Detection of Algae in Fish Tanks Using Optical Absorption

Group 1

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1. Executive Summary

With many people owning fish tanks nowadays the issue of trying to keep the water in them clear is becoming an important issue. Water in fish tanks can become murky due to algae blooming in the fish tanks. Algae blooms can be caused by a multitude of things, most of which have to do with the amount of nutrients in the water. These nutrients come in the form of photosynthesis, nitrites, and nitrates. Photosynthesis, nitrites, and nitrates can find their way into the fish tanks ecosystem from overfeeding the aquatic life in the tank, and they can also come from the aquatic live themselves, from having an over abundant amount of food the fish will produce more waste than if they had the appropriate amount of food. Algae blooms can also be caused by keeping the fish tank too close to external light sources light windows. And an algae bloom can also be an indicator that the lights on the fish tank need changing. This is because some types of algae like lower light than others. Our Device seeks to assist fish tank owners in knowing what is going on in their fish tank by telling them the amount of algae in their fish tank.

The fish tank assistant that we are creating will utilize the optical properties of Beer's Law to help fish tank owners know how much algae is in their fish tanks. The fish tank owners can then use this information that they get from our fish tank assistant to better determine, or make an educated decision on their own, if they need to change their feeding habits for their aquatic pets to live healthier lives. Or if they need to move the location of their fish tank to a darker area, or if they need to change the lights for their fish tanks. The fish tank assistant is also helpful for a fish tank owner to know when they need to clean their tank based on the concentration of algae in the tank. This document will illustrate how our team plans to do this. First discussing all the features of our product, then going through research that was done to look at similar products and then all that will be necessary for us to achieve our goal. Then going over some of our constraints and standards that pertain to the design of our Beer's law using fish tank assistant. Then finally the prototyping, constructing, and testing our device.

2. Project Description

Fish Tank Assistant is an algae detection system designed for first time fish tank owners as well as those who struggle with keeping old tanks clean. Algae blooms are very harmful and can easily be found in warm nutrient rich environments. The system will detect algae using an optical system paired with a thermal camera and notify the owner that the tank needs to be cleaned.

A microcontroller will be used to power, read, and display the outputs of sensors through system integration. All components will be fastened to the housing via custom 3D printed casings and configured around a siphon that will continuously pull the water from the tank into the testing area. The user interface will consist of a physical display on the housing along with wireless internet connection.

2.1 Motivation

Our motivation for the Fish Tank Assistant is to challenge ourselves by creating a system that will monitor the water condition of a fish tank. We aim to gain experience meeting project deadlines, documenting the design process, and professionally presenting a project by creating this system. We expect to put these experiences and the skills learned into practice in our future engineering careers. Furthermore, we seek to create a worthwhile project that is effective while being affordable with the intent to offer fish owners the capability to check their fish tanks for algae using an easy-to-use phone app.

According to a 2019/2020 study, fish are the 3^{rd} most popular house pet with 11.5 million households in the U.S owning freshwater fish. It is not a surprise that Goldfish are the most common freshwater fish to own as a pet. It is tradition to win them at events and purchasing certain varieties can be at a low cost. While acquiring a pet fish is simple, keeping them alive does not seem to be. We've all heard a story about someone's fish dying at some point in our lives and one of those reasons could be due to Cyanobacteria blooms. While Cyanobacteria is commonly found in fresh water and marine water and under the right conditions, blooms can begin to form and inhibit the organisms in the habit.

Widely known as Blue-Green Algae, Cyanobacteria are single-celled microscopic organisms that thrive in warm, nutrient rich slow-moving waters. In the case that the Cyanobacteria quickly grows, blooms will begin to form on the water's surface. This could potentially create too much shade for the other inhabitants requiring sunlight for photosynthesis. Another problem is the production of Cyanotoxins, which are a powerful natural poison, made up of 3 different toxins: neurotoxins, hepatotoxins and derma-toxins. Exposure to these toxins can cause a number of symptoms in both humans and animals and in some cases even death.

While not all blooms are toxic, if a fish tank develops enough growth, it can decrease the oxygen levels in the water and ultimately lead to illness or death.

Taking care of a pet can be tough especially when it is your first experience owning that species. Maintaining the proper environment is crucial when taking care of an aquarium. Finding out the best cleaning schedule and sticking to it can be difficult. Fish are seen as an easy pet, but they do require a responsible owner to change/clean filters as well as changing a percent of the water regularly. Currently systems such as Algae_Tracker provide measurements of green algae, blue-green algae, turbidity, temperature as well as sunlight, wind, and rain, exist for large scale applications like waterways. The typical household method to test blue-green algae is to use a test kit such as API (Application Programming Interfaces) Fresh Water Aquarium Master Test Kit._These kits consist of test tubes, test drops and a color card for manual testing.

In an effort to showcase our acquired knowledge and skills from our respective degree programs, we want to create an easy to use, affordable system that continuously monitors home aquariums for signs of a dangerous environment using optical components specifically designed for detecting the presence of algae in a water sample. We have separated the project into smaller design goals which are divided into subcategories described further.

2.2 Goals

The overall goal for our project is to create an affordable algae detection system while fulfilling the graduation requirements from the University of Central Florida. This is also an opportunity to showcase the skills we have learned over the past 4-6 years. This is going to be the first time many students get the chance to work in groups over extended periods. As a requirement our system needs to perform 3 basic functions as well as have research for additional features.

2.2.1 Basic Goals

The basic goals are the minimum requirements for our project and describe the basics of what we intend for the (insert project name here) to achieve.

1. Create a specific optical design for detecting algae in a hand-drawn water sample.
2. Create a user interface to inform users of the results.

2.2.2 Advanced Goals

The advanced goals are those in which we aim to make our project stand apart from other current products in the same genre. These goals are also intended to create challenges for our team to overcome.

3. Use a siphon system to continuously pull water from the fish tank to create a hands-free system.
4. Design system to run through fish tank pump for detecting its performance.

2.2.3 Stretch Goals

The goals which are the most difficult to achieve are considered stretch goals. These consist of the goals our team would like to achieve but are not required for the project to operate or stand out but are rather the additional features that our team believes would be an overall benefit in creating a more well-rounded and appealing project.

5. Design an additional feature to detect salinity in a saltwater fish tank.
6. Design an additional feature to monitor the water temperature.
7. Create a mobile app user interface.

#	Type of Goal	Description
1	Basic	Configure a spectrometer, charged coupled device (CCD) and a microcontroller in a way that will detect cyanobacteria in a water sample.
2	Basic	Design a printed circuit board that will interface with a digital display for easy customer use.
3	Basic	Incorporate sensors for detecting temperature, turbidity, and pH levels in the sample.
4	Advanced	Design and build an aesthetically appealing, lightweight, and compact holding case.
5	Advanced	Design a mobile application to track the environment's status.
6	Stretch	Build a system to dispense chemicals to treat algae based on tank size.
7	Stretch	Design a system to pull water from the tank into the sample testing area.
8	Stretch	Design system to run tests weekly to track algae levels.

Table 1 Goals

2.3 Functions

There are two methods of detecting algae in water. The first is to use a spectrometer, the second is to utilize Beer's law. A spectrometer works by a laser diode power from a source, in this case from a wall outlet, this laser light then passes through a focusing lens and then to our water sample. The output light from the sample then goes to another lens then to a diffraction grating. The grating separates out the beam into its different wavelength so that a waiting CCD camera or a photodiode. After the CCD it will be passed to a micro controller to be put though some code to give the wavelength. See below.

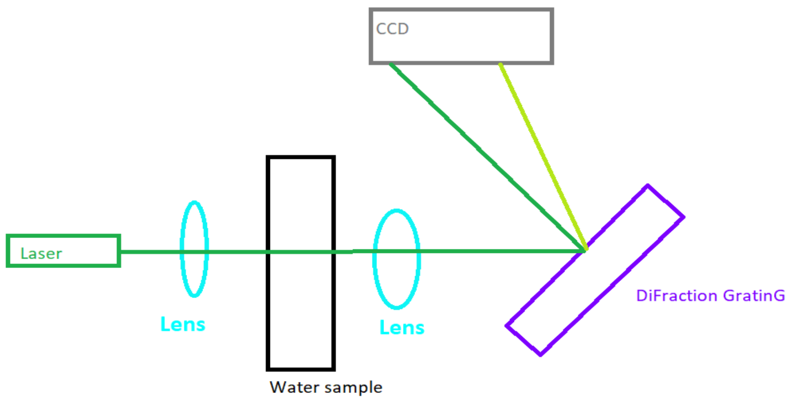


Figure 1: Ruff diagram of a basic set up of a spectrometer to help decide which method would be best.

Method 2, using the properties of Beer's Law. Again, we will start with a wall power supply that will then be passed to the laser diode. This beam of light will go to a beam splitter, with 1 beam going to a power meter, and the other beam going through the sample water. After the sample, the beam will go to another power meter. The equation for transmitters is $T = \frac{Intensity\ out}{Intensity\ in} = \frac{Power\ out}{Power\ in}$. Where P stands for power and I for intensity. So, we can either measure the power or intensity to get transmitters. Knowing the transmittance means we know the amount of light that gets through or how much algae is absorbing the light. See below.

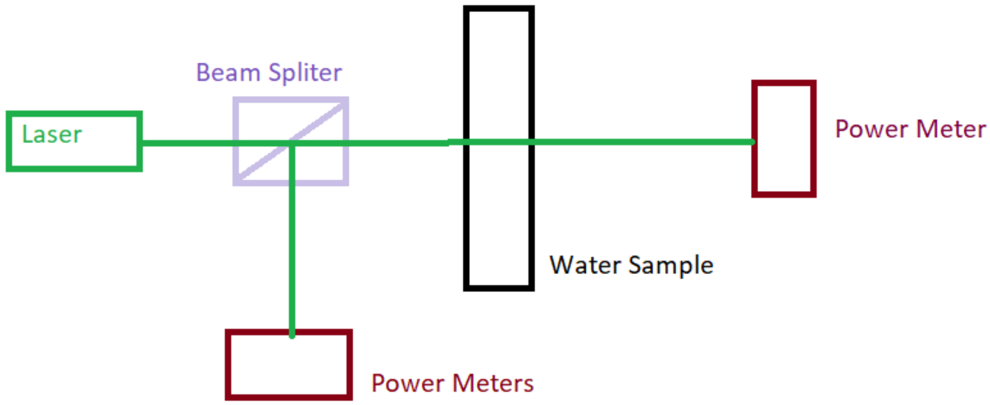


Figure 2: Ruff diagram of the basic set up of using Beer's law to get how much light is transmitted through the system, to help decide which method would be best.

For both of these cases we will need to select a Laser Diode at a specific wavelength of light. Looking at the emission spectrum for algae, most of them have the deepest valley at 540nm. So, that is probably the wavelength we want. The system at its most basic level will be checking to see how much algae is in a water sample.

2.3.1 Factors

The system at its most basic level will be checking to see how much algae is in a water sample. The more quantifiable components of the device are:

Basic Features

- Small footprint, as big or smaller than 12X12 inches. So that it can fit on top of a fish tank or will not take up too much space next to the tank.
- Plugs in to the wall outlet. Almost everything on a fish tank plugs in so it makes the most sense to plug this in.

Advanced Features

- Light weight, under 10 lbs.

Stretch Features

- Durable, meaning it will not get damaged being around all the humidity of the fish tank.
- Will check the pH, meaning it will notify the owner when the tank is no longer at a safe pH level, 6.8-8, depending on the fish.
- Will check water temperature, 65-85 degrees Fahrenheit.

2.4 List of Requirements

Note: Client has not come to a consensus on their requirements yet.

1. Building an app for notification system
2. Build a sensor that would detect the algae using an optical system.
3. Lightweight and portable
4. User Friendly
5. Provide an easy to use and cost-efficient system.
6. Must be accurate

    - Long shot goal: build the system to be automated from the app rather than just notifying the user and they would have to clean it manually.

2.4.2 Electrical

The electrical requirements for the Fish Tank Assistant are listed below:

- A sufficient power supply must be integrated with the chosen microcontroller.
- The chosen microcontroller must power the following:
    - Photodiode
    - Laser pointer
    - Sensors for pH, temperature, turbidity, and user input.
    - Designed PCB with LCD user interface.
    - Cooling Fan

2.4.3 Optical and Spectral Requirements

1. Incident light in the violet-blue wavelength range.
2. High responsivity of photodiode sensor.
3. Beam size equivalent or larger than photodiode sensor.
4. Potential use of thermal camera.

2.4.4 Software Requirements

Goals	Description

Main	Program the microcontroller, sensors, and buttons to make sure the actual product is functional
Advanced	Have the machine operate through a touch LCD screen
Stretch	Build an app to control the product through smart devices and make it as user-friendly as possible.

Table 2 Software Goals

2.5 House of Quality

A House of Quality is a popular Lean Six Sigma product development tool used to support the understanding of how the customer's requirements relate directly to the design. This table focuses on the customer's needs and desires by capturing and prioritizing them based on the relative importance. The Matrix is separated into 7 sections consisting of text, symbols, and calculated fields. Filling out a House of Quality will help teams visualize priorities while also creating a competitor comparison.

Before a House of Quality can be constructed, the customer's needs must be identified. This is going to be used to fill out the first section of the matrix with the same name. Customer needs can be divided into subcategories such as Power, Availability, and Operation. For example, under the operation section a customer needs could be low cost or easy system management. After these needs have been identified and categorized, a priority must be assigned.

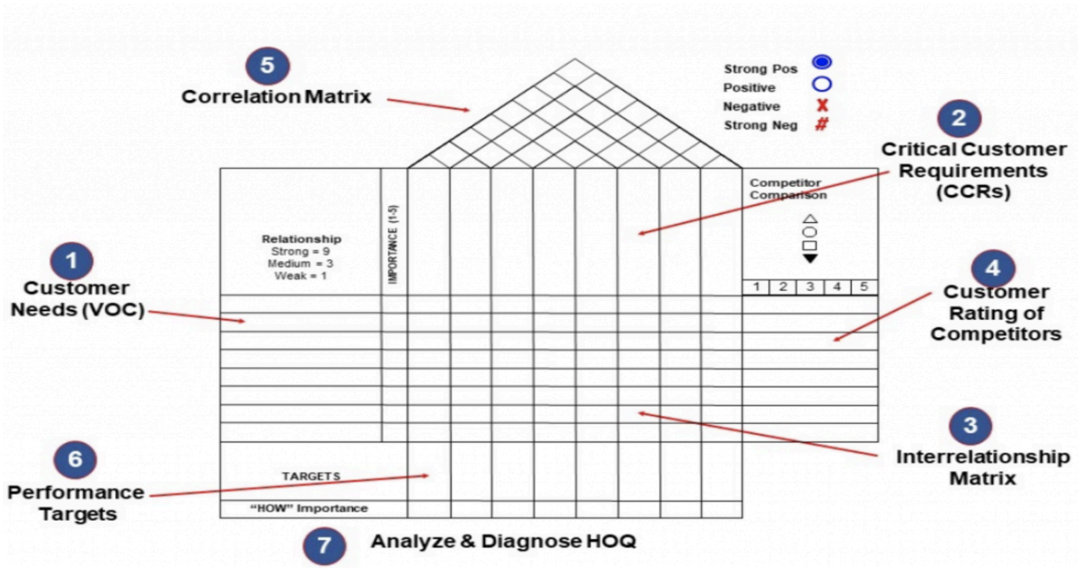


Figure 3: HOQ Breakdown (Courtesy of ISixSigma.com)

The next section is called Critical Customer Requirements, this will contain various technical descriptors provided through design constraints, requirements, and other parameters. Often this section is referred to as Engineering Requirements with descriptors such as dimensions, weight, and power output.

After these sections have been completed the associated relationship boxes under the descriptors and to the right of the needs must be selected. The available options are Strong, Moderate and Weak. Match the box with the corresponding need and requirement and determine the relationship. For instance, how much do the dimensions of the product affect the accuracy or the portability? Dimensions could potentially have a moderate effect on accuracy, additional hardware being added could cause the product size to increase or smaller more expensive devices could be procured to decrease the size.

The Customer Rating of Competitors answers the question of how well existing products are meeting customer wants. A rating of 1-5 is used with 3 representing an equivalent product, 1 being the worst, and 5 being the best. This will help guide the desirable attributes for the Performance targets. Once this matrix is completed it will help reduce design revisions and increase customer satisfaction. The following figure includes the House of Quality for The Fish Tank Assistant.

QFD: House of Quality C. Battles. (2011, May). QFD House of Quality Template. Schrodinger's Ghost.com [Online]. Available: http://www.schrodingersghost.com/?cat=54.

