Poly-Assistive Auto-Focusing and Color-Identifying Utility Lenses

(P.A.U.L.)

Group 6 Authors:

Julie Gallagher	Genaro Morales	Midkhat Satdanov	Kayla Stanley
Electrical Engineering	*Photonics Engineering*	*Photonics Engineering*	*Computer Engineering*

Reviewer Committee:

Dr. Rodrigo Amezcua Correa	CREOL	Professor
Dr. Peter Delfyett	CREOL	Professor
Dr. Mark Maddox	ECE	Professor
Dr. Sonali Das	ECE	Professor

Mentor:

Dr. Chung Yong Chan

Table of Contents

2 Project Description

2.1 Motivation and background

The development of assistive lenses stems from a motivation to enhance the quality of life for visually impaired individuals. There exists a phone application called Be My Eyes in which sighted individuals volunteer to aid visually impaired individuals with everyday tasks such as picking out clothing or navigating public spaces[1]. The visually impaired individuals simply point their phone cameras towards the subject they need assistance with and the volunteer acts as their eyes on the other end of the video call. Be My Eyes is certainly a beneficial and useful application. Yet, it relies on volunteers assisting visually impaired individuals. By developing assistive lenses with various features, visually impaired individuals can gain more independence in their everyday lives and facilitate many tasks that would normally require the assistance of another person.

The process of adjusting the focus in the human eye is called accommodation. The ciliary muscles in the eye control the roundness of the eye's lens and thus are responsible for focusing power, also known as accommodation. When focused on an object in the distance, the ciliary muscles relax, flattening the eye's lens and decreasing the focusing power. Alternatively, when focusing on an object nearby, the ciliary muscles will contract, increasing the roundness of the eye's lens and increasing the focusing power. As humans age, they begin to develop a condition called Presbyopia. This occurs when the ciliary muscles in the eye weaken and are no longer capable of accommodating. Without accommodation, an individual loses their near vision. Reading glasses typically become necessary to focus on anything nearby at this point. Technology capable of adjusting an individual's focusing power would be beneficial for individuals with Presbyopia.

The human eye contains multiple photosensitive receptors, of these, the cones are responsible for color. There are three kinds of cones in the human eye that work together allowing humans to experience the full spectrum of light. The three types of cones are the L-cones, M-cones, and S-cones. The L-cones are most sensitive to red light. The M-cones are most sensitive to green light. The S-cones are most sensitive to blue light. Color vision deficiencies occur when any of these cones have a reduced sensitivity. The M-cones and L-cones have a large overlap in the wavelengths that they are capable of sensing. Due to this, when there is a reduced sensitivity in either the L-cone or the M-cone, it becomes difficult to differentiate the values located in the overlapping wavelengths. This results in the most common color vision deficiency referred to as red-green colorblindness. While this is the most common color vision deficiency, many others exist that impede an individual's ability to distinguish between colors. A technology capable of identifying unique colors and relaying the information to an individual with a color vision deficiency would help said individual overcome their struggles with distinguishing between colors.

By implementing various assistive technologies into a pair of glasses, our lenses can improve the lives of visually impaired individuals. While the initial prototype will be limited to assisting individuals with focusing and color-based concerns, there is potential to add additional features that can contribute to assisting individuals with other, more complex vision-based disabilities. The lenses will be a tool to assist visually impaired individuals with their everyday life by simplifying tasks that are currently taken for granted by most people.

2.2 Goals and Objectives

With this project, we will be developing a set of lenses that can perform various functions revolving around the objective of improving the quality of life for visually impaired individuals.

2.2.1 Basic Goals

- Implement auto-focusing technology onto eyewear, reducing the need for multiple pairs of eyeglasses.
- Detect and identify a variety of colors to assist color vision deficient or otherwise visually impaired individuals.
- Set up an auditory response system with unique responses for each function.

2.2.2 Advanced Goals

- Improve depth of focus and response time of the auto-focusing feature
- Improve accuracy of color identification.

2.2.3 Stretch Goals

- Miniaturization of design for increased portability and comfort.
- Improve the color identification system to recognize at least 8 unique colors.
- Walking stick that sends an audio signal when it passes underneath an object.
- Add a text-to-speech feature that allows the system to read text aloud to the user when prompted.
- Set up an object identification system to assist visually impaired individuals with a variety of tasks.
- Implement a smart navigation system that will help guide visually impaired individuals allowing them to move around independently.
- Integrate smart phone compatibility through an app for potential customization of the auditory response system.

2.2.4 Basic Objectives

- Utilize the infrared sensor to provide an accurate distance and starting point for the auto-focus system.
- Design two motorized focusing systems that function together to focus the image for both the user and the CMOS sensor.
- Have a functioning program that can detect the sharpness of the image detected by the CMOS sensor, then adjust the motorized focusing systems to focus on a sharp image in under five seconds.
- Design a color identification system using three photodiodes and color filters, each corresponding to different wavelengths of light.
- Have a functioning program that can identify colors using the CMOS sensor, then compare the data with the input from the color identification system to accurately identify the colors present.
- Design an audio response system that efficiently delivers information to the user.

2.2.5 Advanced Objectives

- Calibrate the autofocusing system so that it provides a focusing power between –2.5 D to +1.5 D based on focusing while selecting a lens system that reduces chromatic aberrations.
- Get the color identification system within a specified degree of accuracy through a system of photodiodes and a suite of sensor systems that scan through the colors of the object in center view.

2.2.6 Stretch Objectives

- Conduct thorough research on smaller and more compact components that can be integrated or replaced in our design.
- Adjust the color library of the system so that it can detect more sets of colors while adjusting the setup of the photodiode system so that its sensitivity is increased.
- Obtain a walking cane or stick and integrate it into the system to send information to the glasses.
- Create a program using the sensor suite that detects text and maps it to a text library.
- Use computer vision to create a set of detectable objects such as glasses and phones that the goggles can detect and then communicate through the audio system.
- Connect the goggles to a map application such as google maps and use it to give audible directions to the wearer when they are navigating their environment.
- Develop a program in Kotlin that can connect to the goggles, enabling the user to select a preferred language and calibration settings.

2.3 Features and Functionalities

2.3.1 Auto-focus

To support individuals with vision loss such as near-sightedness and far-sightedness, we want to include a system that provides artificial accommodation. To support this, we plan to use a two-lens system that can be ordered to adjust automatically by coupling it with a program utilizing a time-of-flight (ToF) sensor and a complementary metal oxide semiconductor (CMOS) sensor that determines the required distance between the lenses.

The two-lens system is necessary to correct optical aberrations that will arise as we try to focus the system. Optical aberrations are errors caused by uneven spreading of light across a system. While these can be corrected with lens design, our system requires a dynamic moving system to adjust and combat these aberrations, with defocus as our primary objective. Defocus occurs when the optical power of a system goes above or below the power of the eye, which is 60 diopters.

