UCF Senior Design 1

Optical Chlorine Analyzer and Dechlorinator

Divide and Conquer Document
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Chapter 1 - Executive Summary

Chapter 2 - Project Description

2.1 Project Background and Motivation

Senior design is the university's way of taking our learned theories and experiences both in classroom lectures and laboratory experiments and making us apply them in a way that can solve an existing problem. This project encompasses what engineers really do in the world: they observe complex problems and work with available resources as well as personal abilities to develop an innovative solution. Given that our group is composed of two Photonics Science Engineers (PSEs) and two Computer Engineers (CpEs), we wanted an idea that would involve gathering a great amount of data from an optical design and then process that information through well-developed software. Our project seeks to create a responsive system that can detect free chlorine content in a water source and dechlorinate it for consumption. The PSEs will be responsible for designing a system that both detects and dechlorinates the water while the CpEs will be responsible for designing the system which takes the optical signal and converts it to an electrical signal which can be processed by software. Additionally, the CpEs will also develop an application that can be used via Android phone to view information and activate the dechlorination process.

Water treatment plants often use multiple filtration systems to make water safe for consumption, and depending on the desired use can be incredibly in-depth and complex. For our system, we'll use just two steps of this process: UV dechlorination and a reverse osmosis filter. The UV light serves to break down the chlorine in water into ions which become byproducts that can be very easily removed by a reverse osmosis filter. We aim to make a product that can reduce the chlorine content in a water sample by at least 40% and remain within our desired budget.

2.2 – Current Commercial Technologies and Inspirations

2.2.1 – Previous Senior Design Project: Fish Tank Assistant

The Fish Tank Assistant is a previous senior design project which aimed to assist fish tank owners in the upkeep and care of the condition of their enclosure. By using an optical system that uses the Beer-Lambert law in tandem with a thermal camera, the project was able to detect and notify its owner of shifts in the condition of the water. Their group also consisted of two PSEs and two CpEs, which made their idea of particular interest since their documentation answered the major concern of how we'd take an optical signal and convert it to an electrical signal without an electrical engineer (EE). Their primary focus was specifically on detecting and notifying owners of algae blooms, which can occur in any water that fits the following description: warm, slow-moving, and filled with nutrients. According to them, the algae can produce a fast-acting poison known as a Cyanotoxin which can kill any marine life within. Even if this toxin isn't produced in the water, an excess of algae in the water can quickly deplete the oxygen within the tank, resulting in water incapable of supporting the pet fish within. This is the primary motivation behind their desired system.

Their final system was capable of detecting the algae with an interface that the owner could use to easily note how much algae was present and advise when to clean the fish tank. Additionally, they reached a stretch goal of being able to siphon water from a source into a test tube. While they weren't able to reach all their goals, they more than proved that their system was feasible and gave our group the idea to look into contaminants in water and seek to go one step further. That further step is to decontaminate, which is what led us to our next inspiration.

2.2.2 – Current Senior Design 2 Project: UV Light Disinfectant

One of the senior design projects currently in development is a UV light disinfectant. This group aims to detect microorganisms in water and use a specific UV wavelength to kill them. Their PSEs are currently in the process of building the optical system that will detect and kill microorganisms in the water, while their CpE works on developing software to assist the owner of the product and the EE builds the optical signal to electrical signal interface. The working principle for their project is using the UV wavelength of 254 nanometers, which is a particularly effective wavelength to destroy bacteria, parasites, and any other harmful microorganisms in a water source, to disinfect drinking water.

When initially discussing how to build off the algae project, we were made aware of and reached out to this group for information on their idea and current goals and objectives. Due to the high effectiveness of 254 nanometer UV light, most microorganisms that can be dangerous are all handled by this singular wavelength at a power of 1 watt and above. For this reason, we realized that we could not use UV light to kill biological organisms as that would have near identical goals and objectives to this current project. Thus, we researched articles online about water treatment and found that at a similar power of 1 watt and above, one could break down chlorine in water using UV light and use a filter to reduce the concentration of chlorine. For good measure, we reached out to a company which does water treatment using UV light and had them affirm our idea, which is our next section and fits into the category of current commercial technologies.

2.2.3 – Rodem: Smart Sanitary Processes

Our group looked into various companies that use UV light in their water treatment process and eventually decided to get in contact with Rodem. This company uses a variety of sanitization methods to fulfill given parameters a customer requests of them. For example, if the water needs to be used for pharmaceutical purposes, they will incorporate a complex, multi-stage water treatment process due to the necessary purity of the water. Due to their processes having multiple stages, they have experimented with and successfully incorporated various systems which utilize UV light to purify water. Some of their systems use the aforementioned 254 nanometer UV light to disinfect and deal with bacteria, but a few other systems have also used a different wavelength to reduce the concentration of chlorine in their target water sample. After a few phone calls and consistent pestering, we were able to get in contact with someone who gave us an excellent starting point and overview of how UV light dechlorination is done.

Brian Gorchowski is the contact that we eventually reached after asking various employees around Rodem how we should go about UV dechlorination. He is a regional sales manager based in Kentucky who works closely with Rodem. The company he actually works with is known as Nuvonicuv and their primary selling point is their UV-based solutions for disinfecting a variety of surfaces such as air, physical surfaces, and most importantly, water. He described to us how the UV at a certain wavelength range breaks down free chlorine in water into its ions which then reform into byproducts that are very easily removable via a reverse osmosis filter. He also gave us a better understanding of why using UV is beneficial in comparison to using other methods such as activated carbon filters. The specific drawback to activated carbon filters lies in that the damp surface of activated carbon fosters the growth of bacteria, which can easily reduce the purity of the water. While there is a variation of activated carbon which takes this into account and prevents the growth of bacteria, Gorchowski described it as very costly and usually not worth the purchase in their applications. He also gave us a very good target for the specifications of our UV light source, which is about 1200 millijoules per second to have an effect on the free chlorine we seek to deal with. 1200 millijoules per second is about 1.2 watts of power, which means we have a baseline power to ensure our UV light source reaches for our purposes. Additionally, he reaffirmed that even if the power is beneath the aforementioned target, it should remain effective as long as the wavelength is correct. After the phone call, he sent an email with valuable information to help us deduce what wavelength to use.

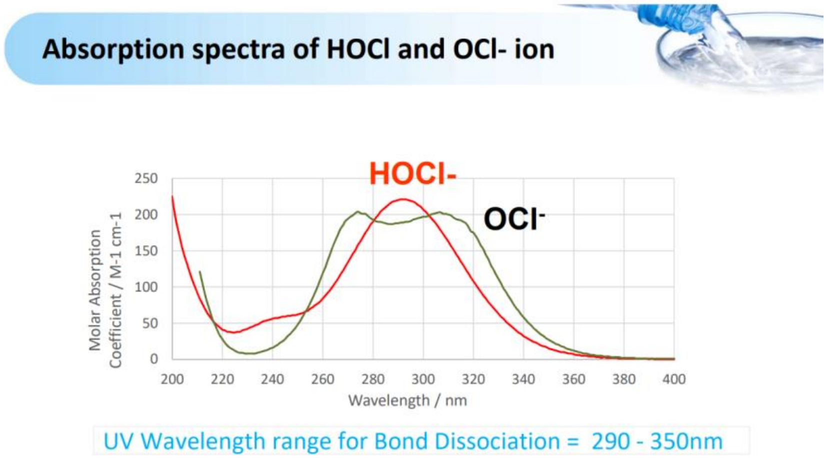

Figure 1. *Absorption spectra for free chlorine in water attained from contact at Rodem.*

2.4 – Goals and Objectives

The Optical Chlorine Analyzer and Dechlorinator should at minimum do what its namesake entails: Detect free chlorine in a water sample and remove at least 40% of it. This will serve as our overall goal, with the previous senior design projects from section 2.2 serving as inspirations for our advanced and stretch goals.

2.4.1 – Basic Goals

Basic goals encompass the bare minimum of what the optical chlorine analyzer and dechlorinator should be capable of.

1. Develop an app that displays concentration of chlorine in the system and can start the dechlorination process.
2. Develop an optical system that can detect and accurately report the amount of chlorine content in water in ppm.
3. Remove at least 40% of the chlorine concentration detected.

2.4.2 – Advanced Goals

The advanced goals of our system should go beyond what the basic goals entail and should still be achievable. They encompass the fine tuning of the system and the mild expansion of certain systems within the product, giving us a path to improving the product's performance once the bare minimum is achieved.

4. Reduce chlorine concentration in water to at or below 0.5ppm (Minimum amount of chlorine ppm in tap water).
5. Expand UV dechlorination system to be capable of reducing the chlorine content in at least 500mL of water (Approximate size of a water bottle).

2.4.3 – Stretch Goals

The stretch goals of our system are typically a path that can be taken but pose a significant challenge to the development of the product. Be it due to having to heavily expand and complicate a subsystem or due to constraints related to budget or product size, we expect to meet these goals only partially after the advanced goals are achieved.

6. Expand the system to be able to test and dechlorinate more than one water source at the same time and expand the application accordingly to give updates without impeding the understanding of the user.

Table 1. *Goals of the Project*

#	Type of Goal	Description of Goal
1	Basic	Configure an optical system involving a laser diode, a beam splitter, photodiodes, and lenses into a viable system for the detection of chlorine content in a water sample.
2	Basic	Develop a mobile application (In this case an Android Application Package for mobile phones) which can display the current status of the system, the chlorine content in the water sample it's analyzing, and start the dechlorination process.
3	Basic	Select a UV light source within the wavelength ranges of 280nm to 320nm that has enough power to cause the chlorine content in the water sample to break down and be removable via reverse osmosis filter.
4	Advanced	Refine dechlorination subsystem of project to be able to remove chlorine content in water sample down to 0.5ppm or lower. (This is lower than the ppm present in common tap water)
5	Advanced	Expand the dechlorination subsystem of the project to be able to remove the chlorine content in a water sample of at least 500mL. (This is the average quantity of water in a plastic water bottle)
6	Stretch	Expand the entire project to be able to test and dechlorinate two water sources at a time and develop the mobile application accordingly to give updates on chlorine content of both.

2.5 – Current Required Specifications

Table 2. *Requirements Specifications*

Requirements	Description	
Chlorine in Water Detection Range	The Optical Chlorine Analyzer and Dechlorinator should be able to detect chlorine concentrations.	0.5ppm - 10ppm
Dechlorination	The Optical Chlorine Analyzer should be able to remove some of the initially detected chlorine in the water.	Remove 40% chlorine content
Response Time	The detector should be able to report results on the app within a minute of the initial data collection.	< 1 minute
Environmental Conditions	There should be a defined operating temperature and pH for the detector. We also want to identify any environmental conditions that could affect the detector.	Room Temperature (~293 K) pH between 6.5 to 7.5
Power Consumption	Define an acceptable power consumption for the sensor if it is deployed at a remote location.	5W-10W
Cost Constraints	We want to make sure the project does not exceed $1,000.	< $1,000
Dimensions	It should be less than 1x1x1(m) to ensure the system is portable and easy to set up in a lab setting.	< 1x1x1(M)
Accuracy	The Optical Chlorine Analyzer and Dechlorinator should give an accurate reading of the current concentration present in the water.	> 88%
Maintainability	The Optical Chlorine Analyzer and Dechlorinator should be able to run for an extended period without maintenance or supervision.	> 1 year

2.6 – House of Quality

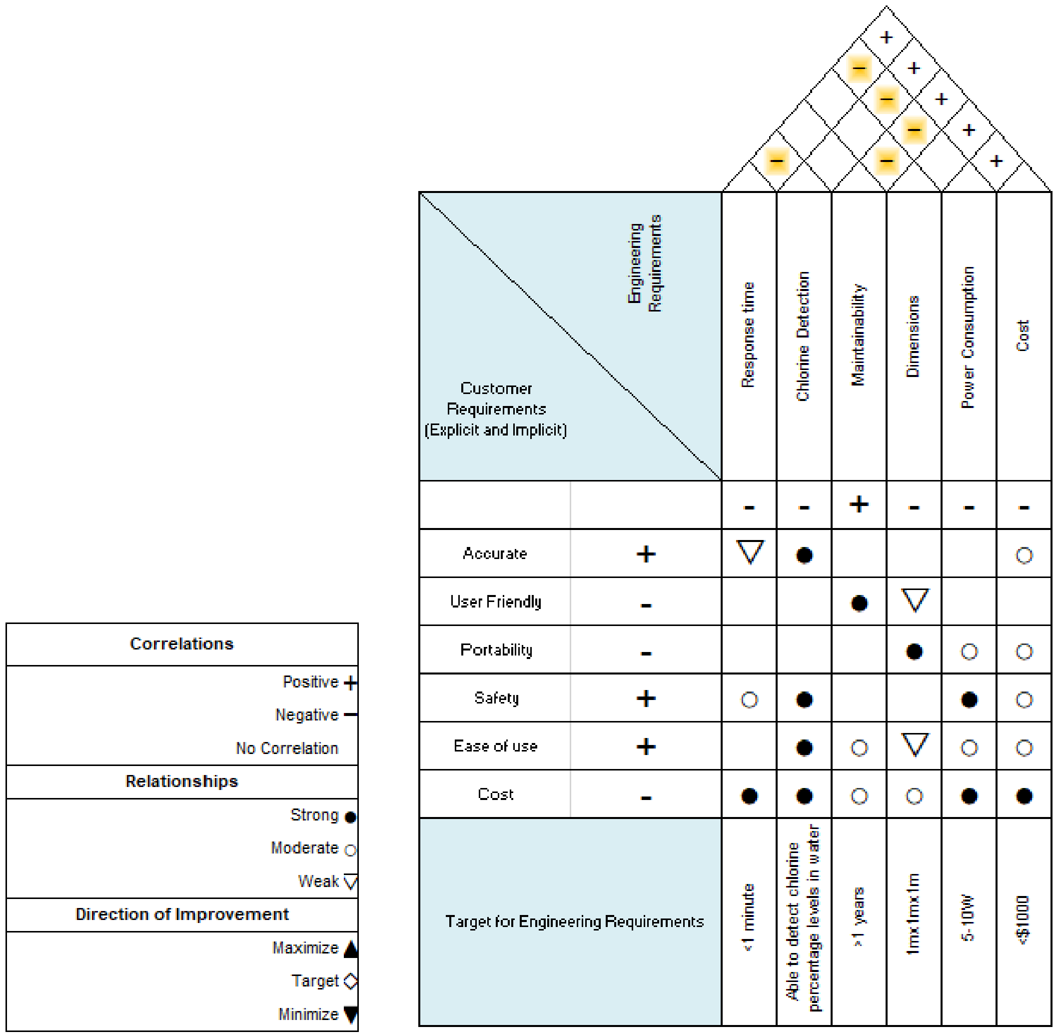

Figure 2. *House of quality*

2.7 - Hardware Block Diagram

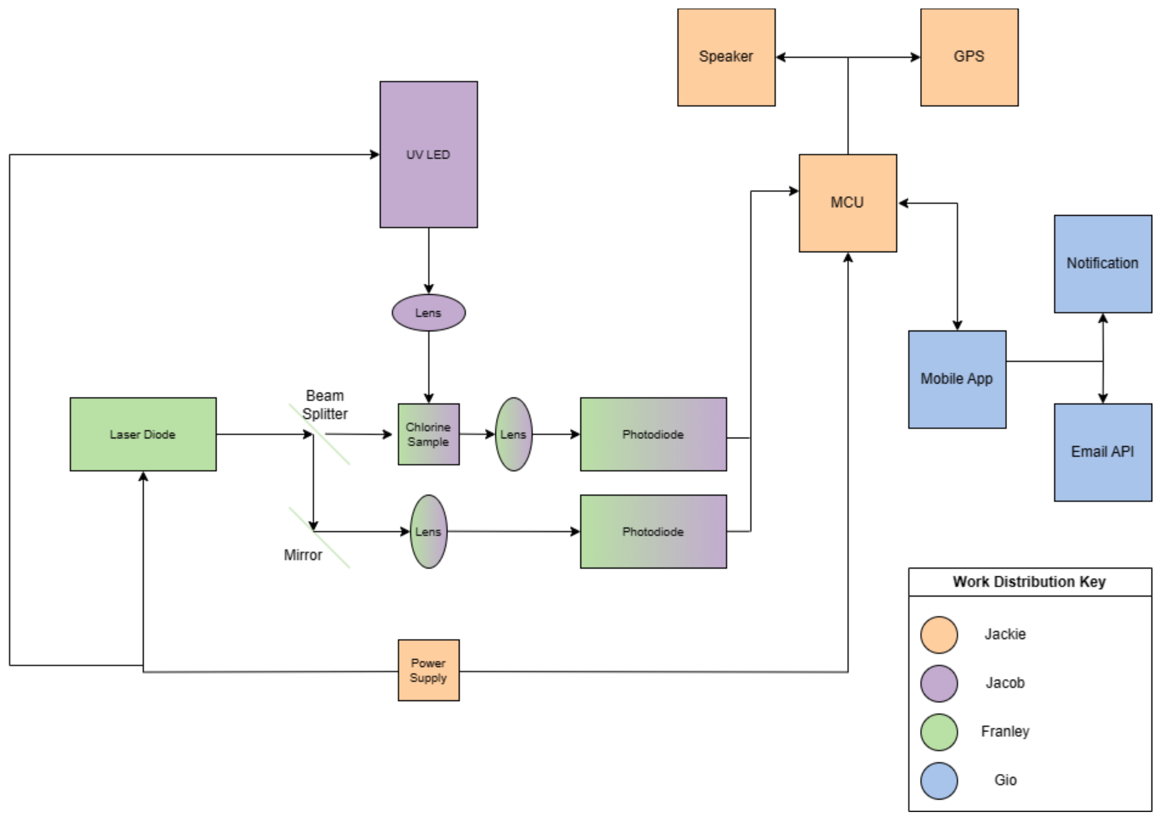

Figure 3. *Hardware Diagram*

Our hardware block diagram comprises several key components working together seamlessly. At its core, a laser diode emits a beam that is split by a beam splitter, leading to two distinct paths. The first path directs the beam towards a photodetector, facilitating the measurement of the beam's power. Meanwhile, the second path guides the beam through a chlorine sample for concentration detection. Following this, the beam encounters a UV LED, crucial for dechlorinating the chlorine sample. All these components interface with a microcontroller responsible for both laser diode control and concentration readings. Additionally, our system integrates a mobile application, providing users with convenient control and monitoring capabilities. This comprehensive setup ensures precise measurement and effective dechlorination, enhancing the usability and reliability of the system.