Project: Fish Tank Assistant
Revision 3
Date: 04/03/2022

Correlations	
Positive	+
Negative	−
No Correlation	

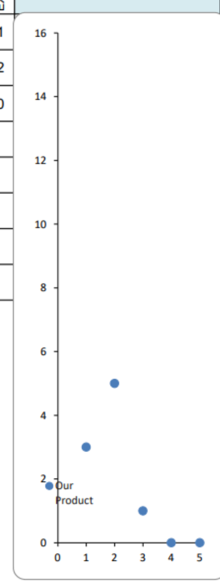
Relationships	
Strong	●
Moderate	○
Weak	▽

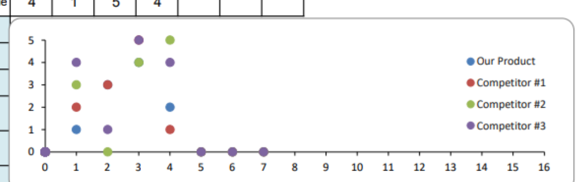
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

+
+ +
+ − +
− − + +
+ + − + +
− − − + − +
− − + − + − −

Row #	Weight	Customer Requirements (Explicit and Implicit) / Engineering Requirements	Cost	Dimensions	Weight	Power Output	Energy Efficiency	Spectral Range	Design Complexity	Our Product	AlgaeTracker	Aqua TROLL 600	EXO2 SONDE
		Column #	1	2	3	4	5	6	7				
		Direction of Improvement	▲	◇	▼	◇	▲	◇	◇	Customer Competitive Assesment			
1	8	Cost	●	○	○	○	○	○	○	3	3	4	1
2	2	Easy to Use	○	▽	▽	▽	▽	▽	○	5	4	1	2
3	4	Durable	●	○	○	▽	▽	▽	○	1	2	4	0
4		Accuracy	●	○	▽	○	○	▽	○				
5		Battery Life	●	○	○	●	●	▽	○				
6		Portable	●	●	●	▽	▽	▽	○				
7		Appearance	●	●	●	▽	▽	▽	●				
8													

	1	2	3	4	5	6	7
Target	Less than $1000	Less than 30cm x 20cm x 60cm	Less than 20 lbs	Between 5V-12V	Will last for at least 120 minutes	~350 - 500 nm	Single Board
Max Relationship	9	9	9	9	9	3	9
Our Product	1	3	4	2			
AlgaeTracker	2	3	5	1			
Aqua TROLL 600	3	0	4	5			
EXO2 Sonde	4	1	5	4			
Column #	1	2	3	4	5	6	7





Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Figure 4 House of Quality (Template Courtesy of SchrodingersGhost.com)

2.6 Product Operation

The Fish Tank Assistant will use a siphon to pull water into the systems enclosure through plastic airline tubing. A section of tubing will be replaced with glass and fastened between focusing lenses that will be penetrated by a blue laser beam. The blue laser beam will be split using a beam splitter before it reaches the water sample. Two photodiodes will be used to accept the split beam outputs and then the system will compare the two intensities and determine whether or not the delta is large enough to be considered a danger to the ecosystem.

The system will also use a thermal camera to monitor the temperature of the sample being pulled through the siphon. A touch liquid crystal display will be integrated as a user interface where data will be displayed based off the sensor's outputs. This display will also be available online via a Wi-Fi module that will allow the information to be accessed from another location and easily manipulated in online analysis.

3. Research and Background Information

Research is extremely important when designing a product for a customer. In the House of Quality, we were able to visualize our priorities based on the information collected from potential competitors, customer requirements, and engineering requirements. Establishing these parameters for the system has helped guide the following design research. We started with a basic concept of the system and have been able to fully actualize it through comparing popular hardware, software, and optical designs and selecting the best components for our product goals.

The following research has been divided by our respective degree components. Electrical Engineering will cover hardware including the microcontroller, power supply, and display. Photonic Science Engineering will focus on optics design including photodiodes, lasers, and lenses. Computer Engineering will discuss software related to programming physical components.

Each section will be divided into smaller sections where components will be chosen and then a specific product comparison will be made to determine the best fit for our design. The following block diagram has been created to capture the main components, overall flow of the system as well as the division of labor. The work will be evenly divided amongst the group with members taking responsibility for the aspects of the system that pertain to their field of study.

Block Diagrams

The Block diagram below illustrates the distribution of labor for the different components of the device that are required in order for the device to work. The labor is broken down in terms of the fields that each member of the team is most familiar with and has the largest understanding of those specific components of the device. It also demonstrates the basic flow of our design, starting with the power supply.

The power supply will be connected to the microcontroller via a USB or barrel cable and from there the sensors, optics, and display need to be integrated based off required inputs. Once the proper calculations have been finalized these modifications will be configured on a single printed circuit board that will be mounted above the optics system. The microcontroller will be programmed to read analog outputs from the sensors and display digital outputs of intensity as well as temperature outputs.

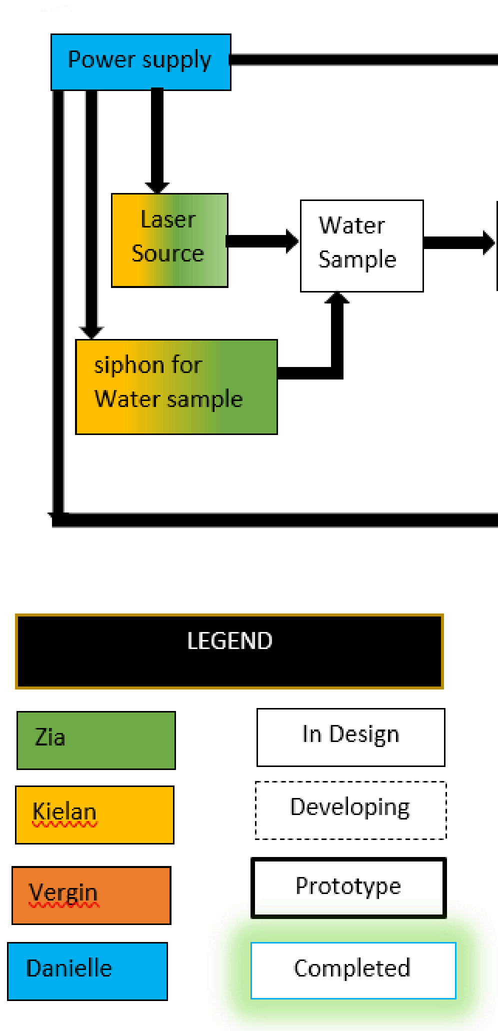


Figure 5: Block Diagram

The Legend above shows the colors that correspond to each group member on the left. With some of the colors in the block diagram being mixed to indicate that more than one project member is working on that component.

Zia McDonnold

- Photonics Engineering Major
- Color on block diagram Green

  Partly Responsible for:
  - Laser source
  - Syphon for water sample

- Optical system

Kielan McMillan

- Photonics Engineering Major
- Color on block diagram Yellow
  Partly Responsible for:
    - Laser source
    - Syphon for water sample
    - Optical system

Vergin Mansour Computer

- Computer Engineering Major
- Color on block diagram orange
  Responsible for:
    - CCD
    - Coding/ Programming

Danielle Nastyn

- Electrical Engineering Major
- Color on block diagram Blue
  Responsible for:
    - Power supply
    - Micro controller/ PCB

- The right-hand side of the legend is the current status or phase of the separate components.
- The solid black border represents design. Meaning that the component is currently in the design phase and research is being conducted to select the correct component.
- The dashed black border represents development. Meaning that it is in the development stage. That is to say that the calculations are being done to determine specific components' properties, i.e., focal length of a lens.
- The bold black border represents the prototype. Meaning that all the components/ parts have been selected and all necessary calculations have been done to ensure that the device should work. At this stage though it will not look like a completed devise, and it may still have some parts on a bread board.
- The cyan border with the green around it represents completed components. Meaning that those parts of the project are done completely, looking as professional as possible, and ready for the final presentation.

3.1 Similar Products

While continuous water monitoring systems that test for blue green algae are abundant, they are focused on large applications such as oceans, rivers, and lakes not small fish tanks. Water quality monitoring systems for small aquariums do exist for parameters such as pH, salinity, and temperature but nothing can be found for continuous algae detection. Systems dealing with algae in fish tanks focus on killing the algae rather than detection which is done typically via test strips.

Companies who produce water quality monitoring systems typically use a multiparameter sonde with ports available for interchangeable sensors. In-Situ and Yellow Springs Instruments offer an array of monitoring solutions with mobile capabilities for bodies of water such as lakes, oceans, and ground water. While these instruments are effective, they are also expensive. The high-quality sensors used in these devices can cost as much as the device itself. Industries testing large environments would have the budget to invest in tools such as these. Owners of a small ecosystem are less likely to spend thousands of dollars on a monitoring system.

The market is lacking a continuous monitoring system for owners of small aquatic environments. While applications do exist for water quality, algae detection is not among them. Often the solution for fish tank owners is to introduce an algae eater to the environment or increase tank maintenance frequency, including regulating light and maintaining a clean environment.

3.1.1 Algae Tracker

Aqua RealTIME is a small company based out of Boulder, CO that designs systems for early water contamination detection and monitoring. In 2020 they were awarded $100,000 by the Environmental Innovation Agency (EPA) to further develop their early detection system for Harmful Algae Blooms. The Algae Tracker is a powerful floating sensor buoy that measures green algae, blue-green algae, turbidity, temperature, and weather conditions.

The Algae Tracker is solar powered and cellular connected which allows data to be collected 24/7 from the self-cleaning sensors. The system uses Algae Link, a helpful dashboard that displays data in easy-to-interpret charts ready to download. Once deployed the system immediately streams live data to the cloud every 15 minutes. This low-cost detection system can be applied in any waterway to reduce response time.

3.1.2 Aqua TROLL 600

In-Situ is a global company that specializes in the design, procurement, and sales of premium environmental monitoring equipment with applications for ground water, wastewater, surface water and drinking water. They offer products in water quality, water level and flow with remote monitoring data collection. These systems provide real time data that can be used to respond to changes instantly.

The Aqua TROLL 600 is a portable and customizable multi-parameter sonde used to test water quality. Built with the latest sensors and technology and is compatible with sensors such as: water/level sensor, barometric pressure sensor and Phycocyanin sensor. This device connects to the VuSitu mobile app via Bluetooth where the user can track and analyze trends.

The Aqua Troll 600 is a customizable and easy to use instrument with a corrosion resistant design to support long deployments and allows for applications in normal and extreme environmental conditions. The system is built with 4 universal smart sensor ports with wet-mate connectors for simple replacements and comes factory calibrated for the user's convenience. The internal power is provided by two alkaline D-cell batteries which allows for 9-12 months of continuous deployment depending on logging rates. An LCD screen is used to access data such as battery life, internal log, and sensor status. The memory is recorded internally on the sonde as well as on a micro-SD card that can be accessed in case of an onboard memory issue.

Blue Green Algae can be detected by the Aqua TROLL 600 when it is coupled with a Phycocyanin sensor. The sensor uses an integrated optical compensation system by using a reference detector to measure changes in the LED light source. A sapphire window is used to reject ambient light sources, allowing the device to be unaffected by environment lighting.

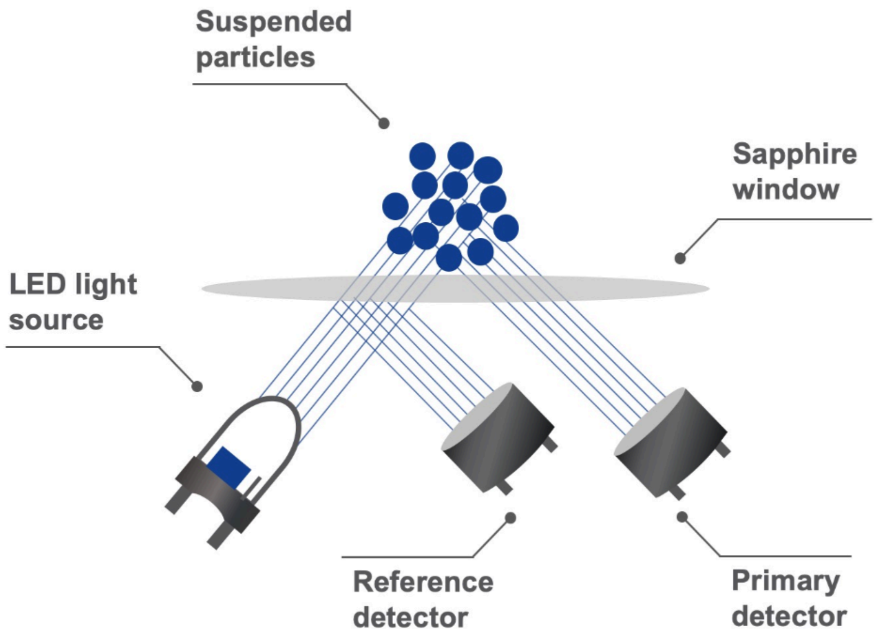


Figure 6: Integrated Optical Compensation (Courtesy of In-Situ.com)

This application starts off at a base price of $3,895 with additional options for venting, sensors, and port plugs. The Phycocyanin sensor is an additional $1,995. With the total reaching almost $6,000 after adding 1 sensor, while this is a reliable product for monitoring large bodies of water, this would not be logical for an average household fish tank.

3.1.3 EXO Sonde Platform

YSI, or Yellow Springs Instruments is a leading manufacturer of water management solutions that require infrequent maintenance in applications from wastewater to climate change. They provide high quality monitoring tools for applications such as saltwater, wastewater, freshwater and more. In an effort to design the ultimate water quality monitoring tool, the EXO Sonde Platform was developed and provides an unmatched range of sensor and parameter options.

The EXO includes the following models: EXO1, EXO2, and EXO3. A main difference between them is the number of smart sensor ports available: 4, 7, and 5 respectively. The battery life on these devices ranges from 60 to 90 days and will be impacted by sensor types and measurement frequency. All models are also equipped with mobile monitoring capabilities via the EXO Handheld or EXO GO.

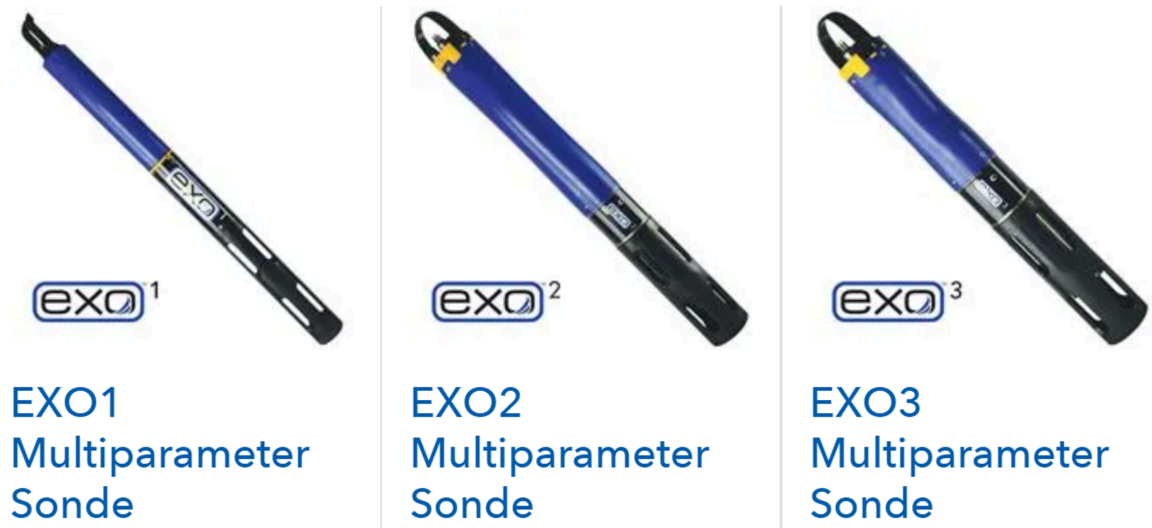


Figure 7: EXO Sonde Platform: EXO1, EXO2, EXO3 (Courtesy of YSI.com)

All EXO sondes have access to an array of smart sensors including the EXO Total Algae PC Sensor. This digital smart sensor has dual fluorescence channels offering outputs on both chlorophyll and blue green algae with onboard memory and processing allowing for easy calibration and configuration of sensors. The data comes from a blue-emitting LED that excites the chlorophyll-a molecule and an orange-emitting LED that excites blue green algae in freshwater. The TAL-PE sensor is used in saltwater applications where the orange LED is replaced with a blue-shifted beam.

The EXO Sonde platform is a flexible product that makes monitoring water quality on a large scale simple. While these sondes are versatile, the battery life is significantly lower than the Aqua TROLL 600. For our application, the Fish Tank Assistant, the basic design of these sondes could be scaled down. The smart sensors used, however, would not be cost effective for our design with the Total Algae PC sensor running over $3,000.

3.1.4 Comparison

Continuous water monitoring systems are extremely popular for large bodies of water including lakes, rivers, and oceans. These devices use smart sensors to detect changes in water quality with common parameters such as temperature, turbidity, and phycocyanin. All products come with mobile interfaces that allow the customer to monitor live data in another location.

