Diamond Eye

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Abstract

Blindness is a disability that affects over 30 million people worldwide. There is a certain technology that is being used today, to alleviate this disability. This technology relies on a wired communication system to supply a retinal implant with power and data. Due to the wiring of the current solution, there have been many disadvantages such as discomfort, infections, as well as posing some high risks within the surgical procedure. The goal of our project is to improve the current technology by eliminating the use of wires in the current communication system, which is used to power and send data to the retinal implant. This can resolve many disadvantages associated with the current product due to the wiring of the system (Argus II retinal prosthesis), and also significantly reduce the cost for patients.

The product is designed to target a specific group of the blind population, such as those who have blindness due to Macular Degeneration. The Diamond Eye will provide essential, low resolution, black and white vision. The Diamond Eye is a product that can potentially raise peoples quality of life from an estimated 26% to 33%, by providing essential vision, with a higher resolution than the current selling product.

The project will entail the design and construction of a wireless data and power transfer communication system via modulated near infrared laser. The laser will be used to transmit the data/power optically and simultaneously through the eye onto a custom phototransducer chip. The chip will then power the retinal prosthesis and supply data obtained from an external sensor (camera). The image that will be seen by the patient will change based on the movement of their eye. Tracking eye movements, and focusing the laser accordingly will be a key development within our project. Other obstacles to be resolved include modulation, demodulation, data and image processing, noise filtering, and closed-loop sensing.

The members of our team are contractors hired by iBionics. Developed solutions are the properties of iBionics, but the information may be used for our school project, but not to the extent of violating the Non-Disclosure Agreement. An additional contract/agreement between our team and iBionics will be made for settling ownership of solutions we develop in the future. Existing intellectual property belonging to iBionics may be used for the report component of the
project.

1 Introduction

1.1 Scope (Noor)

The scope of the project will consist of designing a wireless communication system between a camera and a PV chip by using laser to transmit images and power the chip. A system will also be designed to implement tracking the movement of the eyeball (PV chip) to redirect the laser using a MEMs deformable mirror. Since the communication system and the tracking system designed will be a part of a bigger project, the "Diamond Eye", there will be certain tasks that we will not deal with and are out of our scope.

The group members will not be responsible for the transfer between the PV chip and the electric chip that is attached to the retina. The design of the glasses as well as integrating the system onto the glasses will be out of the scope of this project. Since there will be medical collaboration for this project, the group is not responsible for surgically implanting a chip in a patients eye. Members of the group will not be responsible for performing safety tests or trials on patients.

1.2 Goal (Noor)

1.2.1 Primary Goal

The primary goal of the project will entail the wireless data and power transfer to a PV chip by the use of laser. This will be done by decoding an image, sending the modulated signal to a laser driver, modulating the laser pulses through the laser driver onto a PV chip to power and send a signal, demodulating the output signal and displaying it.

1.2.2 Secondary Goal

The secondary goal of the group project entails the tracking of the eye movement by tracking the eyeball and redirecting the laser beam onto the PV chip.

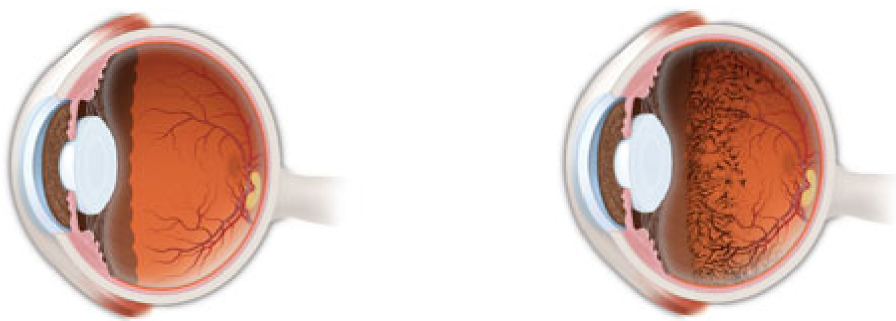
1.3 Overview (Anas & Noor)

According to the World Health Organization [6], there are 285 million people with visual impairment worldwide. 82% of the people living with blindness are aged 50 and above [6]. 50 million out of the 285 million people have blindness caused by degenerative retina diseases [3]. This issue continues to spread across the globe, with very limited solutions being provided, despite the technological advancements present in todays society. There has been extensive research in this domain yet not many companies have been successful at gaining a piece of the market with a successful product. The only company that was able to develop a product that benefits people with blindness is Second Sight, with their Argus II model.

The current technology used to help restore vision to people with blindness is called the Argus II Retinal Prosthesis System developed by Second Sight. The Argus II is the worlds first approved system to help restore vision to people with blindness [5]. The system is so far only approved in the United States and Europe. Not only is the Argus II the first approved system, it is the only approved system that exists today. Aside from Second Sight, two other companies are currently researching visual prosthesis as noted by Maghami et al., [4]. Those two companies are called The Boston Retinal Implant and C-sight. The Boston Retinal Implant is an American based company that is currently developing a visual prosthesis. Similarly, C-sight which is a Chinese based company is also currently developing a visual prosthesis to restore vision to people with blindness. Although the current technology, Argus II is the only option to help restore vision to people with blindness, there are many associated drawbacks that demonstrate the need for a new and better product. These disadvantages will be discussed in further detail in the sections below.

Currently under design is the “Diamond Eye” by a company called iBIONICS. The “Diamond Eye” is a system, if successfully implemented, will revolutionize the field of visual prostheses. Designed to be implemented as a wireless system, the technology will alleviate many disadvantages currently present in the Argus II product. The “Diamond Eye” will provide people with blindness, due to diseases, the ability to see without the risks that are associated with current technologies. One of the results of the research lead to iBIONICS pioneering the use of new materials in medical prosthesis, specifically, diamonds. The project consists of developing some features of the “Diamond Eye”, which are outlined in further detail in the scope of the project below. Once successfully implemented, using wireless technology will enable the company to further enhance the product easily and in the least intrusive way possible to the patient. The “Diamond Eye” uses a microchip encased by diamond casing that is implanted on the retina. The microchip receives data and is powered by a laser which is transmitted from a laser driver that is installed on glasses that must be worn by the patient. There are several problems to consider in the design. Aside from the use of laser to send the data and power the chip, tracking the microchip is a subject of interest for this project. It is of importance to ensure that the microchip is receiving the laser signal fully to be able to correctly receive the power and data. This concern can be resolved by tracking the patients eyeball movement by the use of a camera and image processing. As the design progresses, there will be many concerns to take into consideration and issues to be resolved to ensure a successful and well integrated product for targeted population of people with degenerative retinal disease.

The “Diamond Eye” is designed for people with degenerative retinal diseases, specifically those with Retinitis Pigmentosa and people with Macular Degeneration. Retinitis Pigmentosa is defined by the American Academy of Ophthalmology [1] as a “group of genetic disorders that that affect the retinas ability to respond to light. This inherited disease causes a slow loss of vision, beginning with decreased night vision and loss of peripheral (side) vision. Eventually, blindness results.” Macular Degeneration is an age-related disease that causes a breakdown of the eye’s macula. The macula is the part of the retina that is responsible for your central vision, allowing you to see fine details clearly, it is much more sensitive than the rest of the retina. Many older people develop macular degeneration as part of the body's natural aging process. There are two types of Macular Degeneration, dry macular degeneration and wet macular degeneration [2]. It is estimated that by 2020, 196 million will be living with Retinitis Pigmentosa. Blindness is a disability that significantly affects the quality of life for people with blindness. In addition, blindness has a high societal cost. In 2007, the cost of blindness in Canada was $15.8 billion and in 2020 it is estimated to increase to about $670 Billion worldwide [3]. As a company, iBIONICS will not only revolutionize the field of visual prostheses with the design of the "Diamond Eye", it will also lead to a significant improvement in the quality of life for people with blindness caused by retinal degenerative diseases.



(a) (b)

Figure 1: (a) Normal Retina (b) Retina with Retinitis Pigmentosa [1]

The opportunity to collaborate on this project was provided to the group through SUNLAB at the University of Ottawa. SUNLAB obtained this project as a research opportunity from iBIONICS. Although the project is facilitated by SUNLAB, iBIONICS will be funding the project by providing all the necessary parts to build the prototype. The details of the design that will be implemented will be discussed in subsequent sections but an introduction to the design will be provided here. The project will consist of a camera that will capture data to be transmitted to the Photovoltaic (PV) chip. The data will be processed and converted to a digital stream of bits using a microcontroller and an encoder. The stream of data will drive a laser into transmitting a corresponding trail of bits which simulate the digital signal. The stream of bits steered by a MEMs deformable mirror will be transmitted onto a highly-absorbent Photo-transducer cell that will convert the laser beam into digital signals. The signal will be filtered and sent to a decoder to decode the data into pixels to be displayed by the use of a microcontroller. A tracking system will also be developed to ensure that the laser driver will send the beam to the PV cell with no reflections. This will be done by the use of a camera to capture the movement of the eye. By capturing the movement of the eye, information can be sent to a microcontroller to ensure that the MEMs mirror will always reflect beam accurately. There are many different aspects to the project that will need to be considered and studied carefully. Research methods and detailed designs will be following in subsequent sections.

2 Literature Review

2.1 Wireless Communication (Zac)

Infrared are defined as electromagnetic radiation spectrum at wavelengths between visible light and radio waves, which is between 700nm to 1mm or 300GHz to 430 THz [15]. By replacing cables with wireless infrared transmission we not only extend the physical constrain of applications but also enhance the performance by providing a faster data transmission. An infrared technology is capable of providing wireless communication faster than Wi-Fi and Bluetooth up to Giga bits per second (Gbps) [16]. By using infrared laser, we remove a majority of physical wires that were suppose to be inside the human eye which can ease the difficulties of surgery and remove the discomfort from patients, and since the infrared are not visible for human eye, it will not cause vision distraction. Some other advantages for infrared is that it is in frequencies higher than Radio frequency (RF), so it will be easier to process the noise and also provide us an easier solution for receiver by using photo-transceiver.

2.1.1 Modulation - Manchester Coding

Manchester encoding is a form of digital encoding in which data bits are represented by transitions from one logical state to other [23]. Where the typical encoding method is when the data is 0, the encoded bits become 01 and when the data is 1 the encoded bits become 10. This encoding method was developed by G.E. Thomas. The relation can be shown in Table 1.

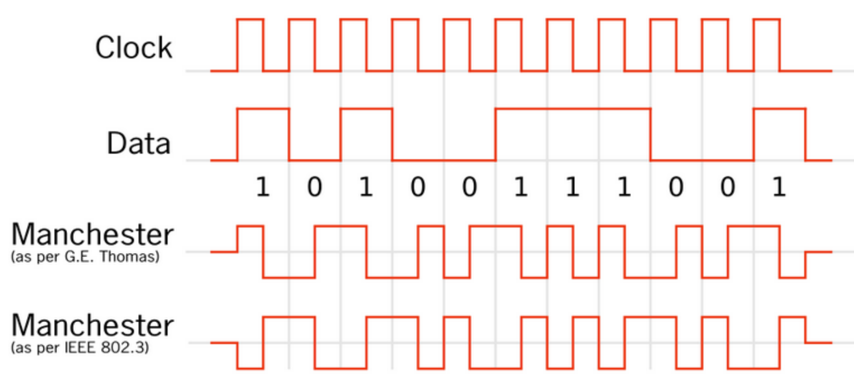


Figure 2: Manchester Coding

Table 1: Mancheser Coding Logic

Data	Clock		Manchester
0	0	XOR	0
	1		1
1	0		1
	1		0

From Table 1 we can see that the advantage of using Manchester Coding is that the signal synchronizes itself by being directly proportional to the clock rate [22]; which helps clock recovery. So the encoded values are also equal to the data bits XOR with clock. By having the signal synchronizing with the clock minimizes the error rate and optimizes the reliability, but the major disadvantage is that Manchester encoded signal requires more bits than the original signal to transmit, i.e. transmission rate is twice the original, [23], which also increase to twice the original bandwidth.

2.1.1.1 Encoding and Decoding Method

The encoding for Manchester can be simplify by translating 0 and 1 data bit to 01 and 10 encoded bits. From Marty [24] sync the encoded bits with the clock he defined. The total packets he send contains 6 bits of initial clock, 8 bits of sync patterns 2 start bits and final the encode data bits. He detects the Most Significant Bit (MSB) every positive trigger of the clock, then encode with every positive and negative trigger of the clock; this way he is synced with the clock and the encoded bits have twice the frequency respect to the original signal. After detecting the MSB he shifts the position of MSB left and detects the next bit.

Marty's decoding method is to detect the transition of encoded bits. He look for whether there is no bit change for a cycle of clock, the program decide there is a bit change in data bit, if not, there will no data bit change; hence the same of previous detect data bit. After detecting every 2 encoded bits, the program shifts left, hold the decoded data bits. After 16 encoded bits or a byte of decoded bits, the program save the values from hold [24].

Before the decoding is proceed, he first check if the received data is synchronized by setting upper and lower threshold. If there is no transition for the received data, the program waits until there is transition. Once a transition is detected, the program check if the bit time is within the upper and lower bit threshold time. If it is then the received data is synced with the clock, otherwise they are not synced. If the data is not synchronized, the program waits for another transition to happen. Once the first transition of the received data is detected, the decoding program start its clock for decoding [24].

2.1.2 Sampling Data

Before we start transmitting data, we need to know how to sample the transmitted data. In [17] is an example done by Michael Smith with Arduino for sampling data at a specific rate with an pre-stored audio file in the header. In his work, he created an internal clocks timer 1 and timer 2 to achieve sampling. He first set the internal clock to be 8000Hz. He uses timer 2 to do a simple Pulse Width Modulation on the desire audio output pin, in his case is pin 11, and the width of the pulse width modulation is determined by timer 1. Timer 1 gives the specification for timer 2s pulse width modulation based on the value of the byte stored in the audio header file. Then finally, he increments the position of the byte from the audio array in the header file to read the next sample.

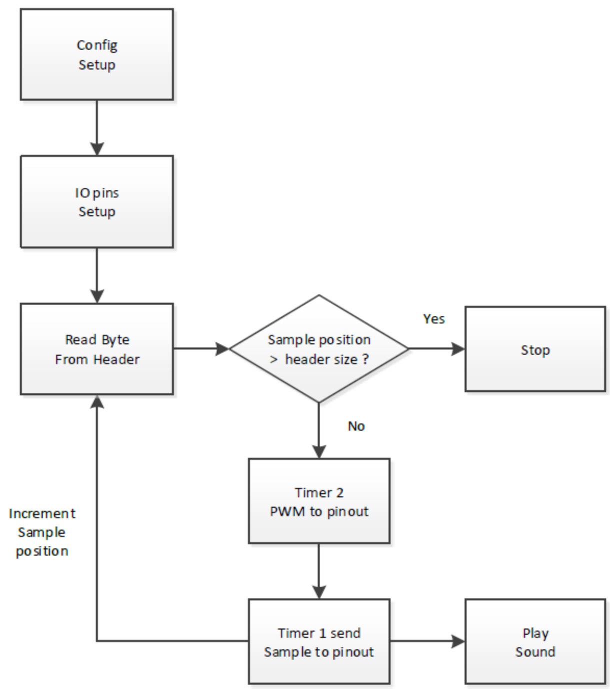


Figure 3: Sample Data Flowchart

2.1.3 Transmission

iforce2d created a cheap laser transmission device with under 5 dollars and are able to transmit audio at a maximum of 100 meters away [18]. In his work found in [18], he uses the sampling method mentioned above and transmit audio from a SD card instead of a header file. He makes use of one of the Arduino sample code called “DumpFileToSerial” to read the SD card which contains the actual audio file and can transmit 14.4kHz to the transmitter Arduino which send the data to TX pin of the Arduino. The TX pin is connected with the laser so the data will transmit over the laser. The signal is not modulated, so his work is better to work indoors where there is less interference. Then he connects RX on the receiver Arduino with a laser receiver. On the receiver Arduino he uses the same code from [17] but modified the sampling source to RX.

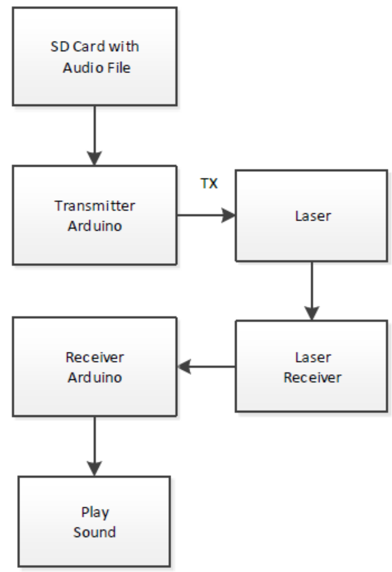


Figure 4: Transmission Flowchart

2.1.4 Powering Lasers

Some existing applications that uses lasers as their power sources like unmanned aerial vehicles (UAVs), robotic devices, and hazardous environment or remote sensor applications [19]. By using lasers as power sources we can optimize our system not only in their physical space, weight but also solving the issues of battery problems. Comparing to the system powered by batteries, powering by laser can potentially increase the operating time, reduction or elimination of recharging events and reduction in weight [19]. Despite the advantages laser powering device brings, it also brings new issues to the system. One of the issues is regarding the current control. Because the laser diode follows an exponential IV curves [20], which means it might require high current to achieve the desire voltage level, but in our cases, the current will be limited by our processors. Second issue that may rise in our application is that the slow response time of the laser diode [20]. To solve this, we can oscillate our signal at the minimum require power for the laser diode to maximum logic voltage, i.e. oscillate from 20% to 99% signal, which will reduce the response time and also provide higher data rate. One of the most significant safety issue for our laser application is the fail safe trigger. Our design need to power down the laser when error is detected which it can be done by wireless feed back by Bluetooth transmission.

2.1.5 Decrease Resolution/ Frame Compression

In our application, we do not need a high resolution camera, but most of the camera module in the market are usually in high resolution to be compatible with the newer micro-controller; hence instead of hardware solution, we require a software solution to achieve our goal. By decreasing the resolution, we not only decrease the amount of data needed to process before sending, but also possibly decrease the delay time due to high resolution.

On the Raspberry Pi forum, many have stated that it is possible to change the resolution of the video camera on Raspberry Pi [25]. The method many use is change the settings for video capturing from Bash command window. But once the resolution is change, we will lose overlays (dom,[25]); hence addition command to scratch the screen to full screen mode.

2.2 Tracking (Anas)

2.2.1 Eye Tracking and Computer Vision

Eye tracking constitutes an integral part of this project. To ensure a proper and constant transmission of data, and to prevent long-term damages to the eye; we must ensure a constant alignment between the laser and the chip inside the eye. To solve this issue, our group discussed different possible solutions. Many factors determined the solution we considered including but not restricted to; Safety, possibility of integration in the final product and ease of implementation. In the next few sections we will be discussing different methods, in addition to advantages and disadvantages.

2.2.1.1 Elliptical Mirros

An *elliptical* is a geometric shape that has two focus points (foci) which always lie on the major (longest) axis, spaced equally each side of the center [8]. Simply, if a beams of light (or sound waves) go through point F1, it will reflect off of the ellipse wall and will always pass through F2 and vice versa.

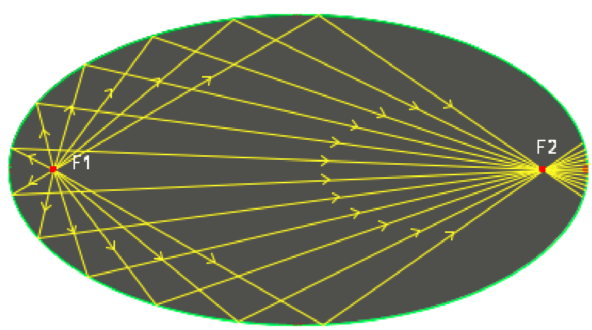


Figure 5: Elliptical Mirrors [8]

This design is aesthetically pleasing, and practical. The idea is to take advantage of this physical phenomenon passing the beam through one of the foci points, and align the PV (Photovoltaics) such that it is located on the second focus point. This way the laser beam will always go through to chip If we ensure proper alignment. This method of design does not require any moving parts nor an external control of a microcontroller to guide the beam.

2.2.1.2 The Design

Focus (1) in this case would be our aim, and Focus (2) will be the PV chip. We are only using a portion of the ellipsoid. Typically, this part will mount on a frame that patients will wear. There are definite challenges if this method is chosen. First, the challenge of creating such an alignment between the chip and focus (1) in an ellipsoidal shape. Typically, users will wear frames that carry the laser transmitter, so this is one of the things we must keep in mind when creating the system. Another challenge is on the long run this method must accommodate patients movements. If patients were to preform physical activities such as running, the constant and random movements will cause a misalignment between the laser beam and the focus, hence a loss of data.

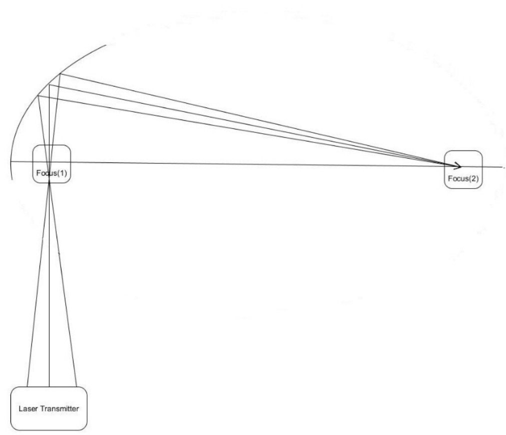


Figure 6: Illustration of Design

2.2.2 Eye Tracking via Computer vision

In this method, a camera detected to tracking the pupils movement will be used. A small camera directed towards the eyeball monitors the pupils movement through image processing, then sends feedback to a microcontroller. Which in turn controls a MEMs - *Microelectromechanical systems* mirror to change direction accordingly. In the following few sections, we are going to discuss different components of the tracking system.