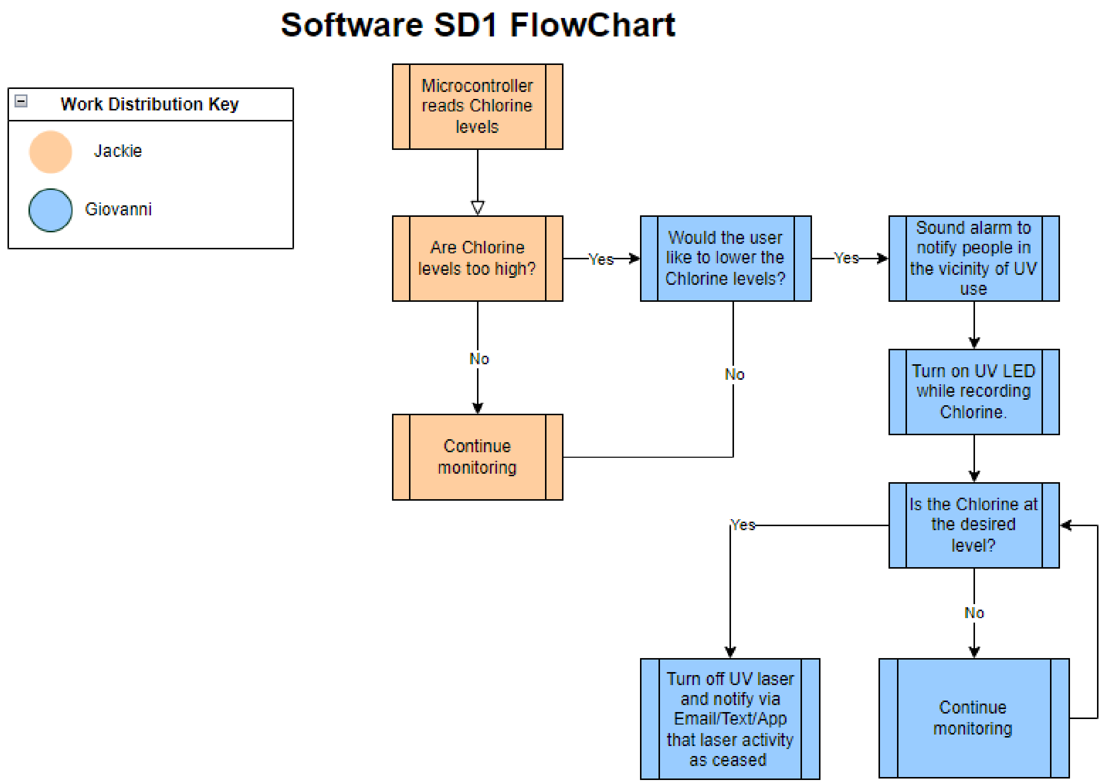

Figure 4. *Software Diagram*

Chapter 3 – Research and Background Information

3.1 Chemistry

Chlorine, a highly reactive chemical element, plays a crucial role in water purification due to its powerful disinfectant properties. In the context of water treatment, two main forms of chlorine are of significant importance: total chlorine and free chlorine. Delving into their chemistry provides insight into their roles and significance in water purification processes.

Total Chlorine: Total chlorine encompasses all forms of chlorine present in a water sample, including free chlorine, combined chlorine, and chloramines. Free chlorine refers to the unbound, active form of chlorine that is available for disinfection purposes, while combined chlorine includes chloramines formed through the reaction of chlorine with ammonia or organic nitrogen compounds. The measurement of total chlorine provides an overall assessment of the chlorine content in the water, offering valuable information for water treatment strategies.

Free Chlorine: Free chlorine, as mentioned earlier, represents the active, unreacted chlorine present in water. In water treatment, free chlorine is particularly effective in disinfecting water by oxidizing and destroying pathogens such as bacteria, viruses, and protozoa. Chemically, free chlorine exists primarily as hypochlorous acid (HOCl) and hypochlorite ions (OCl^-), depending on factors such as pH and temperature. The equilibrium between these two species is pH-dependent, with hypochlorous acid being more prevalent at lower pH values, where it exhibits greater disinfectant efficacy due to its membrane-penetrating properties.

Chlorine's Role in Water Purification: The process of water purification involves the addition of chlorine to water in carefully controlled concentrations to achieve disinfection while minimizing undesirable byproducts. Chlorine acts as an oxidizing agent, disrupting the cellular structures of microorganisms and rendering them inactive. This disinfection process involves several chemical reactions, including the oxidation of organic matter and the destruction of microbial proteins and enzymes. Additionally, chlorine reacts with inorganic compounds, such as ammonia and sulfides, to form chloramines and other disinfection byproducts. Proper monitoring and control of chlorine dosage are essential to ensure effective disinfection while mitigating the formation of harmful byproducts.

3.1.1 Chemical Reactions in Chlorine's Role in Water Purification.

In the realm of water purification, chlorine stands as a stalwart guardian against microbial contamination, employing its potent oxidizing properties to neutralize harmful pathogens. The chemistry behind chlorine's efficacy in water treatment unfolds through a series of intricate chemical reactions, each contributing to the eradication of diverse microbial threats. At the heart of chlorine's disinfection mechanism lies its ability to exist in multiple chemical forms, primarily hypochlorous acid (HOCl) and hypochlorite ions (OCl^-), in equilibrium depending on the pH of the water. This equilibrium, described by the chemical equation:

$$\mathbf{HOCl \rightleftharpoons H^+ + OCl^-}$$

plays a pivotal role in chlorine's effectiveness as a disinfectant. At lower pH values, hypochlorous acid predominates, enhancing its penetration into microbial cell membranes. Conversely, at higher pH values, hypochlorite ions become more prevalent, albeit with diminished disinfectant efficacy compared to hypochlorous acid.

Upon contact with microbial organisms such as bacteria, viruses, and protozoa, free chlorine initiates a cascade of oxidative reactions that dismantle cellular structures and disrupt vital biochemical processes. For instance, hypochlorous acid reacts with cellular proteins, enzymes, and nucleic acids, leading to irreversible damage and microbial inactivation. The chemical equation representing the oxidation of microbial proteins by hypochlorous acid is:

$$\mathbf{HOCl + Proteins \rightarrow Oxidized\ Proteins + HCl}$$

Furthermore, chlorine's disinfection prowess extends beyond direct oxidation to include the formation of disinfection byproducts through reactions with organic and inorganic compounds present in water. Notably, chlorine reacts with ammonia to produce chloramines, which exhibit prolonged disinfection capabilities. The chemical equation representing the formation of monochloramine (NH2Cl) from chlorine (Cl2) and ammonia (NH3) is:

$$\mathbf{Cl_2 + NH_3 \rightarrow NH_2Cl + HCl}$$

This process is particularly significant in chlorinated water distribution systems, where chloramines serve as residual disinfectants, providing ongoing protection against microbial regrowth.

In essence, chlorine's chemistry orchestrates a symphony of oxidation reactions that safeguard water supplies against microbial contamination. Through its diverse chemical forms and reactive nature, chlorine epitomizes the quintessential disinfectant, preserving public health and ensuring the safety and potability of water resources.

3.2 – Optical Research

The design choices we make are based on the characteristics of the chlorine present in the water sample, which is actually known as hypochlorous acid (chemical formula: HOCL) and hypochlorite ions (chemical formula: OCL-). All of the chemistry in section 3.1 was an important foundation to understand the properties of the chemicals we are going to be working with in this project. The absorption spectrum for these two ions is qualitatively demonstrated in figure 1. This tells us what light source we'll need for dissociating the bond with water that enables the reverse osmosis filter mentioned in the project description section of our paper, but for detecting the hypochlorous acid in the water we'll need a different wavelength. The following sections will detail our process for determining how we will detect the free chlorine content in the water and ensure we can accurately find the concentration. We'll need to decide between two separate methods for determining the concentration in the system: spectroscopy and laser attenuation through the water sample. Both of these methods involve knowing the absorption spectrum of free chlorine and as such are similar in terms of final purpose but have differing pros and cons in configurations, price, and complexity. The following sections detail each method and compare them to determine which is best for our purposes.

3.2.1 – Spectroscopy Method for Chlorine Detection

Spectroscopy is commonly done by taking a white light source and shining it through a dispersive element then passing this light through an exit slit. Past the exit slit lies the sample being tested and then a detector that can interpret how much of the light is being absorbed to give the concentration present in the sample based on a known absorption spectrum. The configuration can differ depending on desired result, with the dispersive element possibly being a prism that separates the white light into all of its different wavelengths and then being rotated to “select” the wavelength that passes through the slit. The other common dispersive element used is a diffraction grating, which also separates light into its wavelengths and comes in either reflective form or transmissive form. Reflective gratings reflect the light and change the configuration of the system as a direct result, while transmissive gratings let the light pass through just like a prism and then separate the light into its constituent wavelengths. The difference between them usually comes down to preference as selecting the correct grating is dependent on a multitude of factors involving efficiency and wavelength range, as well as how one wishes to set up their system.

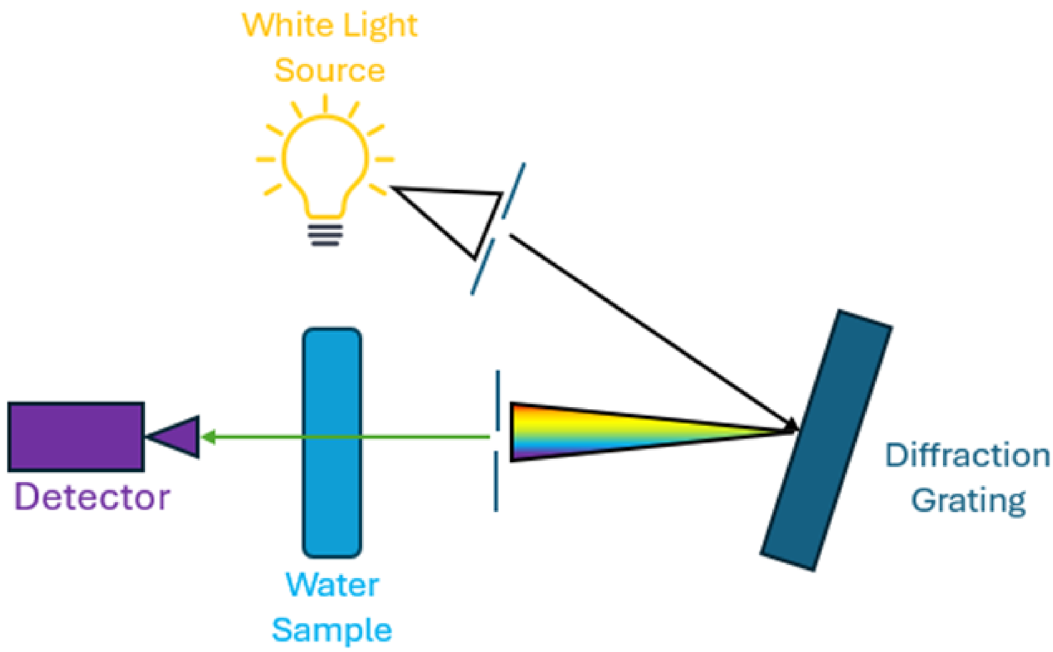

Figure 5. *Basic diagram for how spectroscopy with a reflective diffraction grating would work. Note the second slit the light path encounters being used to “select” the desired wavelength.*

In this project’s case, we wouldn’t use a white light source as hypochlorous acid responds primarily to light in the UV range, reflected in figure 1, which is invisible to the normal human eye. This has the complication of making alignment considerably more difficult, as well as making the possible laser diode we use far more expensive as UV lasers tend to be more costly than visible light lasers.

3.2.2 – Laser Attenuation Method for Chlorine Detection

The next method we considered for detecting the chlorine content in our water sample is through attenuation. This is done by selecting a laser wavelength that is absorbed by our desired sample, firing the laser beam through a beamsplitter, and then having two paths: the first leading to a reference photodiode and the second leading through our sample and then a measuring photodiode. Selecting the right beamsplitter enables us to perfectly split the power of the beam by half, which means that we can easily determine how much the laser power is attenuated by comparing the power at the reference photodiode to the power at the measuring photodiode. By using a known absorption spectrum, we can use the attenuated value to determine how much hypochlorous acid is present in the water sample. This method is simpler to set up and run, only requiring a laser source, a beamsplitter, two lenses, and two photodiodes: one which acts as a control and one which acts as a measure of the laser's attenuation. The simpler set up makes this a viable competitor to the spectroscopy method. Additionally, the total cost is likely comparable to the spectroscopy method. However, this method runs into the same issue that the spectroscopy method runs into, which is that hypochlorous acid absorbs best in the UV range. For this reason, we decided to look into ways that hypochlorous acid could be easier to detect and apply it to either method to determine pros and cons.

3.2.3 – Using Reagents to Ease Detection

Given that the root of issues with detecting hypochlorous acid lies in the fact it absorbs best in the ranges of about 280nm to 350nm, which are in the UV range and make it colorless, we researched some properties of it to see if we could add something to the chlorine and make it appear in the visible range (400nm to 700nm). We came across colorimeter tests, which use a chemical that reacts to the free chlorine present in water to produce a shift in color. This shifted color would enable the use of a visible spectrum laser beam passing through the system to find concentrations, which is far easier to pull off than using a UV light source to complete this task. There are a variety of different ones that can be used to cause this effect, but in this case, we looked at two in particular: DPD and Potassium Iodide.

3.2.3.1 – DPD colorimeter test

DPD (Known formally as *N,N*-diethyl-*p*-phenylenediamine) is a reagent that responds to free chlorine in water and indicates the presence of chlorine by changing to a pink color. It is the test that is most commonly used in the world and

was standardized in the 1950s by Arthur Thomas Palin, or Dr. Palin. The test was created as a direct result of chlorination being used to kill biological contaminants in water to purify it of bacteria and other microorganisms, which became increasingly popular worldwide at the time. All of this is stated to drive home the point that this test is well known, easy to perform, and easy to acquire for experimentation at home. With this much background research into it, it's a very appealing option for our project.
The major pros for DPD in our case are twofold: The first major positive lies in that DPD's reaction with free chlorine content in water is directly proportional to how much DPD is present and the second major positive is that there are a variety of options that use DPD which can be purchased on the market at various prices in bulk. A quick Google search reveals that one can get a number of DPD tests in the price range of $10-$40. A directly proportional response makes it much easier to calibrate the system and accurately denote how much free chlorine is present within our water sample. A variety of options on the market reduces the overall cost of this method and makes the colorimeter much more realistic to attain, with most options available offering at least 50 tests, which should be all we need to calibrate the system. Due to the many positives associated with this option, we conclude that this reagent is a viable solution to our desire to bring the free chlorine content into the visible range for analysis and now seek to explore options and weigh the pros and cons of each one.