To solve this issue, we will implement the two-lens system on a moving rail, allowing it to increase or decrease the optical power of the system as needed. The movement of the rail is determined through the focusing system, which begins when the wearer engages the focus button. A CMOS sensor attached to the goggles then captures an image, and, using its own lens system, determines whether the image is blurry. If the image is in focus according to a set parameter, an audio signal is sent to the wearer to inform them. Otherwise, the focus of the secondary lens is set using an infrared sensor that measures the distance between the goggles and the observed object. An image is taken of the object, and an algorithm determines the contrast on the edges of the image. If the level of contrast is too high behind the sensor, the secondary lens (the moving lens) is moved farther from the primary lens until the image is no longer blurry. If the level of contrast is too high in front of the sensor, then the secondary lens is moved closer to the primary lens. This system would enable a dynamic and user-guided method of transforming the goggles from a “reading mode” to a “traversal mode.”

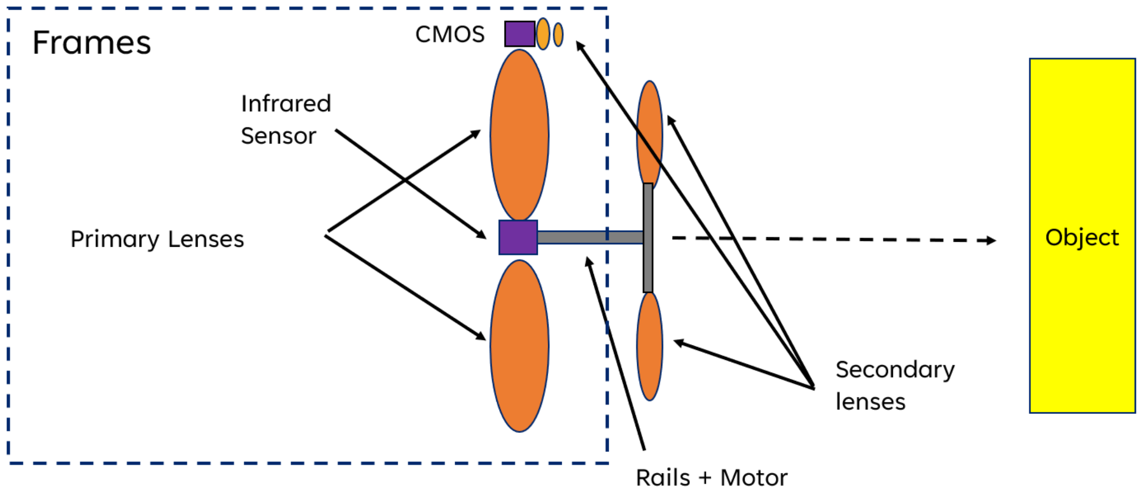


Figure 2.1 Auto-Focusing Feature Diagram

2.3.2 Color Identification

In addition to providing artificial optical power for the wearer, the goggles are intended to assist with colorblindness. Using a dual confirmation system, the goggles would provide audio information on the primary color of an object in central view. This system would work regardless of the user's specific type of color blindness. Similarly to the auto-focus feature, it is activated manually by the user tapping a button.

To determine the color of the object being observed, three photodiodes are mounted onto the goggles with a respective red, green, and blue filter. Light reflecting off the object would pass or reflect off the filters. If it passes, the respective photodiode records the signal and matches it with a corresponding color or shade. This system allows for combinations of up to 8 different colors or shades, namely red, green, blue, cyan, magenta, yellow, white, and black. However, the main drawback of this system is its low sensitivity. To offset this, a strobe light would illuminate the central area immediately in front of the user to provide more reflection and color feedback. This photodiode setup is still supplementary however and would require an additional system.

This other system would involve a CMOS sensor. Upon activation, the CMOS captures an image of the object in central view. Utilizing a program that involves scanning through the captured image and matching each pixel to a color library, the goggles consider the total percentage of a grouping of colors to determine the primary color of the image. In the event that the object captured is composed of more than one primary color, namely if it has a threshold of being composed of 40% of one color and 40% of another, two colors are recorded.

Once both systems capture data regarding the observed object, their outputs are compared. If the output colors do not match, an audio signal is sent to the user informing them to scan the object again. Otherwise, the user is informed through audio of the primary or two primary colors of the observed object.

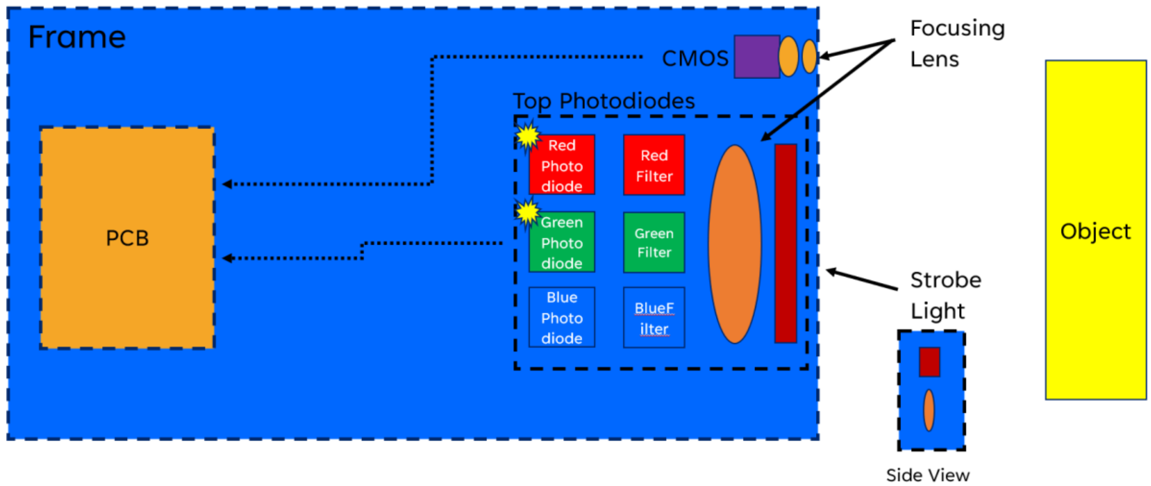


Figure 2.2 Color-Identifying Feature Diagram

2.4 Existing Products

2.4.1 EnChroma Color Blind Glasses

EnChroma color blind glasses are designed to improve the ability to distinguish between colors for an individual with a color vision deficiency. The M-cones and the L-cones in the eye have a large overlap in the wavelengths that they can sense. Any deficiency in either the L-cone, the M-cone, or both can result in red-green colorblindness. Due to this, red-green colorblindness is the most common color vision deficiency. EnChroma color blind glasses do not function by broadening the wearer's ability to see the full color spectrum. Instead, they function by filtering out certain wavelengths of light where the L-cone and M-cone overlap. By filtering out these wavelengths, the overlap between the L-cone and M-cone is reduced. Reducing this overlap increases the contrast between the colors, thus improving an individual's ability to distinguish between red and green[2]. The spectrum of values they are capable of detecting is also reduced. The largest drawback of the EnChroma color blind glasses is that they are limited to only assisting individuals with red or green color vision deficiencies, protanomaly or deuteranomaly, respectively.