2.2.2.1 Computer Vision with OpenCV

When dealing with tracking live object, one is faced with many options to choose from. However, in this section we are going to discuss two of the main algorithms used for this purpose. *MeanShift* or *CAMSHIFT*. Both of these algorithms are used in image processing of live objects. However, each has their pros and cons!

2.2.2.2 MeanShift

Named after the Mean Shift Clustering theorem for calculating and locating the maxima of a density function [9]. This algorithm uses this mathematical concept to track live moving objects. Consider the set of red points in Figure 7 which correspond to pixels of processed image. Also, consider the tracking window "C1" in Figure 7, in which the tracking will take place.

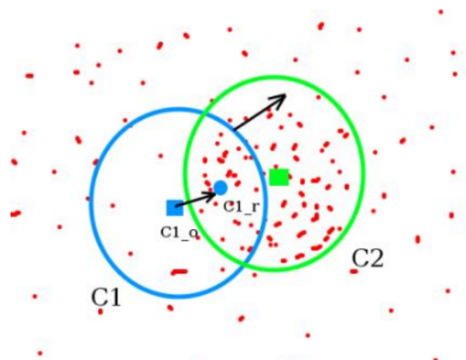


Figure 7: MeanShift [10]

The algorithm specifics the **real** center of the points by scanning through the points and taking the center with respect to density "C1_r". Then it determines that the real center does not match with the geometrical centroid "C1_o" matches "C1_r". This process happens iteratively until the real centroid of pixels matches the centroid of the window. This way when objects move, the real centroid "C1_r" will change locations and the iterative process will track the changes in the image. A sequence of pictures below in Figure 7 shows the algorithm in action.

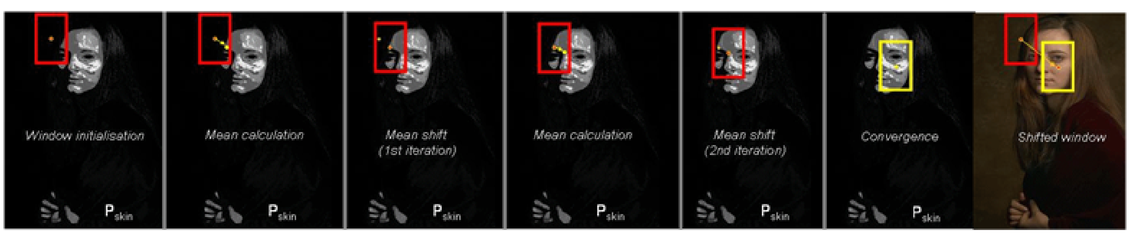


Figure 8: MeanShift Algorithm [10]

Iterations identical to 1^{st} and 2^{nd} iterations happen repeatedly until the center of window and its centroid falls on the same location (or with a small desired error). So finally what you obtain is a window with maximum pixel distribution. It is marked with green circle, named "C2" in Figure 7 it has maximum number of points [10]. OpenCV explains how user can use this algorithm:

"*So we normally pass the histogram backprojected image and initial target location. When the object moves, obviously the movement is reflected in histogram backprojected image. As a result, MeanShift algorithm moves our window to the new location with maximum density.*"

2.2.2.3 CAMSHIFT

The previous algorithm works a great job in tracking objects. However, the size of the window C1 and C2 in Figure 7 never change. This inflexibility in MeanShift causes many issues especially if objects are moving closer and further from the camera rather than a horizontal motion across a fixed frame. CamShift solves this issue by introducing an adaptable frame size that changes size based on the movement of the objects.

CAMshift which stands for *Continuously Adaptive* Meanshift published by *Gary Bradski* in his paper *"Computer Vision Face Tracking for Use in a Perceptual User Interface"* in 1988. It is identical to MeanShift in the initial process. However, upon convergence the algorithm updates the size of the window as follows [10]:

$$s = 2 \times \sqrt{\frac{M_{00}}{256}}$$

Where M_{00} is the zeroth moment of the sum of the x, y coordinates of the pixel probability. Also, the orientation of the window will be updated as well. In Figure 7 the window was chosen to be circle therefore the orientation does not matter. If the window was a rectangle however, the orientation should be considered as it will account for additive flexibility.

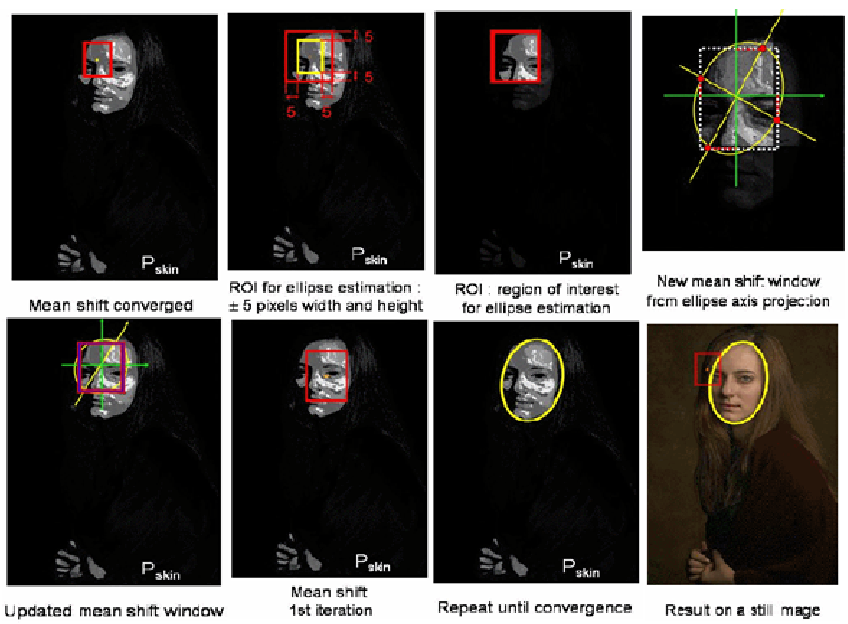


Figure 9: CamShift Algorithm [10]

Gary R. Bradski - the creator of CAMShift- explained in his paper "*Computer Vision Face Tracking for Use in a Perceptual User Interface*" why CAMShift is useful [10]

"*Unlike the Mean Shift algorithm, which is designed for static distributions, CAMSHIFT is designed for dynamically changing distributions. These occur when objects in video sequences* *are being tracked and the object moves so that the size and location of the probability distribution changes in time. The CAMSHIFT algorithm adjusts the search window size in the course of its operation. Initial window size can be set at any reasonable value.*"

2.2.2.4 OpenCV

Is a multiplatform API - Application program interface that contains hundreds of computer vision algorithms. It is compatible with multiple coding languages such as C++, Java and Python which makes it very convenient if its used in conjunction with a computer-board such as a BeagleBone or a raspberry pi, which means that it supports different operating systems such as MacOS, Windows and Linux which simulates the environment on the mini - computers.

OpenCV has a many different static and public libraries and packages that can be embedded and utilized. These packages allow users to take advantage of previously implemented functions that can be manipulated for different usages. These packages include [11]:

- **Imgproc**: an image processing package that includes filtering, geometrical image transformations (resize, affine and perspective warping), histograms, and many more. It allows easy editing and manipulation of images, which means that users do not have to use external resources to do so.
- **Video**: a package that handles motion estimation, background subtraction, and object tracking algorithms.
- **highgui**: an easy-to-use interface to video capturing, image and video codecs, as well as simple UI capabilities.
- **gpu**: stands for *Graphics Processing Unit* and it is simply a group of accelerated algorithms for a faster use.

It also contains method for automatic memory allocation and management, in addition to many functions that make it fixable and user friendly. It allows the ability to configure -since its open source- all the different aspects of the CAMShift algorithm such as the window size.

Another choice to make is whether to implement using Python or C++, since both the mini-computer and OpenCV support both, which one is better to use? Next we list a few pros and cons of each and make a decision based on them [12].

Table 2: Programming Language Pros and Cons

	Pros	Cons
C++	• Huge optimized library • Big community • Platforms and devices	• Weak documentation • Small machine learning library • Visualization and debugging
Python	• Ease of use • Python has become the language of scientific computing • Visualization and debugging • Building web backend	• Weak Documentation • Lack of Support • Slower run time • OpenCV is written in $C/C++$

2.3 Future Applications

2.3.1 Human Eye (Noor)

Due to the complexity of the human eye, the biology describing vision and the mechanisms involved can be extensive. For the purpose of this report, only a brief and related description will be provided. Figure 10, shown below, outlines the main components of the human eye that will be discussed in this section. According to the American Optometric Association [27], to see an object, light is reflected off the object into the human eye through the cornea. The light is then passed through the pupil, which varies in size, to control the amount of light entering the eye. The light rays are further bent and focused on the retina by the lens of the eye. The retina, which is a thin layer of tissue that is located in the back of the eye contains millions of cells called the rods and cones. The rods and cones convert the light into electrical impulses which are sent to the brain via the retinal ganglion cells. The brain then processes the electrical impulses into the image seen. There are many reasons which may lead to the loss of vision, but this report will focus on retinal degenerative diseases.

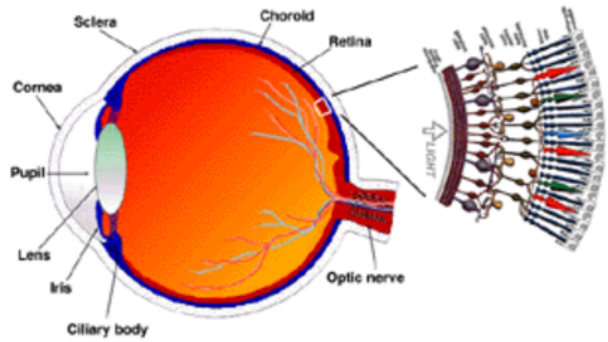


Figure 10: Human Eye Diagram [28]

2.3.1.1 Retinal Degenerative Diseases

Two specific retinal degenerative diseases that will be discussed are Macular Degeneration (AMD) and Retinitis Pigmentosa (RP). People who have developed loss of vision due to these two diseases are the target population for the Diamond Eye. Retinitis Pigmentosa (RP) is a disease that affects the retinas ability to respond to light due to the extinction of the rods and cones cells in the retina [1]. RP leads to the loss of night vision and peripheral vision, then the loss of central vision, eventually leading to blindness. Similarly, Macular Degeneration is and age related disease which is caused by the deterioration of the macula, which is the part of the retina responsible for central vision [2].

Macular degeneration can be developed by aging individuals as part of the bodys natural aging process. There are two types of Macular Degeneration, dry and wet macular degeneration [2]. Dry Macular Degeneration is the most common type or AMD and is caused by the thinning of the tissues of the macula due to aging. Wet AMD occurs in about 10% of the people who have Macular Degeneration and it can lead to more severe damage to vision than the dry AMD [2]. Wet AMD is caused by the growing of abnormal blood vessels underneath the retina. Due to the fact that these two diseases are caused by a failure in the retina, a retinal implant to simulate the retina is the only current solution available.

2.3.1.2 Laser Effects on The Human Eye

The Diamond Eye is a prospective retinal implant that requires the use of laser to transmit information and to power the chip, therefore it is important to note the biological effects of the laser on the human eye. According to the US Department of Energy [29], the effect of a laser on the human eye will depend on the wavelength of the laser as well as how the energy of the laser is directed at the eye. If a laser beam is directly focused on the eye, the damage is much more extensive compared to a reflected beam. A diffused laser reflection will result in a decrease in the irradiance of the laser by spreading out the radiation of the laser [29]. This is due to the fact that energy of the laser is denser when the spot size of the laser is smaller.

Any light that enters the eye is focused by the lens of the human eye before it touches the retina. The human pupil can vary in diameter depending on the brightness of light that is projected onto it. The average diameter of the human pupil can range between 3 mm to 10 mm depending on the intensity of the light shining on it [26]. Therefore, the energy of a laser beam may be intensified up to 100, 000 times due to the focusing of the beam by the lens of the eye [29]. This is important to note due to the possible danger the laser can pose on the retina and possible damage that may arise due to high intensity. Different wavelengths of laser will cause different types of damage, depending on the intensity and the conversion of the light to heat by the retina, therefore causing burns to the eye. Hence, when developing a retinal prosthesis that will obtain power and data from a laser beam, it is vital to consider the intensity of the laser and power transmitted to prevent damage to the eyes. There many factors to consider when developing visual prostheses, a field that has drawn many researchers to be the pioneers in developing a solution for people with vision loss.

2.3.2 Visual Prosthesis (Noor)

Due to the increasing population of people with blindness, there have been many efforts lately to develop a solution such as a visual prosthesis. Visual prostheses are implantable electronics microsystems developed to treat extreme vision impairment [4]. The process can be described by capturing an image of the persons view and by the use of the visual prosthesis, electrically simulating the individuals visual system and hence the brain to view the image. Although visual prostheses may aid people with vision loss to perform simple tasks, it is unlikely that the"collection of spots of light which are seen during electrical stimulation of the visual corte" would recreate perfect vision [4]. A general visual prosthesis system is shown in Figure 11 below, which conveys the use of a camera to capture the image, microprocessors and an electrode array.

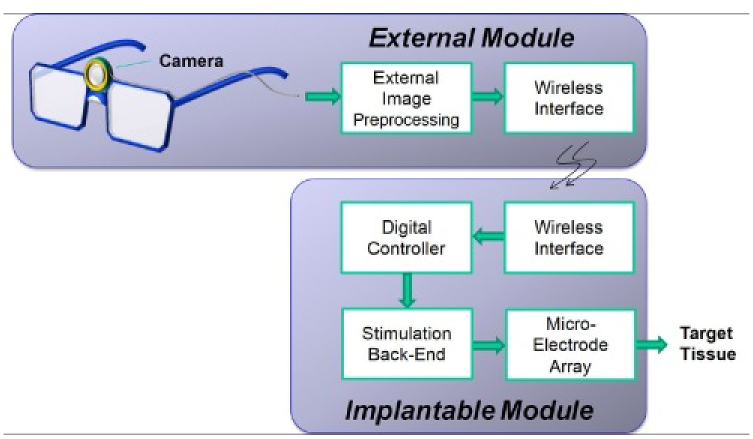


Figure 11: A General Visual Prosthesis System [4]

Although the target tissue can be any part of the human eye, most of the research conducted is for retinal prosthesis. There are many advantages to retinal prosthesis, but the main reason is that the overall procedure for implantation on the retina is straightforward with minimum side effects [4]. Visual Prosthesis has been a topic of research for many groups including The Boston

Retinal Implant (USA), C-Sight (Chinese Project), and Second Sight (USA) [4]. However, only Second Sight was successful at creating a product that has been implanted into a humans eye, the Argus I and II.

2.3.2.1 The Argus II

The Argus Retinal Prosthesis System is the first approved retinal implant to restore partial functional vision to people with blindness, created by a company called Second Sight [5]. Second Sight developed their first retinal implant which was successfully implanted in 6 people [4]. The very first implant, the Argus I, contained 16 electrodes, and was later developed into the Argus II which now contains 60 electrodes [5]. The system operates similarly to the general system shown above in Figure 11. The process used by the Argus II system is outlined in the steps below [5].

1. A video camera captures the scene (as shown in Figure 12 below)
2. Video is transmitted to a computer which is worn by the patient
3. The processed data is sent back to the eyeglasses to be transmitted to the implant
4. The implant receives the data by the use of the attached antenna
5. The data is sent to the electrode array which converts the data into electrical pulses
6. The electric pulses are used to stimulate the cells in the retina

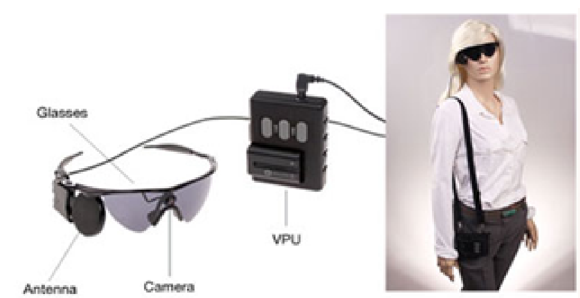


Figure 12: The Argus II Retinal Prostheses System [5]

The Argus Retinal Prosthesis System is currently the only available solution to people with blindness due to retinal degenerative diseases. During the trial of the Argus II, all 30 patients were able to perceive light during the stimulation [31]. However, it is not an ideal system, due to associated disadvantages.

2.3.2.2 Disadvantages of the Argus II

Although the Argus II is the only available solution for people with retinal degenerative diseases, there are many drawbacks associated. Many patients had adverse effects to the implant, and although they were successfully repaired, these should be noted. According to [31], 10% of patients developed conjunctival erosion over the implant, two patients had retinal detachments after the surgery, and one had to have the implant removed. This can also be due to the fact that the Argus is placed by the use of a circumferential vitreous band that surrounds the human eye as shown in Figure 13 below. This can also be the cause of the lengthy procedure to place the implant.

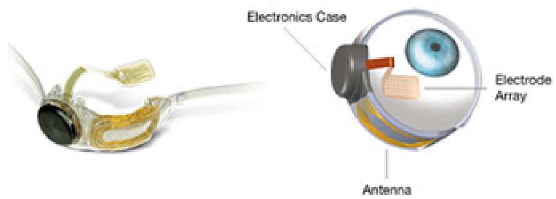


Figure 13: The Argus II Implant [5]

The procedure that patients receiving the Argus II have to go through is a long, complicated, and costly procedure. The procedure is complicated and lengthy due to the necessary placement of the implant and all the wires that are connected to it. The implanted wires also increase the risk of bacterial infections that may be caused during the implant procedure. The procedure can take up to several hours due to the complication of the implant. The length of surgery, increases the cost of the overall Argus II Implant system, making it unaffordable for most people. It is currently estimated to cost $150,000 [32], excluding the cost of surgery. Therefore, although it is the only solution that people with blindness have, the Argus II has many drawbacks as discussed above.

2.3.3 The Diamond Eye (Tony)

The receiver and integrated circuit is enclosed in a diamond case with diamond array on the back which attached and stimulate the retina.

The most important advantage of diamond is that diamond shows great promise as a durable, compatible, wear- and corrosion-resistant coating for biomedical implants. It will significantly reduce the risk of infection, toxicosis, and repellent. The regular electrodes, which is mostly made of metal and dielectric material such as plastic for insulation, is subject to toxication. The cell will repel the unidentified material. However, the diamond case is pure carbon (with doped Nitrogen atom) which is similar to the human cells.

It was found that efficiency of bacterial settlement depends on the presence of proteins in the surrounding media and that NCD surface exhibits the highest resistance to this process, significantly higher than that of titanium [13].

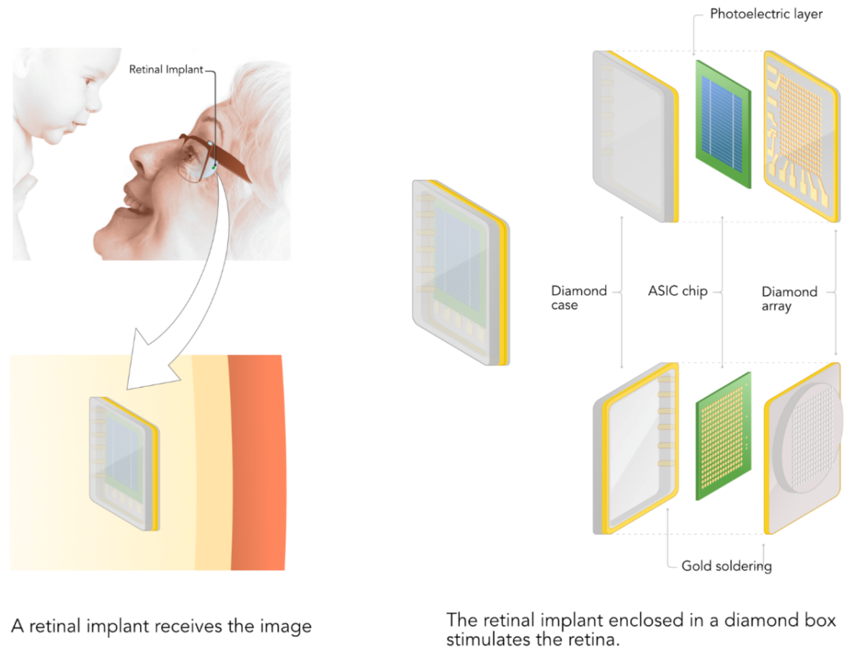


Figure 14: The Diamond Eye: How it works

The second advantage is the large capacity within the limit area. There has been interest in investigating, diamond as a material for use in biomedical implants. Diamond can be rendered electrically conducting by doping with boron or nitrogen. This has led to inclusion of boron doped and nitrogen included diamond elements as electrodes andor feedthroughs for medical implants [14].

In the current design, there are 256 electrodes (pixels) on a $2 \times 2mm^2$ surface. The regular electrodes, which is mostly made of metal and dielectric material such as plastic for insulation, will take a large amount of space. However, the available area on retina for implant is limited. Therefore, dope diamond with Nitrogen atoms will change the conductivity of diamond on nano-scale. Potentially, more electrodes are able to be placed to increase the resolution of display for future development. The next stage would be at a higher resolution with 1024 pixel and diamond technology will provide the ability to locate the desired pixel on the limited surface.

3 System Requirement Specification (Noor)

There are many different individual systems that will be combined together to yield the final project demonstration. However, the final project demonstration will resemble the functionality of the ideal system of iBIONICS, but will not look similar to the mechanical design of the ideal system as can be seen from Section 4.2.1 below. This section of the report will highlight the functional and non-functional system specifications of both the final project demonstration as well as the ideal iBIONICS system.

3.1 Functional

There are certain specifications which are deemed necessary in order for the product to function, hence these are termed functional system requirement specifications. For the final project demonstration, the individual parts will be connected together to yield one final system. The system requires the use of certain parts that are necessary for functionality purposes. These parts include 2 cameras, a function generator, 2 microprocessors, a laser driver, a MEMs mirror, a PV chip (soldered onto a gold plate), and an oscilloscope. The laser driver must be one that produces a laser beam at a certain required wavelength. The system will operate based on a near-infrared laser light, hence a wavelength of 340 nm to 860 nm is necessary to be detected by the PV chip. The source power should be in the range of 30-50 mW, to avoid any biological hazards which may be caused by the laser. In addition, when transmitting the data, the transmission bandwidth should be around 1 MHz, which ensures a fast and efficient system. The microprocessor should be one that will have a sufficiently short response time, to comply with the required response time of tracking, which is approximately less than half a second. In order for the tracking part of the system to function appropriately, the MEMs mirror needs to be controlled by the microprocessor and tilted to cover a range of a few degrees (20-30 degrees). The voltage required by the MEMs mirror is high (a few hundred volts), however, to produce low power (range in the MWs), the MEMs mirror will require very low current (micro-Amps).