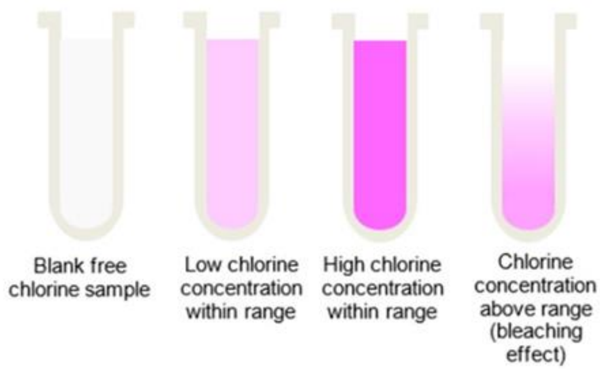

Figure 6. *DPD test diagram describing how DPD reacts with chlorine content. A higher concentration results in a darker color, which means the beam would be attenuated more.*

Since the DPD test is standardized and has a variety of options, we'd have to select between three types of tests: tablet reagents, liquid reagents, and powder pillows. Tablet reagents are pills which need to be crushed and added to a water sample to produce results. They have a specific dose in them which makes it easier to note how much is present in a water sample. They also have a long shelf life and remain stable in room temperature. However, they take longer than their counterpart, which is liquid reagent tests. Liquid reagent tests are just as accurate as tablet testing but are a bit faster than the latter. However, the tradeoff lies in that liquid additions are more variable, with them being described as “difficult to get the dosage exactly right” (**Cite palintest here**). This variability can make it more difficult to be exact and as a direct result is the least safe option for our purposes. Powder pillows are pre-measured amounts of DPD for chlorine testing. They come in the form of little packets that can be ripped open and poured into the sample for testing. Out of all the methods discussed so far, this one seems to take the best parts of the tablet form and make it even better. Since it comes in powdered form, there’s no need to crush it and the consistency across all packets is similar, improving our accuracy. Additionally, one can get several packets for under $50. The tradeoff for this convenience of course comes in the price. It is on average more expensive than the tablet forms, but never really breaks $50 unless a great amount of it is purchased at once. Weighing the pros and cons across all forms, it would seem that the powder pillows are the best choice due to its convenience and consistency without an egregious price increase for purchasing in large numbers. For this reason, we have decided that we’ll specifically use DPD powder pillows if we select DPD as our primary reagent.

Table 3. *Comparison of DPD Reagent Forms*

DPD Reagent Forms		
Form Type	**Pros**	**Cons**
Liquid Form	1) Can come in prices under $10. 2) Has best bang-for-buck in pricing across all forms (Assuming perfect dosage each use)	1) Requires refrigeration for storage. 2) Dosage is dependent on the user, and can be less accurate as a direct consequence.
Tablet Form	1) Has a measured dose that is more consistent than liquid form. 2) Has a long shelf life, can be stored in room temperature conditions. 3) Can buy about 100 tablets for just over $20.	1) More expensive than liquid form on average. 2) Must be crushed before each use and dissolved in a water sample.

Powder Pillow Form	1) Has the measured dose of tablet form, ensuring stability. 2) Has a similar shelf life to the tablet form and remains stable in room temperatures. 3) Can purchase about 100 small powder bags for just under $40.	1) Most expensive form out of all others, twice as expensive as tablet form and four times as expensive as liquid form.

3.2.3.2 – Potassium Iodide colorimeter test

Potassium Iodide is the other possible reagent that can be added to hypochlorous acid to change the color of water. While it is not standardized like DPD, it is a rather common alternative to it that can detect chlorine content just like its counterpart, with some key differences that we must ponder before selecting it. The color that is produced from this combination is a rather murky brown/orange instead of DPD’s pink resultant color. At higher hypochlorous acid concentrations, this brown color can eventually resemble a black color instead. The significance of this lies in that black naturally absorbs all colors very well, meaning that it would make selecting a wavelength for our laser light source much more trivial. Thus, this reagent's greatest strength is that it would most likely boost our signal greatly as more laser power attenuation would take place after passing through the water sample. Additionally, Potassium Iodide is just as capable as DPD in measuring low to high concentrations of chlorine in water, being capable of detecting a chlorine content range below 0.5ppm and up to 300ppm. However, this choice is not easy particularly because of the major downsides we need to consider before selecting this reagent.

The most immediate concern that comes into play is that Potassium Iodide is not the standardized form of chlorine testing. Since this reagent isn’t strictly used for chlorine testing, it can be used for a multitude of purposes such as pharmaceutical treatment for health problems in relation to the thyroid or laboratory purposes. This means that prices are generally much higher across the board and vary from seller to seller. Additionally, this poses a significant risk to our time, as having one of the most important parts of our entire project be more difficult to attain impacts delivery times as well. An even greater concern is that this colorimetric method tests primarily for total chlorine concentrations. The important distinction here is that free chlorine is far easier to remove than total chlorine, due to total chlorine also including chloramines (mentioned in the project description), which are not the primary target of our UV disinfection and could make our results seem less effective overall. Potassium Iodide seems to come primarily in liquid form, with a wide range of prices that can be as low as $40, which rivals powder pillow DPD in price, or as steep as nearly $400 when specifically marketed towards chlorine testing in water while in tablet form, which is the best possible form of this reagent for our purposes but is overly expensive for our budget.

3.2.3.3 – Comparison and Final Selection

When selecting between DPD and Potassium Iodide as our preferred reagent, we considered pricing, general effectiveness, ease of access, and all forms of each reagent. The major pros of DPD due to its standardization, relatively cheap pricing per unit, and ease of use makes it a significantly more appealing choice than Potassium Iodide's major drawbacks, which lie in its price and difficulty to obtain. For these summarized reasons, we've decided to use DPD as the reagent to add to our chlorinated water for the laser attenuation section of our project. With this selection, we have solved the issue of how we're going to determine the concentration of free chlorine in the water without spending a high amount of money on detecting it by stressing the absorption in the UV range. As stated in section 3.1.3.1, the best version of DPD to use for our purposes is in the powder pillow packets, which offer great benefits for its price and make the process of adding and analyzing far easier as a result of its consistent amount in each individual packet.

Table 4. *Final comparison between reagents*

DPD vs. Potassium Iodide		
Reagent	**Pros**	**Cons**
DPD	1) Standardization makes pricing and acquiring significantly simpler. 2) Can detect either free chlorine or total chlorine depending on what the user prefers.	1) Pink coloration makes the signal less prominent in comparison to Potassium Iodide's dark brown.
Potassium Iodide	1) Would have a greater signal than DPD because of the darker color overall.	1) More expensive than DPD on average. 2) More variation on the market makes getting the right form more difficult. 3) Tests only for total chlorine content, possibly making results more difficult to distinguish due to our target of reducing free chlorine.

3.2.4 – Selection of Light Source

The light source for the detection of the free chlorine in our water sample so we can determine the concentration present is one of the most important parts we need to determine. In order to do so, we first need to find the absorption spectrum of the solution created from a mixture of water, DPD, and hypochlorous acid. This absorption spectrum is explicitly shown in figure 7, which has the wavelength in the x-axis and the absorbance in the y-axis. We can see two distinct peaks here: one in the UV range, seemingly somewhere around 330nm and the second peak takes place in the visible spectrum at about 550nm. The UV range peak appears to also have absorbance increases at wavelengths lower than 300nm, but the shift to 330nm from our original known range of 280nm to 320nm is likely caused by the fact the DPD and hypochlorous acid solution has changed the properties, which is to be expected. The next set of peaks occur in the visible spectrum, with one peak occurring between the ranges of 515nm to 523nm, and the other slightly larger peak occurring between 560nm to 570nm.

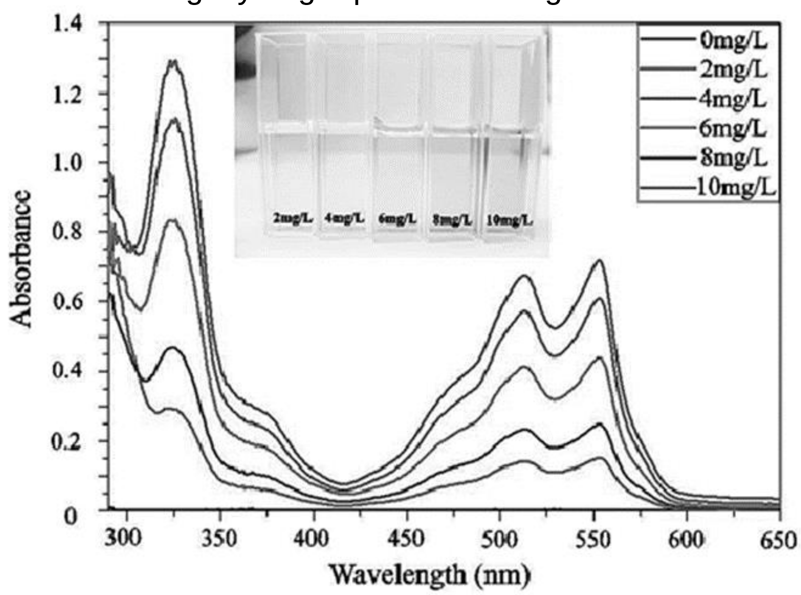

Figure 7. *DPD and Free Chlorine solution absorption spectrum. Note how we retain the known peak in the UV spectrum but have a new set of peaks in the visible range (400nm to 700nm).*

Based on **Figure 3**'s graph, we know that whichever light source we decide on must have a wavelength range be either between 515nm to 523nm or 560nm to 570nm. This falls in the wavelength range for a green laser, which is thankfully somewhat easy to attain in various forms. The forms in question are Light Emitting Diode (LED), laser diode, or a laser pointer. Various vendors sell each kind, so we’ll have to compare the pros and cons of each option and determine which to select out of all of them.

3.2.4.1 - Light Emitting Diodes

LEDs are simple components which emit uncollimated light. They are relatively cheap and rather small, which means selecting this component could require us to be conscious of the distance between each part of our system. Light that passes through the water sample must be collimated, which would require the purchase of an additional lens to go directly in front of our LED, placed at the lens’ focal length. An additional concern related to LEDs is that the light isn’t focused to a point but rather goes outward in a circle around the center, which raises immediate concerns about selecting an LED too powerful resulting in eye injury. While collimated LEDs do exist on the market, the price increase is several times higher and as a result this is simply not an option. One of the best aspects of an LED that isn’t true for most other light sources is that depending on the input current, the emitted power varies up to a max. This makes an LED capable of another degree of flexibility no other light source can emulate.

3.2.4.2 - Laser Diodes

Laser diodes are light sources which offer collimated light and are just as prevalent on the market as LEDs. Their average price is much higher than your standard LED but not as high as an LED that comes collimated. They come in a wide range of wavelengths and powers, including the wavelength range we’d like our light source to operate at. They can also be plugged in or powered by battery. Plug-in variations that are compatible with USB are often around $150 to $200, with a similar price range for wall outlet plug-in variations, which is just barely within our budget but make usage much simpler as a direct result. The other variations, which have a positive and negative connection, are more involved in set up but are often much cheaper as a result, ranging from $50 to $150. It is important to note that despite how expensive this option already is, the wall outlet plug in variations need to have their power supply purchased externally, which is a price increase that definitely needs to be addressed. The strong points of this light source make it a very good contender for our system since it is much safer and comes in a wide variety of forms depending on our specifications, but the steep price associated means we’d need to be very careful in selecting the correct one.

3.2.4.3 - Laser Pointer

Laser pointers are a nice middle ground between LEDs and laser diodes in terms of functionality and price. They can be dirt cheap when bought at the lower quality end, while still retaining solid power, but often sacrificing in the form of the wavelength being less consistent as it shifts by a 10 nm wavelength increase or decrease depending on temperature. In the case of green laser pointers, there is a standardization that works to its detriment for our purposes. Most laser pointers operate at specifically 532nm, which is outside of our optimal wavelengths for our system and could heavily impact results. Additionally, most laser pointers are battery powered, and while some can be continuously charged on USB this is not always the case. The heavy variation of characteristics on the market means that finding the perfect laser pointer for our purposes could be challenging given that most choices that fit our criteria sacrifice one of its supposed pros in comparison to the other options. The laser pointer can have a very good option somewhere on the market, but searching for this perfect option and ensuring it doesn't sacrifice too many positives in comparison can prove to be quite challenging, which makes it an unlikely pick for our purposes.

3.2.4.4 – Comparison

The positives and negatives of each light source are noted once again in the below table, with the highlighted option being the one we choose to move forward with for our system.

Table 5. *Final comparison between light sources*

Light Source	Available in 520nm or 560nm	$200<	Collimated	Requires Additional Equipment	Available in plug in form
LED	✓	✓	✗	✓	✗
Laser Diode	✓	✗*	✓	✓	✓
Laser Pointer	✗	✓	✓	✗	✓

**Can be under $200 but would likely sacrifice aspects of its performance as a result*

3.2.5 UV light's role in Dechlorination

UV dechlorination represents a cutting-edge approach in water treatment, harnessing the power of ultraviolet (UV) radiation to effectively degrade chlorine compounds present in water. Understanding the underlying chemistry of UV dechlorination unveils a fascinating interplay of molecular interactions and photochemical processes.

At the core of UV dechlorination lies the interaction between chlorine molecules and photons of UV light. Chlorine compounds, including free chlorine (hypochlorous acid and hypochlorite ions) and chloramines, contain covalent bonds between chlorine atoms and other elements. When subjected to UV radiation, these chlorine-containing molecules absorb photons with sufficient energy to disrupt these covalent bonds, leading to chemical transformations.
The energy required to break these bonds and initiate dechlorination depends on the specific bond strengths within the chlorine compound. For instance, the bond energies of the chlorine-nitrogen bonds in chloramines are typically higher than those in free chlorine compounds, requiring greater UV energy for dechlorination. However, once the bonds are cleaved, the chlorine atoms are released as radicals, such as chlorine radicals (Cl•), which are highly reactive and readily undergo further chemical reactions.

The primary mechanism by which UV radiation induces dechlorination involves photolysis, wherein the absorbed UV energy causes the chlorine-containing molecules to undergo homolytic cleavage, resulting in the formation of free radicals. For example, in the case of hypochlorous acid (HOCl), the UV-induced homolytic cleavage of the O-Cl bond leads to the generation of hydroxyl radicals (•OH) and chlorine radicals (Cl•), as depicted by the following reaction:

HOCl+UV light→•OH+Cl•

These free radicals subsequently participate in radical-radical or radical-nonradical reactions, ultimately leading to the decomposition of chlorine compounds into harmless byproducts such as chloride ions (Cl^-) and water (H2O). For instance, chlorine radicals can react with organic contaminants present in water, leading to the formation of chlorinated organic compounds or the mineralization of organic matter into simpler, non-toxic compounds.

The release of chlorine gas (Cl_2) from UV dechlorination processes is highly unlikely, as UV dechlorination typically involves the breakdown of chlorine compounds (such as hypochlorous acid, chloramines, etc.) into harmless byproducts rather than the liberation of elemental chlorine gas. During UV dechlorination, chlorine-containing molecules in the water absorb UV radiation, leading to the cleavage of chemical bonds and the formation of reactive species such as chlorine radicals (Cl•). These radicals then undergo subsequent reactions to convert chlorine compounds into simpler, non-toxic substances like chloride ions (Cl^-) and water (H2O). Therefore, the products of UV dechlorination are generally innocuous and pose no risk of releasing toxic chlorine gas. The ideal wavelength range for dechlorination typically falls between 290nm to 350nm, with specific emphasis on targeting the bond dissociation of chlorine-containing compounds. Hypochlorous acid (HOCl), a common chlorine species in water disinfection, exhibits maximum absorbance towards the lower end of this spectrum, around

290nm. Conversely, hypochlorite ions (OCl^-), another prevalent form of chlorine, absorb light more effectively towards the upper end of the spectrum, closer to 350nm. This broad wavelength range ensures comprehensive coverage for breaking down chlorine bonds, facilitating effective dechlorination processes in water treatment applications.

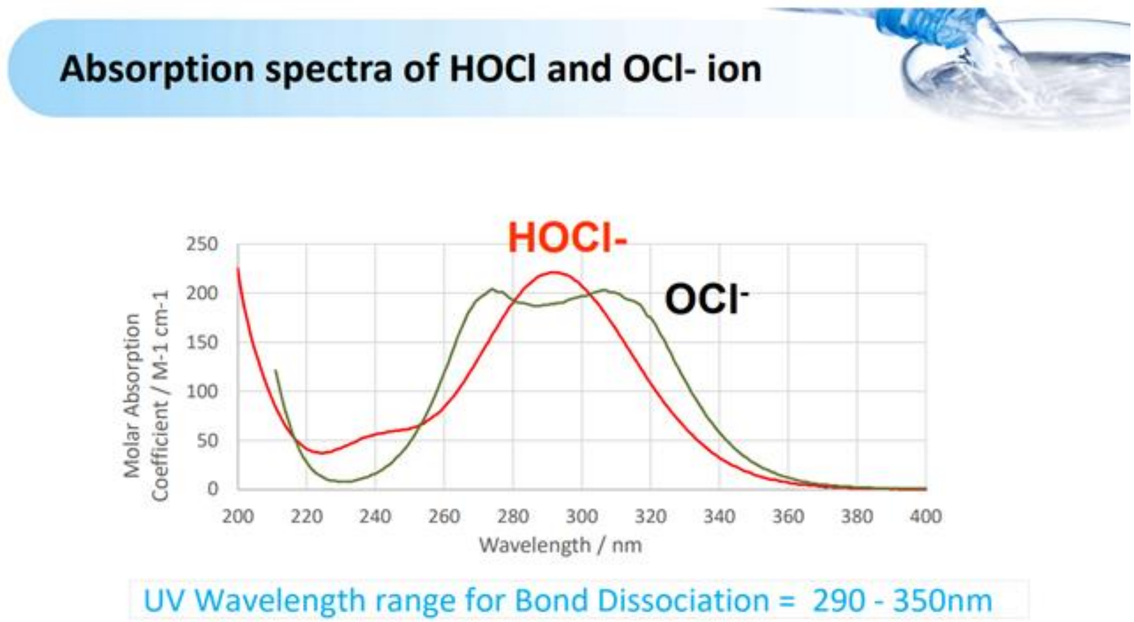

Figure 8. *Absorption spectra for free chlorine in water. Peaks indicate where the chemicals of interest in the water absorb light and dissociate, breaking them down to byproducts easily removed through a reverse osmosis filter.*

3.2.6 Different types of UV Sources

Now that our group has determined that using UV light for our project is the most practical approach, we examined it in more detail. There are numerous sources of UV light, so we must choose the most advantageous one for our project. UVC lights vary from one another. Certain lamps may release UV light at particular wavelengths, while other lamps may emit UV light throughout a wide range of wavelengths. These lamps can also be used to emit infrared and visible light. The efficacy of the lights and the threats to one's health and safety are directly related to the wavelengths that are emitted.