Our lenses do not alter the user's ability to perceive colors. Instead, they can identify colors and relay that information to the user through an auditory response. Regardless of the form of color vision deficiency, they will still be helpful to the individuals. In addition to this, our lenses can help a wide variety of individuals with vision impairments.

2.4.2 Ray-Ban Meta Smart Glasses

Perhaps the product most similar to ours, these smart glasses are a collaboration between Ray-Ban and Meta. They utilize dual cameras, one 5 MP camera and one 12 MP camera. The cameras are capable of recording video as well as capturing photographs. The glasses also have built-in speakers and microphones that allow the user to listen to music or make calls. With voice assistant integration, the user can issue voice commands to interact with the distinctive features. The voice assistant feature is also compatible with certain other voice assistants allowing the user to access more information and control other smart devices[3]. These glasses currently do not have many accessibility features targeted towards assisting visually impaired individuals, but there is immense potential for implementation of more features.

The Ray-Ban Meta smart glasses are incapable of changing focus. They are locked into a single optical power. Auto-focusing is a key feature that our assistive lenses will be capable of. This feature will be greatly beneficial for individuals with Presbyopia.

2.4.3 Bifocal Lenses and Progressive Lenses

Although not new technologies by any means, both bifocal lenses and progressive lenses share the feature of having multiple focal powers on a single lens. These kinds of lenses are typically prescribed to individuals with presbyopia.

Bifocal lenses are eyeglasses that have two distinct optical powers. One portion of the lens, typically the upper portion, is utilized for distance vision. The second portion of the lens is utilized for near vision. This combination of two optical powers removes the necessity of reading glasses.

Progressive Lenses also allow for both distance and near vision, but unlike bifocals, there is a gradual transition between the optical powers allowing for more focusing distances instead of just two.

The auto-focus feature of our lenses will benefit individuals with Presbyopia as well. A key flaw of bifocal lenses and progressive lenses is that the user must be looking through specific areas of the lenses for each optical power. This requires the individual to occasionally have to tilt their head in awkward positions to view their desired subject properly. The assistive lenses will auto-focus down the center of the lenses, thus the individual only has to look in the direction of their subject to focus at the proper distance.

2.4.4 Project I.R.A.S (Intricate Real-time Assistance Spectacles)

I.R.A.S. was a UCF senior design project focused on providing different types of disability assistance using a primarily visual display with information fed through real-time data collection.

I.R.A.S.'s color detection feature was focused on providing real-time assistance. They utilized a Raspberry Pi to convert their input data from an RGB color space to HSV, and then interpreted the resulting image by assigning it a binary value of 1 or 0. The matching color is then written onto a display joined to the glasses.

Additionally, the display system was also used in tandem with a speech-to-text system that was meant to translate French, German, or Spanish into English text or vice versa. The microphone for operating the system was connected directly onto the group's Raspberry Pi.

Both of these systems were meant to be used with an app that the team programmed where it was possible to select the desired language and colors to be detected.

Overall, the design philosophy of I.R.A.S. was significantly different compared to our project. Whereas theirs was meant to be centered around the use of the display feature, our goggles assume that the wearer has significant visual disabilities that our goggles can assist with. While their real-time color detection system is useful for a display-based method, our primary concern with using a similar program is the potential for unintended irritation to the wearer.

2.5 Specifications

Specifications	
Audio Signal-to-Noise Ratio	> 65 dB
Color Identification	> 3 colors
Focus Speed	< 5 seconds
Color Accuracy	> 85%
Focusing Power	-2.5 D to +1.5 D
Step size	1 mm to 2mm
Manufacturability	< $1000
Sensor Resolution	> 5 MP
Motor Maximum Power	< 4W