Similar to the requirements mentioned above, the ideal system requires a laser of wavelength 340 nm-860 nm to be generated from the laser driver. The source power will also be kept within a range of (30-50 mW) to avoid biological hazards to the patients eye. The required transmission bandwidth of the ideal system is 1 MHz or more, as long as the system is functioning appropriately. If the system can be proven to work at a faster rate with no present errors, then the transmission bandwidth can be increased. In addition, for the ideal system, the MEMs mirror, must be placed in such a way so that it can rotate to cover a certain range of the human eyes normal axis (20-30 degrees). It is important to note that for the ideal system, the main power supply will be provided by the use of a battery pack which will be attached to the glasses by electric wires. The battery pack should provide enough power to the entire system for a large number of hours. The power provided by the battery pack should be sufficient to supply the system with enough power, so that it will only need to be recharged once a day. The amount of power needed to supply the entire system will be decided once the system is fully integrated onto the glasses and certain components are specified. Since the ideal system will actually be implemented into the human eye, the placement of the chip inside the eye is a key requirement for the functioning of the system. The chip needs to be placed inside the retina, in such a way that the laser will be easily directed through the lens of the human eye. Therefore, it is important to place the chip on the wall of the retina in a certain way, to receive the he transmitted laser beam. The ideal location of the chip should be situated at the end of main axis of light entering the human eye. In order for the system to operate appropriately, the glasses need to have an Anti-Reflection coating applied to the outside, to ensure that external near-infrared wavelengths are reflected. This is necessary to minimize the errors which may occur due to external near-infrared wavelengths.

3.2 Non-Functional

For the project demonstration, aside from the specified parameters in the above section, any component can be used to carry out certain functions. For example, any camera can be used to capture the image of the persons view, or capture images of the PV chip to use for tracking. However, the camera is still a required component of the system. There are certain things in the system which are not required for the functionality of the system. The non-functional system requirements pertain more to the ideal system rather than the system designed for project demonstration.

In the ideal iBIONICS system, the shape of the glasses which can be seen in Section 4.2.1 Figure 22, is a non-functional system requirement. The size, color, and style of the glasses are also non-functional requirements. In addition to the glasses, the type, size, and color of the battery pack are all non-functional requirements, the only required specification is the power being supplied by that battery pack. Other non-functional system requirements include the integration of the microcontrollers onto the glasses. This requirement is non-functional, because the microcontrollers can be added to an external pack similar to that of the battery pack. However, for the convenience of the patient, most of the parts are integrated onto the glasses.

4 Project Design

4.1 Block Diagram (Zac)

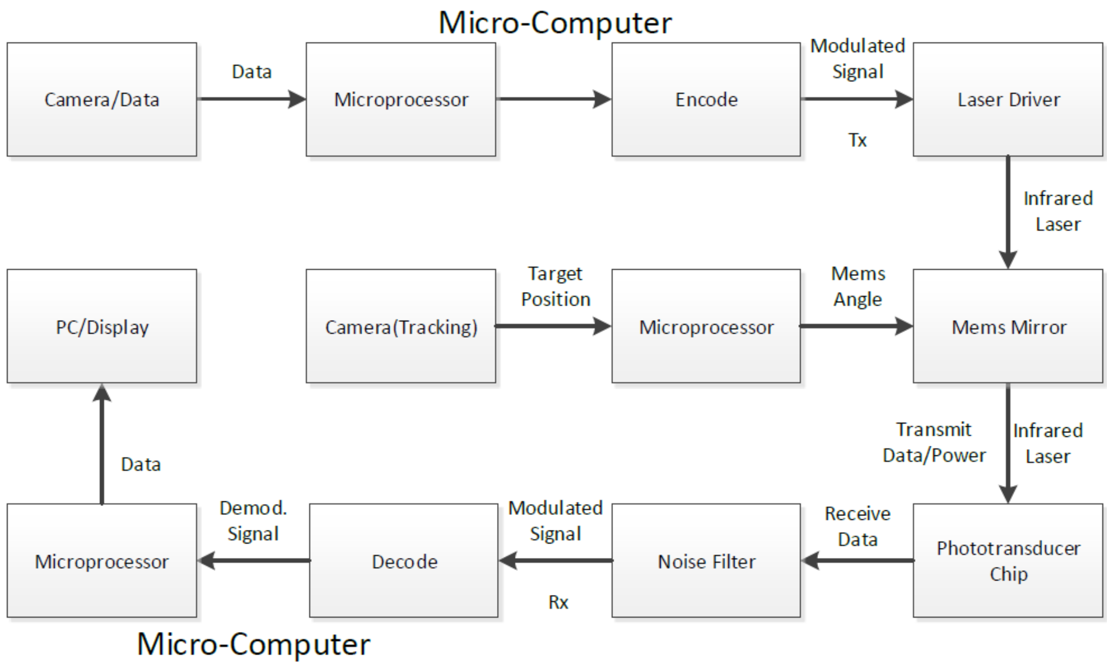


Figure 15: System Block Diagram

As shown in Figure 15, our system require two cameras for two different purposes. One camera is to capture the image into data for transmission, the second camera is to track the movement of the target. The image data from the first camera will be send to a micro-processor, which is Raspberry Pi 3, for image processing and modulation then the modulated data will be send to a laser driver and output modulated laser beam. The image data from the second camera will be processed into coordinates for the Mems Mirror. The coordinates will control how much angle to adjust which controls the reflection angle of the laser beam. Once the PV chip received the signal, a filtering of noise will be applied dependently. The filtered signal will be demodulated back into image data by another Raspberry Pi 3 and output the image.

4.2 Hardware

4.2.1 Mechanical Design (Noor)

Due to the nature of this experiment, two different mechanical designs will be shown in this section. One design will convey how the final project will be demonstrated, while the second one will show what the ideal product should look like. As shown in Figure 21 below, the parts used in the design of this project will not be integrated into one system, but will be kept as individual systems and connected as shown in the figure. The way the parts are connected in Figure 21 below will be used as a guideline for demonstrating the end project.

4.2.1.1 Coordinate System to Determine the MEMs Mirrors Angle of Rotation (Noor)

To ensure that the system is aligned appropriately during the implementation stage of the project, the design of a coordinate system to relate certain components of the project is necessary. This section will entail the design of a coordinate system which will mainly relate the rotation angle of the MEMs (Microelectromechanical systems) mirror to the coordinates of the target in the XYZ plane. When tracking the target, images will be produced by the camera that will show the location of the target in the image. The coordinates produced by this image will relate to the coordinates of the target in the real world. Hence, when the image is produced showing the coordinates of the target, the real coordinates of the target will be computed to provide the X, Y, and Z components of the location of the target. The diagram shown in Figure 16. below highlights the coordinate system that will be used to calculate the angle of rotation for the MEMs mirror.

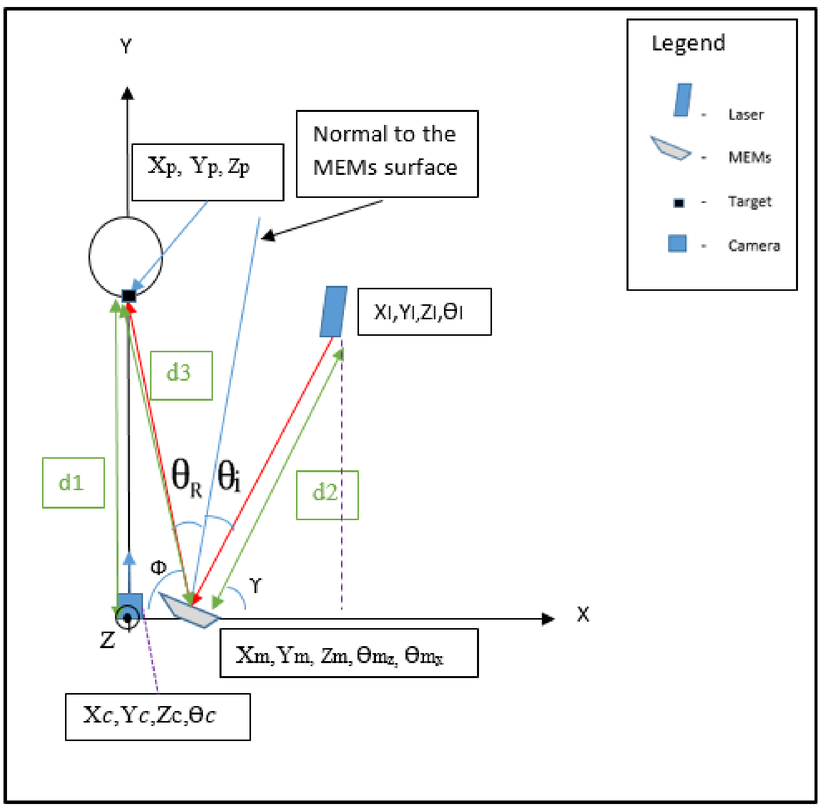


Figure 16: Coordinate System to Determine the MEMs Mirrors Angle of Rotation

As can be seen in the above figure, Figure 16, the camera which tracks the target will be centered at the origin of the designed coordinate system. The camera designated for tracking the target will have the coordinates X_c, Y_c, Z_c, θ_c, and it will be fixed in position as it represents the origin of the coordinate system. The camera will be fixed at coordinates $(0, 0, 0, 90°)$. The laser driver will also be a component that will have fixed coordinates in the above coordinate system. The laser will be represented by the coordinates X_l, Y_l, Z_l, θ_l. The two components in the above design which will be in motion are the target and the MEMs mirror. The target will be moving to random positions within $\pm 30°$ of the $X_p = 0$ coordinate and $\pm 30°$ of the $Z = Z_p$ coordinate. The restriction on the movement of the target is necessary, to ensure that the target remains within the field of view of the camera and the MEMs mirror. The target will have coordinates represented by (X_p, Y_p, Z_p).

Since the location of the target will vary and continue to be detected by the camera, the MEMs mirror must also rotate accordingly to ensure that the laser beam is aimed at the target. As can be seen in Figure 16. above, the MEMs location in the coordinate system can be given by the coordinates $X_m, Y_m, Z_m, \theta_{mz}$, and θ_{mx}. The location of the MEMs mirror will be constant, meaning that X_m, Y_m, and Z_m will remain constant, however, the angles of rotation θ_{mz} and θ_{mx}, will vary. θ_{mz} is the angle which represent the MEMs mirror's rotation angle around the z-axis, while θ_{mx} represents the MEMs mirror's rotation angle around the x-axis. When the mirror is rotated, the angle of incidence will vary. The angle of incidence which represents the angle between the incident laser beam and the normal to the MEMs mirror surface, θ_i, is shown in Figure 16 above. Also shown in Figure 16 is the reflected angle, θ_r, which represents the angle between the reflected laser beam and the normal of the mirrors surface. When the mirror rotates, this will cause the incident angle to vary which in turn varies the reflected angle (θ_r), since both the incident and reflected angles will always be equal in value, according to the Law of Reflection [44].

Therefore, to ensure that the beam of laser is aimed at the target, even when the target is in motion, the angles of rotation of the MEMs mirror must be calculated based on the location of the target in space. Using Figure 16 above and mathematical knowledge of geometric identities such as the Pythagorean Theorem, the Law of Cosines, as well as basic knowledge of the wave nature of light, in particular the Law of Reflection, a derivation was made to compute the angles of rotation of the MEMs mirror. Hence, given an X_p, Y_p, and Z_p coordinates of the target, and knowing the coordinates of the laser, the angles of rotation of the MEMs mirror (θ_{mz} and θ_{mx}) can be derived as seen in Equation 9 and Equation 10 below. By computing the angles of rotation for the MEMs mirror, the mirror will be rotated to the calculated angles so that the reflected beam will be aimed at the target as shown in Figure 16 above, as the target's coordinates were used in the computation. The derivation shown below, starting with Equation 1 and obtaining the angles for the MEMs mirror in Equation 9 and Equation 10, is based on the coordinate system illustrated in Figure 16 above.

$$\theta_l = 270° - (90° - \gamma) \tag{1}$$

$$d_2 = \sqrt{(x_l - x_m)^2 + y_l^2} \tag{2}$$

$$\theta_{mz} = \gamma + \theta_i \tag{3}$$

$$\phi = 180° - (\theta_m + \theta_r) \tag{4}$$

$$cos\phi = \frac{x_m - x_p}{d_3} \rightarrow d_3 = \frac{x_m - x_p}{cos\phi} = \frac{x_m - x_p}{cos(180° - (\theta_m + \theta_r))} \tag{5}$$

Using the law of cosines :$c^2 = a^2 + b^2 - 2ab \cdot cos(\gamma_0)$

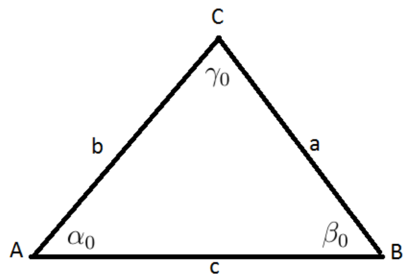


Figure 17: Law of Cosines

$$d_1 = \sqrt{x_m^2 + d_3^2 - 2x_m d_3 cos\phi} \tag{6}$$

$$\begin{aligned}\gamma &= cos^{-1}\frac{a^2+b^2-c^2}{2ab} = cos^{-1}\frac{{d_2}^2+(x_l-x_m)^2-y_l^2}{2d_2(x_l-x_m)} \\ &= cos^{-1}\frac{(x_l-x_m)^2+y_l+(x_l-x_m)^2-y_l^2}{2(x_l-x_m)\sqrt{(x_l-x_m)^2+y_l}} = cos^{-1}\frac{2(x_l-x_m)^2+y_l-y_l^2}{2(x_l-x_m)\sqrt{(x_l-x_m)^2+yl}}\end{aligned} \tag{7}$$

$$\theta_i = \frac{180^\circ-\gamma-\phi}{2} = \frac{1}{2}(180^\circ - cos^{-1}(\frac{2(x_l-x_m)^2+y_l-y_l^2}{2(x_l-x_m\sqrt{(x_l-x_m)^2+y_l}}) - tan^{-1}(\frac{y_p}{x_m-x_p})) \tag{8}$$

$$\theta_{mz} = 90^\circ + \frac{1}{2}cos^{-1}[\frac{2(x_l-x_m)^2+y_l-y_l^2}{2(x_l-x_m)\sqrt{(x_l-x_m)^2+y_l}}] - \frac{1}{2}[tan^{-1}(\frac{y_p}{x_m-x_p})] \tag{9}$$

$$\theta_{mx} = 90^\circ + \frac{1}{2}cos^{-1}[\frac{2(z_l-z_m)^2+y_l-y_l^2}{2(z_l-z_m)\sqrt{(z_l-z_m)^2+y_l}}] - \frac{1}{2}[tan^{-1}(\frac{y_p}{z_m-z_p})] \tag{10}$$

4.2.1.2 Transformation in 3D space (Anas)

To ensure consistency in our system, we must keep track of object location and orientation in our model of the system. Hence, a model of multiple reference frames must be developed, where each object - Camera, target, and mirror possess a distinct reference frame that describes points in its field of view. Assigning multiple frames of reference raises the issue of how other frames of reference observe objects that are defined in terms of the coordinates of other objects. Namely, if the target is defined to be a point on a sphere. The coordinates of said point is known with respect to the frame of reference of the sphere. However, it is completely unknown to the camera's frame of reference.

This problem can be solved by defining transformation matrices, $Q_{Target/Reference}$ between different frames of reference in our model. This allows to track movement of objects in the system space, in addition to position and orientation. Any movement in 3-D space can be decomposed into a sequence of a maximum of three translations plus three rotations that correspond respectively to the six degrees of freedom of the 3-D space. Transitional movements on the X, Y, and Z are defined as X_T, Y_T, and Z_T respectively. The angles of the rotations are also defined with respect to these axes: The roll is defined around the Z axis, the pitch around the Y axis and the yaw around the X axis. By convention, we will associate the angle Ψ with the yaw (rotation around the X axis), the angle ϕ with the pitch (rotation around the Y axis), and the angle θ with the roll (rotation around the Z axis).

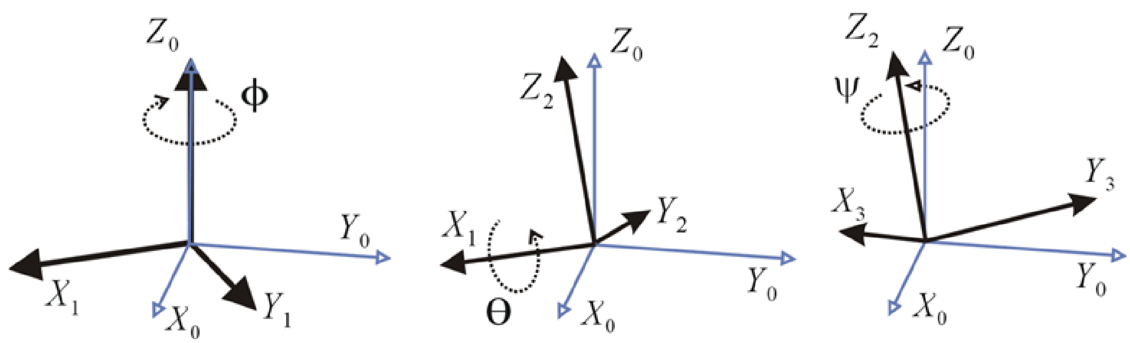


Figure 18: Roll, Pitch, and Yaw Angles. [45]

Transformation matrices allow to transform some information defined with respect to a reference frame, into another. When the relationship between these two frames is defined by means of a set of three translations (X_T, Y_T, and Z_T) and three angles (Roll, Pitch, Yaw). Since our system is a 3D system, all our transformation matrices will be of size $[4 \times 4]$. Coordinates of the target however, will be in terms of $[4 \times 1]$ vectors to allow to valid matrix multiplication. A typical point vector is defined as show below:

$$P_{Target} = \begin{bmatrix} X_{Coordinates} \\ Y_{Coordinates} \\ Z_{Coordinates} \\ 1 \end{bmatrix} \tag{11}$$

A typical transformation matrix Q looks as shown below, the $[3 \times 3]$ matrix on the top left corner -represented by $a_R, b_R, \cdots i_R$- corresponds to rotations on the 3 angles-. The left $[4 \times 1]$ matrix represents the transitional movements on the three axes X, Y, and Z. The bottom $[1 \times 3]$ matrix however, is scaling factor that will always be set to a 0 values on all its indices as one-to-one mapping is desired without any distortion. To keep dimensions consistent a value of "1" in the bottom right corner.

$$Q = \begin{bmatrix} R & T \\ S & I \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} a_R & b_R & c_R \\ d_R & e_R & f_R \\ g_R & h_R & i_R \end{bmatrix} & \begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix} \\ \begin{bmatrix} x_S & y_S & z_S \end{bmatrix} & \begin{bmatrix} 1 \end{bmatrix} \end{bmatrix}$$

Figure 19: Typical Transformation matrix. (Pierre Pieyure Notes)

If a point P is defined for a frame of reference, namely, if we have the information on the position with respect to a certain set of coordinates P_{R1} for example. One can easily obtain the position with respect to another coordinate system R2 by first obtaining the transformation matrix from R1 $\rightarrow$ R2, then multiplying the coordinates of the point with respect to R1. This transformation can easily be shown using below:

$$P_{R2} = Q_{R2|R1} * P_{R1} \tag{12}$$

Where P_{R2} is the $[4 \times 1]$ vector as shown previously, that describes the coordinates of P_{R1} as seen from frame of reference R2. This technique allows us to obtain the coordinates in every frame of reference we have in the system, by only obtaining the transformation matrix between every pair of coordinate systems.

4.2.1.3 Obtaining Transformation Matrices (Anas)

When it comes to obtaining transformation matrices, one can follow many different conventions. Choosing a convention is only a matter of convenience as all conventions produce the same transformation matrices. For this model, the Q_{TRPY} with respect to evolving frames convention will be used. TRPY stands for Translation-Roll-Pitch-Yaw, following the order of elementary operations produces 4 transformation matrices; a $Q_T(X_T, Y_T, Z_T)$ that corresponds to the 3 different translations we can have in 3D space along X_0, Y_0, Z_0. In addition to 3 other matrices $Q_{RZ}(\theta), Q_{RY}(\Phi)$, and $Q_{RX}(\Psi)$ that describe rotations on Z_0 -Roll-, Y_0 -Pitch-, and on X_0 -Yaw-. Those matrices can be obtained by the following this simple procedure:

- Translation of magnitude X_T, Y_T, Z_T along X_0, Y_0, Z_0. that leads to $\Re1$.
- Rotation ≪roll≫ around Z1 of an angle θ that leads to $\Re2$.
- Rotation ≪pitch≫ around Y2 of an angle Φ that leads to $\Re3$.
- Rotation ≪yaw≫ around X3 of an angle Ψ that leads to $\Re4$.

Where each R refers to the resulting coordinate system after preforming each rotation, and that is what is known as *Evolving Frame Convention* as opposed to *Fixed Frame Convention* where rather than preforming rotations or resulting frames, we keep a constant coordinate system throughout the whole problem.