Pulsed xenon lights: These lights are mostly utilized in medical facilities to sanitize the air in operating rooms and other areas. They provide brief, broad-spectrum pulses that encompass visible, infrared, and ultraviolet light. These lights are mostly employed for safety reasons when there are no people in the intended area because they present a number of health risks.

Excimer or Far-UVC lamps: These lamps emit light primarily at a wavelength of 222 nm, falling within the far-ultraviolet spectrum. This wavelength is close to the infrared region of the electromagnetic spectrum. These lamps are utilized for various applications such as disinfection due to their ability to effectively target and deactivate pathogens like bacteria and viruses.

Low-pressure mercury lamps: These are the most often used lamps for pathogen disinfection in water irrigation systems. Its primary emission occurs at a wavelength of 254 nm. This is the primary wavelength for UVC disinfection, though they can also produce other ones.

Light-emitting diodes (LEDs): LEDs, which emit UV light, are a rapidly growing industry standard for both commercial and industrial applications. The demand is rising as they become more widely available. LEDs emit a very specific spectrum. Currently, a variety of LEDs with various peak wavelengths between 250 nm-320 nm, and others are offered on the market.

Table 6. *UV Sources*

Section	UV LED	UV Lamp
Technology	Light, Simple, Compact, Small	Bulky, Heavy, Complex, Large
Lifetime	10,000 – 50,000 Hours	2,000-10,000 Hours
Energy Consumption	Low	High
Warm-up time	Zero	Slow
Environmentally Friendly	No mercury, No Ozone	Mercury used, Ozone generation
Heat Generation	Low	High
Emission Wavelength	Single UV Band, Customizable	Multiple Peaks
Heavy Metal	None	Mercury (20-200 mg)

During our research to find the ideal UV light source for dechlorination, two crucial factors stood out: the specific wavelength of the light and its power output. Research revealed that wavelengths ranging from 290nm to 350nm were particularly effective in breaking down chlorine bonds, directing our attention to UV sources within this range. Additionally, we found that to achieve significant reduction in chlorine levels, an energy output of approximately 1200 millijoules per second (mJ/s) was required to decrease 1 part per million (ppm) to 0.1 ppm. This understanding underscored the importance of selecting a UV light source with sufficient power output to facilitate effective dechlorination. Thus, our exploration of UV sources centered on finding the right balance between the optimal wavelength and the necessary power output for successful dechlorination processes.

3.2.7 Safety Precautions of UltraViolet Light

We're all familiar with the dangers of prolonged exposure to UV light, and it holds true. While most UV rays are blocked by the ozone layer, recent advancements in industry have led to the creation of UVC lights for their effectiveness in disinfection and microbial eradication. However, it's crucial to exercise caution and take necessary precautions. Here are the risks associated with UVC radiation, dependent on factors such as wavelength, exposure duration, and dose:

- UVC radiation can harm the skin and eyes, causing painful injuries and burns.
- Certain UVC lamps emit ozone, which, when inhaled, can irritate the airways and lead to various health issues such as coughing, chest pain, lung damage, throat irritation, and asthma.
- UVC radiation disrupts DNA and RNA in cells, potentially leading to various health problems. Improper exposure could result in virus mutations, making them more difficult to eliminate later.
- Prolonged exposure to radiation increases the risk of developing cancerous tumors, which can be fatal if not detected early.

Therefore, it's imperative to observe proper safety protocols when using UVC light. Avoid direct exposure and never stare directly at it. To address safety concerns, a sensor will be incorporated into the bottle to prevent UVC light emission when the cap is open, ensuring user safety. The UVC light will only function when the bottle cap is securely sealed.

3.2.8 1W UVC LED 3838 310nm 5-7V 150mA Ultra Violet Lamp with Copper PCB

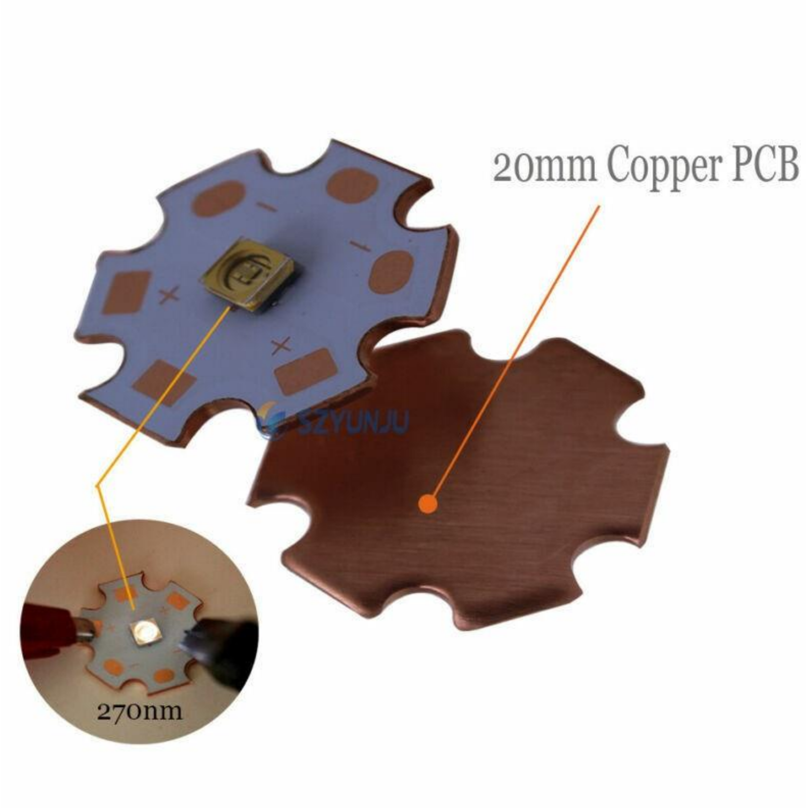

Figure 9. *Copper PCB*

The chosen UV LED, boasting a forward current of 1W and emitting light in the narrow wavelength range of 305-310nm, presents itself as an excellent candidate for our dechlorination system. This wavelength range precisely aligns with the optical spectrum identified for breaking down chlorine bonds, ensuring efficient dechlorination without unnecessary energy expenditure What sets this UV LED apart is its narrow beam angle of 60 degrees, a feature that proves invaluable for our application. By directing the UV light through the lens system, we can tightly focus the illumination to match the average diameter of a water bottle, which typically hovers around 2.5 inches. This precise targeting maximizes the interaction between the UV light and any residual chlorine compounds present in the water, enhancing the overall efficiency of the dechlorination process. Furthermore, the compact dimensions of the UV LED, measuring a mere
20mm x 20mm offer versatility and ease of integration into our system, ensuring seamless operation without compromising space requirements. The low forward voltage (VF) range of 5-8V and forward current of 150mA provide us with the flexibility to select an appropriate power supply that aligns with our energy efficiency goals, further enhancing the sustainability of our dechlorination system. With a radiant flux of 10-15mW and an impressive lifespan of 50,000 hours (about 5 and a half years), this UV LED promises not only reliable performance but also

longevity, minimizing maintenance needs and ensuring consistent dechlorination capabilities over extended an period.

Typical Optical/ Electrical Characteristics @T_a=25℃ 典型的光学/电气特性在 Ta=25°C

Symbol 符号	Item名称	Min. 最低	Typ. 典型	Max. 最高	Units 单位	Test Conditions 测试条件
IE	Radiant Irradiance 辐射照度	—	8.2	—	mW/cm^2	IF=150mA
Po	Radiation Power 辐射功率	20	25	—	mw	IF=150mA
VF	Forward Voltage [1]正向电压	5.0	7.0	—	v	IF=150mA
△λ	Half Width 半波宽度	—	11	—	nm	IF=150mA
λp	PeakWavelength 峰值波长	250	—	260	nm	IF=150mA
$2\theta_{1/2}$	50% power angle 发光角度	—	60	—	deg	IF=150mA
IR	Reverse Current 反向电流	—	—	20	uA	VR = 5V

Notes注:

1.Tolerance of measurement of forward voltage±0.1V、peak Wavelength±2.0nm、Radiation Power ±5%

Absolute Maximum Ratings 绝对最大额定值在TA=25°C

Item名称	Symbol 符号	Absolute Maximum Rating 绝对最大额定值	Units单位
Power dissipation[1]功率	Pd	1050	mW
DC Forward Current[1]正向电流	I_F	150	mA
Peak Forward Current 峰值电流	I_{FP}	150	mA
Reverse Voltage[1] 反向电压	V_R	5	V
Operating Temperature 工作温度范围	Topr	-20 ~ +85 ℃	
Storage Temperature 储存温度范围	Tstg	-40 ~ +100 ℃	
Junction Temperature 结温	Tj	100℃	

Note:

1.1/10 Duty Cycle,0.1ms Pulse Width.1 / 10占空比，0.1ms脉冲宽度。

2.The temperature of Aluminum PCB do not exceed 55℃.基板温度不超过55℃。

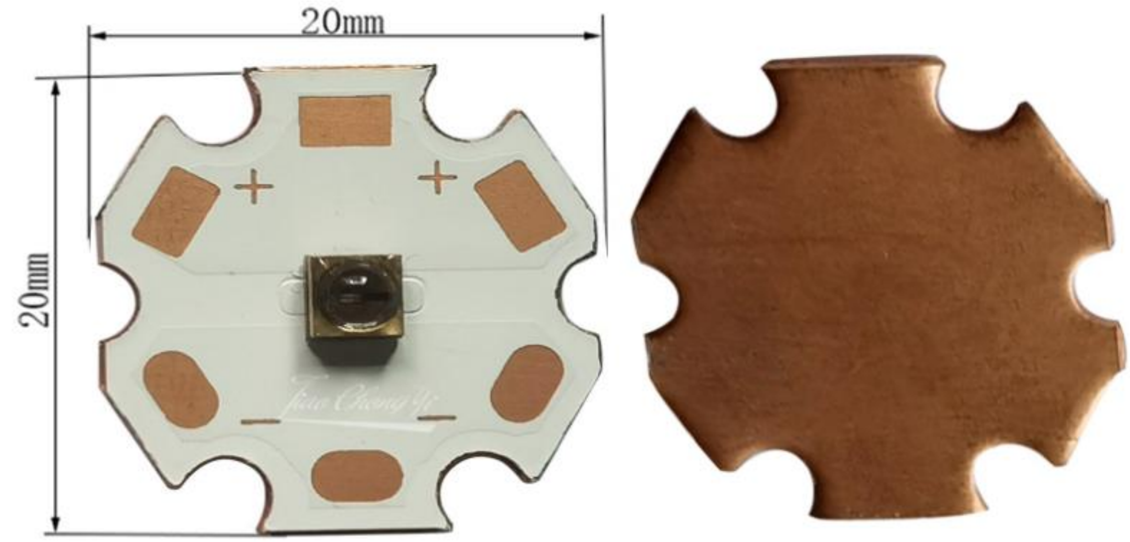

Figure 10. *Dimensions of UV LED PCB*

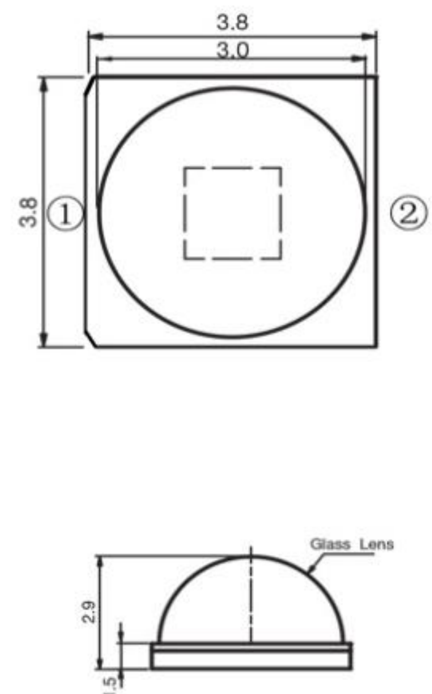

Figure 11. *Dimensions of LED*

3.2.9 UV Fused Silica Bi Convex Len

In the context of UV dechlorination for water treatment, the choice of optical components significantly influences the efficiency and precision of light delivery. The UV Fused Silica Bi-Convex Lens (Item LB4854 from Thorlabs) emerges as a promising candidate for coupling with the selected laser diode in our water dechlorination system. This section focuses on elucidating the optical properties, focusing capabilities, and compatibility of the UV Fused Silica Bi-Convex Lens with the laser diode, underscoring its potential role in optimizing UV dechlorination processes.

Figure 12. *UV Fused Silica Bi Convex Len*

The UV Fused Silica Bi-Convex Lens harnesses the superior optical characteristics of fused silica, ensuring high transmission of UV light emitted by the laser diode. With a half-inch diameter and a focal length of 20mm, the lens facilitates precise focusing of UV light onto the water sample. Its bi-convex design enables the convergence of UV light rays, ensuring efficient concentration onto the target area for dechlorination.

Engineered to complement the specifications of the selected laser diode, the UV Fused Silica Bi-Convex Lens exhibits optimal compatibility for efficient coupling. Featuring a back focal length of 18.5mm and a radius of curvature of 17.7mm, the lens is designed to seamlessly integrate with the laser diode. This compatibility ensures consistent and reliable performance, enabling precise control of UV light delivery in the dechlorination process.

Beyond its optical prowess, the UV Fused Silica Bi-Convex Lens demonstrates exceptional chemical resilience, making it well-suited for water treatment applications. Fused silica exhibits inherent resistance to chemical corrosion and degradation, ensuring long-term reliability in harsh water treatment environments. Additionally, the lens's robust mechanical construction enhances durability, mitigating the risk of damage or deterioration during operation.

The UV Fused Silica Bi-Convex Lens holds immense potential for advancing UV dechlorination technology in water treatment. Its combination of optical precision, compatibility with laser diodes, and chemical resilience positions it as a valuable asset in optimizing UV dechlorination processes. Integration of the lens into our water treatment setup promises to enhance the efficiency, reliability, and effectiveness of UV-based dechlorination systems, paving the way for improved water quality and public health outcomes.