Battery Life	> 2.5 continuous hours
Simultaneous Color Identification	> 1 color

Table 2.1 Specifications

2.6 Block Diagrams

2.6.1 Hardware Block Diagram

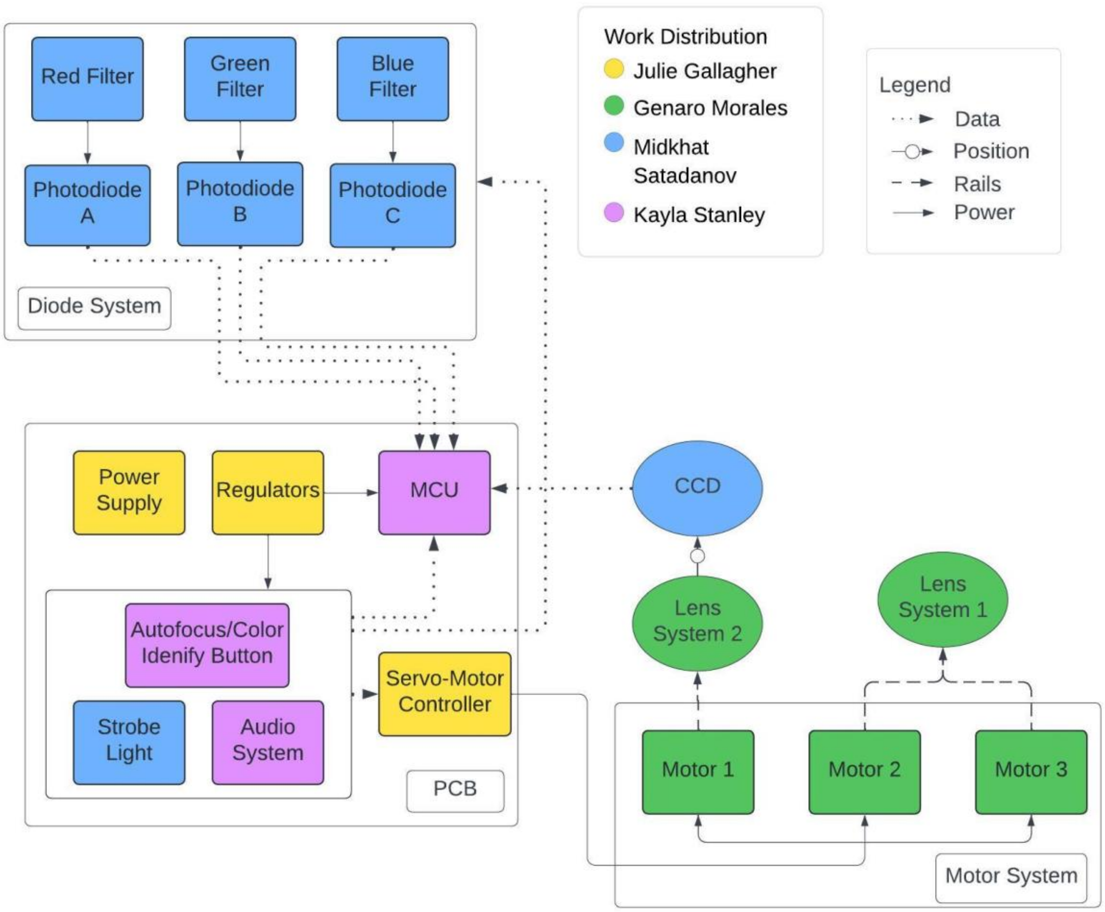


Figure 2.3 Hardware Block Diagram

2.6.2 Software Flow Charts

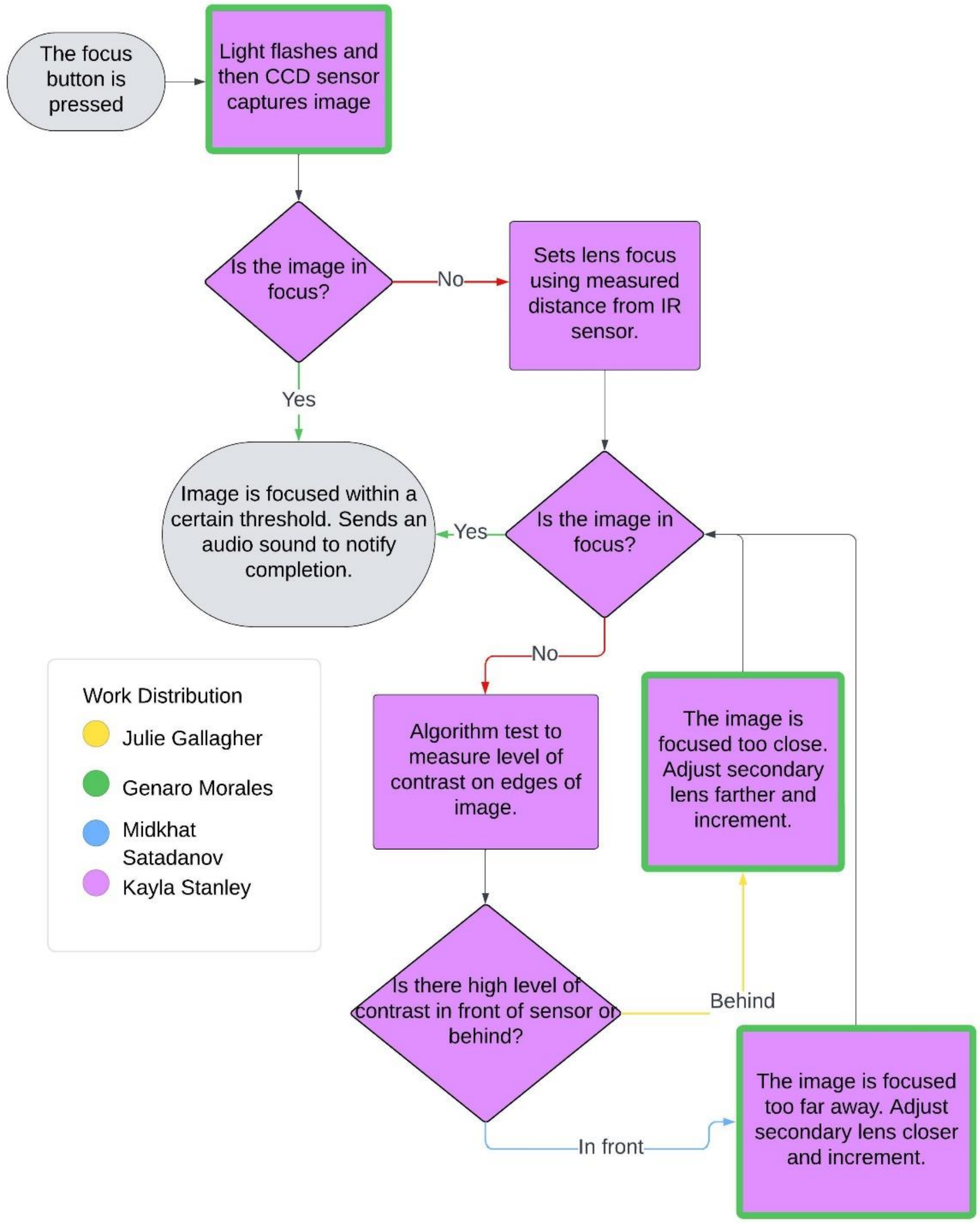


Figure 2.4 Auto-Focusing System Flow Chart

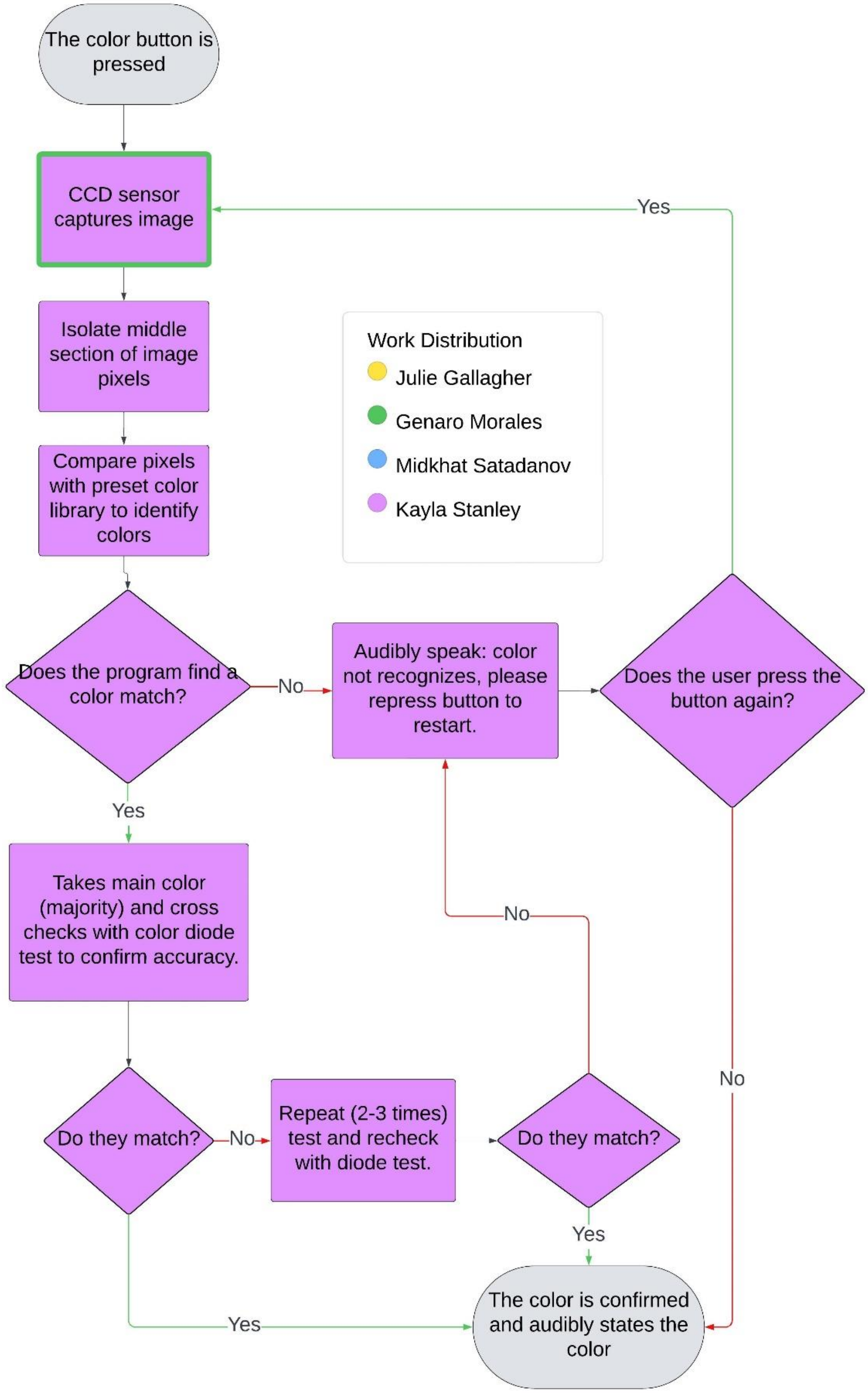


Figure 2.5 Color Identification System Flow Chart

2.7 House of Quality

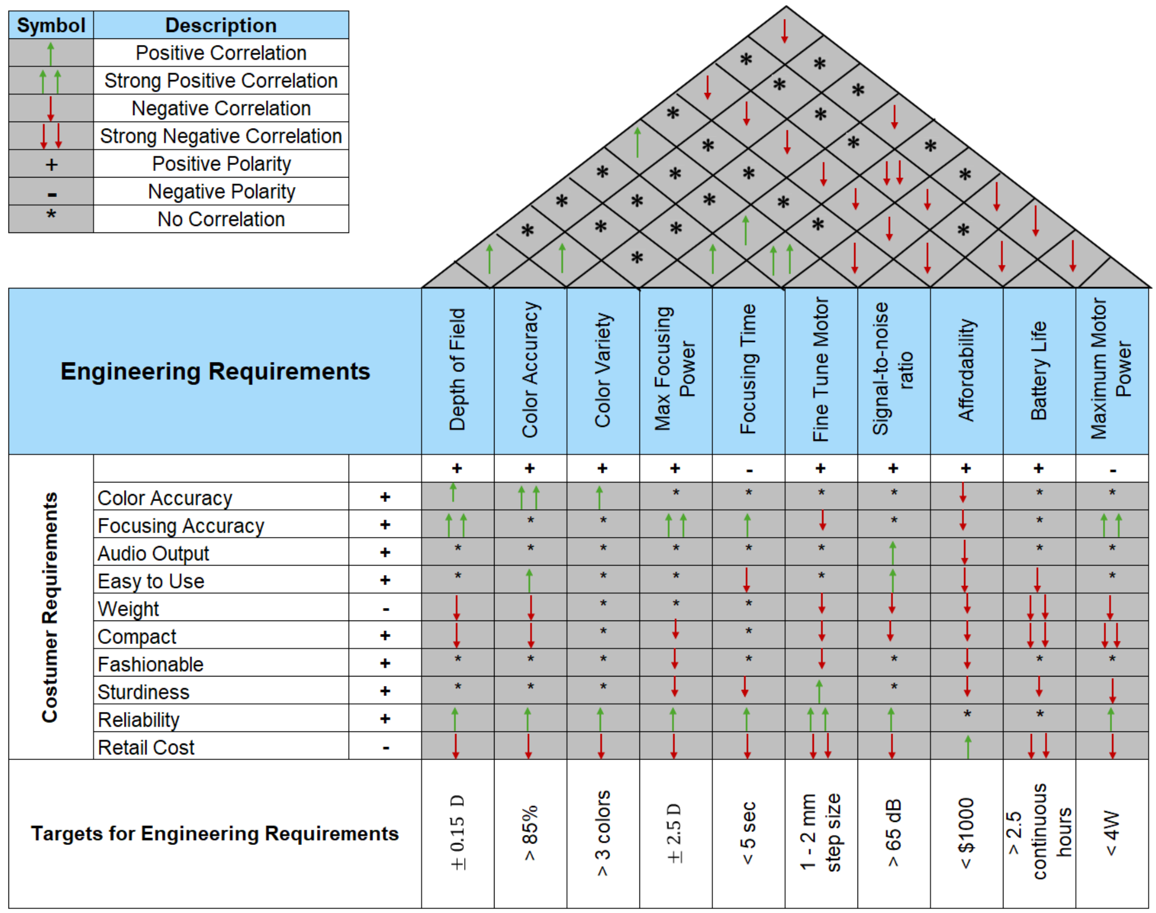


Figure 2.6 House of Quality

3 Research and Part Selection

The primary concerns for the part selection of this project were related to the selection of the lenses and sensors. The final decisions