After obtaining the four previous matrices, our mapping can be finalized by combining them in the following manner:

$$Q_{TRPY} = Q_T(X_T, Y_T, Z_T) * Q_{RZ}(\Theta) * Q_{RY}(\Phi) * Q_{RX}(\Psi) \tag{13}$$

$Q_T(X_T, Y_T, Z_T)$ matrix can be obtained as follows:

$$Q_T = \begin{bmatrix} 1 & 0 & 0 & X \\ 0 & 1 & 0 & Y \\ 0 & 0 & 1 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{14}$$

As for the rotation matrices, Roll, Pitch, and Yaw. They take the following forms:

$$Roll \qquad Q_{RZ} = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 & 0 \\ sin(\theta) & cos(\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{15}$$

$$Pitch \qquad Q_{RY} = \begin{bmatrix} cos(\phi) & 0 & sin(\phi) & 0 \\ 0 & 1 & 0 & 0 \\ -sin(\phi) & 0 & cos(\phi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{16}$$

$$Yaw \qquad Q_{RX} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\Psi) & -sin(\Psi) & 0 \\ 0 & sin(\Psi) & cos(\Psi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{17}$$

$$Q_{TRPY} = \begin{bmatrix} 1 & 0 & 0 & x_T \\ 0 & 1 & 0 & y_T \\ 0 & 0 & 1 & z_T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos(\phi) & 0 & sin(\phi) & 0 \\ 0 & 1 & 0 & 0 \\ -sin(\phi) & 0 & cos(\phi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\Psi) & -sin(\Psi) & 0 \\ 0 & sin(\Psi) & cos(\Psi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\Psi) & -sin(\Psi) & 0 \\ 0 & sin(\Psi) & cos(\Psi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{18}$$

To give:

$$Q_{TRPY} = \begin{bmatrix} cos\theta cos\phi & cos\theta sin\phi sin\Psi - sin\theta cos\Psi & cos\theta sin\phi cos\Psi + sin\theta sin\Psi & x_T \\ sin\theta cos\phi & sin\theta sin\phi sin\Psi + cos\theta cos\Psi & sin\theta sin\phi cos\Psi - cos\theta sin\Psi & y_T \\ -sin\phi & cos\phi sin\Psi & cos\phi cos\Psi & z_T \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{19}$$

We use the previous matrix we can map the coordinates between two frames of reference, we will map the coordinates of the camera and the target, the target and the mirror, in addition to the camera and the mirror. The coordinates can be seen in the sketch below:

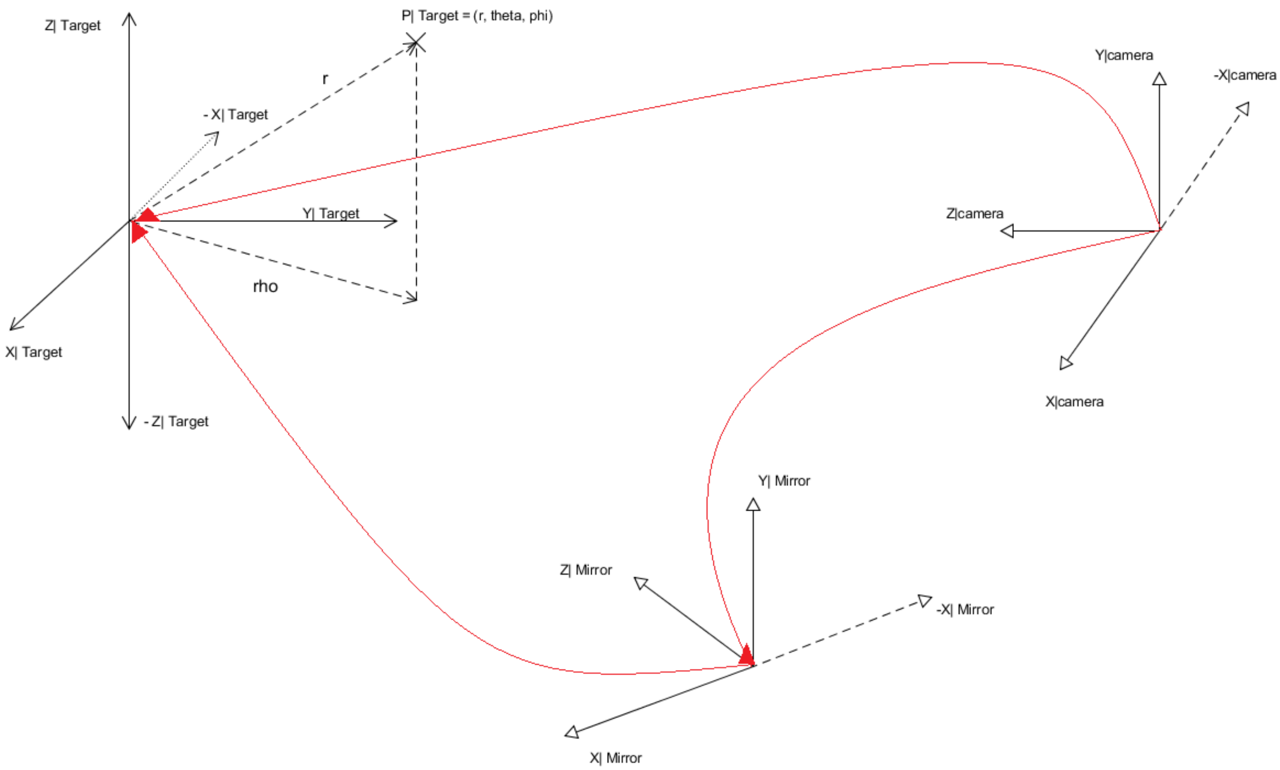


Figure 20: Mapping of Coordinates between Frams of Reference

To easily show how angles change from one coordinate system to another, values of angles will be displayed in a table. The table will show the base reference frame -initial coordinate system-, the target reference frame, and angles of the target frame change with respect to the base frame -initial-

Table 3: Coordinate System Table

Reference Frame	Destination	Θ	Φ	Ψ

(From)	(To)			
Camera	Target	0°	0°	270°
Mirror	Target	0°	Φ_2	90°
Camera	Mirror	0°	Φ_3	0°

Following Table 3, we can easily come up with transformation matrices between the coordinate systems. By plugging in the values in the previous Q_{TRPY} we obtain:

$$Q_{Target|Camera} = \begin{bmatrix} 1 & 0 & 0 & X_T \\ 0 & 0 & 1 & Y_T \\ 0 & -1 & 0 & Z_T \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{20}$$

To find the second transformation matrix $Q_{Mirror|Camera}$ a parameter Φ_2 has to be assumed as the exact value of it will be determined upon implementation. Hence, this transformation will be in terms of distances X_T, Y_T, Z_T and Φ_2

$$Q_{Target|Mirror} = \begin{bmatrix} cos\phi_2 & sin\phi_2 & sin\phi_2 & X_T \\ 0 & 0 & 1 & Y_T \\ -sin\phi_2 & cos\phi_2 & 0 & Z_T \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{21}$$

As for the last transformation, we will take a different approach in finding matrix. Instead of rotations between Mirror and Target, we can transition from mirror to camera then from camera to target. This is an easier approach since the mappings $Q_{Target|Camera}$ and $Q_{Target|Mirror}$ are known. Its worth mentioning that to transition in the opposite direction of a mapping Q, one must take the inverse of Q. This approach allows for easier and less complicated transition between frames of references. Therefore we get:

$$Q_{Mirror|Camera} = (Q_{Target|Camer}) * (Q_{Target|Mirror})^{-1} \tag{22}$$

$$Q_{Mirror|Camera} = \begin{bmatrix} 1 & 0 & 0 & X_T \\ 0 & 0 & 1 & Y_T \\ 0 & -1 & 0 & Z_T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} cos\phi_2 & sin\phi_2 & sin\phi_2 & X_T \\ 0 & 0 & 1 & Y_T \\ -sin\phi_2 & cos\phi_2 & 0 & Z_T \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1} \tag{23}$$

$$= \begin{bmatrix} \frac{cos\phi_2}{cos^2\phi_2+sin^2\phi_2} & -\frac{cos\phi_2*sin\phi_2}{cos^2\phi_2+sin^2\phi_2} & -\frac{sin\phi_2}{cos^2\phi_2+sin^2\phi_2} & X_T + \frac{Z_T sin\phi_2 - X_T cos\phi_2 + Y_T cos\phi_2 sin\phi_2}{cos^2\phi_2+sin^2\phi_2} \\ 0 & 1 & 0 & 0 \\ -\frac{sin\phi_2}{cos^2\phi_2+sin^2\phi_2} & \frac{sin^2\phi_2}{cos^2\phi_2+sin^2\phi_2} & -\frac{cos\phi_2}{cos^2\phi_2+sin^2\phi_2} & Z_T + \frac{Z_T cos\phi_2 + X_T sin\phi_2 - Y_T sin^2\phi_2}{cos^2\phi_2+sin^2\phi_2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{24}$$

After obtaining the previous matrices, we use the following format to convert from one reference frame to another. The following shows how a point in R_1, is seen from R_1 if the transformation matrix Q_{TRPY} is known.

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}_{\Re_0} = Q_{TRPY} \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix}_{\Re_1} \tag{25}$$

4.2.1.4 Mechanical Design of Project Demonstration

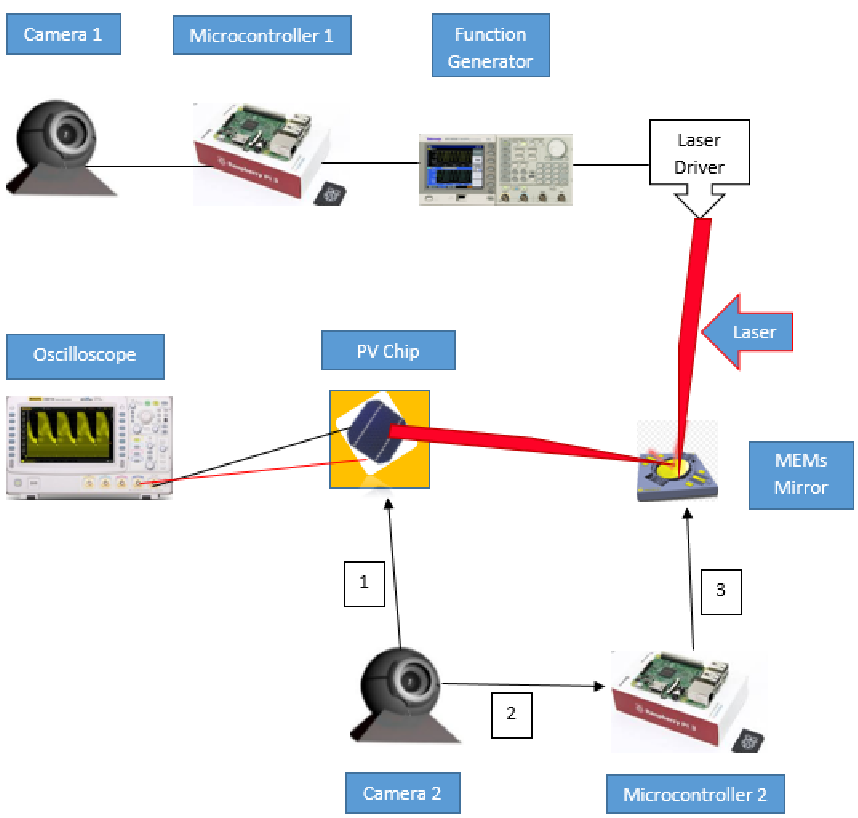


Figure 21: Mechanical Design of Project Demonstration

In Figure 21 above, Camera 1 will be used to represent the camera that is attached to the front of the glasses which are shown in Figure 22, in the following subsection. Therefore, Camera 1 will be designated for capturing the images and videos that represent a patients view. The images and videos are to be processed with a microprocessor that is connected to the function generator. The microprocessor will output results of the image processing as data that will be used to drive the function generator. Depending on the output of the function generator, the laser driver will send the data through the laser beam onto the MEMs mirror as shown in Figure 21 above. The MEMs mirror will have to be positioned in such a way that the reflected laser beam will be directly aimed at the PV chip as shown in the above figure. The exact initial positioning and angling of the MEMs mirror can be determined experimentally in the lab. The PV chip which is shown above in Figure 21, is to be soldered onto a gold plate which is used to show an output onto the oscilloscope. Due to the small size of the PV chip, it is impossible to connect the probes directly onto the chip, therefore, the gold plate is used. By connecting the probes to the gold plate and the oscilloscope, the data transmitted by the laser beam will be displayed on to the screen of the oscilloscope. The connections shown in Figure 21 which begin at Camera 1 and end at the oscilloscope show the first part of the design project which entails capturing the image, transmitting the data, and displaying the transmitted data. That specific part of the project, if connected correctly with an appropriate display of input and output, highlights the main goal of this project.

To achieve the second goal of this project design, the tracking component of the system must be connected and functioning appropriately. Camera 2 which is shown in Figure 21 above, will be used for the tracking part of the design. In this part, Camera 2 will capture images of the PV chip. These images are sent to Microprocessor 2 for image processing, as shown in the above diagram. From the images received, Microprocessor 2 will locate the PV chip and will send an electric signal to the MEMs mirror to adjust it accordingly in response to the new location of the PV chip. The MEMs mirror will be adjusted by tilting and turning it on either axis. Since the MEMs mirror used will be a deformable mirror, the use of an external driver to position the mirror will not be necessary. If the PV chip were to move, to mimic the movement of the human eye, Microprocessor 2 should detect the movement by the use of the images captured by Camera 2 and it should also send a signal accordingly. Camera 2 which is shown in Figure 21 above, represents a camera that will be placed on the inside of the glasses. The camera that will be placed on the inside of the glasses will be used to track the movement of the patients eye in the ideal final product, which is shown in Figure 22 below, in the subsequent section.

4.2.1.5 Mechanical Design of the Ideal System

Figure 22: Mechanical Design of the Ideal System [3]

As seen in Figure 22, the mechanical design of the ideal system looks much different than the design that will be used in the final demonstration, which is shown in Figure 21 above. Figure 22 shows different angles of a well-integrated system that has the same functionality as that shown in Figure 21, but with a sleeker look and a more practical design. Since the ideal system will be worn by the patient, it is important to ensure that the product is integrated properly and not only functions well, but also looks good. It is also important to note the size of the system, since it will be worn by the patient throughout the day. Functionality of the ideal system is similar to that designed in Figure 21 above.

In order for everything to fit compactly onto the glasses as shown in Figure 22, the electric parts will be battery operated. Similar to what was described in the previous section, the outer camera will capture an image of the persons view and that image will be processed by an integrated microprocessor. The data will be sent from the microprocessor to the battery operated laser driver. The laser will be emitted from the laser driver onto the MEMs mirror. The mirror will reflect the transmitted laser beam onto the PV chip which is placed on the retinal wall, inside the patients eye as shown in Figure 23 below. The PV chip will convert the energy from the laser into an electric signal which will be used to stimulate the ganglionic cells of the retina.

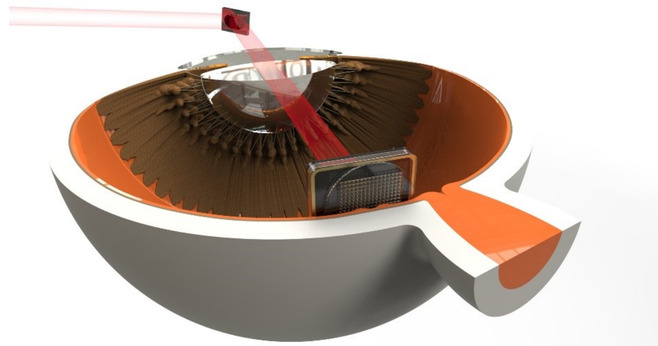


Figure 23: The Placement of the “Diamond Eye” inside the Patient’s Eye [3]

A second camera will be placed on the inside of the glasses shown in Figure 22, which are represented by Camera 2 in Figure 21 above. The camera inside the glasses will be used for the tracking of the PV chip, to ensure that the MEMs mirrors are aimed appropriately. This is done by capturing images of the patients eye which are processed by an integrated microcontroller. The images are processed and the position of the pupil is noted, if the pupil has changed positions, the microcontroller will send an electric signal to the MEMs mirror. After receiving the electric signal, the MEMs mirror will tilt and reposition accordingly, to ensure that the reflected beam is aimed at the PV chip. Ensuring the laser beam is always aimed at the PV chip is very important to ensure that the data is transferred correctly, the power is being supplied to the chip, and also to prevent any minor damage caused to the retina by the reflected laser beam.

As explained above, the functionality of both designs are very similar and will yield to similar outcomes. However, the two systems are very different in that the mechanical design of the project demonstration shown in Figure 21, shows the system with each part separately, while the ideal system shown in Figure 22 demonstrates a well-integrated final product. The mechanical design of the ideal system is very important, as parts need to be placed at certain angles and distances to ensure that the system is functioning appropriately. Not only is the functionality of the system important, but also the cosmetic appearance should be noted for the convenience of the patient. Ensuring that the glasses are smaller, the entire system integrated into the glasses will be more accessible for patients to carry around. The battery pack which is attached to the glasses by a wire is used to supply power to the system, including the laser driver and microprocessors. Since this is the first phase of the product, it will continue to be a work-in progress and there will always be room for future improvements. After doing clinical trials and receiving feedback from patients, the product can be adjusted and updated accordingly in prospective designs.

4.2.2 Electrical Design (Zac & Tony)

4.2.2.1 Electrical Circuit Design

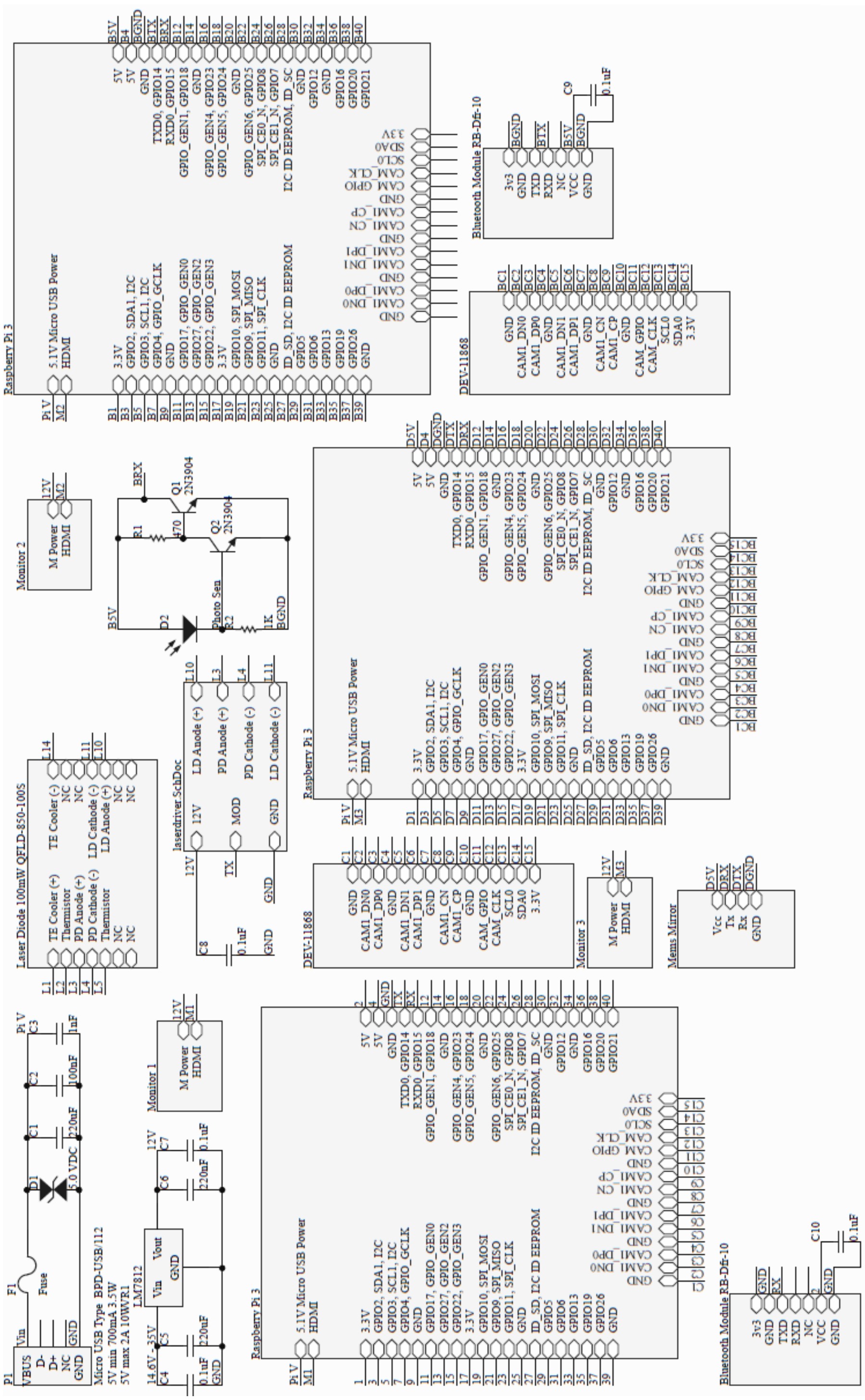


Figure 24: Overall Electrical Circuit Design

- Note: The nodes that have the same name are connected, even if they are not physically connect in the diagram
- For detailed connections, see the sections below [4.2.2.7] [4.2.2.8] [4.2.2.9]

4.2.2.2 Laser Driver

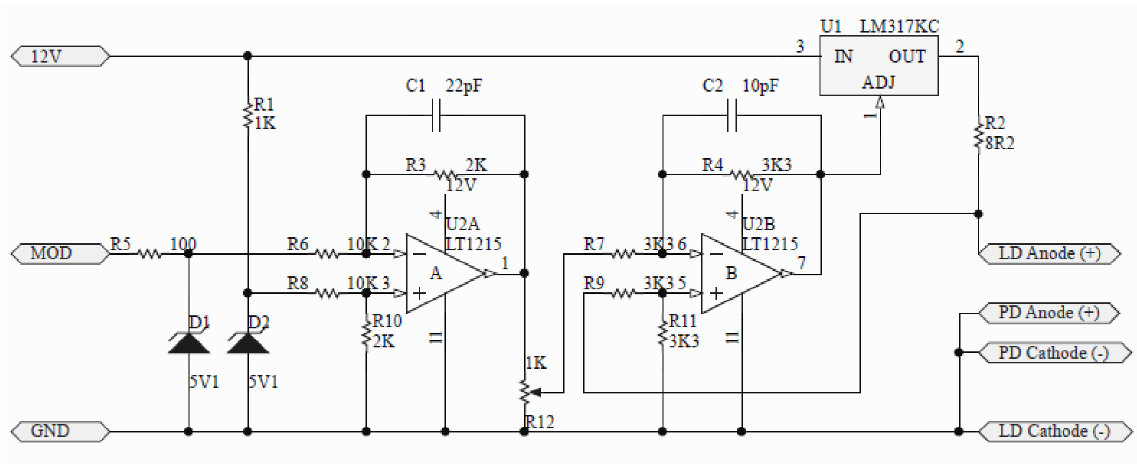


Figure 25: Electrical Circuit for Laser Driver [34]

This design of laser driver support 5V logic level modulated input signal at 1MHz and variable power output for the laser diode, which can be change from the variable resistor from R12 in Figure 25.