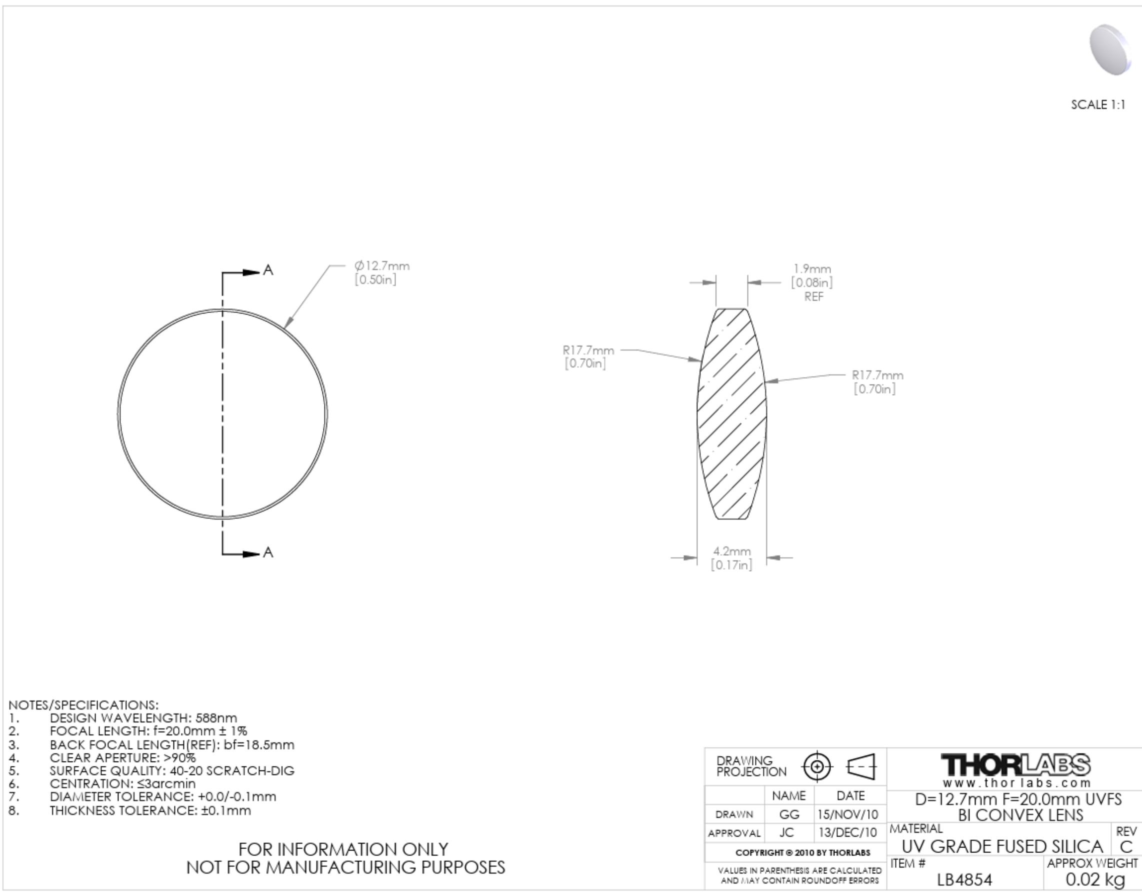

Figure 13. *UV Fused Silica Bi Convex Len Schematic*

3.3 Microcontrollers

Microcontrollers serve as integral components in countless electronic systems, providing the necessary computational power to control and coordinate various tasks within embedded applications. In the context of our senior design project aimed at utilizing lasers for chlorine identification and dissolution, microcontrollers play a vital role in orchestrating the system's functionality. Specifically, they are essential for interfacing with sensors, such as photoresistors, to measure optical loss and infer chlorine presence within the target environment. Moreover, microcontrollers enable seamless communication between the system and a companion mobile application through integrated Wi-Fi connectivity. This communication channel facilitates real-time data exchange, enabling remote monitoring and control of the chlorine detection system. Furthermore, microcontrollers equipped with GPS sensors empower the system with location tracking capabilities, enhancing its utility in diverse operational scenarios. Additionally, microcontrollers can trigger alerts, using integrated speakers, upon detecting elevated chlorine levels, ensuring timely response to potential hazards.

3.3.1 Arduino Uno WiFi Rev2

The Arduino Uno WiFi REV2 offers a blend of familiar Arduino Uno features with the added capability of integrated Wi-Fi connectivity. This makes it a convenient choice for projects requiring wireless communication capabilities, such as interfacing with a mobile application for remote monitoring and control. With the Arduino IDE and extensive Arduino libraries, developers can easily program the Uno WiFi REV2 for a wide range of applications. However, it's essential to note that the Uno WiFi REV2 may have limitations in processing power and memory compared to more advanced microcontrollers like the Raspberry Pi models. Therefore, while suitable for simpler tasks and applications, it may face challenges in handling more complex computations or multitasking requirements.

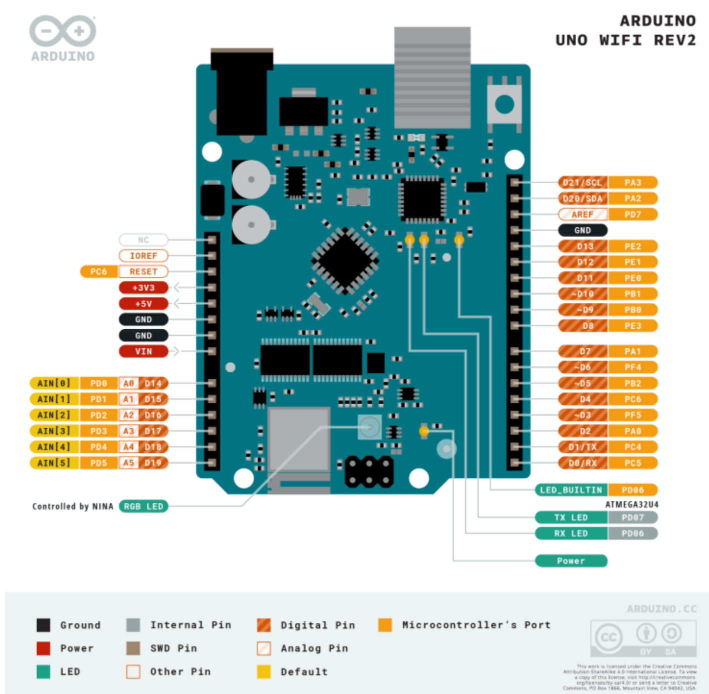

Figure 14. *Arduino uno WiFi Rev2*

3.3.2 Arduino Nano ESP32

The Arduino Nano ESP32 is a compact yet powerful microcontroller option, featuring integrated Wi-Fi and Bluetooth connectivity along with a dual-core processor. This combination of features provides increased processing power compared to traditional Arduino boards, making the Nano ESP32 well-suited for projects requiring more computational capabilities. Its small form factor makes it ideal for applications where space is limited, such as embedded systems or wearable devices. However, similar to the Arduino Uno WiFi REV2, the Nano ESP32 may still have limitations in processing power compared to Raspberry Pi models, which could impact its suitability for highly demanding tasks.

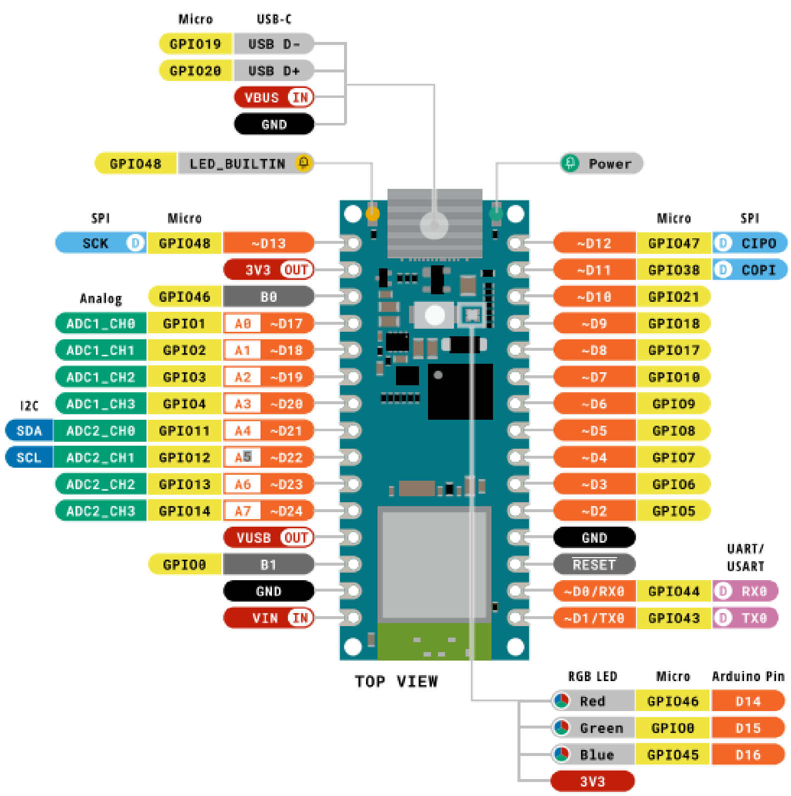

Figure 15. *Arduino Nano ESP32*

3.3.3 Raspberry Pi 4

The Raspberry Pi 4 represents a significant advancement in single-board computing, boasting a quad-core processor, up to 8GB of RAM, and comprehensive connectivity options including built-in Wi-Fi, Bluetooth, and

Ethernet. These features make the Raspberry Pi 4 well-equipped to handle demanding tasks and multitasking scenarios, making it a compelling choice for projects requiring extensive data processing and networking capabilities. Its compatibility with various programming languages, operating systems, and software packages further enhances its versatility. However, its larger form factor and potentially higher power consumption may be considerations in certain deployment scenarios where space and energy efficiency are critical.

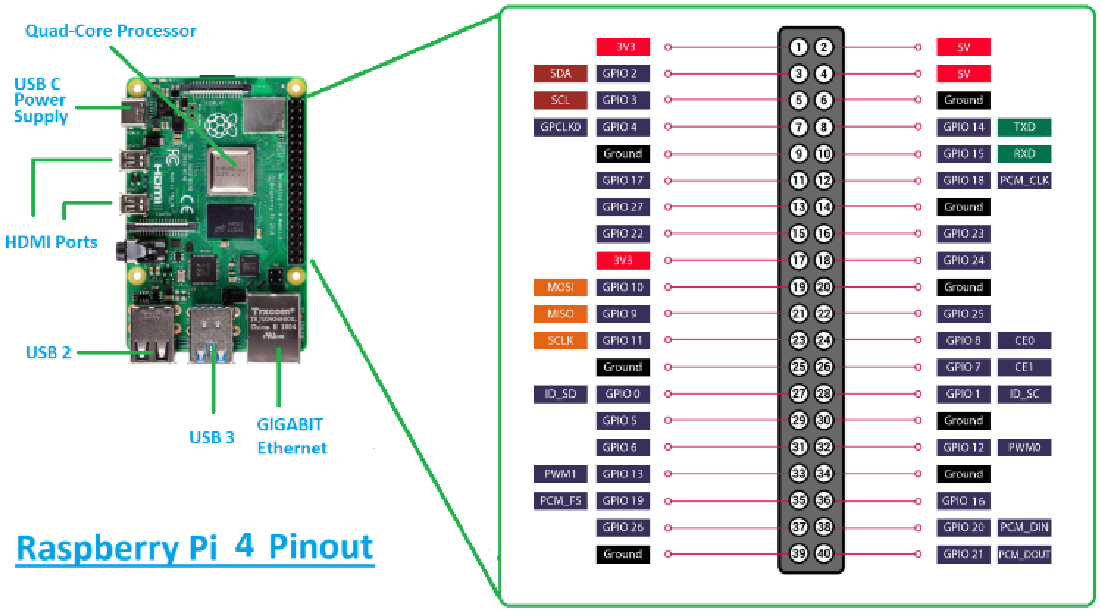

Figure 16. *Raspberry Pi 4 Pinout*

3.3.4 Raspberry Pi Zero 2W

The Raspberry Pi Zero W offers a compact and cost-effective microcontroller solution with built-in Wi-Fi and Bluetooth connectivity. Despite its diminutive size, the Zero W retains the processing power and capabilities of its larger counterparts, making it suitable for a variety of projects where space and budget constraints are paramount. Its compatibility with Raspberry Pi accessories and software ecosystem further enhances its appeal for hobbyists, educators, and developers. However, its limited processing capabilities may pose challenges for tasks requiring extensive computation or multitasking, and its small form factor may limit expansion options compared to larger Raspberry Pi models.

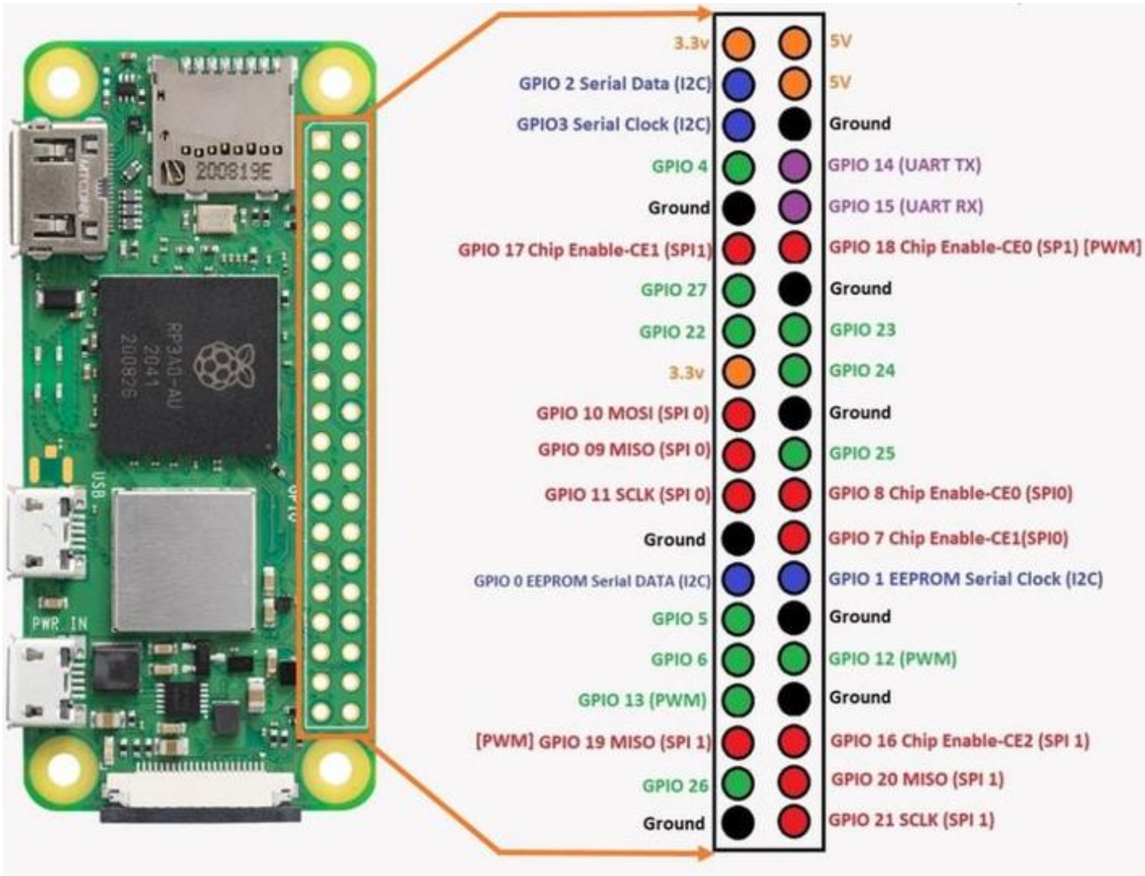

Figure 17. *Raspberry Pi Zero 2W*

3.3.5 Comparison

Table 7. *Microcontrollers Comparison*

Comparison Features	Arduino Uno WiFi Rev2	Arduino Nano ESP32	Raspberry Pi 4	Raspberry Pi Zero 2W
Processor	ATmega4809	Xtensa dual-core (or single-core) 32-bit LX6 microprocessor	Broadcom BCM2711	Broadcom BCM2710A1
Operating Voltage	5V	3.3V	5.1V	5V

Operating Temperature (°C)	-25 to 70	-25 to 70	0 to 50	-20 to 70
Digital I/O Pins	14	14	40	40
PWM Digital I/O pins	5	All pins (5 simultaneously)	40	40
Analog Input Pins	6	8	-	-
DC current per I/O Pin	20mA	12mA	16mA	16mA
DC Current for 3.3V Pin	50mA	-	16mA	16mA
Flash Memory	48KB	16MB (External Flash)	8GB to 1TB+	8GB to 1TB+
SRAM	6144B	512kB	1GB,2GB,4GB,8GB (DRAM)	512MB(SDRAM)
EEPROM	256B	-	512KB	-
Clock Speed	16MHz	80MHz, 240MHz	1.5GHz	1GHz
Length	68.6mm	45mm	55.88mm	65mm
Width	53.4mm	18mm	86.36mm	30mm
Weight	25g	7g	46g	9g

3.3.6 Choice of Controller and Reason

We have chosen the Arduino Uno WiFi Rev2 over the Arduino Nano ESP32 for our project due to several factors tailored to our specific needs. Firstly, our familiarity with the Uno family of boards provides a seamless transition, leveraging existing knowledge and ensuring ease of use. Since our project exclusively requires Wi-Fi connectivity and not Bluetooth, the Uno WiFi Rev2 perfectly suits our needs without the additional complexity of Bluetooth support. Size constraints are not a concern for our project, and opting for a larger board like the Uno WiFi Rev2 simplifies tasks such as soldering, assembling our system, or designing a secure structure to accommodate the board. Moreover, the extensive compatibility with numerous accessories and products designed for the well-known dimensions of the Uno boards enhances the versatility and convenience of our project setup. Overall, the Arduino Uno WiFi Rev2 aligns perfectly with our project requirements, offering familiarity, simplicity, and ease of integration.

3.4 – Development Platform

A development platform serves as an environment for creating, testing, and deploying applications. It has a set of tools, libraries, frameworks, and resources for development across diverse platforms and technologies. Many of these platforms offer code editors, advanced debugging tools, and control systems. Additionally, they are designed to support multiple programming languages, providing flexibility and scalability. Examples of development platforms we explored include Android Studios, Xcode, and Flutter.

3.4.1 Android Studios

Android Studio is the official Integrated Development Environment (IDE) for Android app development. It offers a set of tools such as layout editor, code completion, and debugging utilities for creating high quality applications with efficiency. One of the standout features in Android Studios is the built in emulator, which emulates different Androids devices, enabling the developer to test their applications across different platforms. The emulator enhances the development of the applications since it provides real-time feedback of the application performance and behavior. Android Studios supports programming languages such as Java and Kotlin.