regarding motors, frames, and all other subsequent components are contingent on the decisions we make regarding the parameters of those parts.

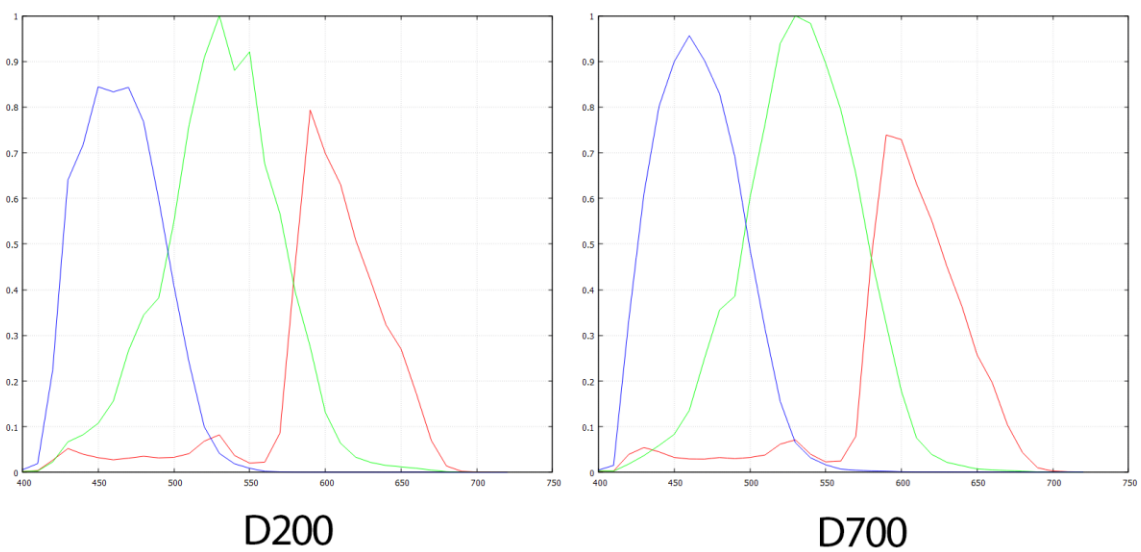
3.1 CMOS vs CCD

Charge Coupled Devices (CCDs) and Complementary Metal Oxide Semiconductors (CMOSs) are two imaging sensors that rely on the photoelectric effect to convert an incoming photon into an electric charge. CCD sensors directly convert this energy into an analog signal, enabling the use of nearly or all of their pixel size to the capture of light. Each pixel's charge is collected at an output node and then sent off as an analog signal to then be converted to digital if needed. This makes their output very uniform.

