%201%29.

[19] Bryant, A., Bush, A., Gill, C., & Pierson, H. (2019). (rep.). *Portable Microscope* (pp. 1–160). Orlando, Florida: University of Central Florida. Retrieved March 23, 2023, from https://maverick.eecs.ucf.edu/seniordesign/fa2018sp2019/g27/.

[20] Richie, S. (2018). EEL4914.Design Constraints and Standards. Orlando; University of Central Florida.

[21] Lemmons, R. (2023, February 19). *The environmental issues - rechargeable batteries*. Climate Policy Watcher. Retrieved March 23, 2023, from https://www.climate-policy-watcher.org/rechargeable-batteries/the-environmental-issues.html

[22] Keeping, S. (2015, October 7). *Designing Compensator Networks to improve switching regulator frequency response*. Digi. Retrieved March 23, 2023, from https://www.digikey.com/en/articles/designing-compensator-networks-to-improve-switching-regulator-frequency-response

[23] IEC. (2021, April 27). *IEC*. IEC 60086-1:2021 | IEC Webstore. Retrieved March 23, 2023, from https://webstore.iec.ch/publication/60968

[24] "IEEE Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications," in IEEE Std 1679.1-2017 , vol., no., pp.1-47, 31 Jan. 2018, doi: 10.1109/IEEESTD.2018.8262521.

[25] Ghosh, P. (2023, March 3). *IPC-2221 standards in PCB design*. Sierra Circuits. Retrieved March 23, 2023, from https://www.protoexpress.com/blog/ipc-2221-circuit-board-design/#:~:text=IPC-2221%20establishes%20

standards%20for%20PCB%20design%20aspects%20such,They%20include%20conductor%20spacing%2C%20creepage%2C%20and%20insulation%20requirements.

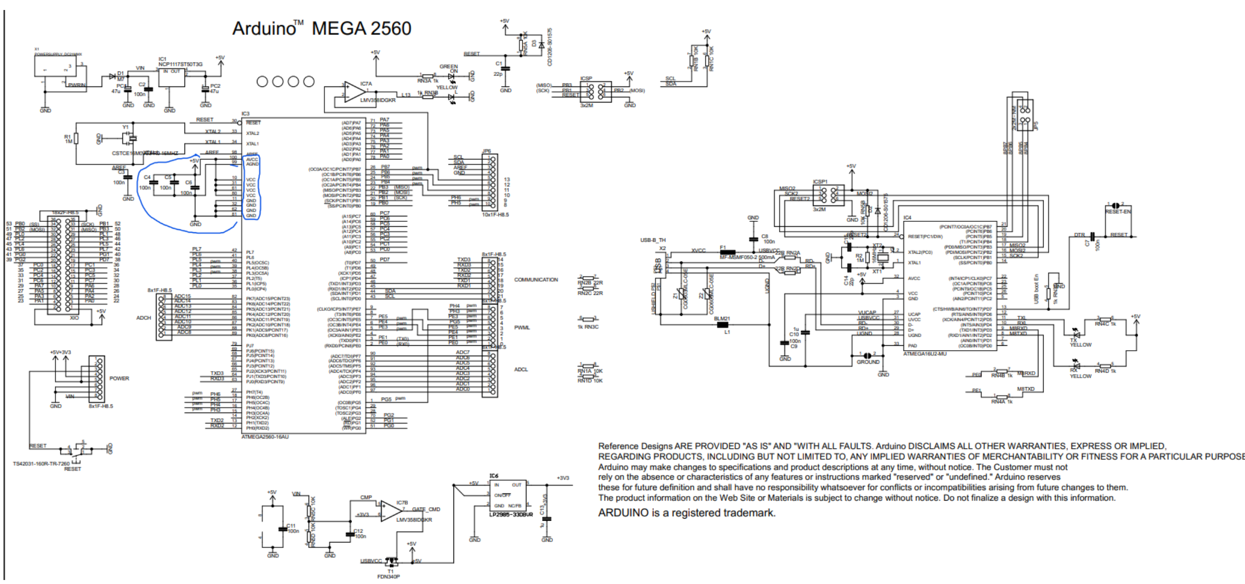
[26] *Arduino Uno REV3*. Arduino Online Shop. (n.d.). Retrieved March 24, 2023, from https://store-usa.arduino.cc/products/arduino-uno-rev3

[27] *MSP-Exp430fr6989*. MSP-EXP430FR6989 Development kit | TI.com. (n.d.). Retrieved March 24, 2023, from https://www.ti.com/tool/MSP-EXP430FR6989

[28] Raspberry Pi. (n.d.). *Raspberry pi 4 model B specifications*. Raspberry Pi. Retrieved March 24, 2023, from https://www.raspberrypi.com/products/raspberry-pi-4-model-b/specifications/

[29] [Decoupling capacitor - Wikipedia]

Appendix B - Schematics and Datasheet Material Used



Appendix C - Permissions or authorizations of

copyrighted materials

Sara Therner (Arduino)
Apr 21, 2023, 07:28 GMT+2

Hi Jacob,

You may use this schematic for your design project. You do not need to ask for our permission but we appreciate it.
Have a look at our trademark guidelines here https://www.arduino.cc/en/trademark which might be of additional use to you.

Best Regards,

Sara Therner
Head of Intellectual Property

This message is confidential and may be legally privileged or otherwise protected from disclosure;
you must not copy or disclose the contents of this message or any attachment to any other person.

Jacob Roth
Apr 21, 2023, 00:30 GMT+2

#body:
Hello,
I am an electrical engineering student creating a design project and I am emailing you to ask for permission for the use of this schematic found here:
https://www.arduino.cc/en/uploads/Main/arduino-mega2560_R3-schematic.pdf

I look forward to hearing back from you.

Thank you,
Jacob