3.4.2 Xcode

Xcode is an IDE designed by Apple that enables developers to develop, test, and distribute apps for all Apple platforms. It offers the developer tool for testing, debugging, and optimizing code efficiently. Within Xcode, developers can access frameworks, libraries, and an integrated emulator that allow the developers to test their iOS apps without needing a physical device. The emulator replicates the behavior and features of different iOS devices, enhancing the development process. Additionally, Xcode supports Swift as the programming language for creating iOS apps.

3.4.3 Flutter

Flutter is a development platform that enables developers to build an application across multiple operating systems such as Android and iOS using a single codebase. It offers a set of tools and collection of widgets, letting the developers build an efficient and appealing user interface. Flutter has a hot reload feature that allows for real time code changes and instant updates for speeding the development process. The primary programming language of Flutter is Dart.

Table 8. *Development Platforms Comparison*

Comparison Features	Android Studios	Xcode	Flutter
Platform Supports	Android Devices	iOS Devices	Android, iOS, Web, Window
Programming Language	Java & Kotlin	Swift	Dart
Performance	Optimized for Android	Optimized for iOS	Optimized for Cross-Platform
Emulator	Yes	Yes	No
IDE	IntelliJ IDEA-based	Xcode IDE	Visual Studio, Code, IntelliJ IDEA, Android Studios
Hot Reload	Yes	Yes	Yes
Widgets	Android Views and Widgets	UIKit	Flutter Widgets

3.5 Tech Stacks

Tech stacks is a collection of technologies, programming languages, and frameworks that work together to build applications. These stacks are typically divided into two components: front-end (client-side) and backend (server-side). The front-end development uses programming languages, frameworks, and scripting languages to build the user interface that clients interact with and perceive. Popular front-end technologies and frameworks include HTML, CSS, JavaScript, React, and Angular. Backend development involves working with databases, server-side frameworks, and programming languages that support the application functionality. Popular backend technologies and frameworks include Node.js, Django, Express.js, MongoDB, and MySQL.

3.5.1 LAMP Stack

LAMP stands for Linux, Apache, MySQL (Structured Query Language), and PHP, is an open-source software for web development. Linux is an open-source operating system that serves as the foundation of LAMP stack. It provides the environment on which the other components of the stack run. Linux is popular because it offers more flexibility and configuration options than some other operating systems. Apache is an open-source web server that processes requests and serves up web assets via HTTP so that the application is accessible to anyone in the public domain over a simple web URL. MySQL is an open-source relational database management system. It is used to store, manage, and retrieve structure data in a database format. MySQL offers features like transactions, indexing, replicating, and stored procedures. PHP open-source scripting language works with Apache to help you create dynamic web pages. It is used to generate dynamic content, interact with databases, handle form, and perform various server-side tasks in web applications.

3.5.2 MERN Stack

MERN stands for MongoDB, Express.js, React, and Node.js, is an open-source framework for web development. MERN is a full-stack application since it has the ability to develop the front-end and the back end using the same programming language. MongoDB is a scalable, flexible NoSQL document database platform designed to overcome the relational databases approach and the limitations of other NoSQL solutions. Unlike other databases, MongoDB documents (data) are stored in BSON format, which is a binary-encoded JSON, allowing for a much faster traversal. The documents in a collection (table) can have different fields and data types, making it a dynamic schema. It also offers features such as automatic sharding for horizontal scaling, built-in replication, and flexible querying.Express.js is the most popular web framework for Node.js. It is designed for building web applications and APIs (Application Programming Interface) and has been called the de facto standard server framework for Node.js. It provides a set of features for handling HTTP requests, routing, middleware integration, and managing server-side logic. Node.js is an open-source, cross-platform, JavaScript runtime environment that executes JavaScript code outside of a web browser. It is built on the V8 JavaScript engine providing high performance and scalability for server-side applications. Node.js uses an event-driven, single-threaded I/O model making it efficient for handling concurrent operations such as files systems operations, networking, and database interactions.

3.5.3 MEAN Stack

The MEAN stack, an acronym for MongoDB, Express.js, AngularJS (or Angular), and Node.js, represents a powerful and popular combination of technologies for building dynamic web applications. MongoDB serves as the NoSQL database, providing a flexible and scalable storage solution for handling diverse data types. Express.js, a minimalist web application framework for Node.js, simplifies server-side development by enabling efficient routing, middleware integration, and request handling. AngularJS or Angular, depending on the version used, facilitates front-end development by providing a robust framework for building dynamic, single-page applications with enhanced interactivity and user experience. Finally, Node.js, a server-side JavaScript runtime environment, powers the entire stack, enabling JavaScript to be used across the full application stack, from client to server. Together, the MEAN stack offers a seamless and cohesive development experience, allowing developers to build feature-rich, real-time web applications efficiently.

Table 9. *Tech Stack Comparison*

Comparison Features	LAMP	MERN	MEAN
Components	Linux, Apache, MySQL, PHP/Python	MongoDB, Express.js, React.js, Node.js	MongoDB, Express.js, React.js, Node.js
Server-side Backend	PHP/Python	Node.js	Node.js
Database	MySQL	MongoDB	MongoDB
Programming Language	JavaScript, Python	JavaScript	JavaScript
Scripting/Style Sheet Language	HTML, CSS, PHP, MySQL	N/A	N/A

Cost	Open-Source	Free version/ Paid version	Free version/ Paid version
Web Server	Apache	Express.js	Express.js
Frontend	N/A	React.js	Angular

3.6 Programming Languages

Programming languages are the foundation of modern software development, providing developers with the tools and syntax needed to instruct computers to perform specific tasks. With an abundance of languages available, each tailored to different use cases and domains, programming languages serve as the primary means of communication between humans and computers. From low-level languages like assembly and C, which offer direct control over hardware and system resources, to high-level languages like Python and JavaScript, which prioritize readability and ease of use, there exists a vast spectrum of languages to suit diverse programming needs. Furthermore, languages like Java, C++, and C# are renowned for their versatility and performance, making them popular choices for building large-scale applications and systems. With the rapid advancement of technology, new languages continue to emerge, each with its own unique features and capabilities, shaping the ever-evolving landscape of software development. Ultimately, the choice of programming language depends on factors such as project requirements, developer expertise, and performance considerations, with each language offering its own set of strengths and trade-offs. This section will go into detail about the languages we are considering and comparing to develop our frontend, backend, and microcontroller with.

3.6.1 Javascript

JavaScript is a fundamental programming language for web and app development, widely renowned for its versatility and flexibility. In the realm of app development, JavaScript plays an important role in both frontend and backend development, making it a preferred choice for building modern applications. On the frontend, JavaScript is used to create dynamic and interactive user interfaces, enabling developers to build engaging experiences that respond to user input and events. Its asynchronous nature and event-driven architecture make it particularly well-suited for handling user interactions and updating the UI in real-time. Additionally, with the advent of frameworks like React, Angular, and Vue.js, JavaScript has become indispensable for building robust frontend applications that deliver high performance and seamless user experiences across various devices and platforms. On the backend, JavaScript's versatility extends beyond the browser, thanks to platforms like Node.js. Node.js allows developers to run JavaScript code server-side, enabling them to build scalable and efficient backend services and APIs. Javascript is a likely language that we will focus on due to its popularity and use with tech stacks such as MERN and MEAN.

3.6.2 Typescript

TypeScript is a superset of JavaScript developed by Microsoft that adds optional static typing and other advanced features to the language. TypeScript extends JavaScript by incorporating features such as type annotations, interfaces, generics, and advanced object-oriented programming constructs, making it particularly attractive for large-scale applications and projects requiring increased maintainability and code organization. By enabling developers to catch errors at compile-time and provide clearer documentation through type annotations, TypeScript enhances code quality and developer productivity. Additionally, TypeScript integrates seamlessly with existing JavaScript codebases and toolchains, allowing for gradual adoption and interoperability with popular JavaScript frameworks and libraries. With its strong typing system, powerful tooling support, and growing community adoption, TypeScript has emerged as a valuable tool for building robust, scalable web applications and enterprise-level software solutions. Being similar to Javascript while having more features makes Typescript a potential language to focus our frontend and backend development on.

3.6.3 C++

C++ is a high-level programming language renowned for its versatility, efficiency, and performance across a wide range of applications. Developed as an extension of the C programming language, C++ introduces object-oriented programming (OOP) features such as classes, inheritance, polymorphism, and encapsulation, enabling developers to write modular, reusable code and build complex software systems. With its rich standard library and support for low-level programming constructs, C++ is well-suited for developing system software, operating systems, embedded systems, and performance-critical applications like video games and real-time simulations. Its strong typing system and compile-time checks contribute to robust and secure software development, while features like templates and generics offer flexibility and extensibility. Additionally, C++ compilers are available on a wide range of platforms, making it a versatile choice for cross-platform development. Despite its complexity, C++ remains a popular language among developers for its power, efficiency, and ability to produce high-performance software solutions. C++ can be used to develop on Raspberry Pi and Arduino microcontrollers which makes C++ a potential language to consider.

3.6.4 Python

Python is a high-level programming language celebrated for its simplicity, versatility, and widespread adoption across various domains. Python prioritizes readability and ease of use, making it an ideal choice for beginners and experienced developers alike. With its clean and concise syntax, Python emphasizes code readability and encourages developers to write elegant, efficient code. Python's extensive standard library and vibrant ecosystem of third-party packages provide developers with a vast array of tools and resources to tackle diverse tasks, from web development and data analysis to machine learning and automation. Known for its dynamic typing, automatic memory management, and cross-platform compatibility, Python offers flexibility and ease of use, enabling developers to quickly prototype ideas and build scalable, maintainable software solutions. Overall, Python's combination of simplicity, power, and community support has solidified its position as one of the most popular and beloved programming languages in the world. Python can be used to develop on Raspberry Pi and Arduino microcontrollers which makes this a potential language to consider.

Table 10. *Programming Language Comparison*

Feature	JavaScript	TypeScript	Python	C++
Type System	Dynamically Typed	Statically Typed	Dynamically Typed	Statically Typed
Use Cases	Web Development, App Development, Frontend and Backend	Web Development, App Development, Frontend and Backend	Web Development, Backend, Microcontrollers	Microcontrollers, Systems Programming
Performance	Slower compared to C++	Slower compared to C++, potential better performance than JavaScript	Slower compared to C++, potential better performance than Javascript with optimized libraries	Fast and Efficient

Memory Management	Garbage Collected	Garbage Collected	Garbage Collected	Manual Memory management

Chapter 4 - Standards and Design Constraints

4.1 Constraints

Our project faces a range of constraints that pose challenges to its successful implementation. Economic constraints, such as our budget limit of $1000, present a challenge in acquiring essential components such as laser sources and hardware. Meanwhile, environmental constraints underscore the need to carefully assess and mitigate potential ecological impacts, particularly in aquatic environments where laser dechlorination occurs. Material selection, waste management, and compliance with environmental regulations further compound these concerns, highlighting the importance of integrating sustainable practices into our project. Ethical constraints, meanwhile, mandate strict adherence to safety protocols and ethical considerations to ensure the well-being of human subjects and minimize environmental harm. By considering these constraints and finding a way to work around them, we aim to develop a project that is economically feasible, environmentally responsible, and ethically sound.

4.1.1 Economic Constraints

In our project, the economic constraint of maintaining a total cost below $1000 is a challenge, particularly in acquiring laser sources necessary for the dechlorination process. These laser sources, vital components of our system, are often priced in the thousands of dollars range, significantly surpassing our budget. Despite the variety of laser sources available in terms of wavelengths and power levels, finding one that aligns with our project requirements while remaining within budget has proven to be difficult. Moreover, the economic constraints extend beyond laser procurement; essential hardware components such as the microcontroller, sensors like GPS and photoresistors, and software hosting services also contribute to the overall project cost.

4.1.2 Environmental Constraints

We must consider various environmental constraints to ensure responsible and sustainable implementation. One significant consideration revolves around the potential ecological impacts of laser dechlorination, particularly in aquatic environments like pools. It's important to conduct thorough assessments to understand how laser use may affect aquatic ecosystems, including the well-being of aquatic organisms and overall biodiversity. Additionally, altering chlorine levels in water bodies can have implications for water quality and safety, requiring careful monitoring to ensure compliance with water quality standards and mitigate any risks to human health or aquatic life. Material selection is also important to consider. By using environmentally friendly materials with minimal environmental impact, such as using 3D printing and using certain plastics such as PLA we can lower the environmental impact of our project. Waste generation is another concern, as laser operations may produce waste materials that require proper management to prevent environmental contamination. Compliance with environmental regulations is important, requiring adherence to laws governing water quality, waste management, and laser usage. Incorporating sustainable practices into the project's design and implementation, such as using environmentally friendly materials and optimizing energy efficiency, is crucial for minimizing environmental impact and promoting long-term sustainability.

4.1.3 Ethical Constraints

The ethical constraints we must consider involve several key aspects, including the safety of human subjects that may be affected due to the water that we remove chlorine from using the laser. Given the potential risks associated with laser use, we must follow strict requirements of safety protocols such as using protective equipment for lasers or chemicals that may pose harm if mishandled. Additionally, the environmental impact of laser-based dechlorination processes is a significant concern, requiring thorough environmental assessments to identify and mitigate any adverse effects on aquatic ecosystems or water quality.

4.2 Standards

There are important standards that must be considered such as laser power standards, software testing standards, and PCB standards. Laser power standards provide essential guidelines for the safe use of lasers, outlining parameters such as power output, wavelength, and safety features to prevent accidental exposure and ensure user safety. Adhering to these standards is paramount in our project, given the use of lasers for dechlorination purposes. Software testing standards establish protocols for the evaluation of software functionality, reliability, and security. By following recognized testing standards, such as those outlined by organizations like the IEEE (Institute of Electrical and Electronics Engineers) and ISO (International Organization for Standardization), we can ensure the robustness and integrity of the software components integral to our project's operation. Additionally, adherence to PCB standards is crucial in ensuring the quality, reliability, and compatibility of our circuit board designs. These standards outline specifications for factors such as layout, materials, and manufacturing processes, facilitating efficient production and interoperability of PCBs within our project. By aligning with laser pointer standards, software testing standards, and PCB standards, we uphold best practices in safety, quality, and performance, thereby enhancing the overall success and effectiveness of our project.

4.2.1 Laser Power Standards

Laser power safety is a concern we need to ponder when designing our system to ensure the user isn’t damaged by our product. Before we discuss power standards, one factor immediately makes our product much more dangerous to the eyes. The laser beam for the detection section of our project has a wavelength between 515nm to 570nm, which falls mostly in the green color range. The human eye collects images at the retina, which is the back surface of your eye. This retina is composed of little rods and cones, which are responsible for vision in dark and illuminated environments respectively. Vision is focused in an area known as the fovea, which is very important for ensuring the image is sharp and easy to see. Due to the spectrum of our eye, as shown in **Figure 18** below, we are most sensitive to green light specifically. This means we have to be particularly mindful about how we direct the laser beam in our system to ensure the user isn’t damaged by the detection section of our product. The simplest way to ensure this concern is minimized is by having our components completely immovable once setup, which can be done by 3D printing casing for each component. This is already planned to be in our design process due to one of our group members owning a 3D printer and having an excess of filament for use in this project.

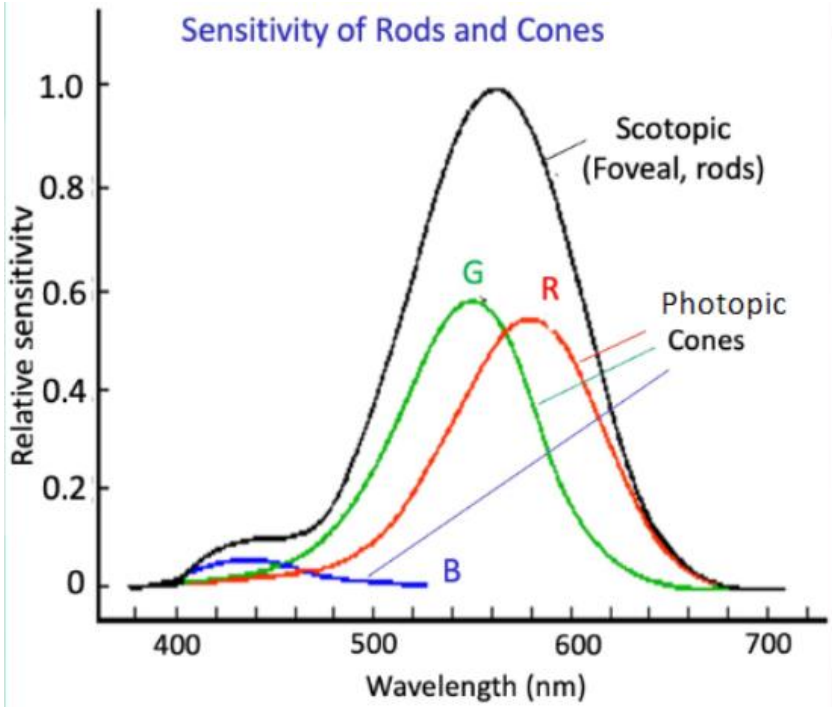

Figure 18. *Sensitivity of the human retina. Notice how relative sensitivity peaks around the green color and is just above red. This minor increase is very notable in practice.*

4.2.2 Software Testing Standards

Adherence to software testing standards is key to ensure the reliability, functionality, and security of our software components. Given the critical role of software in controlling the UV LED, monitoring water quality, and enabling user interaction through the mobile app, rigorous testing protocols must be followed. This entails testing software functionalities such as UV LED control algorithms, sensor data processing, user interface interactions, and data communication protocols. Additionally, software testing standards, such as those outlined by organizations like the IEEE (Institute of Electrical and Electronics Engineers) and ISO (International Organization for Standardization), provide guidelines for testing methodologies, test coverage, test documentation, and quality assurance practices. By adhering to recognized software testing standards and conducting thorough testing throughout the software development lifecycle, we can ensure the robustness, reliability, and safety of our software components, thereby enhancing the overall effectiveness and success of our project.