4.2.2.3 Power

The power supply for Raspberry Pi is inputting from a Micro-USB port which is supplied by 120V from the wall plug. The schematic for the power supply is shown in Figure 26. This can supply at a minimum of 3.5W with 5V and 700mA to a maximum of 10W with 5V and 2A. The data ports are not used, since this is a power supply. The bidirectional TVS protect against overvoltage and negative voltages for a maximum of 2V, and the fuse protects against over-current of around 1A [33]. The large capacitors are for protection from instant charge-up, and the small capacitors are for protection against voltage spikes.

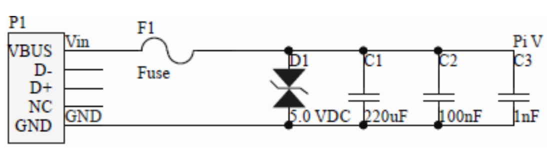


Figure 26: Power Supply for Raspberry

There are 3 core voltage within Raspberry Pi which are 3.3V, 2.5V and 1.8 which are for the processors and Ethernet [33]. Raspberry Pi uses simple voltage regulators to get the desire voltages which can be seen in Figure 27. The core voltages can supply minimum 400mW for 800mW 5V supply from the Power supply.

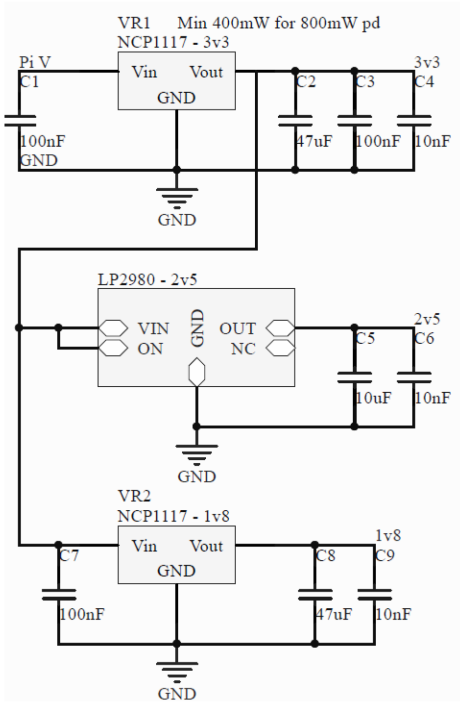


Figure 27: Core Voltages for Raspberry Pi

Since the Laser Driver of this design shown in Figure 25 requires a 12V DC supply, we need an external power supply of a range from 13V to 35V and regulate to 12V. This can simply be done with a power supply station or a fixed power supply and connect with voltage regulator like in Figure 28. The LM7805 can provide a maximum of 12.5V with 1.5A.

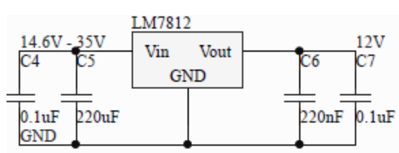


Figure 28: DC supply for Laser Driver

The monitors used in this project will be power with external sources. The power consumed by the HDMI cable is around 40mA to 60mA.

4.2.2.4 Camera

The camera modules are supplied by 3.3V from the Raspberry Pi. The camera modules on average consumes 120mA with standard 1080 pixel video. The circuit diagram can be seen in Figure 29.

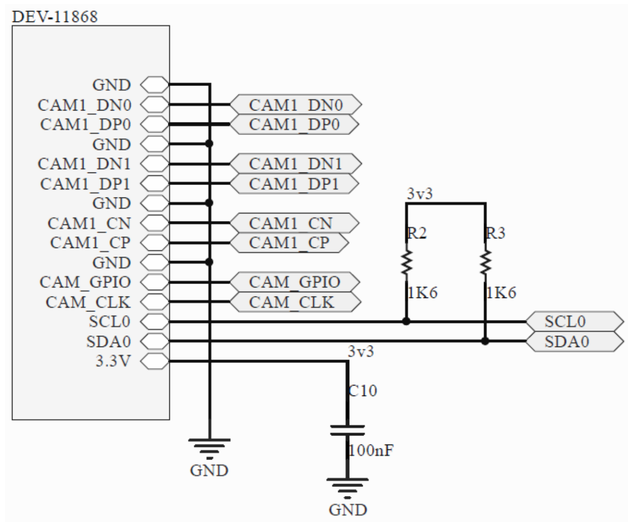


Figure 29: Circuit diagram for Camera Module

The CAM1_DN0 CAM1_DP0 are Data Lane 0. These are the MIPI Data Positive (MDP) and MIPI Data Negative (MDN) pins for the camera. The CAM1_DN1 CAM1_DP1 are similar but it is Data Lane 1 for the camera. The CAM1_CN and CAM1_CP provides the clock pulse of MIPI data lanes for the camera, which are connected to MIPI Clock Positive (MCP) and MIPI Clock Negative (MCN) respectively. These clock signals usually arrive from the camera module generated by the MIPI circuitry. The SCL0 and SDA0 are small serial bus that allows user to control the camera functions such as resolutions [35].

4.2.2.5 General GPIO

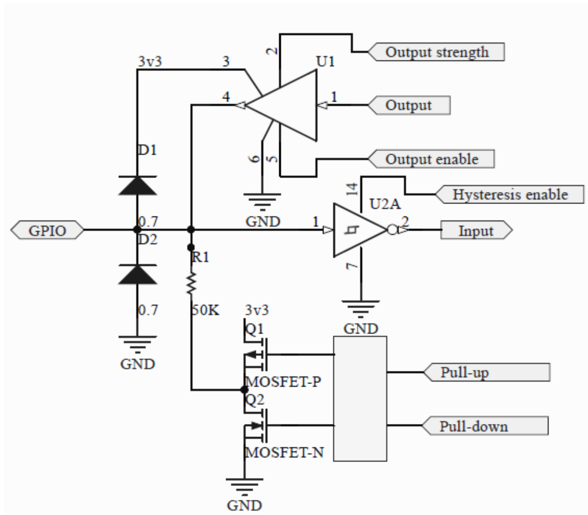


Figure 30: Circuit diagram for General GPIO [36]

The general current that can drawn from a GPIO pin can be 2mA up to maximum of 16mA depending on the configuration of the pins, which with 3.3V as reference voltage, they are capable of drawing maximum 52.8mW. The "Input" of the Schmitt Trigger buffer will then be connect to ADC or digital comparator to detect the input voltage level. The Schmitt Trigger buffer provide noise immunity and prevent chatter on transitions [36]. In Figure 30 only one driver is shown, but there are actually multiple in parallel that provides 2mA each up to 16mA [36].

4.2.2.6 Bluetooth Module

Since the purpose of the Bluetooth Modules is to provide a quick feedback on the system's status, so there are not much circuitry involved. A small capacitor is connected to input voltage, which is 5V, to protect against voltage spikes. The average current that is consumed by the module is around 50mA. The receiving-end Raspberry Pi send the status through Tx into Rx of one of the module and send the data to another module. The transmitting-end Raspberry Pi received the feedback from Rx.

4.2.2.7 Transmitter Circuit Connections

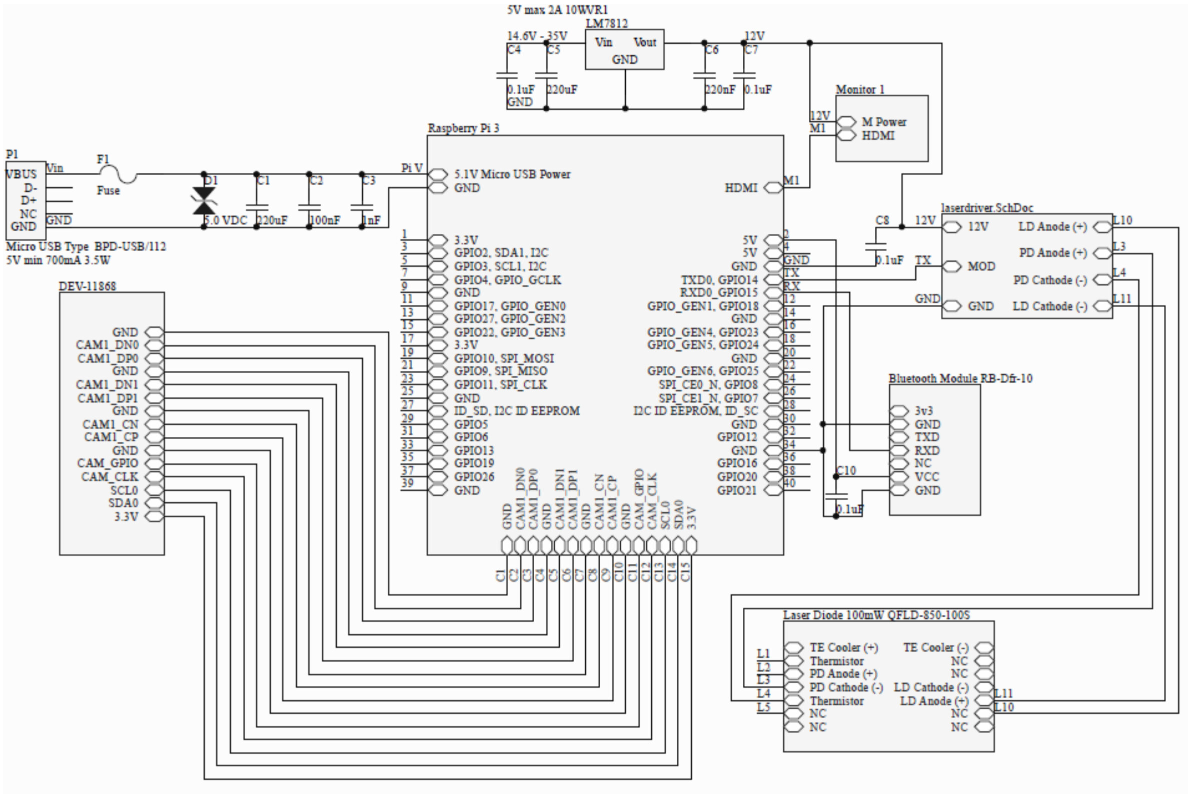


Figure 31: Transmitter Circuit Design

From the transmitting-end, one of the camera captures the image and send the data through CSI to Raspberry Pi. The Transmitting Raspberry Pi will do the necessary processing including encoding and modulation and send the data through its Tx. The signal will enters laser drive that stabilize the signal for the laser diode, then it will drive the laser diode. The laser diode will power off or tune down when a failure is detected, and the trigger will be received through the Bluetooth Module from the Receiver-end, and wait for the Target-tracking Raspberry Pi to correct the angle of laser. Since we are only interested in sending out image data and receiving failure trigger, we can utilize Rx and Rx for different purpose shown in Figure 31.

4.2.2.8 Receiver Circuit Connections

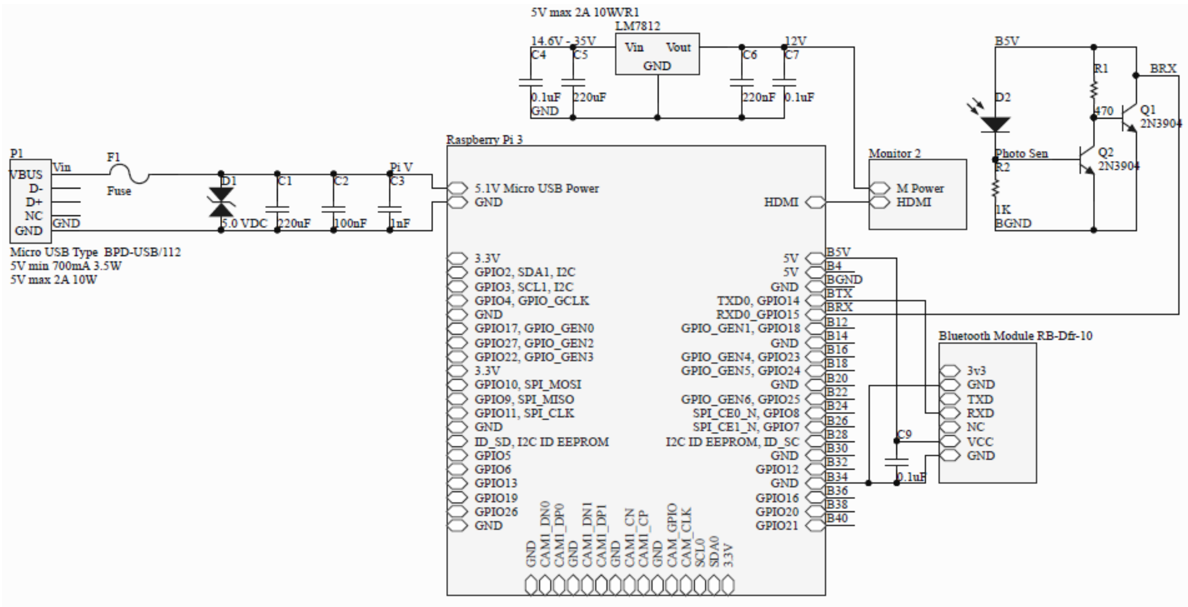


Figure 32: Receiver Circuit Design

On the receiving-end, the PV cells will pick up the signal over free space. A simple amplifier will be necessary to increase the signal level and decrease the data error rate. The amplified signal will be send to the Rx of the receiving Raspberry Pi for demodulation and decoding. Then the receiving Raspberry Pi will do the necessary processing for the user. The Bluetooth Module here will be synchronize with the Bluetooth Module in the Transmitter Circuit. The Raspberry Pi will send out failure signal to the Bluetooth Module if any inconsistency of the laser beam is detected. Then it will be up to the transmitter to take the necessary action to protect the user. A filter to filter out the noise maybe needed, but the specification and the design of the filter will depends on the type of noise we are receiving. We could replace the filter

4.2.2.9 Target-Tracking Circuit Connection

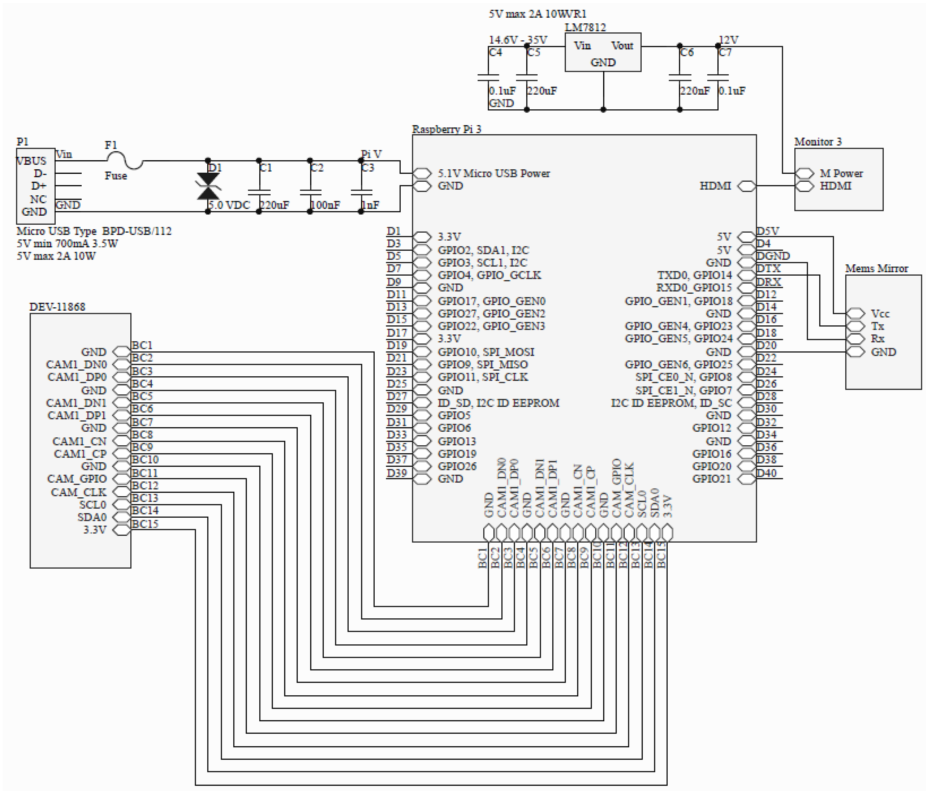


Figure 33: Target-Tracking Circuit Design

The second camera will constantly monitor the target as an image and send the image data to the tracking Raspberry Pi. The tracking Raspberry Pi will do the necessary processing and output the position of the pupil in coordinates. Then the coordinates will be send to the Mems Mirror to do the adjustment of the laser reflection angle. The tracking system is independent from the rest of the system, it will remain functional even if a failure is detected. The tracking system requires to have a fast reaction time to reduce the failure or down time of the transmission system.

4.3 Camera Calibration - (Tony)

4.3.1 Pinhole Camera Model

The Camera Calibration will provide the approximation of intrinsic matrix K. It can be done through opencv or Matlab camera calibration tool [43].
Camera captures the real world object and project it on the film.
Transform the 3-D real world to a 2-D image.

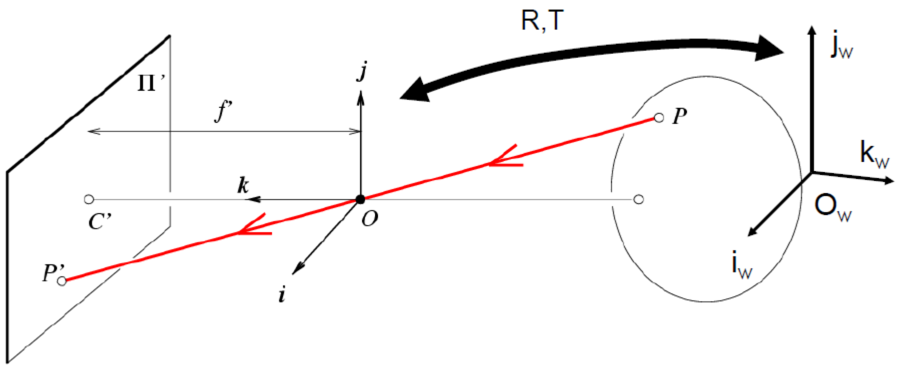


Figure 34: Illustration of Pinhole Model [43]

The light pass through a hole and project onto the film. It will be shown in this section that how to project a 3D world point (X,Y,Z) onto the image plane at coordinate (u_1, u_2). And convert the coordinate into pixel with index a_{ii} where it is the i^{th} row and j^{th} column of the $m \times n$ matrix $(m \times n \; pixels)$[43].
Camera model transformation:

$$u = K \begin{bmatrix} R & t \end{bmatrix} X \tag{26}$$

Where:

- u: Image coordinate $(u_1, u_2, 1)^T$
- K: Intrinsic Matrix which shows the properties of the camera
- R: Rotation Matrix represent the rotation
- t: Translation Matrix which shows the position of camera
- X: World coordinate $(x, y, z, 1)^T$

If the following assumptions are true:

- No rotation or R is the identity matrix
- Camera at position t=(0,0,0)
- No skew (pixel is rectangle, otherwise it might be parallelogram)
- Optical center at (0,0)
- Aspect ratio of pixels are one

$$Then\ the\ equation\ becomes: \begin{bmatrix} u_1 \\ u_2 \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & 0 & 0 & 0 \\ 0 & \alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{27}$$

if optical center is (u_0, v_0) instead of $(0, 0)$

$$\begin{bmatrix} u_1 \\ u_2 \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & 0 & u_0 & 0 \\ 0 & \alpha & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{28}$$

If aspect ratio becomes α/β

$$\begin{bmatrix} u_1 \\ u_2 \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & 0 & u_0 & 0 \\ 0 & \beta & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{29}$$

If the pixel is skewed

$$\begin{bmatrix} u_1 \\ u_2 \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & \lambda & u_0 & 0 \\ 0 & \beta & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{30}$$

If camera is at (C_x, C_y, C_z) instead of (0,0,0)

$$\begin{bmatrix} u_1 \\ u_2 \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & \lambda & u_0 & 0 \\ 0 & \beta & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & C_x \\ 0 & 1 & 0 & C_y \\ 0 & 0 & 1 & C_z \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{31}$$

$$Where\ R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{32}$$

Consider the rotation cases. If the camera rotates counter-clockwise with respect to x, y, z axis by $\theta_x, \theta_y, \theta_z$ respectively, the rotation matrix will be:

$$R = R_x R_y R_z \tag{33}$$

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta_x & -sin\theta_x \\ 0 & sin\theta_x & cos\theta_x \end{bmatrix} \quad R_y = \begin{bmatrix} cos\theta_y & 0 & sin\theta_y \\ 0 & 1 & 0 \\ -sin\theta_y & 0 & cos\theta_y \end{bmatrix} \quad R_z = \begin{bmatrix} cos\theta_z & -sin\theta_z & 0 \\ sin\theta_z & cos\theta_z & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{34}$$

A quick proof shows that the matrix does the rotation. Use R_x as an example.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta_x & -sin\theta_x \\ 0 & sin\theta_x & cos\theta_x \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x \\ ycos\theta_x - zsin\theta_x \\ ysin\theta_x + zcos\theta_x \end{bmatrix} \tag{35}$$

The x coordinate remain the same indicating the point stay in the same y, z plane.

$$y'^2 + z'^2 = (ycos\theta_x - zsin\theta_x)^2 + (ysin\theta_x + zcos\theta_x)^2 = y^2 + z^2 \tag{36}$$

This means the point stays at the same distance from x axis. One can use the same way to show that R_y and R_z have the same performance but rotate with respect to y and z axis respectively.