	Algae Tracker	Aqua TROLL 600	EXO2 Sonde
Operating Temperature	0 ºC to 50 ºC	-5 ºC to 50 ºC	-5 ºC to 50 ºC
Power	Solar	2 Alkaline D Batteries	4 Alkaline Batteries
Water Temperature	0 ºC to 50 ºC	-5 ºC to 50 ºC	35 to 50°C
Turbidity	0 to 200 NTU	0 to 4000 NTU	0 to 4000 FNU
Chlorophyll-a	0 to 200 µg/L	0 to 1000 µg/L	0 to 400 µg/L
Phycocyanin	0 to 1500 µg/L	0 to 1000 µg/L	0 to 100 µg/L
Weight	8lbs (3.6 kg)	3.2 lbs (1.45 kg)	7.9lbs (3.6kg)
Diameter	14in (35 cm)	1.85in (4.7 cm)	3in (7.62 cm)
Height	7in (18 cm)	23.7in (60.2 cm)	28in (71.1 cm)
pH		0 to 14 pH units	0 to 14 pH units
Number of Sensors	6 fixed	4 ports available	7 ports available
Cost	$3,446	$3,895	Quote

Table 3 Similar Products Comparison

3.2 Hardware Research

The hardware required to build the Fish Tank Assistant must be decided on in the design phase. This includes all physical elements such as: the microcontroller, power supply, and sensors. Based on our House of Quality certain aspects of our design are prioritized over others. To make an educated decision on the components used, the following research has been conducted.

The research has been divided into sections where 3 or more options will be considered and compared based on the generic design of the Fish Tank Assistant. A microcontroller will need to support multiple functions, the power supply must meet the selected boards voltage range, the sensors and display must be integrated properly and programmed to produce the desired output.

3.2.1 Microcontroller

A microcontroller is a small computer that can be integrated and programmed to control electronic equipment. These self-contained systems typically include features such as programmable input/output peripherals, a central processing unit, and volatile memory on a single metal-oxide-semiconductor integrated circuit chip. Using high-level programming languages such as C/C++ and Python, code can be written to for systems like the Fish Tank Assistant.

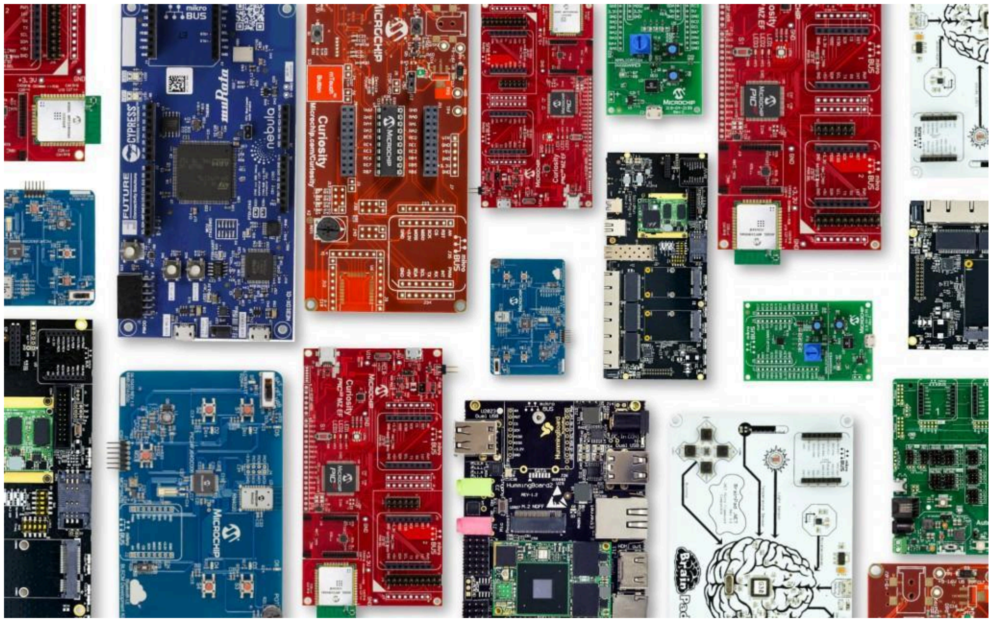


Figure 8: Picture of different Microcontrollers (Courtesy of Mikrow.com)

The Fish Tank Assistant will need a microcontroller to control the components integrated in our final design. Regardless of which board we chose, the steps to completing a successful product will be the same. A power supply must be selected from the available sockets, ports, and pins. The desired sensors, light source and user interface must be configured based on the items required voltage. Once the board is embedded in the new system the last step is to write the appropriate language code, download, and test.

3.2.1.1 Arduino Uno

Arduino was started at the Ivrea Interaction Design Institute with the goal to enable people to enhance their lives through accessible technologies. To be available to everyone, they have created an easy-to-us tool for those without a background in programming or electronics. Their inexpensive boards also have cross-platform functionality as well as open-source extensible hardware and software with project documentation available within the online community.

Arduino offers three ways to program: Arduino IDE 2.0, Arduino IDE 1.8 and Web Editor. Arduino IDE 2.0 is the updated developed software tool for Arduino featuring code highlighting and debugging while the Web Editor will allow for the sketches to be saved securely and synchronized across devices. The Arduino IDE 1.8 should be used for projects based on this version. All tools use a programming language based on C++ with additional functions and offer extensive built-in example codes to assist inexperienced users.

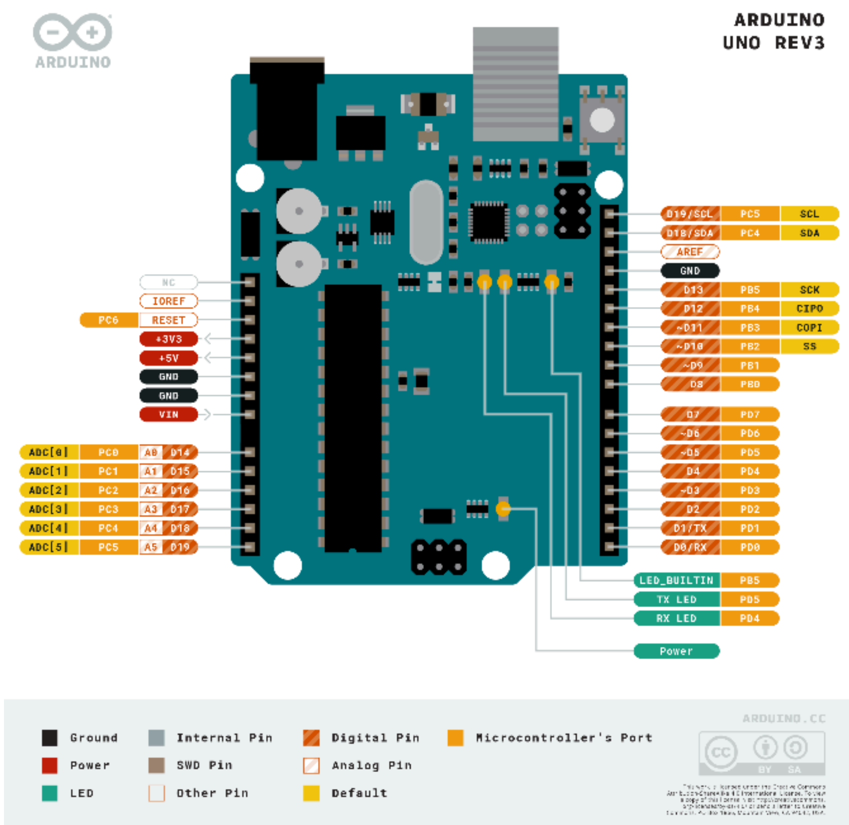


Figure 9: Arduino Uno Pinout Diagram (Courtesy of Arduino.cc)

The Arduino Uno is the first in a series of USB based boards and is a great microcontroller for first time users, the ATmega328P is a replaceable chip and can be easily switched out if an error is made while tinkering with the board. This low power microcontroller has 6 different sleep modes including Idle and Standby. With the flexibility, functionality, and the average cost of a board being around $20, this could be a potential fit for our design.

3.2.1.2 Waspmote

Libelium is a design company that focuses on manufacturing technical solutions that make the Internet of Things available. They developed the Waspmote, which features ultra-low power consumption, digital switches for sensor interfaces, and offers 15 radio technologies including Wi-Fi PRO v3 and Bluetooth 2.1. Using unlicensed protocols and mobile phone technologies, the Waspmote offers a new concept of Wireless Programing.

The Waspmote hardware includes a ATmega1281 microcontroller, a 16GB SD card, 7 analog inputs, 8 digital I/O and an embedded accelerometer. The recommended temperature range is between -20 ºC and +60 ºC but can temporarily support and addition +/-10 ºC. Using the 3 operation modes; Sleep, Deep Sleep, and Hibernate, the Waspmote can compete with other low power consumption Internet of Things platforms.

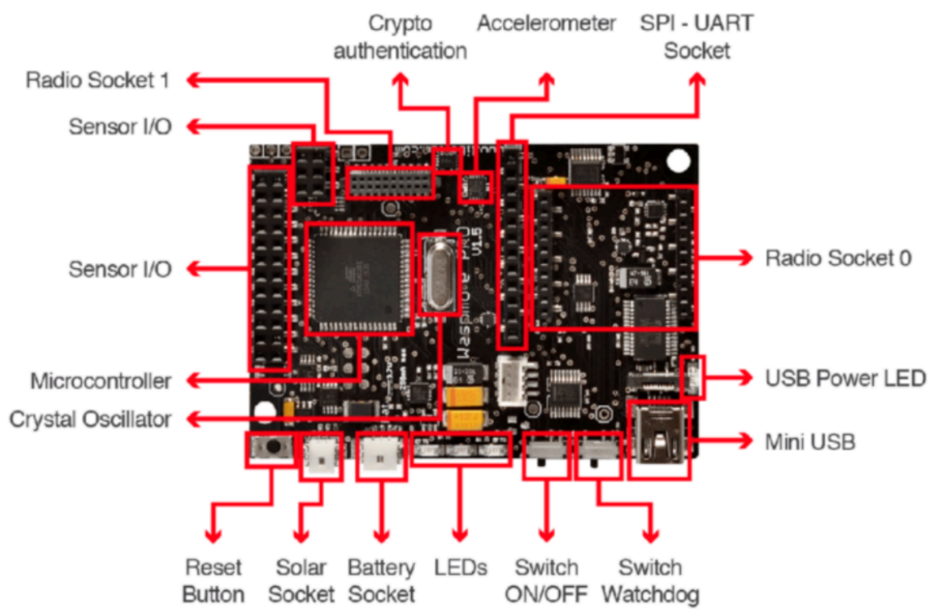


Figure 10: Waspmote Board Configuration (Courtesy of Libelium.com)

Libelium has over 120 sensors available and offers products in parking, security, and water quality. The Plug & Sense has a robust waterproof enclosure with easy to add or change sensor probes. These smart water systems range from $3,000 to over $12,000 depending on the functionality. Unfortunately, due to the component crisis this board is not available currently.

3.2.1.3 Raspberry Pi 3 Model A+

Raspberry Pi is a UK-based foundation that supplies several low-cost computers, microcontrollers, power supplies and more. The latest in the Raspberry Pi 3 range is the A+ that comes with an extended 40-pin GPIO header, MIPI CSI camera port, MIPI DSI display port and dual-band wireless LAN. These features paired with the available Raspberry Pi power supplies and displays could potentially simply the design process.

The Raspberry Pi 3 Model A+ comes with a 64-bit quad core processor running at 1.4 GHz with an input power of 5V via the micro-USB connector or GPIO header. The board also has a micro-SD card connector to support recording data as well as loading operating instructions. The recommended software for this device is the Raspberry Pi Operating System that comes with 35,000 packages containing precompiled software.

Along with providing a small, powerful, and easy to use board, the Raspberry Pi 3 Model A+ can be found online for only $25. Another benefit to using Raspberry Pi is the options for housing such as, with or without a temperature regulating fan. This versatile board has the power, available connections, and program software to be integrated into our final design.

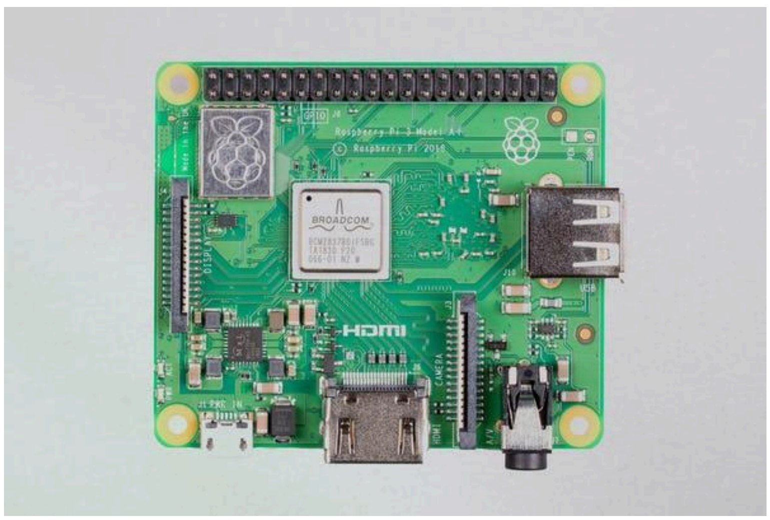


Figure 11: Raspberry Pi 3 Model A+ (Courtesy of RaspberryPi.com)

3.2.1.4 Comparison

There are many variables to consider when choosing a microcontroller for a project. Functions, features, and price are going to influence the decision, for instance Arduino has an open-source community filled with projects, datasheets, and tutorials to guide new system integrators.

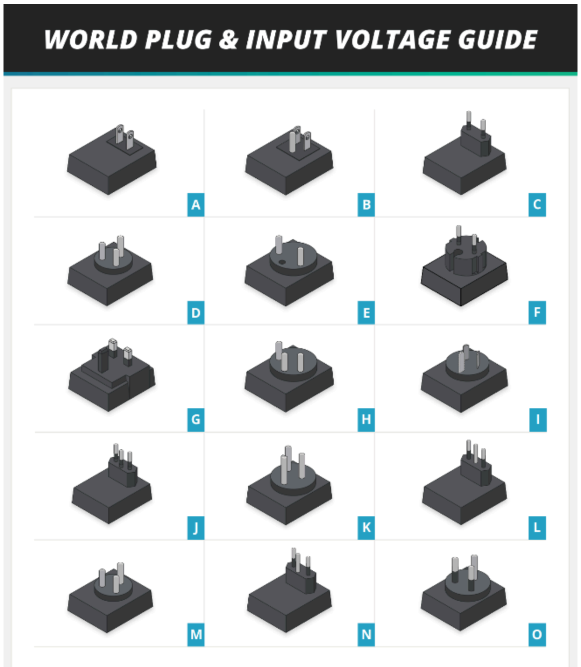
	Arduino Uno	Waspmote	Raspberry Pi 3 A+
Processor	ATmega328	ATmega1281	BCM2837B0

Frequency		14.74 MHz	1.4 GHz
CPU	16 MHz		1.4 GHz
SRAM	2 KB	8 kB	
EEPROM	1 KB	4 kB	
FLASH	32 KB	128 kB	
SD Card		16 GB	Micro-SD Format
Weight	25 g	20 g	23 g
Dimensions	76 x 19 x 64 mm	73.5 x 51 x 13 mm	66 x 56 x 14 mm
Temp Range	-40 ºC to +125 ºC	-30 ºC to +70 ºC	0 ºC to +50 ºC
Clock	16KHz	RTC (32kHz)	

Table 4 Microcontroller Comparison

3.2.2 Power Supply

There are three main ways to supply power to a microcontroller; wall adapter, USB, and batteries. The power level will be determined by the requirements of the components chosen based off the House of Quality. Microcontrollers have a set voltage range that should be considered when selecting a power supply. The greater the voltage range the easier it is to add additional peripherals.