CMOS sensors on the other hand contain pixels that, instead of having their charges collected across the entire sensor, are instead directly amplified and converted to digital at each pixel before being packaged at the output. While this decreases the uniformity, light collection area, and simplicity, the parallel mechanism of each pixel performing operations separately increases overall speed.

3.1.1 CMOS vs CCD Color Quality

For the color recognition system, we have a choice on whether we wanted to proceed with a CMOS or CCD sensor. Our requirements for the system need us to be able to differentiate the colors of the image taken to a degree that is as accurate to the colors seen by a typical human eye as possible. To match this correctly, we use the Commission Internationale de l'Eclairage's definition of an ideal spectral sensitivity function (SSF)



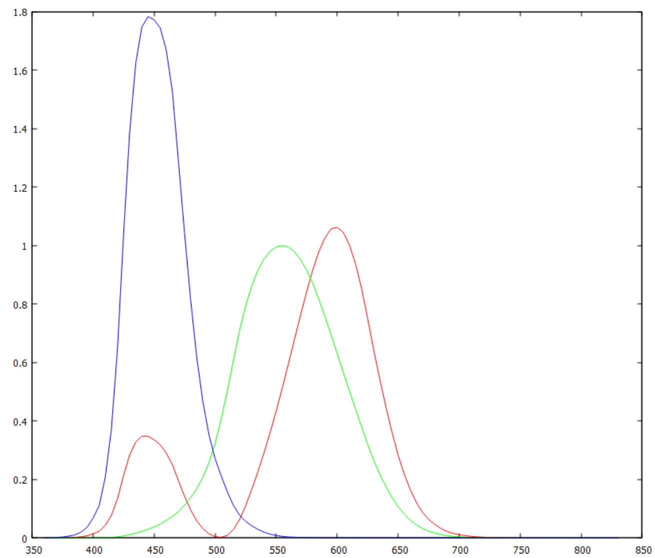


Figure 3.1.1 SSF of CMOS (left) vs CCD (right) compared with human SSF (bottom)

Due to these requirements, the first and foremost concern was to identify which type of sensor would be more accurate for color detection. It became clear from our research that, when all other factors remained the same, the difference in the produced color gamut and color temperature gamut was nearly indiscernible. Our research indicated then that the more important facets in determining color were the color correction of the camera itself, the camera profile, and the characterization of the sensor.

3.1.2 CMOS vs CCD Image Quality

Since the choice between the two sensors does not come down to color quality, the choice must be determined by both image quality and economic concerns. In terms of image quality, the primary concern regarding CMOS sensors is their lower signal-to-noise ratio (SNR). This is caused by each individual pixel needing to pass through an amplifier first before it can be converted to a digital signal, introducing noise into the application. However, one article claimed that as recently as 2020, this difference in noise ratio has been eliminated in newer CMOS models. However, our design may incorporate older CMOS sensors, making this a valid concern.

3.1.3 CMOS vs CCD Cost and Power Consumption

On average, the integrated design of CMOS sensors puts their price lower than CCDs. A major appeal of the CMOS is its camera-on-a-chip quality, enabling greater miniaturization.

Additionally, the power consumption of CMOS sensors tends to be much lower. With these factors in mind, our team has chosen to move forward with pursuing a CMOS sensor for our project, although a CCD will be considered and compared.

3.2 Time-of-Flight (ToF)

For our auto-focusing feature to function properly, we'll need to measure distance. This can be accomplished by utilizing the principle of time-of-flight. The measured distance will be utilized as the starting point for our auto-focusing system. Range-sensing systems and devices rely on know constants such as the speed of light or the speed of sound to measure distances[4]. They function by measuring the time it takes for a wave to travel through a medium from the source to its destination and back to the source. While electromagnetic waves are typically used, other types of waves can also work if the velocity at which the wave travels in the medium is known. Time-of-flight devices have

3.2.1 Direct vs Indirect ToF

There are two methods in which a device can utilize ToF, direct and indirect[5]. Direct ToF functions by emitting a signal as a pulse of either light or sound. The velocity of light and sound are both known, thus either will work. In either case, the signal travels to an object, reflects off of it, then returns to the source. The distance (d) can then be calculated using Equation 1[4] since the velocity (v) and the time (t) are known. Of course, it should be taken into consideration that since the signal traveled to the object and back, it is traveling twice the distance. Direct ToF has the advantage of more accuracy for longer distances. A disadvantage of direct ToF is that it requires incredibly fast sensors capable of measuring the time difference. Another disadvantage is that they are highly susceptible to noise interference.

$$d = \frac{v \times t}{2} \tag{1}$$

Indirect ToF also functions by emitting a signal of either light or sound. The difference, however, is that indirect ToF does not emit a pulse. Instead, a continuous modulated wave is emitted that travels to the object, reflects, and returns to the source. In this case, the phase difference (θ) of the wave when it returns to the source is used to measure the distance instead of the travel time. Equation 2[6] can be utilized to calculate the distance using indirect ToF. Here the modulation frequency (f), will determine the accuracy of the measurement. A higher modulation frequency will result in shorter wavelength and subsequently more accuracy at shorter distances. That being said, to measure at longer distances, a lower modulations frequency will be necessary as it produces larger wavelengths. This results in a loss of accuracy over longer distance. Indirect time-of-flight has the advantage of being more accurate at short distance and can be utilized for 3D imaging.

$$d = \frac{v \times \theta}{2\pi f} \tag{2}$$

We are utilizing direct ToF, because this will provide better accuracy at longer distances, giving us a better starting point for the auto-focusing to work from.

3.2.2 Ultrasonic Sensor

Ultrasonic sensors utilize sound waves to measure distance. Under normal conditions, sound travels at a velocity of 340.29 m/s[7]. For the source wave, an alternating current is converted into ultrasound, which is then transmitted in a wide cone-shaped beam. The ultrasound wave continues by echoing off of an object and returning to the sensor. The cone-shaped beam is typically around 30° which is much larger than you would expect from a light sensor[7]. While the large beam is still capable of detecting objects regardless of size, the drawback is that the exact location of the object is much less precise. The surface of the object being detected also greatly affects the performance of the ultrasonic sensor. Hard surfaces will produce better echoes, while soft surfaces will reflect fewer sound waves. Sound requires a medium for displacement, thus an ultrasonic sensor would not function in a vacuum. Perhaps the largest disadvantage of an ultrasonic sensor is that it is not as effective at very short distances. They typically have a detection range between 4 cm and 255 cm. Considering sound does not travel as quickly as light, ultrasonic sensors do have a slower response rate. An ultrasonic ToF sensor would be unsuitable for detecting objects moving quickly. A huge advantage of ultrasonic sensors is that sound works under all lighting conditions, with no noise from ambient light sources. Ultrasonic sensors definitely the most affordable option for ToF.