The film contains $m \times n$ pixels that is represent by an $m \times n$ matrix A where each element inside is one pixel.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{37}$$

The film has height "h" and width "w" respectively. Therefore, each pixel has height $\frac{h}{m}$ and width $\frac{w}{n}$. A coordinate (u_1, u_2) is in the area covered by a_{ij} where

$$i = \lceil \frac{u_1}{\frac{h}{m}} \rceil \qquad j = \lceil \frac{u_2}{\frac{w}{n}} \rceil \tag{38}$$

Therefore, it will provide a pair (i, j) that represent the pixel.

Approximation from 2D to 3D.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} C_x \\ C_y \\ C_z \end{bmatrix} + R^{-1}K^{-1} \begin{bmatrix} i \\ j \\ 1 \end{bmatrix} \tag{39}$$

4.4 Software (Anas)

Eye tracking is essential in this project to ensure a constant and direct beam of laser for maximum efficiency in transmitting data. This is done by tracking the pupil and controlling a MEMs mirror accordingly to redirect the beam of laser straight into the eye. Therefore, our plan is to track the movement of the pupil using a camera directed towards the eyeball. The camera streams a live video of the pupil and send the information into the raspberry pi, which in turn processes the video and studies it for any changes or movements. Based on the output of the previous process, certain decisions are made using algorithms the we will develop to control the MEMs mirror which is also connected to the raspberry pi.

To make this process possible, certain tools will be employed. Here we will talk discuss these tools and discuss their significance to the overall process.

PuTTY: PuTTY is a free and open source network file transfer, terminal emulator and serial console API -Application User Interface-. *"Using this type of interface, there is no need for you to be sitting at the same machine you are typing commands to. The commands, and responses, can be sent over a network, so you can sit at one computer and give commands to another one, or even to more than one"* [37].

It handles protocol issues and allows users to interface and communicate with different devices whether serially or wirelessly. In our scope, we will use PuTTY to SSH into the raspberry pi Linux shell and use it remotely, rather than developing straight into the raspberry pi, this is merely to avoid any errors and because openCV is more windows friendly. Some features that are useful in our context are [38]:

(i) The storing of hosts and preferences for later use.

(ii) Control over the SSH encryption key and protocol version.

(iii) Control over port forwarding with SSH (local, remote or dynamic port forwarding), including built-in handling of X11 forwarding.

SSH: Stands for Secure Socket Shell, it is a way of logging in to a multi-user computer from another device -Can be a computer or a microcontroller-, over a wired/wireless network. Raspberry Pis are equipped with their own Linux environment. Such environment support and allow development in multiple different programming languages such as; C, C++ and Python. Although the Raspberry Pis Linux environment resembles that of Desktop computers -Ubuntu is an example- and can be used as a standalone environment for development, we chose to develop on PC as it user friendly and offers easy to use IDEs - integrated development environment such as eclipse and code blocks-. Then using SSH we will be able to control the Raspberry Pi over WIFI. Another reason to use SSH is a technical one; especially in early stages of development, we will be running many tests and debugging code. We want to minimize the contact with the parts to avoid any electrostatic discharge that might end up damaging the parts.

X11: Is a network protocol that allows remote graphical access to applications over a network. For our project, we will use it to stream graphical user interfaces -GUIs- through the network in conjunction with the SSH.

Xming: is a display server for X11. It coordinates the input and output of its clients to and from the rest of the operating system, the hardware, and each other.

By now you must be wondering, why insist on using Raspbian Linux -Raspberry Pis official operating system- rather than using Windows 10s free Raspberry Pis OS. And this is due to many reasons, some concern out project directly such as [39]:

(i) Although Windows 10s Raspberry Pis OS is good for developing on the RPi. However, it still does not support USB webcams nor the official Raspberry Pi camera module.

(ii) Another important reason is, Raspbian Linux has over 3 years of community support including (tutorial videos, websites, forum posts, etc.) that has been accumulating due to many projects that have been done on sing Raspbian on the RPi, this is only just beginning for Windows 10 on the Raspberry Pi. This means more libraries that can be of great benefit and solutions to problems that we might encounter along the way

(iii) Raspberry Pis Windows 10s OS can only be programmable using a Windows 10 machine, which is not be the case for all our group members. Being a Linux distribution, Raspbian is cross-compatible and can be ran and developed on different machines including Linux and Mac.

For our development, we will use Python 2 as it is the official and default Python of Raspbian. Raspbian is deeply integrated with OpenCV and is recommended for computer vision applications. Python 3 is yet to be fully reliable for this application in particular. As for using C/C++ for this purpose, a thorough comparison was done in the literature review.

4.4.1 Remote Access to Raspberry Pi's shell

Before we start developing our code we need to first set up our devices for remote access. The setup is a lengthy and time-consuming process. A single step in installing OpenCV can take up to 3 hours with raspberry operating at full capacity (this timing was done on a Raspberry Pi 2, since we are using the Raspberry 3, this duration may vary). Since the process is very long and require multiple lines of code, I will be demonstrating with the help of the following block diagram.

The following diagram explains what should be done on each end (Raspberry and Computer). It is far from a complete step by step tutorial, but it serves merely to show the procedure carried out. It demonstrates the main steps, packages and lines of code used, ignoring redundant obvious steps logging in is an example [39].

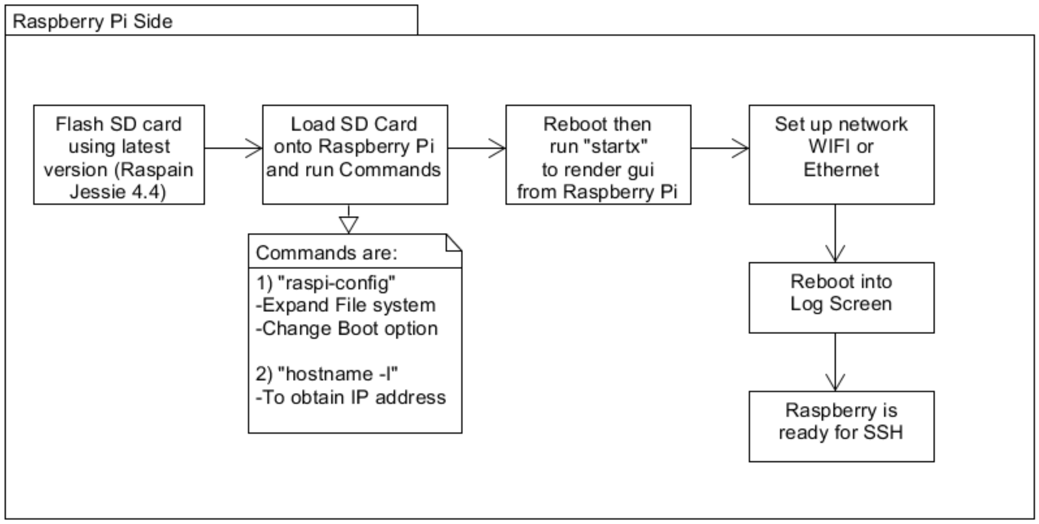


Figure 35: Raspberry Pi Side

Now that we have the Raspberry Pi ready for the SSH, we can use remote access to further complete the setup. Now we will be setting up PuTTY and all the other tools we will use. In addition to the camera. After that in a separate diagram, we will show the shell procedure and how to download and install packages we need for OpenCV. The next diagram helps us test the system, and ensures that the Raspberry Pi recognizes all the components. In addition to testing out X-forwarding and video streaming.

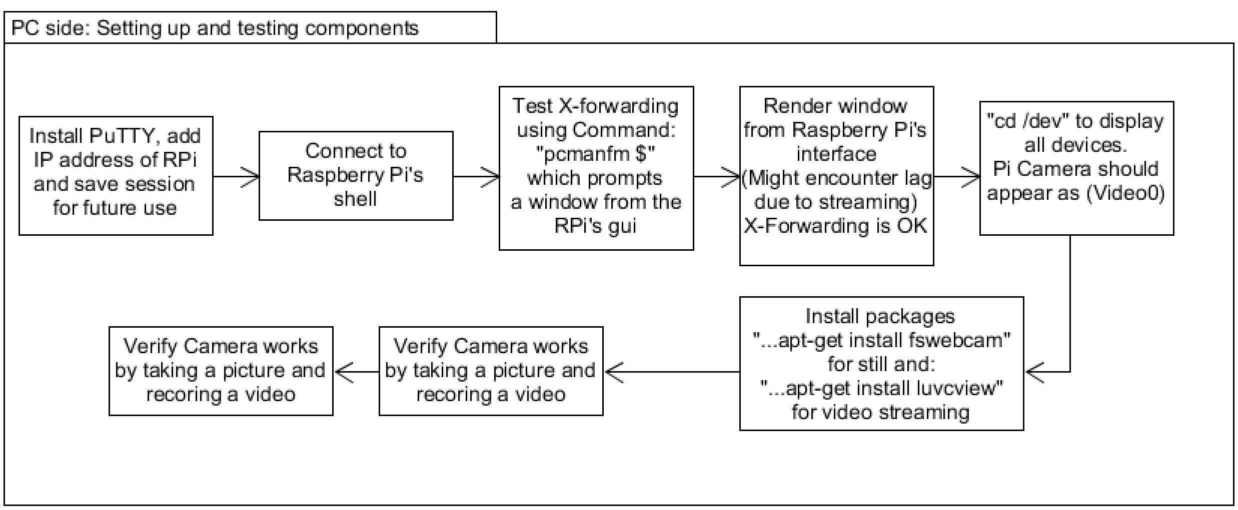


Figure 36: PC side: Setting up and testing components

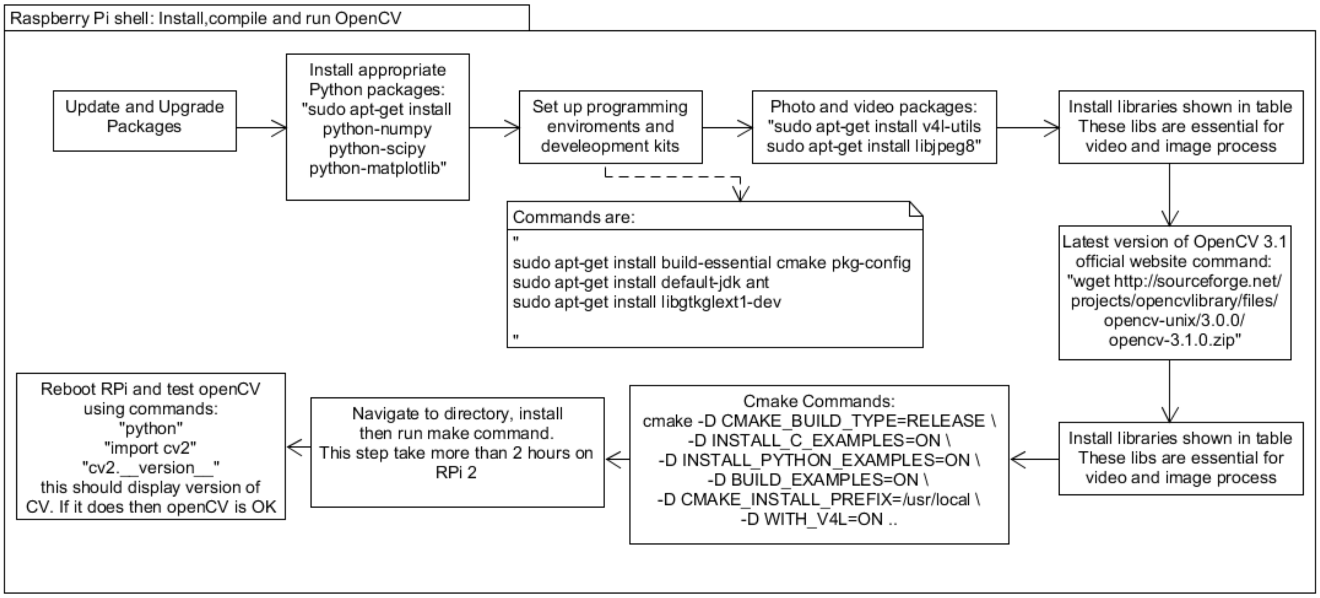


Figure 37: Raspberry Pi shell: Installing, Compile and run OpenCV

The previous procedure shows an overview of the setup process. It also highlights the most important packages and libraries that should be installed. It is a long process but it should only be done once. We will be able to process videos and images. Depending on the type of camera used, the two packages “luvcview, fswebcam” might not be necessary. Same might apply for some packages shown in the table below, some of them might be updated or replaced by newer one. We will wait until the implementation as the Linux command line will guide us to an appropriate action for each package.
Additional important libraries and packages [40]:

Table 4: Table of Commands and Libraries

• libjpeg8-dev \	• libv4l-0 \
• libjpeg8-dbg \	• libv4l-dev \
• libjpeg-progs \	• python-numpy \
• libavcodec-dev \	• libpython2.7 \
• libavformat-dev \	• python-dev \
• libgstreamer0.10-0-dbg \	• python2.7-dev \
• libgstreamer0.10-0 \	• libgtk2.0-dev \
• libgstreamer0.10-dev \	• libjasper-dev \
• libxine2-dev \	• libpng12-dev \
• libunicap2 \	• libswscale-dev\
• libunicap2-dev \	• swig \

As for testing the raspberry pie Camera, the following two lines will be used:

```
$ raspistill -o output.jpg
```

The previous line displays a still image. If it executes successfully; it indicates that the camera is working and we are ready to proceed! The still image "output.jpg" will be saved in the pwd -present working directory-.

4.4.2 Image and Video Processing of the Pupil

Accessing a single image of your Raspberry Pi [41]:

Now that we know how to capture images, we are ready to process. In the next section, we will be discussing the commands used for image processing and the major steps involved in the procedure. We will start by capturing an image, after initializing our camera so we can reference it later. The command used to capture the still image is:

```
camera.capture(rawCapture, format="bgr")
```

where *rawCapture* is a predefined object that gives, the users access to the raw stream of the camera to avoid unnecessary compression. Also, the choice of format *bgr* over others is merely for compatibility reasons with the OpenCV libraries.

Accessing a video stream of your Raspberry Pi [41]:

For this task in particular, experts in this field advised against using the default video capture function *cv2.VideoCapture*, rather they advised to use the raw format *picamera*. Although it might be easier to use but for video processing purposes it requires the installation of many other drivers which is something we choose to avoid. To capture the video, we use a for loop as shown below:

```
for frame in camera.capture_continuous(rawCapture, format="bgr", use_video_port=True):
        # grab the raw NumPy array representing the image, then initialize the timestamp
        image = frame.array
```

Where camera.capture_continuous allows for access to the camera stream.

4.4.3 Pupil Dectection

For this task, we will use predeveloped Haar Cascades, Haar cascades are simply the way openCV detects objects. They are templates than can scan through video or images and look for certain shapes or objects. OpenCV allows the option to either reuse predeveloped Haar cascades or even creating your own from scratch. As for this application, there are many different cascades that can be found online and modified for our use. In case we run into any issues, the option of making our own cascade stands but for now we will only consider it as plan B. Many factors can play in whether we choose to make a new Haar cascade. For one our parameters might vary than those of the ready cascade, these parameters can play a huge role such as the size of the pupil, the distance from the camera, whether the processing is happening in gray scale or not, the accuracy of the cascade. We will leave that to testing to determine if the cascade is useful for our application.

4.4.4 Controlling the MEMs

Now that we can capture video streams, process them using the cascade and detect an eye. The final step is where it all comes together to control the mirror and guide the laser beam. The following algorithm (pseudocode) describes the process:

```
Capture video and store stream (buffer) in reference → vidStream

Apply Haar cascade (haarcascade_eye.xml) on vidStream to detect pupil.

Store pupil reference → pupilRef

Origin location of pupilRef → current_origin

Loop:

        Monitor pupilRef and track for changes.

        Determine is change is significant.

        if change is significant:

                        Determine new location of origin → new_origin.

                        Distance and direction between old_origin and new_origin.

                        Adjust MEMs mirror and laser beam based on previous result.

End Loop
```

4.4.4.1 Conclusion

A “Significant” change is one of the parameters to be determined at the time of implementation. The Haar cascade outputs the radius and origin of the pupil in every iteration. Therefore, depending on what we consider “significant”, proper adjustments should be made. A “significant” change might not take in consideration the radius, but might consider a shift in origin of say a half or three quarter of a centimeter rather than a few millimeters. In detection of moving object the radius and especially in pupil detection and since the eye is a constantly moving part, a few dozens of changes might occur every second. Which means that we also might consider time as a factor as well (maybe twice or a single change in a sec).

4.5 Wireless Communication

4.5.1 Manchester Encoding Bit Error Rate Analysis

$$s_0(t) = p(t) \ Represent \ a \ logic \ 0 \ is \ Transmitted$$
$$s_1(t) = p(t) \ Represent \ a \ logic \ 1 \ is \ Transmitted$$

Where p(t) is:

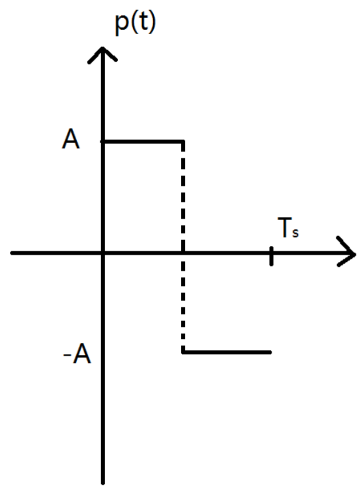


Figure 38: Illustration of Transmitted Signal

The analysis is based on the following conditions:

- The noise is Additive White Gaussian Noise(Stochastic Process is stationary and Gaussian) with mean power spectral density $S_n(f) = \frac{N_0}{2}$
- No error control algorithm
- The a *priori probability* of logic 1 sent is p; and so 0 sent is q=1-p

Signal space is 1-Dimension. Therefore, the complete orthonormal bases only have

$$\phi_1(t) = \frac{s_1(t)}{\sqrt{A^2 T_s}} = \frac{-p(t)}{\sqrt{A^2 T_s}} \quad (As \ the \ base \ of \ the \ signal \ space) \tag{40}$$

Signal Constellation diagram will be:

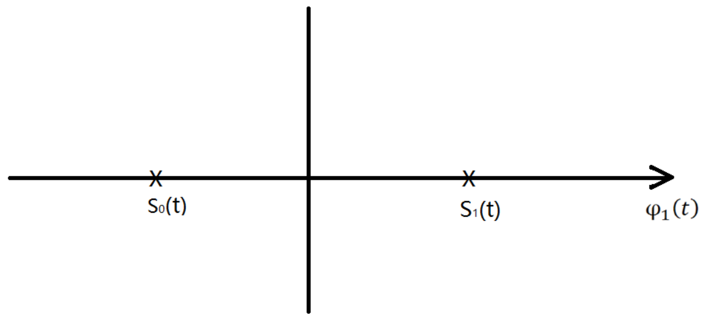


Figure 39: Signal Constellation Diagram

It is obvious that the engergy of the signal $s_1(t)$ and $s_2(t)$ are the same and it is E_s or E_b:

$$E_b = E_s = ||s_1(t)||^2 = ||p(t)||^2 =< p(t), p(t) >= \int_{-\infty}^{\infty} p^2(t)dt = A^2 T_s \tag{41}$$

$$||s_1(t)|| = ||s_0(t)|| = \sqrt{E_b} \tag{42}$$

The distance square between the two signals is:

$$||s_1(t) - s_0(t)||^2 = || - p(t) - p(t)||^2 = 4||p(t)||^2 = 4A^2 T_s \tag{43}$$

Let the received signal be r(t) and average probability of error be P_e

$$P_e = p * P(error|s_1 \ was \ sent) + q * P(error|s_0 \ was \ sent) \tag{44}$$

Define some region R^+ on the signal space that the receiver will decide s_1 was sent if r(t) falls into region R^+

$$P_e = p * (1 - \int f_R(r|s_1 \ was \ sent)dr) + q * \int f_R(r|s_0 \ was \ sent)dr \tag{45}$$

Note: the integral is on region R^+

$$P_e = p - \int (p * f_R(r|s_1 \ was \ sent) - q * f_R(r|s_0 \ was \ sent))dr \tag{46}$$

In order to minimize P_e, we need to maximize the term $\int (p*f_R(r|s_1 \ was \ sent) - q*f_R(r|s_0 \ was \ sent))dr$ Therefore

$$R^+ = \{r|p * f_R(r|s_1 \ was \ sent) - q * f_R(r|s_0 \ was \ sent) \geq 0\} \tag{47}$$

The decision rule becomes:

$$p * f_R(r|s_1 \ was \ sent) \geq q * f_R(r|s_0 \ was \ sent) \rightarrow s_1 \ was \ sent \tag{48}$$

$$p * f_R(r|s_1 \ was \ sent) < q * f_R(r|s_0 \ was \ sent) \rightarrow s_0 \ was \ sent \tag{49}$$

If the noise is AWGN, the conditional density function is a Gaussian distribution with mean $= ||p(t)||$ if s_1 was sent, $-||p(t)||$ if s_0 was sent. Variance $= \frac{N_0}{2}$ The decision rule becomes:

$$p * \frac{1}{\sqrt{\pi N_0}} * e^{-\frac{r - ||p(t)||^2}{N_0}} \geq q * \frac{1}{\sqrt{\pi N_0}} * e^{-\frac{r + ||p(t)||^2}{N_0}} \rightarrow s_1 \ is \ sent \tag{50}$$

$$p * \frac{1}{\sqrt{\pi N_0}} * e^{-\frac{r-||p(t)||^2}{N_0}} < q * \frac{1}{\sqrt{\pi N_0}} * e^{-\frac{r+||p(t)||^2}{N_0}} \rightarrow s_0 \; is \; sent \tag{51}$$