WORLD PLUG & INPUT VOLTAGE GUIDE

Country	Plug type	Voltage	Hz
Nicaragua	A, B	120 V	60 Hz
Niger	A, B, C, D, E, F	220 V	50 Hz
Nigeria	D, G	230 V	50 Hz
Norway	C, F	230 V	50 Hz
Okinawa	A, B	120 V	60 Hz
Oman	C, G	240 V	50 Hz
Pakistan	C, D, M, G	230 V	50 Hz
Palau	A, B	120 V	60 Hz
Panama	A, B	110 V	60 Hz
Papua New Guinea	I	240 V	50 Hz
Paraguay	C	220 V	50 Hz
Peru	A, B, C	220 V	60 Hz
Philippines	A, B, C	220 V	60 Hz
Poland	C, E	230 V	50 Hz
Portugal	C, F	230 V	50 Hz
Puerto Rico	A, B	120 V	60 Hz
Qatar	D, G	240 V	50 Hz
Reunion	E	220 V	50 Hz
Romania	C, F	230 V	50 Hz
Russian Federation	C, F	220 V	50 Hz
Rwanda	C, J	230 V	50 Hz
St. Kitts/Nevis	A, B, D, G	230 V	60 Hz
St. Lucia	G	240 V	50 Hz
St. Martin	C, F	120/220 V	60 Hz
St. Vincent	A, C, E, G, I, K	230 V	50 Hz
Samoa	I	230 V	50 Hz
San Marino	C, F, L	230 V	50 Hz
Sao Tome & Principe	C, F	220 V	50 Hz
Saudi Arabia	G	220/230 V	60 Hz
Senegal	C, D, E, K	230 V	50 Hz
Serbia	C, F	230 V	50 Hz
Seychelles	G	240 V	50 Hz
Sierra Leone	D, G	230 V	50 Hz
Singapore	C, G, M	230 V	50 Hz
Slovakia	C, E	230 V	50 Hz
Slovenia	C, F	230 V	50 Hz
Somalia	C	220 V	50 Hz

Country	Plug type	Voltage	Hz
South Africa	C, M, N	230 V	50 Hz
Spain	C, F	230 V	50 Hz
Sri Lanka	D, M, G	230 V	50 Hz
Sudan	C, D	230 V	50 Hz
Suriname	C, F	127 V	60 Hz
Swaziland	M	230 V	50 Hz
Sweden	C, F	230 V	50 Hz
Switzerland	C, J	230 V	50 Hz
Syria	C, E, L	220 V	50 Hz
Tahiti	A, B, E	110/220 V	60 Hz
Taiwan	A, B	110 V	60 Hz
Tanzania	D, G	230 V	50 Hz
Thailand	A, B, C, F, O	220 V	50 Hz
Timor-Leste	C, E, F, I	220 V	50 Hz
Togo	C	220 V	50 Hz
Tonga	I	240 V	50 Hz
Trinidad & Tobago	A, B	115 V	60 Hz
Tunisia	C, E	230 V	50 Hz
Turkey	C, F	230 V	50 Hz
Turkmenistan	B, C, F	220 V	50 Hz
Turks & Caicos	A. B	120 V	60 Hz
Tuvalu	I	220 V	50 Hz
Uganda	G	240 V	50 Hz
Ukraine	C, F	220 V	50 Hz
United Arab Emirates	D, G	220 V	50 Hz
United Kingdom	G	230 V	50 Hz
United States	A, B	120 V	60 Hz
US Virgin Islands	A, B	110 V	60 Hz
Uruguay	C, F, I, L	230 V	50 Hz
Uzbekistan	C, I	220 V	50 Hz
Vanuatu	C, G, I	220 V	50 Hz
Venezuela	A, B	120 V	60 Hz
Vietnam	A, C, F	220 V	50 Hz
Virgin Islands	A, B	110 V	60 Hz
Yemen	A, D, G	230 V	50 Hz
Zambia	C, D, G	230 V	50 Hz
Zimbabwe	D, G	220 V	50 Hz

Figure 12 : World Plug & Voltage Guide (Courtesy of CUI.com)

An AC/DC Wall Adapter can be used to power a system via the barrel jack, USB Micro-B, or the USB port. These wall transformers are available in various current and voltage configurations. Two criteria to consider when using a wall adapter are what region the product is intended to be supplied to and how many conductors the system requires. The International Electrotechnical Commission publishes a guide that shows the different plugs available by letter designation as well as a table of every country listed with their corresponding plug type, voltage, and hertz.

In many international markets outlets are configured with three conductors, two carry power while the other is used as a ground conductor to protect against unsafe voltages. The United States uses both A and B plug types, but special adapters can be purchased to interchange the conductor configuration. A benefit to using a wall adapter is that the system will not lose power unless the outlet being used does.

The USB port can also be used as a good power source for circuits accepting 5V of direct current. The connection could be made to a wall through the previously discussed adapter, or the system could be powered by a personal computer. The system will need to be powered by a PC while the program is being downloaded. Some new microcontrollers even come with a USB-c connector as another power supply option.

Power can also be supplied to the system via batteries connected to the barrel jack. This can be useful for small, portable systems that do not require continuous power over extended periods of time. Typically, 3.6 volts is the minimum voltage needed to power a microcontroller, which is equivalent to three rechargeable NiMh AA or AAA batteries. Battery packs are also available for systems that require higher voltage ratings. Batteries unfortunately have limited capacity and at some point, will need to be charged or replaced.

3.2.2.1 Comparison

A decision needs to be made on the power supply based on the selected components requirements. A battery or battery pack could be used to power the system but would run into the issue of needing to replace or recharge the batteries intermittently based off the continuous running time. A wall adapter would allow the Fish Tank Assistant to detect algae without interruption contingent upon the outlet supplying power.

	Batteries		
Manufacturer	Duracell ProCell	Rayovac UltraPro	Ultra-Last
Item Number	DURPC1500	RAYALAAA-CP24	ILN4AASL-1000
Voltage	1.5V	1.5V	1.2V
Format	AA, LRA	AAA, LR03	AA. LR6
Chemistry	Alkaline	Alkaline	Nickel Cadmium
Product Category	Primary Common	Primary Common	Consumer Rechargeable
Weight	0.0583 lbs	0.655 lbs	0.1875 lbs
Pack	24	24	4
Price	$15.12	$7.99	413.49

Table 3 Battery Comparison

	Wall Adapter

Manufacturer	Snark Pedal Power Supply	FlickerStar	Moog Minifooger
Item Number	SnarkSA1	B07ZM46WKF	MFoogerPwr
Input Voltage Range	100-120V AC 50-60Hz	100-240V AC 50-60Hz	100-120V AC 50-60Hz
Output Voltage	9V DC	9V DC	9V DC
Output Amps	400mA	1000mA	550mA
Cost	$12.99	$10.98	$19.99

Table 4 Wall Adapter Comparison

3.2.3 Communication Mediums

There are five main ways microcontrollers communicate: Wi-Fi, Bluetooth, Zigbee, GSM, and Radio RF. The most popular are Wi-Fi and Bluetooth with the main difference between them being the purpose of the radio signal communication. Wi-Fi allows multiple users access to high-speed internet while Bluetooth is used for sharing data over short ranges. To connect our device to a mobile app we would require access to the internet, preferably wirelessly, which can be achieved through the integration of a Wi-Fi module.

	Bluetooth	Wi-Fi
Bandwidth	Low	High
Hardware Requirement	Bluetooth adapter on all the devices connecting with each device	Wireless adapter on all devices of the network and a wireless router
Ease of Use	It is simple to use and switching between devices is easier.	It is more complex and requires configuration of hardware and software.
Range	10 meters	100 meters

Security	Less secure comparatively	Security features are better. Still, there are some risks.
Power Consumption	Low	High
Frequency Range	2.400 GHz and 2.483 GHz	2.4 GHz and 5 GHz
Flexibility	Supports limited number of users	It provides support for many users
Modulation Techniques	GFSK (Gaussian frequency shift keying)	OFDM and QAM

Table 7 Comparison Chart (Courtesy of TechDifferences.com)

3.2.3.1 Wi-Fi

Wireless Fidelity or Wi-Fi is a networking technology that allows devices wireless access to the internet. These systems use different radio frequencies to determine the speed and coverage of the data being transmitted. Each frequency band offers multiple channels to decrease interference and overlap. Systems like computers, smart TVs and smartphones come equipped with a wireless adapter called a Wi-Fi card.

Microcontrollers can access the internet wirelessly through Serial Communication or UART interfaces. Serial Communication uses strict protocols and a serial digital binary method to exchange data securely. There are 3 main types of serial communication: simplex, half duplex, and full duplex. The most used mode is full duplex and allows data to be sent and received simultaneously. Universal Asynchronous Receiver Transmitter is a popular serial communication technique used in applications such as GPS receivers, Bluetooth modules, and other wireless systems.

3.2.3.1.1 ESP8266 Wi-Fi Module

Espressif Systems offers the ESP8266, a self-contained Wi-Fi networking system that can be connected to microcontroller-based designs through SPI/SDIO or I2C/UART interfaces. The ESP8266 has 3 operating modes coupled with several proprietary techniques that allow for ultra-low power consumption. Its mobile design makes it attractive to wearable devices as well as other applications to Internet-of-Things. This compact device has a working voltage of 3-3.6V which can be achieved by the selected microcontroller.

3.2.3.1.2 ESP8285

The ESP8285 is based on the ESP8266 with a major change being the 1MB built-in flash to decrease the size and increase the market appeal for wearable technology. It can be used as a stand-alone application or can be integrated with a host MCU. External sensors or devices can be interfaced through GPIOs, and a software development kit is available with sample codes. These low-cost boards can be found online for as little as $3.59 before tax and shipping.

3.2.3.1.3 ESP32

The ESP32 was designed for the best performance through robustness, versatility, and reliability. It includes state-of-the-art power chips for dynamic power scaling, power modes, and fine resolution clock gating. The quicker processor, larger memory, and robust security make this microcontroller ideal for bigger projects. The ESP32 also includes features such as touch sensitivity pins, more GPIO pins, and faster Wi-Fi.

3.2.3.4 Comparison

ESP microcontrollers have advantages such as low power consumption, easy integration with Arduino, and Wi-Fi connection. This family of microcontrollers would be ideal for our design because they can be used to control devices and collect data from sensors. Espressif Systems is a semiconductor company based in China that is focused on developing wireless communication. They have developed a number of mobile Wi-Fi modules such as ESP8266, ESP8285, and ESP32.

Categories	Items	ESP8266	ESP8285	ESP32
WiFi Parameters	WiFi Protocols	802.11 b/g/n	802.11 b/g/n (HT20)	802.11 b/g/n
	Frequency Range	2.4G-2.5G (2400M-2483.5M)	2400 MHz ~ 2483.5 MHz	(2.4 GHz), up to 150 Mbps
Hardware Parameters	Peripheral Bus	UART/SDIO/SPI/I2C/I2S/IR Remote Control	UART/SDIO/SPI/I2C/I2S/IR Remote Control	UART/SDIO/SPI/I2C/DAC/ADC/JTAG
	Operating Voltage	3.0~3.6V	2.7 V ~ 3.6 V	2.3 V ~ 3.6 V
	Operating Current	Average value: 80mA	Average value: 80mA	500mA
	Operating Temperature	-40°C~125°C	–40 °C ~ 85 °C	-40°C~125°C

	Package Size	48.4mm x 25.5mm	15mm x 17.8mm	54.6 mm x 27.94 mm
Software Parameters	Wi-Fi Mode	station/softAP/SoftAP+station	Station/SoftAP/SoftAP+Station	Infrastructure Station, SoftAP, and Promiscuous
	Security	WPA/WPA2	WPA/WPA2	ECC/RSA

Table 5 ESP Comparison

3.2.4 Display

Many microcontrollers have built-in circuitry for 3 main display drivers such as: Liquid Crystal Display (LCD), Light Emitting Diodes (LED), and Organic Light Emitting Devices (OLED). These displays are used to output messages and desired results from the system. LCDs are flat panel displays divided into layers with liquid crystal or plasma in the middle of a glass electrode that lights up when power is applied across it. LEDs use gallium arsenide or gallium phosphide that emit light when heated. Both applications are extensively used in dot matrix or segmental displays of alphanumeric characters.

3.2.4.1 Liquid Crystal Display (LCD)

LCDs are made up of glass filters, polarizing film, and electrodes surrounding a liquid crystal layer, backed by a reflective surface. These displays use a reflector to produce images because they do not emit light directly. The most common dimension for LCDs is 16 columns by 2 rows but also has many applications for larger scales including high resolution displays. This thin, low power consumption technology made products like TVs and smartphones possible.

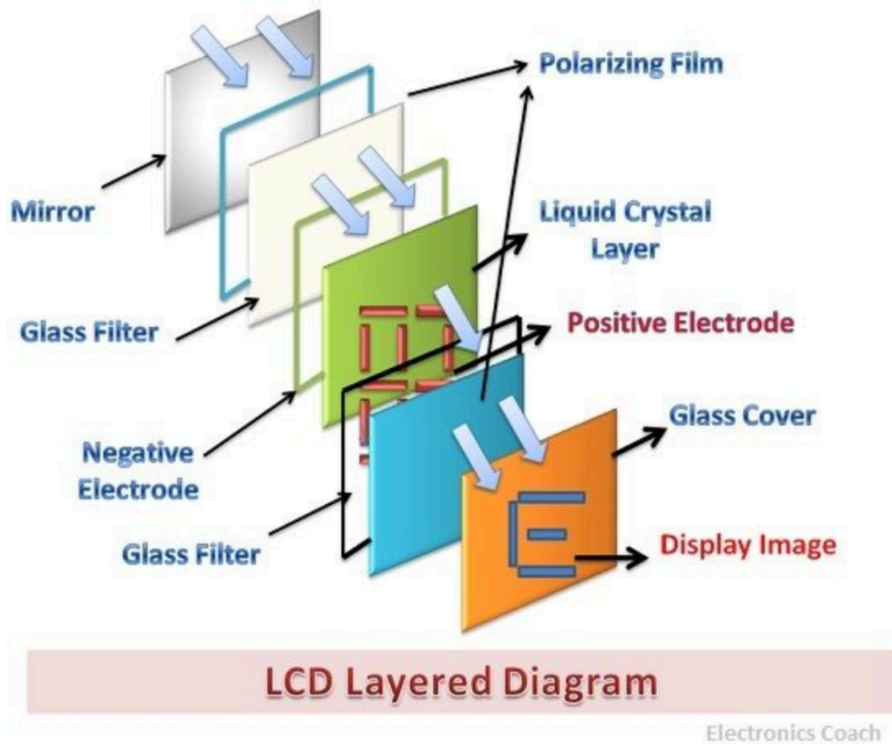


Figure 13: Layer of an LCD (Courtesy of ElectronicsCoach.com)

LCDs offer a touch screen feature with an additional layer of non-conductive material such as glass placed on top of the display screen. Conductive sensing elements that can detect drops at specific locations are configured before being covered by the capacitance layer. This has small lines containing a charge that can be impacted by a conductive material encountering the screen. These displays typically have low power consumption and cost but also require AC, due to DC reducing the lifespan.

3.2.4.2 Light Emitting Diode

An LED is a PN junction that uses a translucent semiconductor material with galvanized arsenide's that naturally emits yellow or red light when heat is applied. These displays use a panel of LEDs arranged evenly throughout as a screen and have made developments such as flexible screens, curtain displays, and are widely used in applications such as stadium and advertising screens.

3.2.4.3 Comparison

Microcontroller displays come in a variety of sizes ranging from simple single character outputs to large capacitive or resistive touch screens. System requirement will dictate the minimum size and type required. Small LCD character displays and LED displays are undesirable for products requiring a substantial data output interface. LCD and OLED screens offer capabilities like a tablet or smartphone that can display data in the form of charts and other helpful displays.

	LCD			LED)	OLED
Manufacturer	Newhaven Display International	4D Systems	East Rising	Adafruit Industries LLC	Waveshare
Manufacturer Product Number	NHD-0420H1Z-FSW-GBW	4DLCD-32	ER-TFT035-6	MI-T35P6RGBF-AA (6432)	14747
Description	Character LCD	Graphic LCD	Touch LCD	RGB LED Dot Matrix	RGB OLED
Diagonal Screen Size		3.2 in	3.5 in		1.5 in
Display Format	20 x 4			64 x 32	
Display Type	STN	TFT	TFT		
Viewing Area	60mm x 28mm	48.6mm x 64.8mm	50.5mm x 75 mm	385mm x 190mm	26.86mm x 26.86mm
Voltage Supply	4.7V ~ 5.5V	3.3V ~ 3.6V	2.5V ~ 3.3V	5V	3.3V ~ 5V
Controller Type	SPLC780D	ILI9341	ILI9488	MBI 5024	SSD1351
Operating Temperature	-20°C ~ 70°C	-20°C ~ 60°C	-20°C ~ 70°C	-20°C ~ 60°C	-30°C ~ 70°C
Price	$22.66	$22.99	$19.25	$64.95	$18.95

Table 9 Display Comparison

3.3 Optical Research

Our optical research is based on the absorption spectrum of Chlorophyll A and Beer's law. Chlorophyll A is the green pigment present in the algae found in freshwater and saltwater which commonly appear and grow in fish tanks. There are three kinds of chlorophyll pigments, including chlorophyll A, there is chlorophyll B, C1, and C2. Chlorophyll A is significant in all algae; other pigments are often present, which gives the various kinds of algae the colors we view them as according to (ucmp [1]). From the given table, chlorophyll A is present in all the algae presented; however, the combination of chlorophyll A and chlorophyll B is what gives the green color for the green and Euglenophyta algae because each of these pigments absorbs light in the violet-blue and orange-red spectrums and reflect wavelengths in the yellow to green range. Other algae, such as brown and golden-brown algae, have the orange red Fucoxanthin pigment, while the yellow-green pigment Diadinoxanthin is present in the yellow-green algae. The combination of chlorophyll A and chlorophyll C absorbs the other wavelengths creating a yellow-green, golden-brown, or brown color from the reflected light and the accessory pigments. Red algae's color derives from the absorption spectrum of chlorophyll A and its two red and blue-green accessory pigments, Phycoerythrin and Phycocyanin, respectively. Fire algae are the most troublesome kind of algae as they are responsible for the deadly red tides worldwide. More precisely, the dinoflagellate algae are the Pyrrophyta algae that cause these harmful algae blooms. The color of the red tide is a combination of Chlorophyll A, C2, and Peridinin. This combination absorbs light in the violet to green spectrum and reflects light in the yellow to red spectrum giving the red tide its color and name.