4.2.3 PCB Standards

Chapter 5 - Comparison of ChatGPT with other Similar Platforms

5.1 Generative AI

Generative AI stands as a forefront innovation in artificial intelligence (AI), showcasing machines' remarkable ability to produce new content closely resembling human-like patterns. These systems learn from extensive datasets to create text, images, or code that mimic human production. Notably, models like GPT (Generative Pre-trained Transformer) and GANs (Generative Adversarial Networks) have propelled generative AI into various domains, including natural language processing, computer vision, and creative arts. Generative AI models operate by discerning underlying patterns within the data they're trained on. Leveraging this understanding, they generate new content by predicting subsequent sequences or creating samples fitting within the learned data distribution. For instance, GPT generates coherent text based on user prompts, while GANs craft realistic images from random noise. While offering immense promise, generative AI also presents significant challenges. Ethical concerns arise as these models can potentially produce misleading or harmful content without proper control or monitoring. Additionally, biases within training data may influence model outputs, requiring careful consideration. Despite these challenges, generative AI pushes the boundaries of AI research and applications. As researchers and developers work to address limitations and risks, it holds the potential to revolutionize industries, foster creativity, and enhance human capabilities.

5.1.1 ChatGPT

ChatGPT, developed by OpenAI, stands as a significant milestone in the evolution of natural language processing and conversational AI. Its ability to engage users in meaningful dialogues, provide assistance with queries, and even generate creative content has revolutionized the way we interact with AI-powered systems. ChatGPT has found applications in customer service chatbots, virtual assistants, and content generation tasks. However, its capabilities are not without limitations. Despite its impressive performance, ChatGPT may occasionally produce nonsensical or irrelevant responses, especially in contexts requiring nuanced understanding or handling of ambiguity. Additionally, the model's susceptibility to biases present in its training data poses ethical concerns, as it may inadvertently perpetuate misinformation. Nevertheless, ChatGPT's intuitive interface and seamless integration across various platforms make it a valuable tool for facilitating communication and enhancing user experiences.

5.1.2 Google BARD Gemini

Gemini, like any complex AI tool, has limitations to consider. While the free tier offers strong language processing and access to Google Search for information retrieval, it currently only supports English and may not be available in all regions. Additionally, the most powerful version, Gemini Ultra, requires a paid subscription. Even with access to the latest information, Gemini's creative outputs, like code, might require human editing to ensure accuracy and polish. The ability to analyze information and provide relevant sources through Google Search makes it a valuable research assistant. Even with lower computational requirements compared to some competitors, Gemini delivers efficient performance. The current text-based version offers a glimpse into its future potential for handling diverse formats like visuals and code. However, there are areas for improvement. While Gemini can hold conversations, complex, nuanced back-and-forth exchanges that rely heavily on context might prove challenging. Additionally, getting the most out of Gemini can sometimes involve trial and error, requiring multiple attempts to achieve the desired outcome with specific tasks. Overall, Gemini is a versatile tool with immense potential. By acknowledging its limitations and capitalizing on its strengths, you can unlock its capabilities for various tasks, from research and information gathering to creative endeavors.

5.1.3 Microsoft Copilot

Microsoft Copilot represents a pioneering advancement in software development tools, leveraging AI to enhance coding efficiency and productivity. By analyzing code patterns and contextual information, Copilot provides developers with contextually relevant code suggestions, auto-completions, and even entire code snippets. Its ability to streamline coding processes and foster collaboration among developers can revolutionize software development workflows. However, Copilot is not immune to limitations and challenges. Despite its productivity benefits, the model may occasionally generate incorrect or suboptimal code suggestions, potentially leading to errors or inefficiencies in software development projects. Additionally, concerns arise regarding security vulnerabilities and biases present in the training data, highlighting the importance of rigorous validation and oversight. Nonetheless, Copilot's potential to accelerate software development cycles and empower developers with intelligent coding assistance remains promising.

5.1.4 Perplexity AI

Perplexity AI specializes in computer vision applications, offering robust capabilities for image recognition and interpretation. Its ability to accurately identify objects, scenes, and text within images has widespread applications across industries, including healthcare, manufacturing, and surveillance. Perplexity AI's efficiency and automation in processing visual information have the potential to streamline operations and unlock valuable insights from visual data. However, the platform is not without challenges. Ensuring accuracy and reliability across diverse environmental conditions and image types requires comprehensive training data and ongoing validation efforts. Additionally, biases inherent in AI algorithms may lead to skewed or inaccurate results, particularly for underrepresented or minority groups. Nonetheless, Perplexity AI's potential to drive innovation and efficiency in computer vision tasks underscores its significance in the field of artificial intelligence.

5.2 Comparison of AI

Table 11. *AI Comparison*

	ChatGPT	Gemini	Microsoft Copilot	Perplexity AI
Limitations	Limited code knowledge, data access cutoff date	Limited free tier functionality, outputs may require editing and human reviews	Limited conversation depth, subscription required for full access	Limited use per day, no human like conversation in engagements
Pros	Free tier available	Multiple answer drafts	Visual features	Ask prompts to be searched in specific categories such as Across all nternet, Youtube, Wolfram Alpha, etc. Academic Accuracy

Cons	Not ideal for code-related tasks, outdated information and can be prone to misinformation, difficult math problems can't be answered	Limited conversation capabilities, trial and error for specific tasks	Requires developer environment and a subscription cost	Limited free use, limited conversation capabilities, does not integrate seamlessly with other apps/services

5.3 Benefits to Senior Design

Incorporating AI tools like ChatGPT into the Senior Design process offers significant advantages, particularly in brainstorming and generating project ideas that cater to the diverse expertise of team members. With a team of two Computer Engineers and two Photonics majors, ChatGPT is a valuable resource for brainstorming sessions by facilitating collaborative exploration and the generation of relevant project concepts. One notable benefit of using ChatGPT in brainstorming sessions is its capacity to generate a wide array of creative ideas based on the input provided by team members. Through interactive dialogue, team members can pose questions or prompts related to potential project topics, exploring various areas of interest within the domains of computer engineering and photonics. For instance, inquiries could delve into emerging technologies, industry trends, or interdisciplinary intersections between computer engineering and photonics. Additionally, ChatGPT proves beneficial in explaining certain error codes or bugs in a manner that is easier to understand compared to some forums like StackOverflow. By inputting error messages or bug descriptions, team members can leverage ChatGPT to decipher complex technical issues and gain insights into potential solutions.

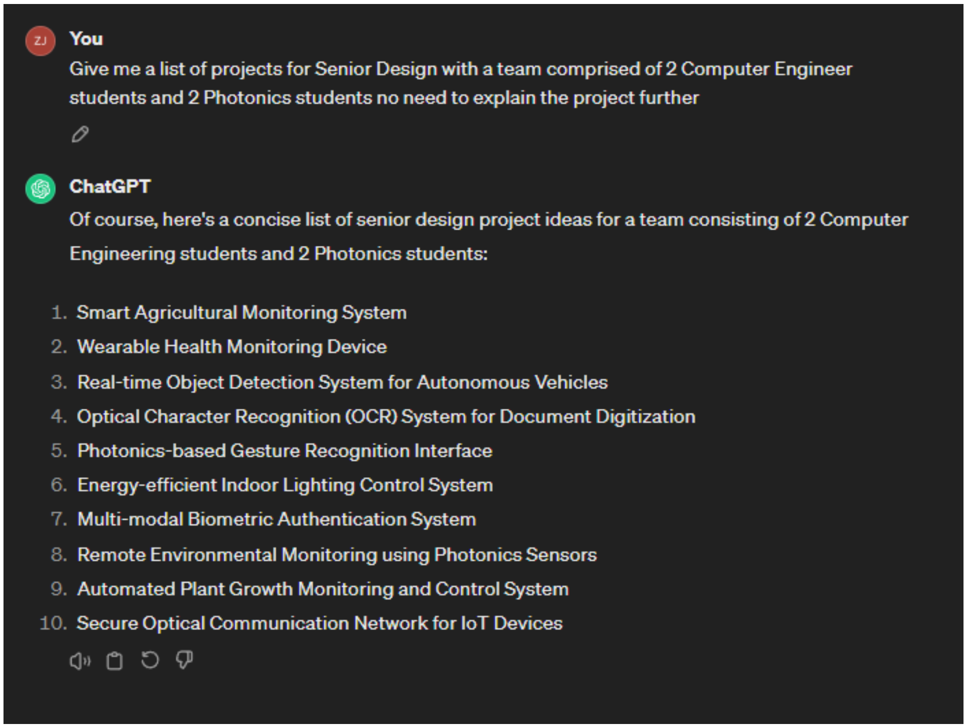

Figure 19. *ChatGPT user prompt & response.*

{image/reference of ChatGPT explaining an error code}

5.4 Harms to Senior Design

Some challenges that may arise from using certain AI tools like ChatGPT is the reliance on resources that may not always be up to date. This limitation can impede the integration of new discoveries or emerging technologies into project designs. Given the rapid pace of advancements in various fields, including computer engineering and photonics, outdated resources may fail to capture the latest developments, leading to missed opportunities for innovation and optimization within Senior Design projects. In the context of coding and software development, the use of deprecated assets or outdated frameworks poses a considerable risk. Deprecated assets refer to elements within a coding environment or framework that have been marked as obsolete or no longer supported by developers. When these deprecated assets are inadvertently utilized in project development, it can result in compatibility issues, decreased performance, and increased susceptibility to bugs or vulnerabilities. The consequence of relying on deprecated assets can cause project slowdowns, as time and resources are diverted towards identifying the cause of issues and implementing solutions. The use of deprecated assets may hinder the scalability and maintainability of Senior Design projects, as they may lack support for modern features or fail to align with current best practices in software development.

{Example of ChatGPT using outdated information/framework/assets}

Chapter 6 – Hardware Design

6.1 – Optical Design

Our optical design embodies two systems, a chlorine analyzer which will detect the concentration of Chlorine in a sample and a dechlorinator which will reduce the concentration of chlorine in a sample. Employing spectroscopy, the initial phase focuses on detecting chlorine within the water sample. A pivotal component in this phase is the beam splitter, which diverts a portion of the beam into a power meter, enabling precise readings of the laser output.

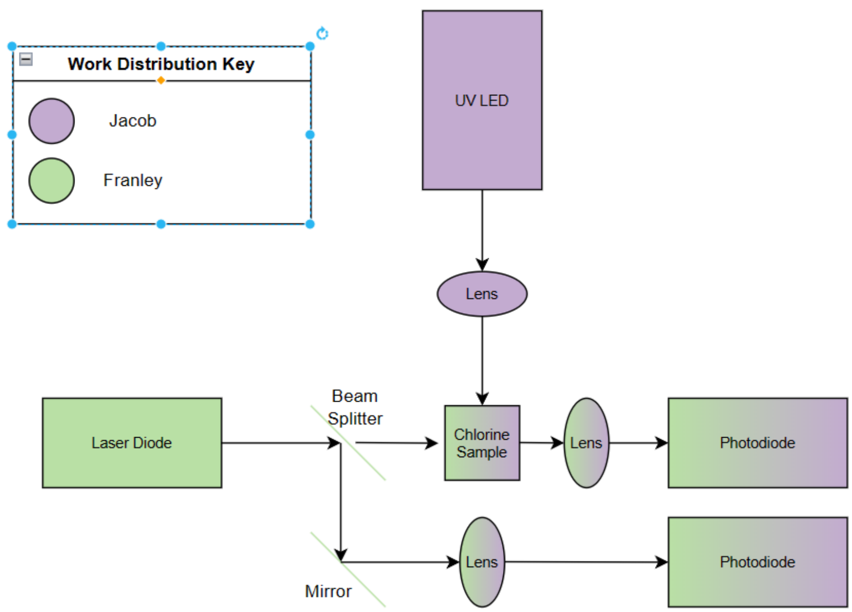

Figure 20. *Current block diagram of optical design*

Transitioning to the dechlorinator aspect, a UV LED is incorporated, which passes through a lens system meticulously designed to concentrate the UV light onto the water sample, effectively dechlorinating it. Notably, the chlorine detection component operates actively, continuously monitoring concentration levels to facilitate real-time adjustments and observations within the system. This integrated optical design ensures comprehensive functionality, offering both analytical insights and practical treatment capabilities for water purification processes.

Chapter 7 - Software Design

The project’s software is divided into two main components. The first component is the mobile application, designed to provide a user-friendly interface for interacting with the dechlorination system. Through the application, users can input commands and monitor the system real-time results by the dechlorination process. The second component is the embedded system, which serves as the bridge connecting the microcontroller and the mobile application. The microcontroller will be responsible for managing data communication, sensor inputs, and signals between the hardware and the mobile application interface.

7.1 Development Platform-Flutter

We chose Flutter for developing the mobile application due to its ability to create a single User Interface across different operating systems using a single codebase. This approach will allow us to reach a wider range of audience, as the application will be accessible on both Android and iOS platforms. Utilizing Flutter ensures a consistent user experience, as the application code remains the same across the operating systems. One of the advantages of using Flutter is simplifying maintenance and updates in the future. Since we only need to modify a single codebase, managing the application becomes significantly more efficient, leading to enhanced user satisfaction.

7.2 MERN Stack

Due to the complexity of implementing the backend in Flutter, we chose MERN stack to use the power of Node.js, Express.js, MongoDB for our mobile application’s backend system, since React.js is used to make the Front end. One of the advantages of the MERN stack is dependence on a single programming language, JavaScript, throughout the development process. MongoDB is a highly scalable document database that makes it easy to store and retrieve data in JSON (Java Script Object Notation) documents. Express.js is a server-side application framework that wraps HTTP (Hypertext Transfer Protocol) requests and responses and makes it easy to map URLs to server-side functions (MongoDB3). Node.js is a runtime environment that can be used to run JavaScript code on the server side. This allows developers to use the same language for both the front and back ends of their applications.

7.3 Programming Languages

The front end of the Optical Chlorine Analyzer and Dechlorinator (OCAD) mobile application is developed using Flutter to create the User Interface with a set of widgets with the help of Dart programming language. On the other hand, the back end of the application is powered by JavaScript using the framework like Node.js, Express.js, and MongoDB to handle the server, data storage, and API. The combination of Flutter front end and JavaScript for the back end will provide an efficient development experience.

7.3.1 Dart

Dart is the primary language used in Flutter. Dart is a client-optimized language for developing fast apps on any platform. Its goal is to offer the most productive programming language for multi-platform development, paired with a flexible execution runtime platform for app frameworks. Dart shares similarities with Java, particularly in its support for object-oriented programming (OOP) concepts like classes, inheritance, and interfaces. This familiar OOP structure makes it easier to transfer to Dart. Also, Dart includes built-in support for asynchronous programing, allowing developers to write efficient code in handling tasks. By combining the strengths of OOP with asynchronous programming, Dart has become a powerful tool for developing high-performance applications.

7.3.2 JavaScript

JavaScript is a high-level programming language most well known as the scripting language for Web pages. It enables dynamic and interactive features on websites by manipulating Document Object Model (DOM). JavaScript can run on both the client side, where it supplies objects to control a browser and its DOM, and the server side, where it provides objects relevant to running JavaScript on a server. This versatility makes JavaScript a great tool for full-stack web applications.

7.4 Mobile Application

When the mobile application is initially launched, it will guide the user through a login process where they will be prompted to enter their credentials. If the user does not already have an account, they will have the option to create one. This step is crucial for accessing the features of the Optical Chlorine Analyzer and Dechlorinator with the application. By logging in, the user’s information can be securely retrieved from the database, enabling the application to display relevant OCAD results customized to their account.