3.2.3 Light-Emitting Diode/Infrared Sensor

Light-emitting diodes (LEDs) are utilized to produce a signal made of light. The speed of light is another well-known constant that does not require a medium to travel. In addition to that, air has a minimal impact on the speed of light. Light has a velocity of approximately 3×10^8 m/s. LED sensors are typically very compact and lightweight. The use of light has the huge advantage of a faster response rate since light is considerably faster than sound. The faster response would allow for much faster focus acquisition. Since light does not require a medium to travel through, these ToF devices could be utilized in space, although we will not need to for our purposes. Just as ultrasonic ToF sensors are susceptible to sound based noise, LED ToF sensors are susceptible to light-based noise. Ambient light could interfere with the accuracy. Sunlight and reflective surfaces can significantly with the distance at which the sensor is capable of operating. An LED ToF sensor also produces a cone-shaped signal, but the angle depends on the optics utilized to focus the light. This angle will greatly impact the precision of the device. While it may seem that a smaller angle would be more beneficial for its precision, in some cases, a wider angle is preferred as it'll detect a wider area. For diode-based ToF devices, there are short-range, mid-range, and far-range sensors. There are several factors that impact the distance at which a sensor will function, including the power output, the wavelength of light, the optics used to focus the light, and the sensitivity of the receiver. LED sensors are typically found to be power efficient and are perfect for short-range applications.

As mentioned previously, ambient light can result in noise and interfere with the accuracy of the sensor. Different wavelengths of light can be used to circumvent this to some extent, such as ultraviolet (UV) or infrared (IR) light. Infrared LEDs are commonly used for distance measuring purposes, because they have reduced interference from visible light. They are also eye-safe and much less noticeable since they operate outside of the visible spectrum. The maximum distance of LED ToF sensors is around 15 m. As the detection range of the LED ToF sensor increases, the cost also increases in cast. IR LED sensors are also typically more expensive than visible LED sensors. While faster and potentially more accurate than an ultrasonic ToF sensor, LED sensors capable of the required distances for our needs are much more expensive.

3.2.4 Laser Diode/LIDAR Sensor

Laser diode ToF sensors also produce a light-based signal. Since lasers are used in this case, the accuracy is much higher. They also have significantly greater range than the previously mentioned ToF sensor. Laser ToF sensors can measure at ranges of 300 m and beyond. This increase in range is due to the minimal divergence that lasers experience. This allows for incredible precision and accuracy, even at large distances. LIDAR utilizes the principles of ToF with laser diodes to produce three dimensional representations of objects or spaces. While not necessary for our purposes, this technology has the potential to lead to many incredibly beneficial accessibility features. The drawbacks of laser diode ToF sensors is that they can be potentially dangerous and harmful to human sight. Due to this, they typically produce light outside of the visible spectrum such as IR light. This also adds to the discrete nature of the sensor as it will not be visible to the human eye. All these benefits do come at a cost, however. A laser diode or LIDAR based ToF sensor is significantly more expensive than any other kind of ToF sensor. As the range and accuracy increases, the cost also tends to increase, so that must be considered greatly. For our purposes, we do not require the incredible range and precision that lasers provide and were not planning on utilizing this kind of sensor. The prohibitive cost further solidified our decision not to use a laser diode ToF sensor.

3.3 Motors

In the selection of motors for our design, several factors must be considered such as: size, weight, and positional accuracy. We evaluated several types of motors.

3.3.1 Stepper Motor

In terms of size, stepper motors are typically available in smaller sizes than other types of motors and since we are working with a space-constrained environment this will benefit us. It also appears to be the least expensive when it comes to the motors we researched on. Comparing the torque vs speed of the stepper and servo motors, as the graph in Figure 3.2.1 shows, at lower speed the stepper motor shows higher torque, meanwhile the servo motor shows lower and more constant torque than stepper. Stepper motors often encounter limitations in high-speed applications due to insufficient torque, leading to a potential loss of position [8]. But, for our design purpose we don't need high speed as that could detriment our design if we are to use high speed (>2,000 rpm). On the downside if we were to choose a stepper motor, we will need to incorporate encoders, as that will help us get precise information on the position of our lenses from the starting position. This could affect our design as that means adding this to our overall costs. The stepper motor has no feedback feature as it works in an open-loop circuit. That's the reason behind having to add an encoder to the design.

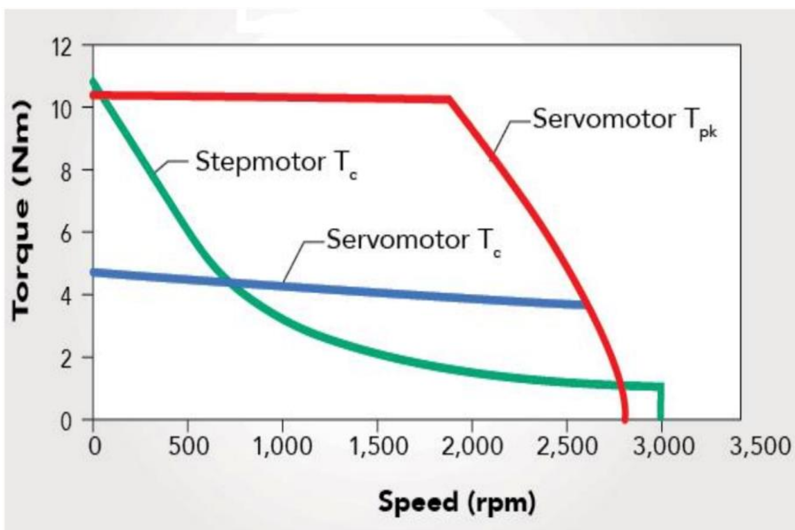


Figure 3.3.1 Torque vs Speed of Stepper Motor and Servo Motor

3.3.2 Servo Motor

When performance is a priority, servo motors demonstrate superior capabilities [8] compared to stepper motors. Our next factor to take into consideration is the cost of the motor, it is commonly known that servo motors can be more expensive than steppers as they have more complex features. However, the critical metric for our design is positional accuracy. Servo motors utilize closed-loop control, incorporating feedback to maintain precise positioning without additional components [8]. But we should take into consideration if we want this feature in our servo motor it will cost significantly more. As our design requires input from a sensor for position instructions, having a servo motor that can connect to an MCU and can give feedback is more beneficial than any of the other motors. Another feature of the servo motor is it can rotate in both directions, forward and backwards. But let's look at the different types of servo motor:

3.3.2.1 ROBOTIS Dynamixel AX-12A

The first example of servo motor is the Dynamixel AX-12A which is also known as a servo robot actuator. It has all in one integrated DC Motor + Reduction Gearhead + Controller + Driver + Network in one DC servo module [9]. All of the sensor management and position control is handled by the servo's built-in microcontroller [9]. Meanwhile this sounds like a good option, we must think about price and this servo motor is more on the costly side.