Algae	Chl A	Chl B	Chl C1	Chl C2	Accessory pigments
Green Algae (Chlorophyta)	H	H	-	-	-
Euglenophyta	H	H	-	-	-
Golden-Brown algae & Diatoms (Chrysophyta)	H	-	H	H	Fucoxanthin
Fire Algae (Pyrrophyta or Dinophyta)	H	-	-	H	Peridinin
Red Algae (Rhodophyta)	H	-	-	-	Phycoerythrin & phycocyanin
Yellow Green Algae (Xanthophyta)	H	-	H	H	Diadinoxanthin
Brown Algae (Phaeophyta)	H	-	H	H	Fucoxanthin

Table 10 Algae Pigment Comparison (based on Mar Drugs article [2] Copyright approval pending)

Furthermore, the absorption spectrum of chlorophyll A has the most evenly distributed absorption peak heights in the violet-blue and orange-red spectrums, whereas chlorophyll B and C both have absorption peaks in the violet-blue range that are twice the height of the peaks in the orange-red range. Chlorophyll A's absorption characteristics make the light source wavelength specification for the system absolute. The light needed for our system will have to be in the violet-blue range.

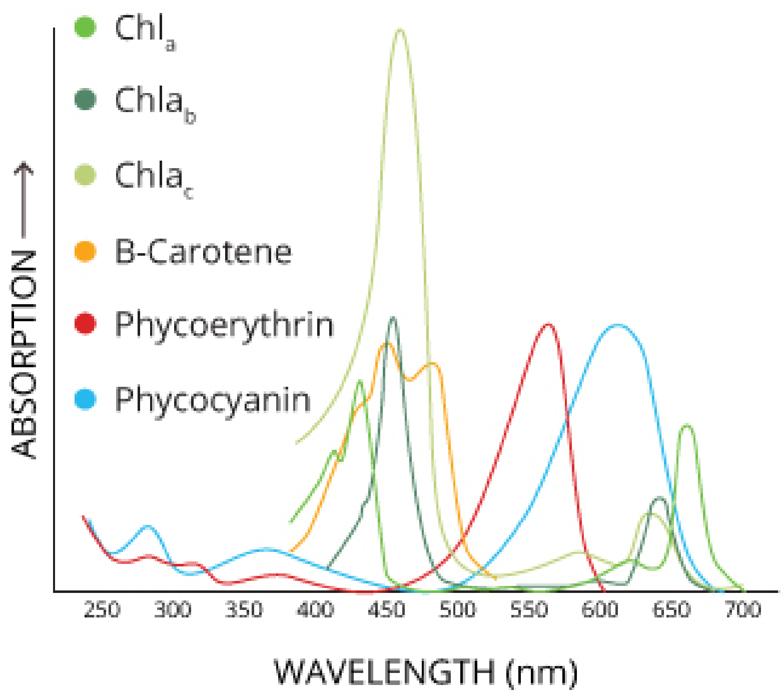


Figure 14: Pigment absorption spectrum (Courtesy of Fondriest [3] Copyright approval pending)

We have decided to use Beer's law $Transmitted\ power = \frac{I_{out}}{I_{in}}$. The source light will be split through a beam-splitter allocating 50% of the transmitted power to a photodiode, representing the input power. In contrast, the other half will transmit through a glass tube containing the sample water causing it to diverge. A lens will then correct the divergence to focus the beam onto the second photodiode representing the output power. In theory, if there are no algae present, there will not be any light absorption which will give 100% transmitted power; however, when algae are present, the percentage of transmitted power will reduce from 100%, indicating absorption has occurred. When absorption occurs, we assume that Chlorophyll A is present and causes a percentage of light loss in transmission.

3.3.1 Light Source

The light source was the first focus of our research as it is the deciding factor whether the design succeeds or fails. Therefore, the first specification to fill was whether a collimated or uncollimated light source would be the most cost-effective and design-efficient option. The overall optical design would require a collimated light source. If we chose an uncollimated source, we would need to design and purchase the correct focusing elements to collimate the beam to the preferred waist size.

We decided to start light research into possible uncollimated sources such as LEDs while keeping our affordable requirement in mind. Our research continued only a little further after discussing the need for LED drivers, which would require more funds and more space for the physical requirements. We decided to turn our attention back to collimated sources such as collimated LEDs and laser diodes. Collimated LEDs would still require a driver but had the potential for a less complicated and less costly design. However, we ended with equivalent results and decisions for collimated LEDs and laser diodes due to needing a driver or additional equipment that restricted or violated our physical design requirements. The final light source considered was a laser pointer filling the collimation specification and the physical design requirements.

With the preferred light source determined, we combined the algae and chlorophyll A research to ascertain the source specifications needed. We started with an in-depth investigation into more source material to verify the absorption spectrum of chlorophyll A for determining the best peak wavelength to operate our optics system. The sources of information varied from research articles to online spectrum generators. In total, the number of resources investigated was eight. The first one was used to understand what pigments are in algae and how they can affect the colors of different algae and confirm they all contained prominent levels of chlorophyll A from our initial search. We then investigated what chlorophyll and algae are according to (sciencing [4]). We then considered the types of algae common in fish tanks (Tankarium [5]) gives 15 examples of common algae, although not all of them are listed with their scientific names and are listed under descriptive laypeople's names. We did notice some of the algae by their class of algae, such as red algae and brown algae, and a few types of bacteria called cyanobacteria, the bacteria that creates the blue-green algae. Although these cyanobacteria are not true algae, they still use photosynthesis which requires chlorophyll A; this means our system can detect even the algae that are not classified as true algae. The absorption spectrum of chlorophyll A has absorption peaks in the violet-blue range and the orange-red range while reflecting the green-yellow range.

Due to the location of the highest absorption peak being in the violet-blue range, we decided it was the best option for our source. We then decided to investigate which peak wavelength would work best for the system by considering what wavelength would be available on the market, such as wavelengths that are a factor of five. These wavelengths are most likely to be readily available for purchase on the market and would not require any special orders. Based on the spectrum from Fondriest [3], we looked to verify that this spectrum was accurate using a couple of other sources. Our second source was (ib.bioninja [6]), which generated two spectrums, one defined as "The action spectrum indicates the overall rate of photosynthesis at each wavelength of light" and the "absorption spectrum," which was the spectrum we were interested in. We then investigated our third source, Wikimedia [7]; all three sources gave a similar spectrum which we tabulated below.

Light Characteristic	Absorption	Reflection	Absorption
Color Range	Violet - Blue	Bluegreen - Yellow	Orange - Red
Wavelength (in nm)	400 - 470	470 - 590	600 - 700

Table 11 Absorption and Reflection Range of Chlorophyll A

The peak absorption range is a vital piece of information for our system to work correctly; it is the absorption of the light that will represent the presence of algae via the Chlorophyll A absorbing some of the optical power transmitting through it in that wavelength range. Due to the importance of the absorption wavelength, we estimated that the peak wavelength was about 450 nm or a little less; however, we decided to use 450 nm for our optical source specification. Our attention then focused on the market research into laser pointers available on the market. The following table compares the light sources we considered from the available products on the market.

Source	Available 450 nm Peak Wavelength	Available in 10 mW or less	Collimated	Under $50	Additional Equipment Needed
Laser Diode	✔	×	✔	×	✔
Uncollimated LED	✔	×	×	✔	✔
Collimated LED	×	×	✔	×	✔

Laser Pointer	✔	✔	✔	×	×

Table 12 Light Source Comparison

3.3.1.1 A Multi-Platform Optical Sensor for In Vivo and In Vitro Algae Classification [8]

Our main source of product research for our optical design ideas was this research instrument. While not a marketed product but a research instrument, it still offered valuable optical insight into algae detection and optical design. This system was far more capable of multiple optical measurements due to its need to identify the different algae in large body ecosystems. Chlorophytes are beneficial to aquatic life, providing food to many animals. At the same time, cyanobacteria are harmful; however, both contain chlorophyll A, the pigment our system aims to detect. While algae are beneficial to free ecosystems, it is typically not a pleasant sight for fish owners who want to view their fish without obstruction.

For this reason, we are only interested in detecting algae rather than identifying it. This research instrument measured the analytical volume and the absorbance of the specimens they were looking to identify. However, instead of a single wavelength light source, they chose a broadband source with a range in the UV to NIR spectrum of light far outcompeting our system's single wavelength source for absorbance measurements. In addition, their LEDs were optically enhanced to measure the analytical volume and were six in total. Each LED operated at an individual peak wavelength, displayed in the following table along with the numerical wavelength of the broadband source.

Color (Wavelength) Range	LEDs	Broadband
Ultraviolet (nm)	371	185
Violet (nm)	402	
Green (nm)	523	
Yellow (nm)	572	To
Orange Yellow (nm)	595	
Orange Red (nm)	612	
Near Infrared (nm)	-	1100

Table 13 Light Source Peak Wavelengths and Broads Spectrum Range

Nonetheless, our expectations and goals are different from their system, which led us to decide on the single wavelength for which we aim to detect the presence of all types of algae that may impact the visual appeal of fish tanks.

3.3.2 Laser Pointer Market Availability

A challenging product search began to locate an affordable laser pointer operating at the 450 nm wavelength. There are many blue (450 nm) light laser pointers available. Still, the problem arises when the most abundant product is a laser pointer operating at extraordinarily high powers, such as 2000 milliwatts like the one offered by Biglaserpointers [9]. This laser pointer would have made it easy for us to use due to the extensive online information provided on their website. The information they included was extensive and covered every piece of information needed for designing an optical system, such as the beam divergence, the peak wavelength, optical power, beam distance, and eyewear safety required. We saw many other laser pointers in the 450 nm wavelength at varying prices, but the majority of the ones available had optical powers too strong for our system to use. These laser pointers, called high-power burning laser pointers, pose a severe hazard, are expensive, and are not suitable for our optical design. Our second option was for a cheap simple laser pointer most would think of for playing with their pets or using as a presentation aid is around five milliwatts of optical power, like the one offered by the Jearyeng Amazon store [10]. While cheap and safe for use in our system, many laser pointers come in a violet wavelength of 405 nm, which is not ideal for Chlorophyll A to absorb and is not within our optical design specification. Finally, we came across a laser pointer operating at five milliwatts and transmitting at the preferred blue (450 nm) wavelength offered by Alpec [11]. They offered what we were looking for, but the online information compared with the high-power burning laser pointers was disappointing and was not the most affordable. We decided to make a comparison of the products we found to calculate the best option for the final product which we tabulated here.

Laser Pointer	Price	Peak Wavelength	Optical Power	Power Source	Laser Class	Additional Information Provided
Biglaser pointers [9]	$109	455 nm	2000 mW	2 x 16340 Li-ion Batteries	IV	Yes
Jearyeng Amazon store [10]	$14.88	405 nm	5 mW	2 x AAA Batteries	III	No
Alpec [11]	$84.99	450 nm	5 mW	2 x AAA Batteries	IIIA	No

Table 14 Laser Pointer Comparison

The table suggests the best option out of all of them is the Alpec laser due to the safety concerns of the Big laser pointers and the low peak wavelength of the Jearyeng. However, due to the higher price, we decided to order some test laser pointers at a much more affordable price at the same optical power for testing purposes and to use as prototypes when designing the circuits, which would minimize the risk of damaging the preferred laser pointer, which would give us room to make small mistakes on the test laser pointers saving us time and funds.

3.3.3 Photodiode and Thermal Camera

The photodiode research conducted to determine the most suitable kind for our design started with general research into photodiodes. A silicon photodiode seemed like the obvious option. However, we wanted to be thorough in our investigation of photodiodes in general. According to Allaboutcircuits [12], silicon is the optimal choice for visible light due to its sensitivity to this light range (400 nm to 700 nm). Although this seems ideal, one of the downsides of photodiodes, in general, is their temperature instability according to Ecstuff4u [13]. If not counteracted with climate estimations and stabilizers through cooling systems, this instability could pose system inefficiencies. While cold temperatures have the potential of posing instability, the probability is low due to the heat created by electrical components and typical indoor housing temperature remaining constant enough for performing calibrations in the initial testing. For our optical design, it was essential to find photodiodes with a high responsivity around our desired peak wavelength of 450 nm. While this sounds easy at first, it can become a long search given the abundance of silicon photodiodes available in the market. Silicon photodiodes with a sensitivity or responsivity around the red (650 nm) to yellow (580 nm) wavelength range would most probably have low sensitivity or responsivity to the blue (450 nm) wavelength at which we planned to operate. A few of the potential photodiodes were tabulated for comparison. However, some sellers did not offer many details on the products, which weighed heavily on our preferences out of the ones listed.

Photodiodes	Price	Peak Wavelength Sensitivity/ Responsivity	Active Area
SD-076-12-12-011-Photodiode [14]	$14.95	Undefined	$2.9\ mm^2$
MTD5052N [15]	$7.46	525 nm	undefined
MTD5052W [16]	$7.46	525 nm	$0.62\ mm^2$
BPW21R VISHAY [17]	$8.02/each for pack of 3 or more	565 nm	$7.5\ mm^2$

Table 15 Photodiode Comparison

Figure 15: Silicon Photodiode (Courtesy of TME [17] Copyright approval pending.)

Based on the comparison of the four different photodiodes, the TME photodiode is our preference out of the given four. Because of its low cost for each diode and the complete information provided for the product, it proves to be the best option for our project requirements. Furthermore, the active area of the photodiode also played a significant role when deciding on our preference, as the TME photodiode has the largest chip active area out of all. The active area size would benefit the design as we would not need to worry too much about focusing the beam down if we decided to focus it onto the photodiode instead of overfilling the active area with light. The low product cost also meant we would be able to purchase a few backup photodiodes if one or both needed in the design were damaged.

There were concerns that the peak sensitivity wavelength was 115 nm away from our peak wavelength, so we investigated the spec sheet for the photodiode, which allowed us to find the sensitivity graph, which showed that for the wavelength of 450 nm, the sensitivity was 0.7 which was plenty for our design needs.

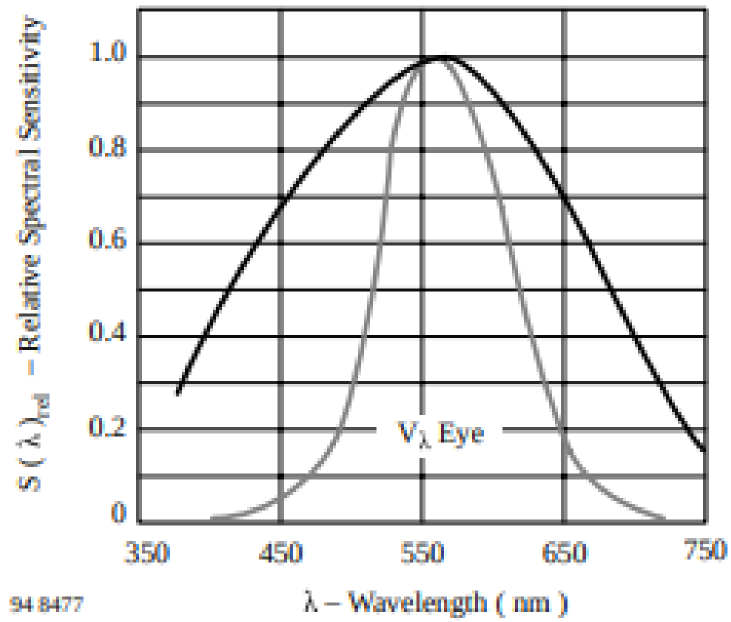


Figure 16: Relative Spectral Sensitivity Plot for Photodiode (Courtesy of TME [17] Copyright approval pending.)

All further research into photodiodes and useful equations for potential calculations later are sourced from (isl.stanford [18]) copyright pending or from other sources listed later.

Due to this instability, the water temperature of the fish tank is both an essential variable for the calculation of light absorbance and a necessary part of fish care. Therefore, fish care is our main reason for researching temperature monitoring designs and options. Consequently, we decided on a small thermal camera for this task for which it would be aimed at the water tube allowing for the camera to sense the surrounding temperature in the optical component enclosure and the water temperature through the water being siphoned through the tube, giving a highly efficient way to monitor fish tank temperatures. The thermal camera we considered was from Digikey [19] referred to as an MLX90640 thermal camera breakout. The small camera uses an array of 768 pixels (32x24 pixels) for imaging while only requiring 3.3 to 5 volts to operate. The standard viewing angle is 55° and features 64 FPS. It also features an accuracy up to 1°C for a temperature range of -40° to 300°C.