Simplify the above form will get

$$r \geq ln(\frac{q}{p})\frac{N_0}{4||p(t)||} \rightarrow s_1 \; is \; sent \tag{52}$$

$$r < ln(\frac{q}{p})\frac{N_0}{4||p(t)||} \rightarrow s_0 \; is \; sent \tag{53}$$

Therefore, the threshold of the decision rule is $ln(\frac{q}{p})\frac{N_0}{4||p(t)||}$ Consider the case that the a *priori probability* of a logic 1 or 0 is sent are the same (p=q=0.5).
The threshold becomes zero. And then

$$Pe = 0.5 * P(r \leq 0|s_1 \; was \; sent) + 0.5 * P(r > 0|s_0 \; was \; sent) \tag{54}$$

$$The \; received \; signal \; r(t) = s(t) + n(t) = \sum_{i=1}^{\infty} R_i * \phi_i(t) \; where R_i =< r(t), \phi_i(t) > \tag{55}$$

$$R_i =< s(t) + n(t), \phi_i(t) > \; where \; \phi_i(t) \; are \; complete \; orthonormal \; bases \tag{56}$$

$$R_1 =< s(t) + n(t), \phi_1(t) >=< s(t), \phi_1(t) > + < n(t), \phi_1(t) > \tag{57}$$

$$< s(t), \phi_1(t) > \rightarrow Signal \quad < n(t), \phi_1(t) > \rightarrow Noise$$

$$R_2 =< s(t) + n(t), \phi_2(t) >=< s(t), \phi_2(t) > + < n(t), \phi_2(t) >=< n(t), \phi_2(t) > \tag{58}$$

$$Similarly, \; R_i =< n(t), \phi_2(t) > \; for \; all \; i \neq 1$$

$$Because \; s(t) = \pm\sqrt{A^2 T_s} * \phi_1(t) \qquad < s(t), \phi_i(t) >= 0 \; for \; all \; i \neq 1 \tag{59}$$

Therefore, only R_1 contains information of the signal.

$$Let \; N \; be \; the \; projection \; of \; AWGN \; process \; n(t) \; onto \; the \; signal \; space \; or$$

$$N =< n(t), \phi_1(t) > \tag{60}$$

$$N = \int_{-\infty}^{\infty} n(t) * \phi_2(t) dt \; is \; a \; linear \; combination \; of \; n(t) \tag{61}$$

Because n(t) is a Gaussian process, all random variables within n(t) are jointly Gaussian. Additionally, any linear combination of jointly Gaussian random variables is still Gaussian. Therefore,N is a Gaussian Random Variable.

$$\mathbb{E}\{N\} = \mathbb{E}\{\int_{-\infty}^{\infty} n(t) * \phi_1(t) dt\} = \int_{-\infty}^{\infty} \mathbb{E}\{n(t)\} * \phi_1(t) dt = 0 \tag{62}$$

Since n(t) is stationary and Gaussian. The autocorrelation function is

$$\mathbb{E}\{n(t_1) * n(t_2)\} = R(t_1, t_2) = R(t_1 - t_2) = \mathbb{F}^{-1}\{S_n(f)\} \quad S_n(f) = \frac{N_0}{2} \tag{63}$$

$$\mathbb{E}\{n(t_1) * n(t_2)\} = \frac{N_0}{2}\delta(t_1 - t_2) \tag{64}$$

Then:

$$\mathbb{E}\{N^2\} = (\int_{-\infty}^{\infty} n(t)\cdot\phi_1(t)dt)^2 = \mathbb{E}\{\int_{-\infty}^{\infty} n(t)\cdot\phi_1(t)dt \int_{-\infty}^{\infty} n(t)\cdot\phi_1(t)dt\}$$

$$= \mathbb{E}\{\iint_{-\infty}^{\infty} n(t_1)\cdot\phi_1(t)\cdot n(t_2)\cdot\phi_1(t_2)dt_1dt_2\} = \iint_{-\infty}^{\infty} \mathbb{E}\{n(t_1)\cdot n(t_2)\}\cdot\phi_1(t_1)\phi_1(t_2)dt_1dt_2$$

$$= \iint_{-\infty}^{\infty} \frac{N_0}{2}\delta(t_1-t_2)\cdot\phi_1(t_1)\phi_1(t_2)dt_1dt_2 = \frac{N_0}{2}\int_{-\infty}^{\infty}\phi_1(t_2)\phi_1(t_2)dt_2 = \frac{N_0}{2} \tag{65}$$

$$Var\{N\} = \mathbb{E}\{N^2\} - \mathbb{E}^2\{N\} = \mathbb{E}\{N^2\} = \frac{N_0}{2} \tag{66}$$

Therefore,N is a Gaussian random Variable with mean=0, variance=$\frac{N_0}{2}$

$$P_e = 0.5 * P(N > \sqrt{E_b}) + 0.5 * P(N < -\sqrt{E_b}) = Q(\sqrt{\frac{2E_b}{N_0}}) \tag{67}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-\frac{t^2}{2}}dt \tag{68}$$

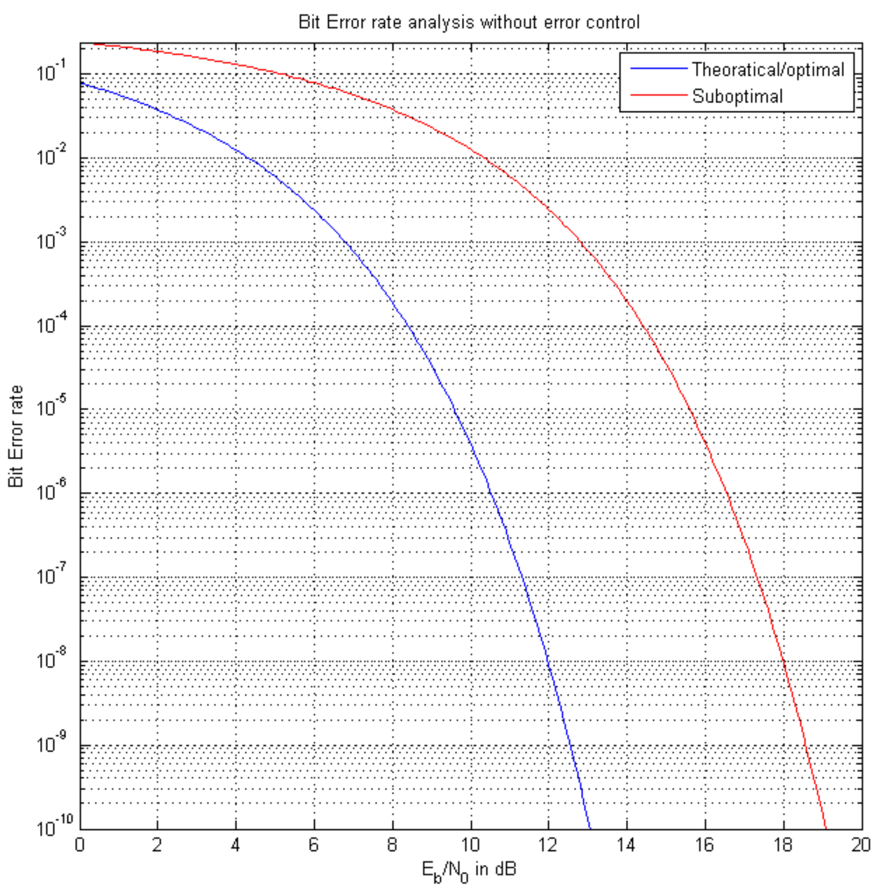


Figure 40: Bit Error Rate Analysis without Error Control

The actual performance will not be the optimal case discussed above, because the assumptions made before the analysis may not satisfied in real life. If the probability of error is much worse than expected, the error control algorithm will be introduced for future application.

4.5.2 Matched Filter

In order to achieve the above probability of error, we need to design a receiver to maximize the signal to noise ratio.

To maximize the SNR, a filter at the receiver is required. Suppose the filter has an impulse response h(t).

$$Signal\ Power\ at\ filter\ output\ is: |s(t) * h(t)|^2 = |\int_{-\infty}^{\infty} s(\tau) \cdot h(t-\tau) d\tau|^2 \tag{69}$$

Where $*$ is the convolution operator in this case.
The Cauchy Schwartz inequality

$$= |\int_{-\infty}^{\infty} s(\tau) \cdot h(t-\tau) d\tau|^2 \leq |\int_{-\infty}^{\infty} |s(\tau)|^2 d\tau| \cdot |\int_{-\infty}^{\infty} |h(t-\tau|^2 d\tau| \tag{70}$$

THe equality hold in and only if $s(\tau) = \alpha h(t-\tau)$ for any positive α.

$$Noise\ Power\ at\ filter\ output\ is: \int_{-\infty}^{\infty} S_n(f) \cdot |H(f)|^2 df \tag{71}$$

Where $S_n(f) = \frac{N_0}{2}$ is the noise mean power spectral density function.
$H(f)$ is the fourier transform of h(t). And noise output power can be further simplified to (based on Parseval's Theorem):

$$\int_{-\infty}^{\infty} S_n(f) \cdot |H(f)|^2 df = \frac{N_0}{2} \int_{-\infty}^{\infty} |H(f)|^2 df = \frac{N_0}{2} \int_{-\infty}^{\infty} |h(t-\tau)|^2 df \tag{72}$$

The SNR at the filter output is:

$$\frac{|\int_{-\infty}^{\infty} s(\tau) \cdot h(t-\tau) d\tau|^2}{\frac{N_0}{2} \int_{-\infty}^{\infty} |h(t-\tau)|^2 df} \leq \frac{|\int_{-\infty}^{\infty} |s(\tau)|^2|^2 \cdot |\int_{-\infty}^{\infty} |h(t-\tau)|^2 d\tau|^2}{\frac{N_0}{2} \int_{-\infty}^{\infty} |h(t-\tau)|^2 df} = \frac{2|\int_{-\infty}^{\infty} s(\tau)|^2|^2}{N_0} \tag{73}$$

But $|\int_{-\infty}^{\infty} s(\tau)|^2|^2 = |\int_0^{T_s} |p(t)|^2 dt|^2 = E_s = E_b$ which is energy for a symbol. Also,it is engergy per bit transmited since one symbol only contains one bit in this case.

The maximum SNR can be achieved is $\frac{2E_b}{N_0}$ (this value is consist with the value derived from (67)) with a matched filter whose impulse reponse is $h(t) = \alpha \cdot s(T_s - t) = \alpha p(T_s - t)$.

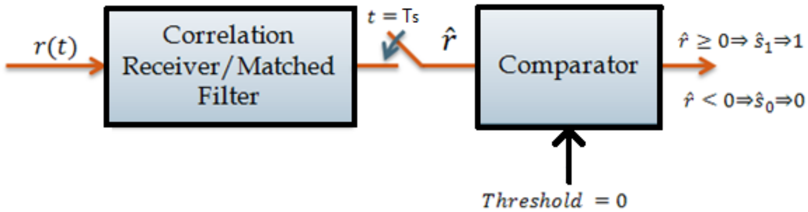


Figure 41: Receiver with Matched Filter

If filter is not matched:

$$P_e = Q(\sqrt{\frac{2E_b}{N_0}} \cdot \frac{< p(t), h(T_s - t) >}{||p(t)|| \cdot ||h(T_s - t)||}) = 0.5\, then\ it\ would\ be\ red\ curve\ Figure 40 \tag{74}$$

5 Project Material (Zac)

5.1 Material and Instrumentation

Table 9: Material and Instrumentation List

Purpose	**Item**	**Requirement**
Capture Image	Camera	Standard camera for micro-processor
Process Image	Micro-processor	Camera interface (CSI)
		Tx Rx at least 1MHz
		At least 1GHz CPU
Drive laser with modulated signal	Laser Driver	Support at least 1MHz
Transmit Data	Laser	Infrared Laser around 850nm wavelength
		Start with standard power for laser
		Before realizing, need to replace with small power
Capture Eye position	Camera	Standard camera for micro-processor
Process Eye position	Micro-processor	Camera interface (CSI)
Reflect Laser	Mems Mirror	$\pm 5°$
		Rotational frequency > 1Hz (1 sec)
Detect laser	Photodetector	Fast response time
		Standard output logic voltage
Decode	Micro-processor	At least 1GHz CPU
		Tx Rx at least 1MHz
Feedback	Bluetooth Module	Support short distance
Easier access to photodector	Gold plate	Large enough to be able to access with probe
Visual the signal	Oscilloscope	Support at least 1MHz

In our application, we are required to have two cameras, which one of them capture the image and another one for capturing the movement of the eye. The images from either of the cameras are processed through two separate micro-processors. One of the micro-processors process the image into data and encoded with Manchester Encoding Scheme and another micro-processor is analyzing the position of the eye. The encoded signal has to be at least 1MHz because the Photodetector supports at least around 1MHz; hence most of the transmission systems have to support at least 1 MHz. Infrared laser has a wavelength within 700nm to 1mm, but we chose to use Near Infrared laser at 850nm. Our system also requires to be able to adapt to the eye movement, so we use Mems Mirror to achieve. The mirror has to rotate minimum of 1 sec delay, which is 1Hz, for the delay to be unnoticeable. The decoding micro-processor has to be similar to the encoding micro-processor, here we chose to be the same.

5.2 Budget

Table 10: List of Parts and Cost (Provided by SUNLAB & iBionics)

Part	**Part Number**	**Quantity**	**Description**	**Cost**
1MHz Laser Driver				
LM317	LM317HVT/NOPB	1	Voltage regulator	3.79
LT1215	LT1215CN8#PBF	1	U1/A (op amp ic)	8.7
C1	C315C220K5G5TA	1	22pF capaciator	0.52
C2	C315C100KDG5TA	1	10pF capacitor	1.89
R1, R2	CF14JT10K0	2	10K resistor	0.3
R3, R4	CF14JT2K00	2	2K resistor	0.3
R5, R6, R7, R8	CF14JT3K30	4	3.3 K resistor	0.6
R9	CF14JT100R	1	100 ohms resistor	0.15
R10	CF14JT1K00	1	1 K ohms resistor	0.15
R11	FKN200JR-73-8R2	1	8.2 ohms resistor	0.8
VR1	3292W-1-102	1	Variable Resistor 1k ohm	22.5
D1, D2	1N5231BTR	2	500mW_Z5V1	0.36
Micro-Controller				
Raspberry Pi 3	RASPBERRY PI 3	3	Micro-Controller	201.27
Camera				
Rapsberry Pi Camera Module	DEV-11868	2	5MP	84.46
Mems Mirror				

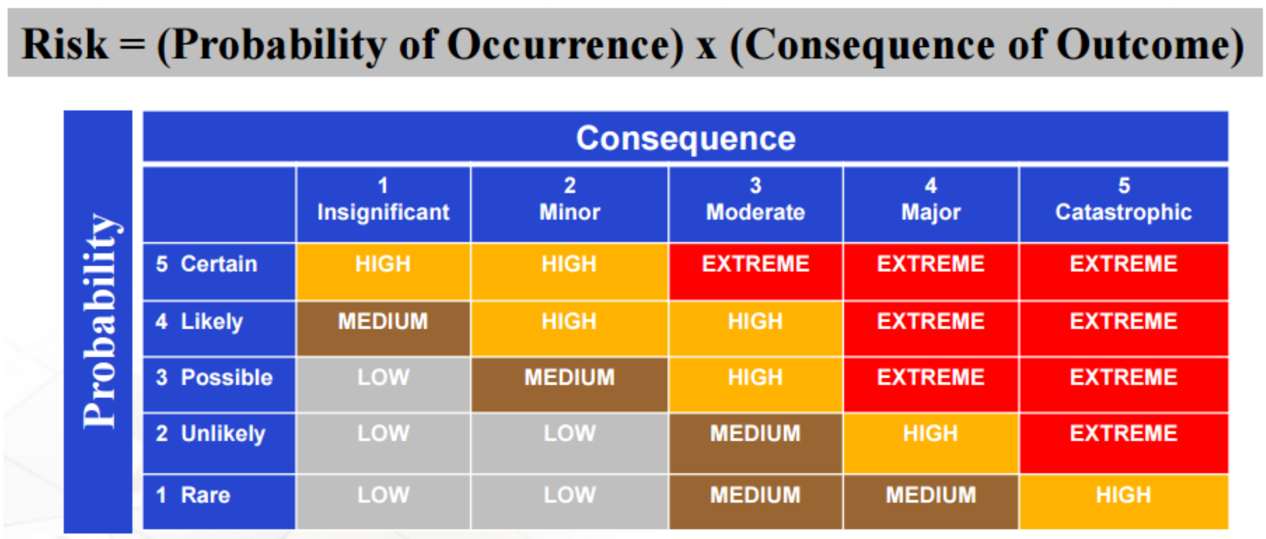
Semi-Custom Development Kit				8875
Linux Development Kit	Raspberry Pi Wireless (Bluetooth) Option			1950
Mirror	3.6mm Diameter	3	Bonded	0
Actuator	A7B1.1, DIP24-035	3	±7° Die Size 5.20x5.20mm Gold Coating	0
Laser				
Laser Diode	QFLD-850-100S	1	Single mode fiber coupled laser diode 100mW 850nm	1000
Fiber Collimator	CFC-11X-B	1	Adjustable FC/PC Collimator f = 11.0 mm, ARC: 650-1050 nm	252
Others				
Artificial Eye	EKIND 60mm	1	Clear Plastic Fillable Ball	7
Mannequin Head	SHANY	1	Cosmetics Female Styrofoam Head	15
Ellipsoidal Mirror		1		
Bluetooth Module	RB-D6-10	2	Provide Feedback	40
TOTAL				**12442.79**

- Laser Driver components, Micro-controller, Camera, *www.digikey.ca*
- Bluetooth Module, *www.robotshop.com*
- Mems Mirrors, Actuators, Development kits, *www.mirrorchletech.com*
- Laser Diode, Fiber Collimator, *www.qphotonics.com*
- Artificial Eye, Mannequin Head, *Amazon*

6 Risk Management Plan (Noor)

6.1 Identification of Hazards

Every project consists of some associated risks and hazards. According to Laflamme (2016) [7], a hazard can be defined as a source of harm to people or objects under certain work conditions, while a risk is the probability that harm will occur if a person is exposed to that hazard. To ensure the safety of all the individuals involved in the project as well as the safety of potential clients, a complete study of the hazards and the risks involved must be considered. Also, certain possible failures or risks during the implementation of the project must be identified with a provided alternative. Table 11 below shows the different hazards with associated risks as well as the degree of each risk as calculated from the Risk Matrix shown in Figure 42. below.



Risk = (Probability of Occurrence) x (Consequence of Outcome)

Probability	Consequence				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 Certain	HIGH	HIGH	EXTREME	EXTREME	EXTREME
4 Likely	MEDIUM	HIGH	HIGH	EXTREME	EXTREME
3 Possible	LOW	MEDIUM	HIGH	EXTREME	EXTREME
2 Unlikely	LOW	LOW	MEDIUM	HIGH	EXTREME
1 Rare	LOW	LOW	MEDIUM	MEDIUM	HIGH

Figure 42: Risk Matrix [7]

Table 11: Project Hazards and Associated Risks

Hazard	Consequence	Risk Level	Control Measures
Laser	At high powers, laser may cause burning of the eye.	**Medium Risk** – Unlikely occurrence – Moderate consequence	– Use safety protective wear (laser masks provided in the lab – All group members must be WHMIS certified before working in the lab .

Electric Power Supply	May cause electric shock	**Low Risk** – Rare occurrence – Minor consequence	– WHMIS training – Not using high voltages – Only need enough current to power laser drive.

6.2 Risks of Implementation

When the implementation stage of the project begins, there is a risk of failure associated with the completion of each task that must be identified with provided alternatives. These risks are described step-by-step below.

(i) Failure to capture image: If the purchased camera fails to capture an image, it can be replaced by the purchase of an alternative camera.

(ii) Failure of image processing: There is a risk that the image may not be processed appropriately and is not modulated into digital data. If this problem arises, we can work on transmitting binary data to ensure the rest of the project flows according to schedule, until this issue is resolved.

(iii) Failure of laser driver: If the laser driver fails to produce an appropriate signal, the component can be replaced by an alternative purchased part.

(iv) Failure to angle laser properly: Adjust the MEMs mirror to have exact aim of the PV chip, detect to make sure laser is shooting in the right angle.

(v) Failure to detect data sent: Check the microprocessor and make sure the chip is properly placed on the gold detection plate. Replace chip/microprocessor.

(vi) Failure to Track pupil: Use alternative methods outlined in literature review, for example an ellipsoidal mirror.

(vii) Failure to move MEMs after tracking: Manually change the angle of the laser according to the feedback obtained from the tracking until the problem with the MEMs is fixed by reprogramming the microprocessor or by replacing the MEMs mirror.

Therefore, there are many risks of failure that may occur during the implementation stage of this design project. It is important to be able to identify these risks and plan for alternative ways to resolve any issues that may arise. This will lead to an easier transition during the physical implementation of the design.

7 Division of Responsibilities

7.1 Team Qualification (All)

7.1.1 Shuo Han

I have solid understanding for communication systems including but not limited to the concept of SNR, BER, Extinction Ratio, Randomness Analysis, and Stochastic Processes, etc. It will help us to solve problems and delivered proper solutions during our design project. Also, I have strong math and physics back grounds that will enhance our group ability of theoretical analysis.

Experiment is also my strength. I worked as an undergraduate research assistant in summer 2014 at Godin Lab. The related concepts including micro-fabrication, photolithography, and integrated microfluidic circuits control. In fall 2014, I worked as a volunteer at Sun Lab with Ross Cheriton who is supervised by Professor Karin Hinzer. I took measurements of external quantum efficiency, photoluminescence, I-V characterization of solar cells. I worked at Mitel Hardware Development Team in 2015. With a full year of industrial experience, I had chances to work in different area including Compliance Engineering, Component Engineering, and Hardware Development. Works including schematics capture, Layout review, measurements of emission and immunity of electronic products, hardware debugging and trouble shooting

When I worked at Mitel Networks Corp, I participate weekly meeting, report progress, and discuss with team members to improve solutions. I believe, as a team, we are able to manage the project properly.