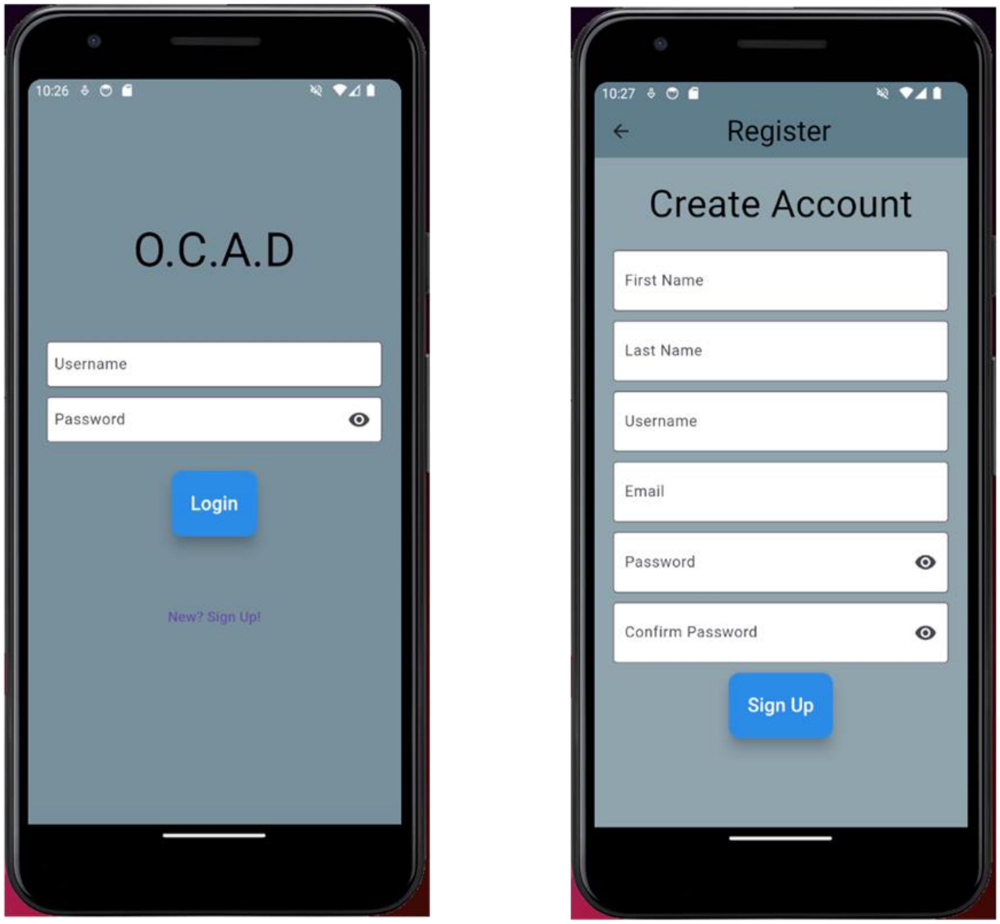

Figure 21. *Login and Register prototype for mobile application.*

Upon successful login, the application will seamlessly transition the user to the dashboard page, where they will find a real-time display of the current chlorine concentration in the water. This concentration indicator employs a color-coded system, utilizing red, yellow, and green to visually represent different concentration levels. If the concentration exceeds 4 ppm, the display will be highlighted in red, signaling a high concentration. In the range of 0.6ppm to 3.9ppm, the display will switch to yellow, indicating a moderate concentration. If the concentration falls below 0.5 ppm, the display will turn green, signaling a low concentration level. This color scheme allows users to quickly assess and understand the chlorine levels briefly, facilitating decision making regarding water treatment measures.

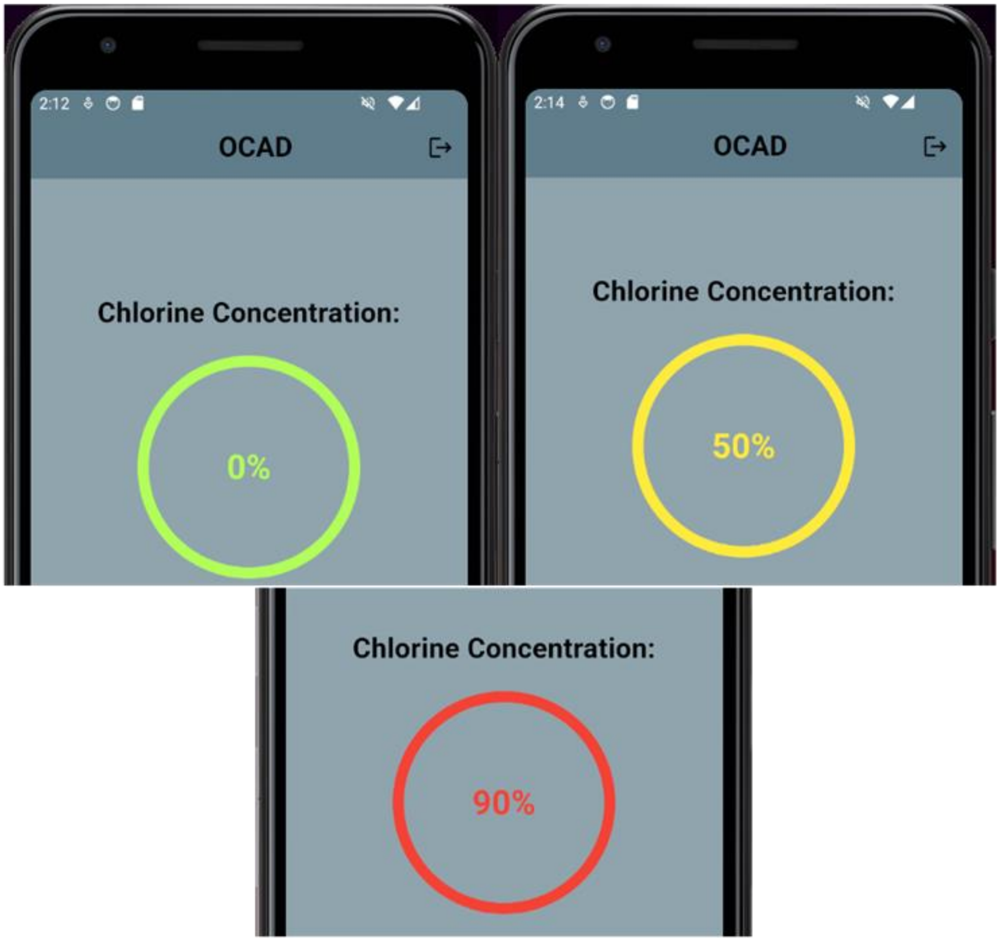

Figure 22. *Prototype Display of Chlorine Concentration.*

Depending on the concentration displayed, users will have the option to initiate a dechlorination process to lower the concentration levels. Upon pressing the start button, it will change the color to signify activation, followed by a message confirming the commencement of dichlorination. As the process progresses and achieves the desired chlorine concentration, users can stop it by pressing the start button again, effectively deactivating the process. Additionally, if the concentration naturally reaches 0 ppm and the user has not manually stopped the process, it will automatically shut off. This responsive system ensures efficient management of chlorine levels, providing users with control and peace of mind regarding water treatment processes.

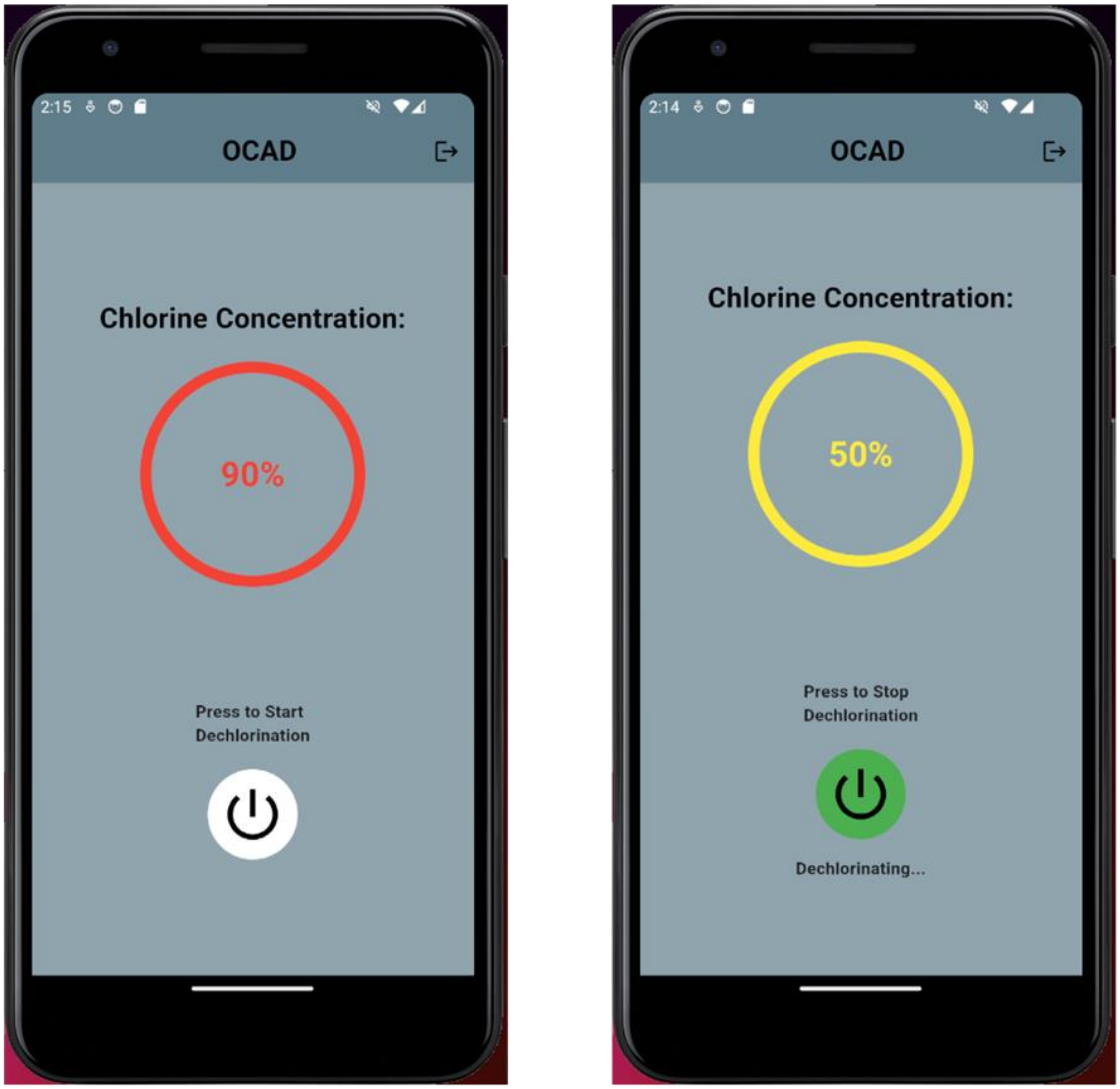

Figure 23. *Activate and deactivate dechlorination process prototype.*

7.5 Mobile App Flowchart

Figure 24 illustrates the user journey within the mobile application, showcasing the navigation and control features embedded in the system. Upon launching the application, it begins in “start”, representing the beginning of the user interaction with the application. The next couple of steps are the paths the user can take to access the features, information, and interaction with the system.

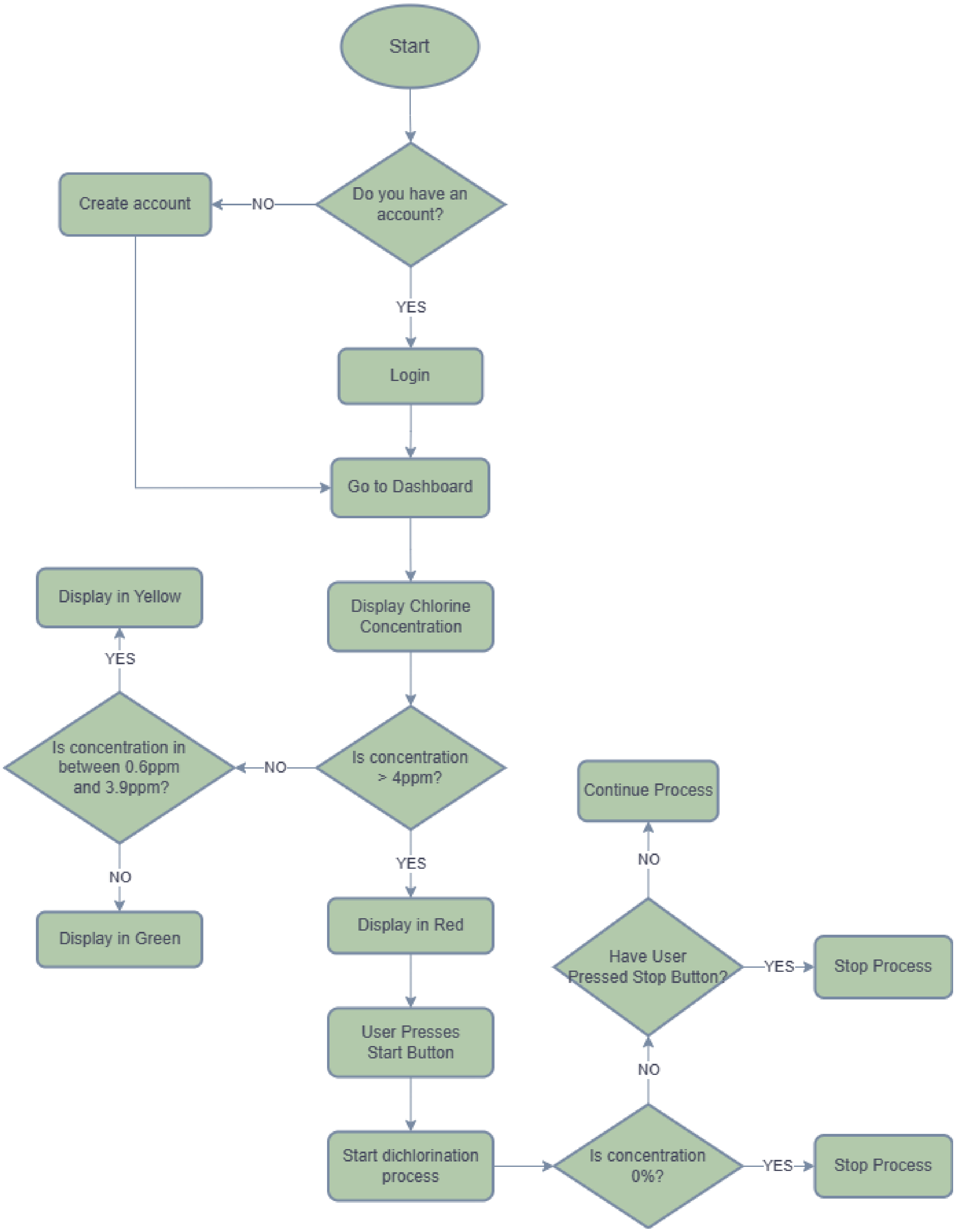

Figure 24. *App Flowchart.*

Chapter 8 - System Fabrication/Prototype Construction

Chapter 9 - System Testing and Evaluation

Chapter 10 – Administrative Content

10.1 – Project Budgeting and Financing

The funding for our group project budget is expected to be contributed to evenly by the members within the group. The anticipated budget for this project is $1,000 to ensure the cost for each member is low. The budget is subject to change depending on the final hardware diagram (Specifically the gas detection section) and optimizing the system to achieve the parts per million or billion requirements. The budget includes a provision for replacement components that may arise throughout the project. Table 2 illustrates several key components necessary for initiating the development of an Optical Chlorine Analyzer and Dechlorinator.

Table 12. *Current Project Budget*

Component	Quantity	Unit Cost	Total
Laser Diode	1	$200	$200
Reagents	1	$40	$40
Arduino UNO Wi-Fi REV2	1	$53.80	$53.80
Microcontroller compatible speaker	1	$5.99	$5.99
GPS Module	1	$12	$12
Power Supply Adapter	1	$9.99	$9.99
Photodiode	2	$10	$20

Beam Splitter	1	$188.88	$188.88
Mirrors	2	$46.59	$93.18
UV Light source	2	$15	$30
Focusing Lens	2	$20	$40
PCB	1	$40	$40
Total			~$733.76

10.2 – Initial project Milestones

Our group was formed within the first week of senior design 1 and we are anticipating finishing senior design 2 in the summer. The team has planned milestones to keep us ahead of schedule due to having to finish the project in less time due to the shorter summer semester. The tentative schedules for senior design 1 and senior design 2 are shown in the tables below.

Table 13. *Senior design 1 project Milestones*

Task	Start Date	Anticipated End Date	Duration
Project Brainstorming	01/09/24	01/18/24	2 weeks
Divide and Conquer	01/18/24	02/02/24	2 weeks
Buy Parts	03/15/24	04/01/24	2 weeks
30 Page Milestone	2/2/24	2/23/24	3 weeks
60 Page Milestone	2/23/24	3/15/24	3 weeks
90 Page Milestone	3/15/24	3/29/24	2 weeks
120 Page Milestone	3/29/24	4/15/24	2 weeks

Individual System Testing	4/15/24	5/7/24	3 weeks
System Integration/Testing	5/7/24	5/28/24	3 weeks

Table 14. *Senior design 2 project milestones*

Task	**Start Date**	**Anticipated End Date**	**Duration**
Build Prototype	TBD	TBD	TBD
Test & Redesign	TBD	TBD	TBD
Finalize Prototype	TBD	TBD	TBD
Peer Presentation	TBD	TBD	TBD
Final Report	TBD	TBD	TBD
Final Presentation	TBD	TBD	TBD

Chapter 11 - Conclusion