Figure 17: Thermal Camera (Courtesy of Digikey [19] Copyright approval pending)

3.3.4 Lenses and Beam-splitter

For our design, we wanted to split the power of the source light by equal power and have the beam concentrated when it reaches the photodiodes. We have considered having the beam focus to a point onto the photodiode or collimating the beam to overfill the photodiode sensor. We have considered two separate ways of designing the focusing lens. The first is to use a plano-convex lens combined with a plano-concave lens positioned plano side to plano side, which allows for a collimated beam to focus down to a minimal point by going through two plano-convex lenses due to the negative curvature acting like a positive curvature when the beam travels through the plano side first. We considered this design as it would potentially allow for more customizable focal lengths by choosing the different focal lengths of each lens. Our second design uses a lens capable of focusing, diverging light to a point, and converging it at its focal length. For this alternative design, we would use a bi-convex lens capable of focusing diverging light down to a point. In addition, a bi-convex lens would bestow us with the simplicity of using a single lens. The single-lens design is also more affordable than the alternative design and permits simplicity in deciding how to mount the optics in the final product. We then considered the focal lengths we would want to consider as the focal length could not be too long.

Otherwise, we would be unable to place the photodiode at or a little behind the focal length. The reason for wanting to place the photodiode after the focal length is if we decided we wanted the beam to overfill the photodiode sensor, which is 7.5 mm^2 completely. We also wanted to have the ability to place the photodiode before the focal length for the same reasons as we are considering overfilling the photodiode sensor. In our physical specifications of the project, we decided we wanted to keep the dimensions no larger than a cubic foot which implied we should keep the focal lengths under two inches to allow for wiring and the other more significant components, which would take up a more considerable amount of space. We also had to consider the mounting as we plan to 3D print our optical mounts in contemplation of saving on costs. With that information in mind, we looked at three different possible focal lengths that we would be able to use in our system. The focal lengths considered were 25 mm, 30 mm, and 40 mm. Out of these three choices, we considered where the focal length would be established with regards to the water tube as we wanted it to be at the exiting surface or in the center of the water tube. If we decided on choosing the center of the water tube, we would need to subtract the outer radius of the tube from the focal length for that side of the lens. This subtraction posed a potential complexity problem when aligning the system if the measurement outside of the tube was a fraction of a millimeter.

Furthermore, we consider the potential of beam distortion from longer optical paths where the potential for air or temperature differences could cause turbulence and decrease the optical power. Another parameter we had to consider was the diameter of the lens and what size would work best for us. Due to our optical design aiming for simplicity instead of complexity and having significant time constraints, we wanted to substantiate that our alignments would not be complicated or too sensitive, which could be the case if we tried handling small optics. We also considered the accuracy capabilities of 3D printers that are accessible to us and wanted to make sure we did not try to use optics that would be too difficult to create competent mounts for from the 3D prints. Our last specification would be for an anti-reflective coating in the visible range which Thorlabs labels as an A coating, and we also wanted to compare the difference between UV-fused silica lenses and NBK-7 lenses due to UV-fused silica lenses not exhibiting any laser-induced fluorescence. We started our market research for potential matches to our specifications based on these desired specifications. We decided to look through Thorlabs optics as our optical engineers are the most familiar with this optics brand and its specifications. The following table compares the different lenses with our desired specifications.

Lens	Focal Length	Diameter	Available coating	Material	Price
LB1761-A [20]	25.4 mm	25.4 mm	(A) 400 –700	NBK-7	$40.21
LB1757-A [21]	30.0 mm	25.4 mm	(A) 400 –700	NBK-7	$39.38
LB1027-A [22]	40.0 mm	25.4 mm	(A) 400 –700	NBK-7	$38.27

LB4879-A [23]	35.0 mm	25.4 mm	(A) 400 –700	UV-Fused Silica	$149.73
LB4096-A [24]	50.0 mm	25.4 mm	(A) 400 –700	UV-Fused Silica	$115.35

Table 16 Bi-convex Lens Comparison

From the comparison, we have decided we prefer the NBK-7 material as it is more affordable than the UV-fused silica. However, we came to the following conclusion from the three NBK-7 lenses we considered. First, if we chose a focal length of 25.4 mm, this violates the design specification of being an integer. We then considered the 40 mm focal length lens, and while it is an integer, it is 1.5 centimeters longer than the 30 mm focal length. Due to the split millimeter and the long focal length of the third lens, we decided that the 30 mm focal length would be most favorable as there would be less chance of beam distortion using the smaller focal length.

We also investigated what we were looking for in a beam-splitter which included the price, size, power ratio split, and the anti-reflective coating. Research on the beam-splitter was mostly market research as these were the parameters we desired. The price was our first concern as we aimed to keep the project affordable; secondly, it had to have a 50:50 power ratio split for our calculations to be accurate.

For the beam-splitter size, we wanted the incident surface area large enough for the beam size to fit on easily. However, the size should not exceed two inches to conserve physical space in the enclosure box. Lastly, the desired coating should be anti-reflective to help the desired wavelength (450 nm) transmit and reflect accurately while all other ambient light not in the specified coating wavelength reflects. Before researching, we previously established a few of the lens parameters, including the required coating and the desired lens diameter. We decided that the lens diameters should be no larger than an inch, and the anti-reflective coating should be in the visible range.

Figure 18: 50:50 Ratio Beamsplitter (Courtesy of Thorlabs [25] Copyright approval pending)

We currently have two functional designs, both of which will require a lens for the side that will travel through the water sample. We have designed this based on the housing properties for the water sample. The housing will be a cylindrical tube of material most likely to be a glass with a refractive index of around 1.5.

Beam-splitters	Less than $150	Split Ratio 50:50	VIS AR (400 to 700 nm) Coating	1" Beam Incident Surface
Circular Plate Beam-splitter BSW10 [25]	✔	✔	✔	✔
Cube Beam-splitter BS013 [26]	×	✔	✔	✔
Wedge Beam-splitter BSF2550 [27]	✔	×	×	×
Square Plate Beam-splitter BSW10R [28]	✔	✔	✔	×

Table 17 Beam splitter Comparison

3.3.5 Salinity Detection

For one of our stretch goals, we wanted to detect salinity levels for saltwater tanks or when freshwater tanks are having the water replaced. So, the first part we researched was the kinds of salt used in fish tanks. A quick online search helped us understand the importance of salt type used for fish tanks. For freshwater aquariums, use sodium chloride, just table salt. However, it is not as simple for saltwater tanks to use ordinary salt because it does not contain minerals that the fish need, so buying marine salt is necessary for saltwater tanks.

Once we accounted for the difference in salt, we investigated the differences and found the overall dissimilarities were not significant enough to differentiate in the absorption spectrum. From the investigation, we realized that the absorbance spectrum for sodium chloride was in the NIR (780 nm to 2800 nm) to IR (780nm to 1 mm) range, for which we would require additional equipment. Therefore, we decided to leave salinity level detection as a future manufacturing goal that we are considering as another attachment or upgrade from this system for which mass production would reduce the overall cost, which we are not capable of doing.

However, if we were to design this upgrade, we would require a broadband source in the current design and superior detection devices to differentiate between the different wavelengths. In addition, the coatings on all optical elements would need to be changed, and drivers for the source would be required. Due to these expensive and time-consuming requirements, we have opted to leave this for potential future development.

3.3.5.1 Available Market Product Comparison

For marketability, we decided to investigate how consumers typically check the salinity levels in their tanks, and we came across many products, all of which were cheaper alternatives to anything we were able to design in the period we had. Due to this reason, we decided to leave salinity detection up to large-scale manufacturing as the following products are examples of how large-scale manufacturing leads to a more affordable sales price, which is desirable to consumers. For visualization purposes, we constructed a table for comparison of the products along with our own design upgrade based on the price of an available broadband light source.

Product	Price of Product/ Cost of Upgrading	Fast Shipping	Easy Integration into Current Optical Design

Digital Salinity Tester for Salt Water [29]	$39.99	Free 2-day Amazon Prime	Circuit integration with tip submerged into fish tank with protective caging surrounding it to keep fish out
2-in-1 Combo pH & Temperature Meter Water Quality Tester [30]	$32.99	Free 2-day Amazon Prime	Circuit integration manual operation required for powders
Instant Ocean Aquarium Water Test Hydrometer [31]	$8.62	▪ Available in Store ▪ Same Day Shipping $8.62 ▪ 1-2 Day Shipping for $5.17	Manual dipping required
Our Salinity Meter Upgrade SLS201S [32]	Minimum of $1,120 for Broadband Light Source	2-Day Shipping $47.18	NaCl NIR absorption using additional equipment and drivers for source operation

Table 18 Alternative Salinity Equipment Comparison

3.3.6 Propagation in Water Tube

In our design, we have decided to use a glass tube for the testing to occur. Glass was the best option for our needs for its sustainability and durability. We were not overly concerned about the sizing of the tube if it had an outer diameter more significant than the beam size at the incident surface. The beam would diverge once transmitting through the water and back through the tube, so we predetermined to need a focusing lens before the photodiode. We investigated square acrylic tubing originally for optical simplicity. However, this proved to be extremely difficult to find. We investigated as much as possible and only produced two viable options for square glass or acrylic tubing. Our alternative option was for a cylindrical tube which would cause more extensive diversion of the light when propagating through it and cause more complex calculations. We were hoping to obtain square tubing for our optical design for these reasons.

3.3.6.1 United States Plastic Core [33]

This plastic tubing is 1.25 inches in outer diameter, one-inch inner diameter, one-inch thick, and made of acrylic, so the refractive index is 1.49. At a price of only $3.91 per foot with a minimum of six intervals required to place an order, there were a few downsides at this point. After confirming our optical design, we decided to obtain this component. However, this is where the problem arose. The minimum order amount was $23.46, which was not much of a problem, but the shipping costs claimed to be $40 or more when we went to check out. For our system, we specified we wanted the system to be as affordable as possible, which eliminated this product from our options. If later our project were manufactured on a large scale, the costs for this tubing would be lower per foot, resulting in a simplified optical design and lower market price.

3.3.6.2 Plexiglass Acrylic Sheets [34]

Plexiglass acrylic sheets were our second option for a square tube. Constructing a square tube ourselves was not as desirable as premade square tubing. However, in the beginning, it was still more desirable for our optical design and simplified calculations, so we decided to go forward with the investigation. The constructed tube would need to be perfectly waterproof to protect all optical and electrical components from water damage. Furthermore, the tubing would need perfectly straight edges for the best results. The question then arises about how to effectively connect the last panel if it was to be sealed on the inside and outside, requiring careful application of the sealant to the inside joining edges while not allowing for any mistakes resulting in water leakage. More concerns arose after the previous one, including time consumption, fitting a cylindrical siphon tube into a square optical water tube, water pressure stress, sustainability, durability, and social constraints such as sealant chemicals harming the fish or bacteria build up on the sealant. Our final decision was to opt for a cylindrical tube for the design.

3.3.6.3 Cylindrical Tubing

Cylindrical tubing was not our ideal choice; however, research began with the other options becoming less desirable due to time or economic constraints. Initial concerns focused on the tubing curvature and its effects on the beam. Next, calculations began to estimate the beam behavior when incident on a tube. Our options for the tube material included

- Undefined glass with a refractive index of 1.5
- Acrylic with a refractive index of 1.49
- Pyrex glass with a refractive index of 1.47

The other refractive indexes to remember were air and water 1.0 and 1.33, respectively. We then considered Brewster's angle $\theta_B = \arctan\, arctan\left(\frac{n_2}{n_1}\right)$ and total internal reflection which occurs when $\theta_i > \theta_{critical}$ and $\theta_{critical} = \arcsin\, arcsin\left(\frac{n_2}{n_1}\right)$ if $n_1 > n_2$.

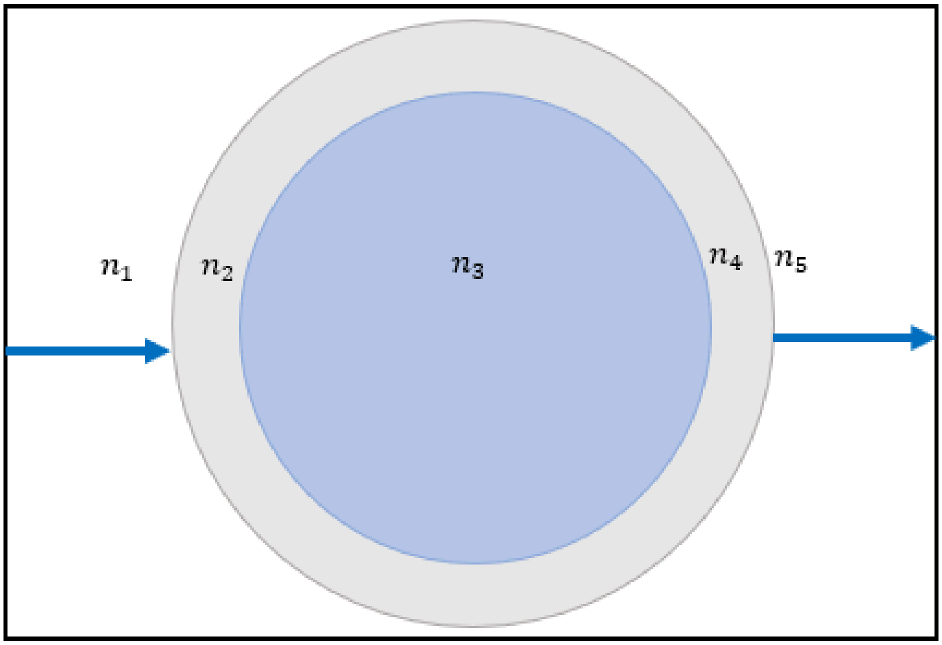


Figure 19: Water Tube Cross Section Model

We calculated Brewster's angle and the critical angle, referencing the corresponding interface for each of the different possible material types. A 90° incident angle was used for the design for easy alignment purposes while eliminating the need for manual adjustments of other optical components. Using Snell's law, the angles are calculated and compared with Brewster's angles and the critical angles to determine if total internal reflection or polarization occurs.

Undefined Glass n=1.5				
Surface	Incident Angle θ_i	Refracted Angle θ_r	Brewster's Angle θ_B	Critical Angle θ_c
Air to glass	90°	41.81°	56.31°	-
Glass to water	41.81°	48.75°	41.56°	62.46°
Water to glass	48.75°	41.81°	48.44°	-
Glass to air	41.81°	90°	33.69°	41.81°

Table 19 Undefined Glass Material Propagation Calculations

Acrylic n=1.49				
Surface	Incident Angle θ_i	Refracted Angle θ_r	Brewster's Angle θ_B	Critical Angle θ_c
Air to glass	90°	42.16°	56.13°	-
Glass to water	42.16°	48.75°	41.75°	63.2°
Water to glass	48.75°	42.16°	48.25°	-
Glass to air	42.16°	90°	33.87°	48.75°

Table 20 Acrylic Material Propagation Calculations

Pyrex Glass n=1.47				
Surface	Incident Angle θ_i	Refracted Angle θ_r	Brewster's Angle θ_B	Critical Angle θ_c
Air to glass	90°	42.86°	55.77°	-
Glass to water	42.86°	48.75°	42.14°	64.79°
Water to glass	48.75°	42.86°	47.86°	-
Glass to air	42.86°	90°	34.23°	42.86°

Table 21 Pyrex Glass Material Propagation Calculations

We assume polarization occurs based on the slight contrast between Brewster's angles and the incident angle. We believe it does not happen anywhere in the water tube for total internal reflection. We then used geometric optics to determine the beam behavior assuming the beam was slightly elliptical. We modeled the water tube off two meniscus lenses with the convex edges positioned away from each other to imitate the tube. Our optical source is a laser pointer, so the light is collimated throughout the optical system until it is incident on the glass tube.