3.3.2.2 MG90S

The MG90S servo motor is a compact and lightweight motor that is used in many robotics' designs. The motor offers a decent torque as it allows up to 1.8kg/cm at 4.8 V operating voltage. The gears are made of metals, which in contrast to other materials, like plastic, makes it more durable when it gets jammed. When it comes to pricing, the MG90S is a good option as its price ranges around $4-$5 each. The downfall of this servo motor is that it has an open-loop design which means we will need sensors (encoders) to know the position of our lenses.

3.4 Microcontroller Boards

When it comes to selecting an MCU board there are many components to consider and factor in when choosing the best fit. In general, for our specific project, we need to look at processing power, camera interface, number of I/O ports, memory size, and power consumption. We researched several boards.

3.4.1 Raspberry Pi 4

The Raspberry Pi 4 is a potential option due to its impressive high processing power, capable of handling the complex task of image processing efficiently. It also has versatile connectivity options, including a dedicated CSI camera interface, plenty of CPIO pins to accommodate several peripherals, USB 3.0 ports, up to 8GB of RAM configurations, and built-in Wi-Fi/Bluetooth. It definitely is more on the expensive side in comparison to simpler microcontroller boards that might not have some components like the Wi-Fi and Bluetooth options. These might be unnecessary, and we can save money with a simpler board. The higher processing power also means that this board is less ideal for portable, battery-powered applications like our wearable glasses as battery life would be shortened as a result. It also lacks real-time processing capabilities which leaves potential problems in the future. Timing is also hindered by its reliance on a full Linux OS which can result in longer boot times.

3.4.2 Espressif ESP32-S3

On the other hand, the ESP32 is focused on low-power applications and is more battery-powered/wearable friendly. This is because it has many battery-extending power modes. But in comparison, it definitely has much more limited processing power in comparison to the other types of MCUs such as the Raspberry Pi 4 which could be a dealbreaker since we are dealing with image processing which can require high computational power. It offers the Wi-Fi/Bluetooth connectivity option and real-time performance for time sensitive applications as well as a built-in analog-to-digital converter which makes it easier to work with analog sensors without adding additional hardware. The ESP32 is much more of a budget friendly option and its smaller size works better with our more compact design build for the glasses. But the biggest tradeoff is its smaller memory, averaging around 512KB SRAM and 16MB external PSRAM, and less camera interface support.

3.4.3 Seeeduino Lotus

The Seeeduino Lotus is a potential Arduino-compatible board that's biggest strength is its compact size and easy integration with a sensor that we would be utilizing for this project. This can speed up prototyping especially with the large libraries available within the Arduino ecosystem. Along with this, the board is overall extremely inexpensive and still offers both digital and analog I/O pins and USB integration. Its biggest drawbacks come with a cost of low memory, offering only 2KB of SRAM and 32KB flash memory, and very limited processing power. This board has the lowest processing power of the previous boards we've looked at, it is not very suitable for more power-heavy tasks like image processing which is a huge component of our project. It also lacks a camera interface which means it would be difficult to incorporate capturing and processing images.

10 Administrative Content

10.1 Budget and Financing

Component	Name	Price	Quantity
CMOS Sensor	EOS Rebel T3 12.2 MP APS-C CMOS sensor	$23.98	1

CMOS Lens	Garage sale	$20	1
Primary Lenses	Garage sale	$20	2
Secondary Lenses	Garage sale	$20	2
Railing	Linear Rail Guide Linear Sliding Guideway with 1pcs Linear Bearing Sliding Block	$12.80	3
Button	Adafruit mini	$0.20	2
Frame	3D Printed	-	1
Motor	STEPPERONLINE Stepper Motor Nema 17	$12.99	2
Photodiode	Comimark 5Pcs BPW34 Silicon PIN Photodiode DIP-2	$6.89	3
Pack of Color Filter	SAMNISOO 30 pc color filter	$17	1
Strobe Light	Evan Designs Quickburst Strobe Light	$5.85	1
Servo-Motor Controller			1
PCB	easyEDA	$70	1
Raspberry Pi	CanaKit Raspberry Pi 4 4GB Basic Kit with PiSwitch	$69.99	1
Power Supply	Rechargeable power supply	$15	1

Table 10.1 Finance Table

10.2 Milestones

Senior Design 1	
Week	Goal
1-2	Form groups and finalize project concepts.
3	Divide and Conquer 10-Page due
4	Divide and Conquer review meeting w/t Chan/Wei
5-6	Post on website & Divide and Conquer Revision due

7	Create Gantt chard & Design Constraints and Standards due
8	Conduct research and initial design stages for 60-Page draft
9	Reach half point 30-pages of 60-Page draft
10	Finalize 60-Page draft and turn in.
11	Attend 60-Page draft review meeting and begin to make adjustments.
12	60-Page report revision due.
13	Begin work on 120-page paper and finalize designs.
14	Finish up 120-page paper
15	Final report and mini demo video due.

Table 10.2 Milestone Table

References

[1] "Be My Eyes - Bringing Sight to Blind and Low-Vision People." Be my Eyes. https://www.bemyeyes.com/ (accessed August 28, 2024.

[2] "How EnChroma Glasses Work." EnChroma. https://enchroma.com/pages/how-enchroma-glasses-work (accessed August 28, 2024.

[3] "Discover Ray-Ban meta Smart Glasses." Ray-Ban. https://www.ray-ban.com/usa/discover-ray-ban-meta-smart-glasses/clp (accessed August 28, 2024.

[4] R. Horaud, M. Hansard, G. Evangelidis, and C. Ménier, "An overview of depth cameras and range scanners based on time-of-flight technologies," *Machine Vision and Applications,* vol. 27, no. 7, pp. 1005-1020, 2016/10/01 2016, doi: 10.1007/s00138-016-0784-4.

[5] J. Kvam, "Time of Flight:Principles, Challenges, and Performance.," 2017. [Online]. Available: https://www.st.com/content/dam/technology-tour-2017/session-1_track-4_time-of-flight-technology.pdf.

[6] L. Li, "Time-of-Flight Camera – An Introduction," *Texas Instruments White Paper*. [Online]. Available: https://www.ti.com/lit/wp/sloa190b/sloa190b.pdf

[7] J. Choi, "Range Sensors: Ultrasonic Sensors, Kinect, and LiDAR," in *Humanoid Robotics: A Reference*, A. Goswami and P. Vadakkepat Eds. Dordrecht: Springer Netherlands, 2019, pp. 2521-2538.

[8] "Performance characteristics of servo and stepper motors| International Journal of Innovative Science and Research Technology," *Ijisrt.com*, 2023. https://www.ijisrt.com/performance-characteristics-of-servo-and-stepper-motors

[9] "ROBOTIS Dynamixel AX-12A | SmartRobotWorks.com," *Smartrobotworks.com*, 2024. https://www.smartrobotworks.com/AX-12A.asp (accessed Sep. 27, 2024).