7.1.2 Tsa Chun Liu

Ever since I was a teenage I have always like to tear electronics apart to see the components within. The intense attraction towards electronics becomes one of the main reason on why I want to study electrical engineering. As I learned more about electrical engineering in school, I become more interested and want to learn more knowledge especially in Telecommunications, which is what I chose for the forth year electrical engineering option. Over the academic years, I have been one of the top students in the class and have been on Deans Honours List in the second academic year. During the current forth year, I have accomplished DGPA of over 8. During my second academic years, I have also been invited to be one of the student representative for external program evaluation for electrical engineering program.

Theoretical analysis is only one of my strength, I am also very comfortable in hands on experiments and development. Over the years, I have been involved with several projects with school and companies such as iRobot Project with University of Ottawa, Unmanned Aerial Vehicle Project with Romaeris Corp, Motor Driver Develop Assistant for Footwear & Recreation Technology Research Institute in Taiwan and currently working on Diamond Eye project as a contractor with SUNLAB in University of Ottawa and iBionics. I have gain a lot of engineering experiences such as working with variety of microcontrollers, Arduino and ICs, circuit analysis and design, programming with C/C++, soldering and technical drawing. Programs such as MATLAB, Altium Designer, Multisim, LaTex, MPLAB, Quartus II and Microsoft office are examples of programs that I have worked with. The platforms that I have experience on are Windows and Linux on Raspberry Pi and Udoo Neo.

The personal professional goal for myself is to have discovery or development of product to have an impact to the rest of the whole, to improve the life quality of our future.

7.1.3 Anas Zurkiyeh

I currently work in The Human Rights office of the University of Ottawa as a Project Manager. My job requires creating and managing web content for the office, along with other various tasks such as creating accessible documents, providing training to new members and so on.

I have worked on an engineering project where I was asked to create an API -Application Program Interface- that would configure and manage a gyroscope in conjunction with a WIFI module using C. The gyroscope is used in a sensing node for a UAV -Unmanned Air Vehicle-. Multiple sensing nodes distributed throughout the UAV form a network of sensors that provide various real-time information such as temperature, altitude, row, pitch, yaw and many more. My application saved my team a significant amount of time as configuring each node can take up to 5 minutes. Working on this project, I have acquired lots of experience along with critical set of skills both in hardware and software which will come handy in our capstone project.

I am really interested in Robotics and the integration of software and hardware. That was the main reason I chose Control Systems as my stream. There is no denying that robots -although still in their early stages- play a critical role in our daily lives, and it still has so much more to offer. Almost every major project has a controls system of some sort (Microprocessor, Microcontroller,. . .) and this capstone project is no exception! So this is a great opportunity to showcase to my peers how important controls systems are, and hopefully the start of a long career in robotics for myself!

7.1.4 Noor Allami

I am a 4th year electrical engineering student, currently enrolled in the Power option. I dont have any relevant work experience to bring into the group, but I have taken many courses with related material that meet the design requirements of this project. I am also currently enrolled in a course which focuses on Optoelectronics and Photonics, which will provide me with greater insight on how lasers work. This will be a great advantage since the main focus of the project is to convert a wired system into a wireless system by the use of laser. In the past 3 years, I have learned circuit design and analysis, electronics, and the fundamentals of wireless communication, which are key to this project. I am also able to code with C, and can proficiently use MATLAB, MULTISIM, and PowerWorld Simulator.

I was also able to improve on my technical writing skills though the Technical Report Writing course, as well as my Project Management skills through the Professional Ethics course. That also includes planning and time management by the use of Gantt chart and other commonly used methods. I have a Bachelors Degree in Community Rehabilitation and Disability Studies from the Faculty of Medicine, at the University of Calgary. My previous degree will be of benefit to me in terms of the report writing and some knowledge in biology. It will also be useful in understanding the social implications of this specific design project on people with disability, specifically people with blindness.

7.2 Milestones (Zac)

7.2.1 Report

Table 12: Milestones of Report for Tony

	Expected Due Date	Completion Data
CV	04-Oct-16	04-Oct-16
Diamond Eye Review	12-Oct-16	12-Oct-16
Electrical Design	25-Oct-16	25-Oct-16
Pinhole Camera Model	01-Dec-16	01-Dec-16
Bit Error Rate	01-Dec-16	01-Dec-16

Table 13: Milestones of Report for Anas

	Expected Due Date	Completion Data
Overview	04-Oct-16	04-Oct-16
CV	04-Oct-16	04-Oct-16
Tracking	12-Oct-16	12-Oct-16
Software Design	25-Oct-16	25-Oct-16
Conclusion	31-Oct-16	31-Oct-16
Kinetic Model	01-Dec-16	01-Dec-16

Table 14: Milestones of Report for Noor

	Expected Due Date	Completion Data
Overview	04-Oct-16	04-Oct-16
CV	04-Oct-16	04-Oct-16
Scope/Goal	04-Oct-16	04-Oct-16
Human Eye/Diseases	12-Oct-16	12-Oct-16
Mechanical Design	25-Oct-16	25-Oct-16
System Requirement	25-Oct-16	25-Oct-16

Risk Management	31-Oct-16	31-Oct-16
Conclusion	31-Oct-16	31-Oct-16
Meeting Minutes	14-Dec-16	14-Dec-16
Coordinate System	14-Dec-16	14-Dec-16

Table 15: Milestones of Report for Zac

	Expected Due Date	Completion Data
CV	04-Oct-16	04-Oct-16
Wireless Transmission	12-Oct-16	12-Oct-16
Encoding Decoding	12-Oct-16	12-Oct-16
Block Diagram	25-Oct-16	25-Oct-16
Electrical Design	25-Oct-16	25-Oct-16
Project Material	18-Oct-16	18-Oct-16
Milestone/Gantt	25-Oct-16	25-Oct-16
Electrical Design More Detail	14-Dec-16	14-Dec-16

7.2.2 Project

Table 16: Milestones of Project for Tony

	Expected Due Date	Completion Data
Component Measurements	14-Jan-17	
Send Data with Wire	14-Jan-17	
Send Data with Laser	31-Jan-17	
Laser & Tracking	20-Feb-17	
Send Video	31-Mar-17	
Integrate & Final Testing	12-Apr-17	

Table 17: Milestones of Project for Anas

	Expected Due Date	Completion Data
Component Measurements	14-Jan-17	
Tracking System/Mems Mirror	13-Feb-17	
Laser & Tracking	20-Feb-17	
Send Video	31-Mar-17	
Integrate & Final Testing	12-Apr-17	

Table 18: Milestones of Project for Noor

	Expected Due Date	Completion Data
Component Measurements	14-Jan-17	
Tracking System/Mems Mirror	13-Feb-17	
Laser & Tracking	20-Feb-17	
Send Video	31-Mar-17	
Integrate & Final Testing	12-Apr-17	

Table 19: Milestones of Project for Zac

	Expected Due Date	Completion Data
Component Measurements	14-Jan-17	
Send Data with Wire	14-Jan-17	
Send Data with Laser	31-Jan-17	
Laser & Tracking	20-Feb-17	
Send Video	31-Mar-17	
Integrate & Final Testing	12-Apr-17	

7.3 Schedule (Gantt Chart) (Zac)

7.3.1 Report

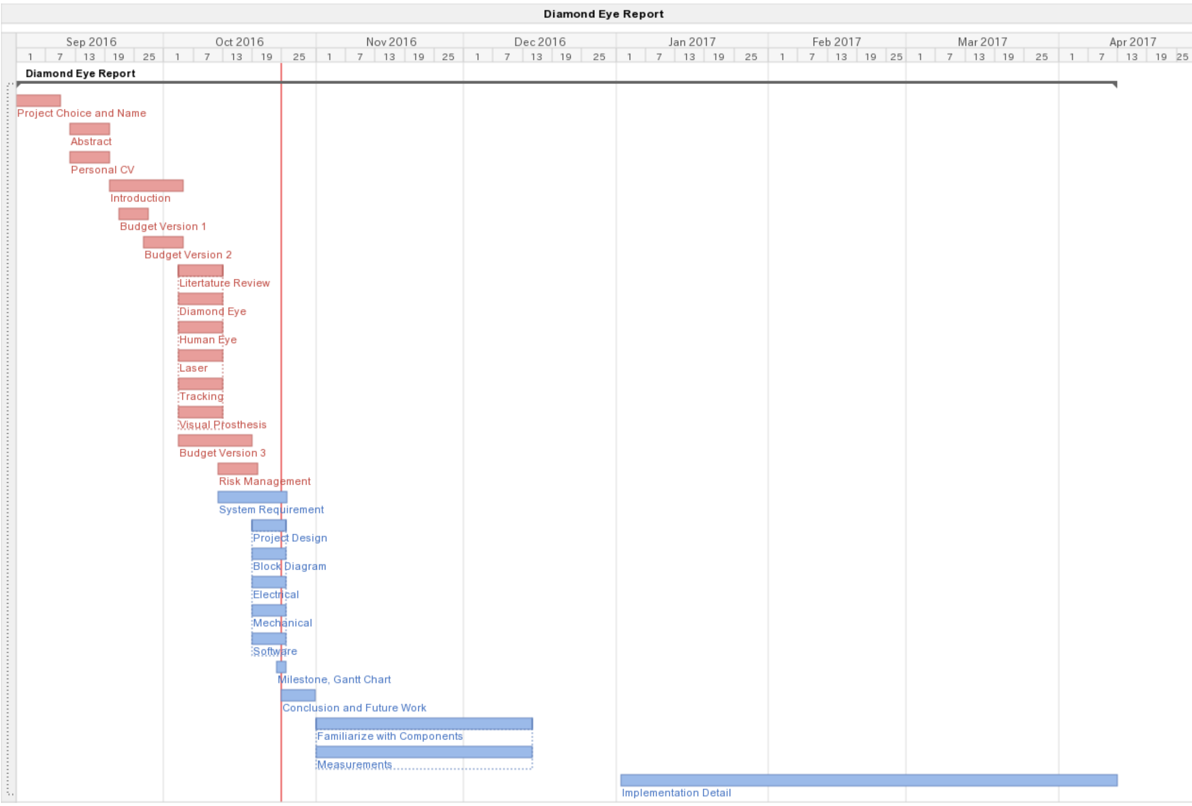


Figure 43: Gantt Chart for Report

7.3.2 Project

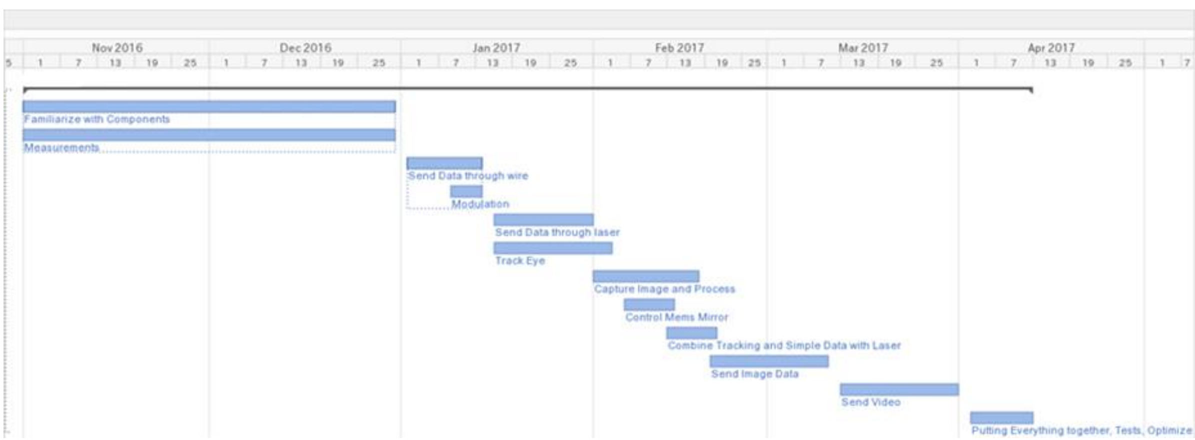


Figure 44: Gantt Chart for Project

8 Conclusion (Noor & Anas)

Due to the growing population of people with blindness as well as technological advancements, there has been a notable increase in effort by researchers to design a solution. Most of the solutions under study are visual prosthesis for people with retinal degenerative diseases. iBIONICS is a start-up company that has designed a "Diamond Eye" implant, and is currently investigating different designs to complement the implanted chip. This project is designed to study the feasibility of implementing a visual prostheses system to help people with blindness, specifically people with Macular Degeneration or Retinitis Pigmentosa. Research was conducted to examine how the product should be designed. This was done by reviewing related literature to decide on different methods which are suitable for the design.

Following the general system for a visual prostheses, the project will be designed by processing an image and transmitting the data to the implanted chip by the use of microcontrollers, a laser driver, and a MEMs mirror. To ensure a constant transmission of data and error elimination, tracking the pupil of the human eye is necessary. Detailed hardware and software designs are provided in the above sections. The project that will be demonstrated will not look mechanically similar to the ideal system which will be implemented on glasses. Therefore, although the setup will differ, the functionality of both systems will be very similar.

8.1 Future Work

Over the remaining duration of the semester, the group will work on choosing and studying the different components required for the design. In addition, a plan will be placed to discuss the implementation part of this design project. Once initial testing has been conducted and satisfactory results were obtained, certain aspects of the design can be adjusted for improvement of the overall performance of the system. When transmitting and receiving data, after binary data is sent and received, further adjustments can be made to transmit more complex data such as an image or a video. Since this is the first product of iBIONICS, there will always be room for future development. This product will continue to be an on-going design and enhanced for the convenience of the patient.

A Meeting Minutes (Noor)

- December 6, 2016 (1.5 Hours)
  - Members Present: uOttawa Team: All members, iBionics: Anne, Steven, Michel, SunLab: Ross, Grant
    * Briefing iBionics in terms of our progress
    * Discussing future direction of the project for the course
    * Discussing objective and goals in terms of project for iBionics
- December 3, 2016 (3 Hours)
  - Members Present: All members present
    * Reviewed each others parts of the presentation
    * Revised power points
    * Finalized presentation
    * Decided on next meeting to practice
- November 30, 2016 (3 Hours)
  - Members Present: All members present
    * Designed an outline for the presentation
    * Added in the missing information for the repot
    * Adjusted the division of responsibility tables
    * Finalized the coordinate system and camera calibration sections
    * Divided the presentation among the team members
- November 29, 2016 (3 Hours)
  - Members Present: All members present
    * Started working on the presentation
    * Finishing up the coordinate system
    * Laying out the responsibility chart for each team member
    * Started reviewing report to make necessary adjustments
- November 23, 2016 (3 Hours)
  - Members Present: All members present
    * Continued to work on the tracking part of the report, adding in the coordinate system
    * Divided the presentation among the group members
- November 22, 2016 (3 Hours)

- Members Present: All members present
    * All group members worked on different aspects of the coordinate system, to complete the design for the report.
    * Camera to image, image to real life, and the design set-up as well as the tracking method.
    * Equations were developed to track target from one coordinate system to the next
- November 22, 2016 (1 Hours)
  - Members Present: All members present
    * Met with Ross
    * Discussed progress of the report and feedback obtained on report
    * Discussed the possible use of a photo diode instead of the PV chip for the beginning stages of implementation for the tracking, just to ensure enough power is supplied and then we can switch to the PV chip, to prevent any damage to the PV chip as they are expensive
    * The MEMs have been sized, waiting on funding approval to purchase them.
- November 16, 2016 (3 Hours)
  - Members Present: All members present
    * Feedback from TA about the report
    * Discussed how to proceed with report
    * Discussed removing human aspect of project into future implications section within each heading
    * Discussed how to divide the rest of the work among team members to complete report
- November 15, 2016 (3 Hours)
  - Members Present: All members present
    * Received feedback from TA and professor
    * Feedback was to remove human aspect with respect to the report
    * Installed the second Raspberry Pi
    * Worked on coordinate system
- November 9, 2016 (3 Hours)
  - Members Present: All members present
    * Started setting up one of the Raspberry Pi microcontrollers
    * Tried to set up the second one, but ran out of time
    * Drew a coordinate system for the MEMs, laser, camera and eye; coordinate system

still needs to be labelled and equations need to be computed.

    * Drew a coordinate system for the tracking of the eye, from 3-D real eye to 2-D image from a camera. Designed general equations to be used for the related coordinate system.

- November 8, 2016 (3 Hours)
  - Members Present: All members present
    * Worked on trying to understand the mapping from the real world onto 2-D images.
    * Trying to calculate the MEMs coordinate system
    * Reviewed operation of MEMs online
    * Studied converting real life objects into 2-D images
- November 8, 2016 (1.5 Hours)
  - Members Present: All members present
    * Met with Ross
    * Discussed the different components that have arrived
    * Discussed the different types of MEMs mirror to be ordered
    * The MEMs software is MATLAB and C compatible
    * Need to provide Resumes for iBionics for grant applications
- October 28, 2016 (1.5 Hours)
  - Members Present: Anas, Noor and Zac
    * Finalizing the report
    * Worked on conclusion
- October 25, 2016 (1.5 Hours)
  - Members Present: All members present
    * Meeting with Ross
    * Looked at ordered parts
    * Discussed tracking: only need to track a few degrees, no need to cover a large range
    * MEMs: use high voltage (few hundred volts), but very low current, overall power is very low (mW range)
    * Discussed different software methods for laser modulation, C will yield the fastest modulation, but Python will be more user-friendly
    * Discussed progress of report and possibly reviewing mid-term report upon completion
- October 19, 2016 (3 Hours)

- Members Present: All members present
    * Identified what needs to be completed for project design
    * Divided the rest of the report
    * Worked on Budget and Project Design sections of the report

- October 18, 2016 (3 Hours)
  - Members Present: All members present
    * Updated the online pdf of the report
    * Reviewed the completed sections of the report
    * Identified incomplete sections
    * Discussed Project Design

- October 12, 2016 (3 Hours)
  - Members Present: All members present
    * Finished up Literature Review
    * Discussed potential hazards and risks of project
    * Wrote up Hazard Management Section
    * Discussed System Requirements
    * Wrote up System Requirements sections

- October 11, 2016 (3 Hours)
  - Members Present: All members present
    * Worked on Literature Review Sections individually in the lab

- October 5, 2016 (3 Hours)
  - Members Present: All members present
    * Assigned different sections of literature review to group members
    * Began writing literature review
    * Noor- The Human Eye and Visual Prostheses sections
    * Anas- Tracking section
    * Zac- Laser section
    * Tony- Diamond Eye Section

- October 4, 2016 (3 Hours)
  - Members Present: All members present
    * Discussed possible eye tracking methods
    * Started formulating a skeleton for literature review

    * Signed Hazard and Risk Management Paperwork for project

- October 4, 2016 (2 Hours)
  - Members Present: Noor, Tony and Zac
    * Biweekly meeting with Ross
    * Discussed the use of Raspberry Pi for tracking
    * Discussed ellipsoidal mirror possibility
    * Choosing camera for eye tracking
- September 28, 2016 (3 Hours)
  - Members Present: All members present
    * Researched facts for introduction
    * Typed up introduction
    * Combined a parts list
- September 27, 2016 (3 Hours)
  - Members Present: All members present
    * Worked on combining ideas for introduction
    * Discussed what to include/exclude from introduction
    * Discussed scope and goals
    * Discussing parts to be ordered
- September 26, 2016 (1 Hour)
  - Members Present: All members present
    * Skype meeting
    * Discussed details of the meeting with Ross with Tony and Zac
    * Discussed what needs to be done this week (Intro and parts list)
    * Set up online collaboration folder (google drive)
    * Working individually on points for introduction to bring together the next day
- September 22, 2016 (1 Hour)
  - Members Present: Anas and Noor
    * Met with Ross
    * Discussed Project details
    * Discussed specific expectations
    * Discussed sourcing of systems to be used
    * Discussed preparing a design and preparing a parts list as asked by Ross

- September 21, 2016 (3 Hours)
  - Members Present: Tony, Zac, Anas and Noor
    * Met with TA and discussed design before implementation
    * Tried to meet with Ross, set up a meeting for tomorrow
    * Researched MEMs mirror and possible cost
    * Worked on Introduction for report
- September 20, 2016 (3 Hours)
  - Members Present: Noor, Tony, Zac, and Anas
    * Got some paper work signed to have access to the lab in ARC building
    * Signed safety paperwork for course
    * Discussed some possible ways to design a tracker
- September 18, 2016 (4 Hours)
  - Members Present: Anas, Noor, Zac and Tony
    * Met with Ross and iBIONICS (Michel Pigeon)
    * Got an introductory presentation to iBIONICS as a company
    * Presented with the "Diamond Eye" Project
    * Discussed our role within the "Diamond Eye" Project
    * Discussed and signed NDA (Non-disclosure agreement)
    * Discussed possible compensation for intellectual property of the project, no arrangements were made yet.
- September 14, 2016 (3 Hour)
  - Members Present: Zac, Anas, Tony and Noor
    * Discussed Abstract
    * Discussed possible block diagrams (high-level)
    * Discussed some question and concerns to be clarified
    * Solidifying our understanding of the project and our role within the project
- September 13, 2016 (2 Hours)
  - Members Present: Tony, Zac, Noor, and Anas (First official group meeting)
    * Met with Ross
    * Introduction of project to all group members by Ross
    * Introduction to the lab which will be used to develop project
    * Discussion of possible lab supplies which may be used

    - Setting up a possible meeting with iBionics
- September 6, 2016 (4 Hours)
  - Members Present: Tony and Zac (group was not formed yet)
    - Met with Ross and Professor Hinzer
    - Brief on iBionics project, paperwork, and instructions of each project
- July 5, 2016 (3 Hours)
  - Members Present: Tony and Zac (group was not formed yet)
    - Met Professor Karin Hinzer
    - Discussed project topics and overview of each project

B MATLAB Code

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