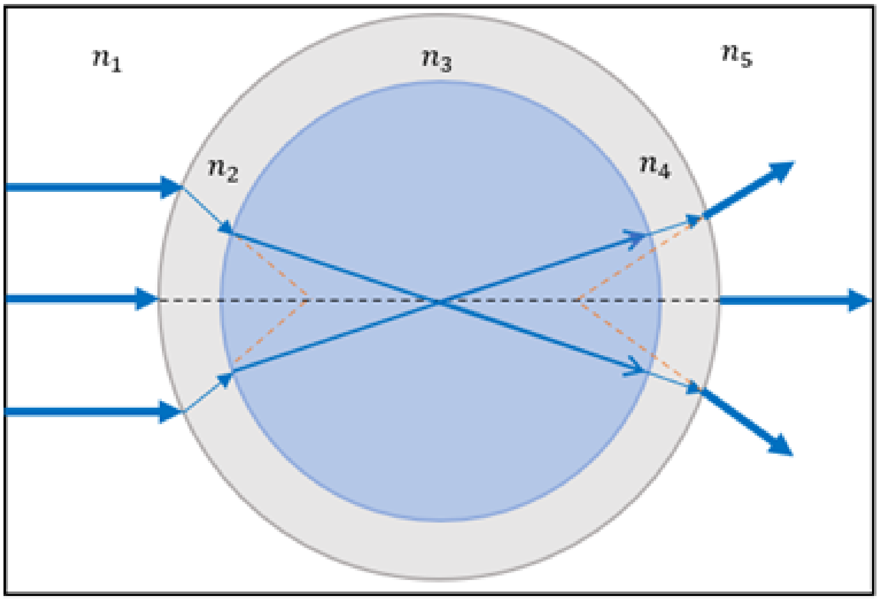


Figure 20: Geometric Optic Ray Tracing Through Water Tube

The 90° incident beam on the first interface of air and glass transmits the light while reflecting some power along the same incident path. The light refracts inside the glass, converging onto the next surface without passing through focus. The second interface between glass and water intersects the rays before they can focus to a point inside the glass. We assume polarization starts at this surface, reflecting one type of polarized light into the glass tube while transmitting the other kind into the water. The light now converges to the focal point and then diverges onto the third surface after passing through the focal plane. When light reaches the third surface, we believe the rest of the polarization occurs at this surface. The rays on the surface refract through it at an angle traced back to the focal length corresponding to the previous surface focal plane. The rays then diverge through the glass onto the last surface, where the beam is again traced back to the focal point, and the transmitted beams diverge out of the glass tube. We theorize that most polarized light is light with polarization parallel with the glass tube resulting in mostly vertically diverged light creating a vertical line as the beam shape. Prior calculations of the final refraction angle or, in other words, the exiting angle was supposed to be 90°; however, according to the geometric optical estimates, the beam should be diverging when exiting the tube.

We investigated what we perceived as inconsistencies in the calculations which we resolved after looking back at the geometrics. The result was that normal to the surface for curved surfaces, like our tube, are considered everywhere and are not as defined for flat surfaces. Once finishing the design and parameter research, we investigated the market for available products looking for glass tubes that would fit our geometrical calculations. The optimal tube would need to be within relative proximity to our geometric calculations. Due to the physical requirements of the housing system, we decided a short tube would be preferred to save space and reduce the accumulative weight. We were able to find glass tubing with relative ease; however, most of the tubing was overly long, which, if purchased, would mean we would need to find a way to cut it without causing significant cracks or harming ourselves. Without access to a glass cutter and wanting to be time-efficient, we decided on 4-inch-long Pyrex glass tubes meant for blowing borosilicate glass [35]. With an outer diameter of 12 mm and an inner diameter of 8 mm, we started the calculations for the focal lengths using $f = \frac{R}{2}$ where R is the radius of curvature.

Surfaces	Radius of Curvature	Focal Length
First Surface (outer diameter surface)	6 mm	3 mm
Second Surface (inner diameter surface)	4 mm	2 mm
Third Surface (inner diameter surface)	-4 mm	-2 mm
Fourth Surface (outer diameter surface)	-6 mm	-3 mm

Table 22 Water Tube Calculations

3.3.7 Unrealized Upgrades

Due to our project's requirements of maintaining affordability and time restraints, some of the desired upgrades may not be achievable for the given time frame and budget. However, we wanted to research to see if more funds were available while maintaining the time frame. One such upgrade was the ability to detect ammonia in the water. Ammonia is one of the waste products produced by fish and the decomposition of organic waste. When fish metabolize protein or breath, ammonia is created and excreted through their gills and waste. Ammonia is also made from organic products such as decomposing food or decaying algae. Even a tiny amount of ammonia is harmful to fish and occurs naturally from the previous information. According to the fish lab [36], this toxicity can cause organ and gill damage to fish if not corrected quickly. However, it is not apparent when ammonia is present in the tank because it is not visible to the human eye. Therefore, it can be a severe problem killing fish if the owner is not diligent in their fish tank care and monitoring. According to the fish lab [36], this toxicity can cause organ and gill damage to fish if not corrected quickly.

For this reason, if possible, we would like to create an NH3 (ammonia) detection system, whether through optical design or the dissection and repurposing or reprogramming of premade

NH_3 detectors available in the current market while still maintaining affordability. Previously we researched creating an optical design salinity level detection; however, we ran into economic problems where we would need to acquire a broad spectrum collimated light source. The market availability of broad-spectrum light sources was attainable; however, they were not in a price range within our affordability requirement. For this reason, we excluded this upgrade from the optical design, but we did not give up on the possibility of repurposing one of the listed products in our project. We theorize that by either obtaining a small cheap camera to watch the device or integrating it into our electrical system for the digital products, we would then be able to turn on the salinity meter and send the information to the system allowing for the user to monitor the salinity levels.

Salinity levels are significant for not only saltwater fish but also freshwater fish. According to Petco [37], "The chloride in salt can help to reduce the toxic effects of nitrite on aquatic life." However, while the salt can be beneficial to freshwater tanks under strict guidelines, it can also cause damage and harm to all fish, including saltwater fish, because fish drink water and use their kidneys to filter out the salt. When salt levels are too high, it can cause kidney damage and potentially death to the fish. In addition, freshwater fish can become stressed and lethargic when salt levels are too high. At the same time, salt is used to cure fish of parasites and specific health issues. Much like sodium chloride, ammonia's absorption spectrum is in the nonvisible light spectrum, which is not within our source light capabilities.

We investigated digital ammonia meters, and while we did find many options, most were expensive, meant for gaseous ammonia, or not meant for water submersion use. However, according to Petco, we came across fully submergible nondigital ammonia meters that could last up to a year [38].

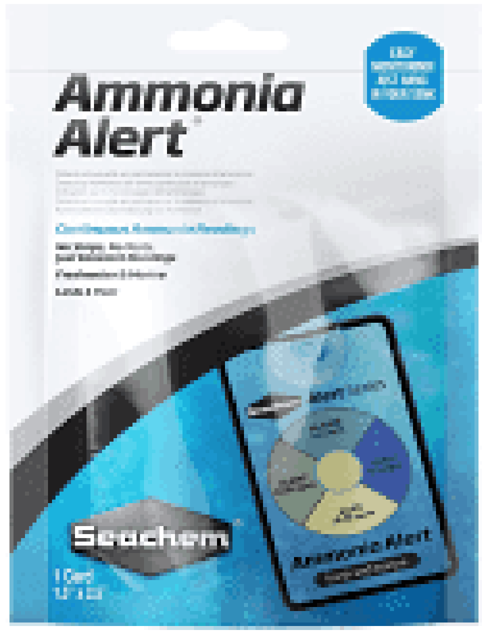


Figure 21: Preferred Product for Unrealized Ammonia Detection Upgrade (Courtesy of Petco [38] Copyright approval pending)

We believe we could use a simple digital camera capable of detecting color changes that will change with ammonia concentrations to alert users to any changes in color. We could potentially place the camera inside a waterproof box descending from the bottom of the system with a transparent viewing window aimed directly at the submerged ammonia detector, much like our plans for our thermal camera where it will sit across from the water tube to detect the water temperature through the siphoned water. The cameras considered for monitoring the ammonia levels in the previously described way are tabulated to compare pros and cons for each one.

Figure 22: (Courtesy of Arducam Amazon Store [39] Copyright approval pending)

Cameras	Price	Interface	Light	Ease of Integration
Arducam 5MP Wide Angle USB Camera for Computer [39]	$39.99	USB	Visible with IR filter	Easy plug in
Arducam Mini Module Camera Shield [40]	$25.99	Raspberry pi or Ardunio	Visible spectrum with IR filter	Requires circuit integration
HiLetgo 2pcs [41]	$8.99	Ardunio	Undefined	Requires circuit integration

Table 23 Camera Comparison

From the tabulated comparison, the preferred camera is the Hiletgo for affordability; however, it may be time-consuming to integrate into the system along with the soldering and coding required to operate along with the I2C needed to run it. The Arducam mini-module camera would require similar integration but at a higher price. The Arducam 5MP has an effortless integration, however, it is the most expensive out of the three options. The cost of the Arducam 5MP camera is not a deal-breaker; however, due to its time-saving integration, which may be the deciding factor in creating this upgrade for our system. Our time restraints for building our project are more restraining because we will be completing it in the span of a summer semester.

For this reason, we have made sure not to take on more than we can manage and are diligently considering what is manageable without scrambling to meet deadlines. If we had access to significant funds and retracted our affordability requirements, we would choose a broadband tunable light source capable of remotely controlling the source light wavelength. This light source would allow us to measure salinity, ammonia, and chlorophyll A and potentially offer the ability to calculate the water pH balance based on the salinity levels. Another upgrade we considered was designing a visual fish monitoring system for which users could watch their fish remotely, allowing for round-the-clock behavior monitoring. This monitoring could be a bonus for many fish owners who have problems with aggressive fish but do not know which fish is causing the issues. It could also benefit owners with sensitive fish who do not adapt well after cleaning the fish tank. The list of benefits is endless for remote monitoring systems. At the same time, other uses could include measuring ambient lighting, water levels, or other mischievous pets who try to have a fish dinner when owners are not around.

Further upgrades we considered were pump efficiency monitoring, so the user could determine if their fish tank pump was working to their expectations. However, all of these upgrades would take a significant amount of time that we didn't have even with more funds. The time restraint has been the most extensive obstacle in our optical design and what we could potentially build in the set time frame given the team's limited availability.

3.4 Software

In this part, we are concentrating on finding the best language that we can program the device with to be able to produce the correct data needed to be output.

3.4.1.1 C Language

As a procedural language, C is used for its low-level memory access so that programs run efficiently and first. Consequently, the program is popular and most common to use as it is on many computer platforms.

Pros:

1. **Portable language:** The C programs written in one computer can run on any computer without any change of the program code or having a slight change.

2. **Building block for other languages:** It is the easiest to understand and can be a building block and the base of coding in any other language

3. **Structured programming language**: A C program is a procedure-oriented language with a collection of function modules and blocks that form a complete program. The structured blocks make it easy to debug, test, and maintain the program.

4. **Easy to learn:** It is extremely easy to learn the C language and acts as the basis for understanding other complex languages. It uses a syntax like the English language for easy understanding.

5. **Built-in function:** The C language gives you the opportunity to use several built-in functions in the C library to develop a program.

6. **User-defined function:** Apart from the standard function in the C library, you can create your own user-defined function to solve a specific problem. Adding more functions in the C library makes your programming work easier.

7. **Explore hidden objects:** In the C program, you can easily access hidden or blocked objects from the use of other programming languages.

8. **Speed-up programs:** Since other languages are based on c program, it speeds up a program that is developed using other programming languages.
   The programs in C run faster than in other languages.

9. **Compile language: It** enables the program code to be compacted into an executable instruction rather than being translated by the interpreters.

10. **Low level of abstraction:** The C programming language is close to system hardware specifications making it easy to know how the higher-level language works and interacts with the machine.

Cons:

1. Data security: There is a lot of buffer overflow in the C language, and this can lead to overwriting the information in the memory. When pointers are updated with incorrect data, it will result in memory corruption.

2. No run-time checking: The C language does not allow run-time checking making it difficult to fix the bugs if you extend the program. Mostly it does compile type checking.

3. No strict type checking: When passing data to the parameters, there is no strict data type checking since we can pass an integer value to the parameter. No confirmation of the right data type is used.

4. No code-reuse: C language does not have OOP features that support source code reusability. It does not support constructors and destructors.

5. Namespace concept: C language doesn't support program namespace thus; it is impossible to declare two variables at the same time as in the C++ program.

6. No OOP concepts: Object-oriented programming concepts like data abstraction, polymorphism, inheritance, and other C++ programming concepts are not supported in the C language. Every algorithm in C is a set of function calls.

7. Effects on Today's programming: C program does not support enough library functions which can be used to handle today's complex programming environment.

8. Real-world problems: It cannot be used to solve real-world programming challenges.

9. Extending the program issues: When you extend the program, it will be exceedingly difficult for you to fix any errors and bugs. The C language is effective when dealing with simple projects.

10. High-level constructs: You need to manually create the high-level constructs in the C programming language. Third-party libraries and other solutions need to be configured before use.

3.4.1.2 C++ Language

Pros:

1. **Portability**
C++ has a feature called portability, or platform independence, which allows users to run the same program on a variety of operating systems and interfaces.

If you write a program in LINUX OS and then switch to Windows OS for some reason, you will be able to run the identical program on Windows without any errors. This functionality proves to be extremely useful to programmers.

2. **Object-oriented**

One of the most key features of C++ is object-oriented programming, which encompasses concepts such as classes, inheritance, polymorphism, data abstraction, and encapsulation. These features allow for code reuse and make a program more trustworthy.

Not only that, but by considering data as an object, it aids us in solving real-world problems. Because C lacked this functionality, it was built, and it has proven to be extremely useful.

This feature spawned a slew of new job opportunities and technology. C++ was created by merging concepts not only from C but also from Simula 67, the first object-oriented programming language.

3. **Multi-paradigm**

C++ is a multi-paradigm programming language. The term "Paradigm" refers to the style of programming. It includes logic, structure, and procedure of the program. G*eneric, imperative, and object-oriented are three paradigms of C++.*

Let us now try to understand what generic programming means. **Generic programming** *refers to the use of a single idea to serve several purposes*. **Imperative programming***, on the other hand, refers to the use of statements that change a program's state.*

4. **Low-level Manipulation**

Since C++ is strongly associated with C, which is a procedural language closely related to the machine language, C++ allows low-level manipulation of data at a certain level. Embedded systems and compiler are created with the help of C++.

5. **Memory Management**

C++ gives the programmer the provision of total control over memory management. This can be considered both as an asset and a liability as this increases the responsibility of the user to manage memory rather than it being managed by the Garbage collector. This concept is implemented with the help of DMA (Dynamic memory allocation) using pointers.

6. **Large Community Support**

C++ has a large community that supports it by providing online courses and lectures, both paid and unpaid. Statistically speaking, C++ is the 6th most used and followed tag on StackOverflow and GitHub.

7. **Compatibility with C**

C++ is compatible with C. Virtually, every error-free C program is a valid C++ program. Depending on the compiler used, every program of C++ can run on a file with .cpp extension.

8. **Scalability**

Scalability refers to the ability of a program to scale. It means that the C++ program can run on a small scale as well as a large scale of data. We can also build applications that are resource intensive.

Cons:

1. **Use of Pointers**

Pointers in C/C++ are a difficult concept to grasp and it consumes a lot of memory. Misuse of pointers like wild pointers may cause the system to crash or behave anomalously.

2. **Security Issue**

Although object-oriented programming offers a lot of security to the data being handled as compared to other programming languages that are not object-oriented, like C, certain security issues still exist due to the availability of friend functions, global variables and, pointers.

3. **Absence of Garbage Collector**

As discussed earlier, C++ gives the user complete control of managing the computer memory using DMA. C++ lacks the feature of a garbage collector to automatically filter out unnecessary data.

4. **Absence of Built-in Thread**

C++ does not support any built-in threads. Threads is a new concept in C++ which was not initially there. Now, C++ can support lambda functions.

3.4.1.3 Python

When you are learning a new language, let us say Python, you must be aware of the benefits and drawbacks of that language. This will help you to get a better knowledge of how you can take full advantage of the Python programming language.

With knowing the Python advantages and disadvantages, we can build robust applications. Let us start with the advantages and disadvantages of Python.

Advantages of Python

1. Easy to Read, Learn and Write

Python is a **high-level programming language** that has English-like syntax. This makes it easier to read and understand the code.

Python is easy to **pick up** and **learn**, that is why a lot of people recommend Python to beginners. You need less lines of code to perform the same task as compared to other major languages like **C/C++** and **Java**.

2. Improved Productivity

Python is a very **productive language**. Due to the simplicity of Python, developers can focus on solving the problem. They do not need to spend too much time in understanding the **syntax** or **behavior** of the programming language. You write less code and get more things done.

3. Interpreted Language

Python is an interpreted language which means that Python directly **executes the code** line by line. In case of any error, it stops further execution and reports back the error which has occurred.

Python shows only one error even if the program has multiple errors. This makes **debugging** easier.

4. Dynamically Typed

Python does not know the type of variable until we run the code. It automatically assigns the data type during execution. The programmer does not need to worry about declaring variables and their data types.

5. Free and Open-Source

Python comes under the OSI approved open-source license. This makes it free to use and distribute. You can download the source code, modify it and even distribute your version of Python. This is useful for organizations that want to modify some specific behavior and use their version for development.

6. Vast Libraries Support

The standard library of Python is huge, you can find all the functions needed for your task. So, you do not have to depend on external libraries.

But even if you do, a **Python package manager (pip)** makes things easier to import other great packages from the **Python package index (PyPi)**. It consists of over 200,000 packages.

7. Portability

In many languages like C/C++, you need to change your **code** to run the program on different platforms. That is not the same with Python. You only write once and run it anywhere.

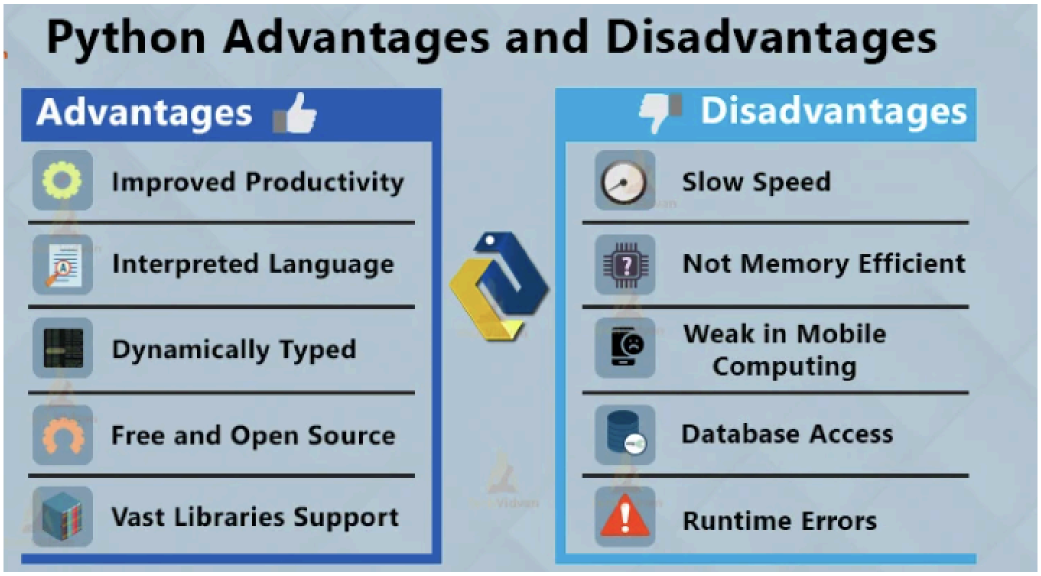


Figure 23: Python Advantages and Disadvantages (Courtesy of ...) Copyright approval pending)

Disadvantages of Python

1. Slow Speed

We discussed above that Python is an **interpreted** language and **dynamically-typed** language. The line by line execution of code often leads to **slow execution**.

The dynamic nature of Python is also responsible for the **slow speed** of Python because it must do extra work while executing code. So, Python is not used for purposes where speed is an important aspect of the project.

2. Not Memory Efficient

To provide simplicity to the developer, Python must do a little tradeoff. The Python programming language uses a **large amount of memory**. This can be a disadvantage while building applications when we prefer memory optimization.

3. Weak in Mobile Computing

Python is used in **server-side programming**. We do not get to see Python on the client-side or mobile applications because of the following reasons. Python is **not memory efficient,** and it has **slow processing power** as compared to other languages.

4. Database Access

Programming in Python is **easy**, but when we are interacting with the database, it is behind.

The Python's database access layer is primitive and underdeveloped in comparison to the popular technologies like **JDBC** and **ODBC**.

Huge enterprises need smooth **interaction** of complex legacy data and Python is thus rarely used in enterprises.

5. Runtime Errors

Python is a dynamically typed language so the data type of a variable can change anytime. A variable containing integer number may hold a string in the future, which can lead to **Runtime Errors**.

3.4.1.4 JAVA

Java is known as one of the most-liked programming languages of our time. The language has existed for two decades. Several specialists believe that *Java is one of the most effective programming languages ever created*. It is the most widely used programming language and is designed for the distributed environment of the Internet. But, like every coin has two faces, Java produces its own limitations and benefits. Today, we will demystify some important pros and cons of Java, which will help you to get a clearer view of its working.

Advantages of Java

1. Simple

Java is straightforward to use, write, compile, debug, and learn than alternative programming languages. Java is less complicated than C++**;** as a result, Java uses automatic memory allocation and garbage collection.

2. Object-Oriented

It permits you to form standard programs and reusable code.

3. Platform-Independent

Java code runs on any machine that does not need any special software to be installed, but the JVM needs to be present on the machine.

4. Distributed computing

Distributed computing involves several computers on a network working together. It helps in developing applications on networks that can contribute to both data and application functionality.

5. Secure

Java has no explicit pointer. Apart from this, it has a security manager that defines the access of classes**.**

6. Memory allocation

In Java, memory is divided into two parts one is heap and another is stack. Whenever we declare a variable JVM gives memory from either stack or heap space. It helps to keep the information and restore it easily.

7. Multithreaded

It has the potential for a program to perform many tasks at the same time.

Disadvantages of Java

1. Performance

Java is memory-consuming and significantly slower than natively compiled languages such as C or C++.

2. Look and Feel

The default look of GUI applications written in Java using the Swing toolkit is quite different from native applications.

3. Single-Paradigm Language

Static imports were added in Java 5.0. The procedural paradigm is better accommodated than in earlier versions of Java.

4. Memory Management

In Java, Memory is managed through garbage collection, whenever the garbage collector runs, it affects the performance of the application. This is because all other threads in the must be stopped to allow the garbage collector thread to work.

3.4.1.5 Assembly

Advantages Of Assembly Language

1. Programs written in machine language are replaceable by mnemonics which are easier to remember.
2. Memory Efficient.
3. It is not required to keep track of memory locations.
4. Faster in speed.
5. Easy to make insertions and deletions.
6. Hardware Oriented.
7. Requires fewer instructions to accomplish the same result.

Disadvantages Of Assembly Language

1. Long programs written in such languages cannot be executed on small sized computers.
2. It takes a lot of time to code or write the program, as it is more complex in nature.
3. Difficult to remember the syntax.
4. Lack of portability of program between computers of different makes.
5. No SDKs (System Development Kit).

Comparison for hardware programming

Languages	Comparison for hardware programming		
	Advantages	Disadvantages	Which will be used?

C	• Portable • Building blocks for other languages: • Structured programming language • Easy to learn • Build-in function • User defined function • Hidden objects • Spread up programs compile language • Low level of abstraction	• lot of buffer overflow • Data security • No run-time checking • No strict type checking • No code-reuse • Namespace concept • No OOP concepts • does not support enough libraries • cannot be used to solve real-world problems • Extending the program issues • Manual High-level constructs	X
C++	• Object-oriented • Multi-paradigm • Low-level Manipulation • Memory Management • Large Community Support • Compatibility with C • Scalability	• Use of Pointers • Security Issue • Absence of Garbage Collector • Absence of Built-in Thread	X
Python	Easy to Read, Learn and Write Improved Productivity Interpreted Language	Slow Speed Not Memory Efficient Weaknesses in Mobile Computing Database Access Runtime Errors	

	Dynamically Typed Free and Open-Source Vast Libraries Support Portability		
Java	**Simple** **Object-Oriented** **Platform-Independent** ***Distributed computing*** **Secure** **Memory allocation** **Multithreaded**	memory-consuming **Single-Paradigm Language** **Memory Management**	
Assembly	1. Programs written in machine language are replaceable by mnemonics which are easier to remember. 2. Memory Efficient. 3. It is not required to keep track of memory locations. 4. Faster in speed. 5. Easy to make insertions and deletions. 6. Hardware Oriented. 7. Requires fewer instructions to accomplish the same result.	1. Long programs written in such languages cannot be executed on small-sized computers. 2. It takes a lot of time to code or write the program, as it is more complex in nature. 3. Difficult to remember the syntax. 4. Lack of portability of programs between computers of different makes. 5. No SDKs (System Development Kit).	

Table 24 Hardware Programing Comparison

Conclusion:

We will use a combination of C and C++ as our main programming language to code the microcontroller given the fact that they are the most versatile with great libraries that would allow us to build the skeleton of the code and execute it to make the product function and operational.

In senior design 2, we concentrated on programming the Arduino uno microchip using the Arduino IDE as well as the Nextion program to program the LCD screen. We were able to find the skeleton for the code needed to be able to connect the two programs together and be able to apply the changes to buttons on the interface on the LCD screen. Using Nextion software we were able to make pages that would be triggered by buttons on the main page in the interface.

3.4.2 Software Programming/ App Programming

3.4.2.1 JAVA

Pros:

1. Java is simple
2. It features object-oriented programming
3. Java is a high-level language with only a mild learning curve
4. It is a secure programming language
5. Java is a distributed language
6. Java offers various APIs for application development
7. It supports multithreading

Cons:

It requires a significant space for memory

When compared to native languages, Java is memory-consuming and slower. As it is a high-level language, each line of code requires interpreting into machine-level code. This can slow performance because of the extra level of abstraction and compilation. Java's garbage collector is a useful feature, but it sometimes causes performance problems as well due to excessive memory and garbage collection usage.

Java code is verbose

Being that it is a high-level language remarkably like the way humans speak, Java code has many words in it. This results in long, complex sentences at times. While the language focuses on being more manageable than others, it compromises this with long explanations and sometimes overly complex codes because of its wordiness.

It lacks a native look and feel when used for desktop

Developers must use different language-specific tools to create a program's graphical user interface (GUI) in Java. While mobile apps typically are not a huge problem, Java is weak when it comes to desktop user interfaces and user experience. There are quite a few GUI builders available for Java programmers to choose from. However, choosing the right fit for a specific project's GUI takes additional research.

3.4.2.2 Swift

The Advantages of Using Swift for iOS Development

Swift is effective and reliability inherited from different compiled programming languages and the accessibility of scripted ones. Here are the key advantages of coding for iOS in Swift instead of Objective-C:

1. **Time-efficient solution –** Swift is known for being a quick language to code in, as it usually takes less time to create a program with Swift than with Objective-C. It is much simpler to write in Swift and read the code. In addition, this language is more compact, which means that the tasks are shorter and do not require as much coding;

2. **Improved scalability –** this code allows adding new features and inviting additional programmers easily. Moreover, Apple is gradually paying increased attention to it, while Objective-C takes the second place. Swift has already gone beyond a restricted circle of Apple devices and started to run Linux as well. There is a bright future ahead of this language, and many developers have already decided to jump in;

3. **Safety and performance –** in addition to being a highly efficient and quick solution, Swift has excellent security. With this innovative approach to coding, programmers can locate and get rid of bugs amazingly fast and without trouble. This creates clean and readable codes. Its typing interface reduces the possibility of bugs remaining overlooked.

The Disadvantages of Swift

- **Lack of support for earlier iOS versions** – while there is a slim chance you will need to work with something earlier than iOS7, the problem remains.

- **Small following** – despite its number of fans growing, Swift still has a small circle of coders who work with it. Again, as the language grows, increased developers will start using it.

Comparison For Software Programming:

	Comparison of Software programming

Languages			
	Advantages	Disadvantages	Which will be used?
Java	• Simple • Object oriented • High-level language • Secure • Distributed language • APIs for app dev • Multithreading	• significant space for memory • verbose • lacks a native look and feel when used for desktop	
Swift	• Generics that are powerful and simple to use • Protocol extensions that make writing generic code even easier • First class functions and a lightweight closure syntax • Fast and concise iteration over a range or collection • Tuples and multiple return values • Structs that support methods, extensions, and protocols • Enums can have payloads and support pattern matching • Functional programming patterns, e.g., map and filter	• Lack of support for earlier iOS versions • Small following	X

	• Native error handling using [redacted] / [redacted] / [redacted]		

Table 25 Software Programing Comparison

Conclusion:

We decided to go with Swift as it will allow us to program and develop an IOS app since a lot of users use iPhone as well as the fact that swift is user friendly and easy to learn and execute work as well as having those many advantages listed above.

In Senior Design 2, we decided to forgo the creating of an APP idea as the system needed to be operated on the LCD screen and we were under time constraint, therefore, we concentrated on programming the LCD with the user interface on the Nextion software and were able to connect it with programming the touch buttons on the Arduino IDE. We were able to design and successfully upload the design unto the LCD screen but due to time constraints and unforeseen equipment failure at the last minute we were unable to display the values unto the screen, we were able to do that earlier in the testing phase however we were unable to successfully have it read the photodiode readings due to the microchip failed at the last minute as well as other difficulties that arise before the demonstration. We were able however to display those values through serial monitor showing that the code runs successfully with no errors on the Arduino IDE after replacing the microchip and we were able to calculate the light absorption as well as detect the readings from the photodiodes with no errors while compiling and successfully programming the new microchip.

3.5 Housing Material

For the housing that our project will be contained in we are looking for material that will not allow the laser pointers light to leak out. We want a martial that does not let the laser pointer’s light out because the laser pointer is a class 3 laser, in the blue spectrum of light. Since it is in the visible spectrum of light the human eye has receptors, cone cells, in the fovea of the eye. And the lens of the eye focuses the light onto the fovea. We will be running the laser pointer at verry low power to limit the risk of injury, but it is still of upmost importance to take safety as the highest priority in designing any product. And to keep the health and safety of the user at the forefront of the design.

So, we want the housing to be as opaque as possible. Originally, we were thing of using Plexiglas, but it is verry hard to find Plexiglas that are plain clear, or clear and slightly frosted. All the Plexiglas that was not clear or clear and slightly frosted were expensive, and our group is trying to keep costs less than or equal to $1,000. If a 12 inch by 12-inch sheet of Plexiglas costs $16-$25 dollars, and we need 6 of them, that would be a total of $96-$150 for the housing. That is going to destroy our budget.

Next, investigate acrylic sheets. Acrylic sheets come in a multitude of colors, but much like the plexiglass it is quite expensive. Also, all the acrylic sheets that could be found online were smaller than what could be used for our project. Because we are keeping our complete set up as big as, or within 12 inches by 12 inches by 12 inches. So, when it only comes in 8 inches by 9 inches it is not going to work for us.

Housing Material Comparison						
Product	Temperature Tolerance	Surface Texture	Dimension (inches)	Durability	Number of extra components required to connect sides together.	Price
HDPE Sheets made by KLEARSTAND	-100°C to 80°C	Smooth, Glossy	12 X 12 X 0.125	Is resistant to abrasion, for marine use	1	$22.99 for a 5 pack
ABS Plastic Sheets made by USAMADE	-20°C to 80°C	Textured side and smooth side	12 X 12 X .062	High Tensile and Impact Strength	1	$22.99 for a 5 pack
Black ABS Plastic Sheet made by Zuvas	Bends at 93℃	Textured side and smooth side	12 X 16 X 0.06	Shatter proof and flexible	1	$23.99 for a 6 pack
Baltic Birch Plywood Sold by Anderson Plywood	Flammable, but can be painted to make it nonflammable.	Smooth wood	3MM 1/8" x 12" x 12"	That would depend on the paint	2-3	$28.7 For a 6 pack
Thick Acrylic Blue 2114	Is not given	Smooth	12 x 12 x 1/8	Colored, Opaque, Shatter	1	$11.69 for one sheet

Sheet by Falken Design				Resistant, UV Stabilized		
Plexiglas: Thick Acrylic Non-Glare, Matte P95 Sheet by Falken Design	Is not given	Smooth on one side and frosted on the other side	24 x 24 x 1/8	Frosted, Non-Glare , Shatter Resistant, UV Stabilized	1	$31.87

Table 26 Housing Material Comparison

Figure 24: The Black ABS Plastic Sheet made by Zuvas [45]

The one we chose to go with is the yellow highlighted one above, also see the above figure of what it looks like. The Black ABS Plastic Sheet made by Zuvas, it is both affordable at $23.99 and durable, being shatter proof. Also, it comes in a 6 pack with our final housing unit needing to have 6 sides, each being 12 inches by 12 inches, making this one the best option over the others.

The second choice would be the HDPE Sheets made by KLEARSTAND. It is the second choice because it is a 5 pack of 12 inches by 12 inches, so there would not be enough sheets for each side. The same issue arises for the for our third chose, the ABS Plastic Sheets made by USAMADE. It is the right size and price, but it only comes in a 5 sheets pack, so we will still be short one sheet to have six sides.

3.5.1 Housing Design

For the design of the housing unit, we need, or we have chosen to keep the housing unit as big as or smaller than 12 inches by 12 inches by 12 inches. In other words, a cube that is a foot in all directions. We want to keep it in this cube of 12 inches by 12 inches by 12 inches, because it is going to be needed to be kept near the fish tank that it is being used on. If the fish tank is kept at this size of, 12 inches by 12 inches by 12 inches, then it will be easier for the user to please near the fish tank, and therefore easier for them to install to use.

For the shape of the housing unit that our fish tank algae detection system, to keep it in those 12 inches by 12 inches by 12 inches, it will be most convenient to make it a cube or rectangular prism shape. It is more convenient to make it because a cube or rectangular prism shape because most of the materials available on the market like Black ABS Plastic Sheet made by Zuvas, that we chose to go with, are square sheets being 12 inches by 12 inches by 12 inches, therefore it will be easier to make a cube, and there will be no need to cut the Black ABS Plastic Sheet made by Zuvas sheets. If there is no cutting necessary, then the risk of breaking the Black ABS Plastic Sheet made by Zuvas sheets will go down significantly. There will still be a need to drill holes in the Black ABS Plastic Sheet made by Zuvas sheet to put a latch on it, to have our tubing for the water siphon coming out into the fish tank and to connect some of the parts on the inside.

We want the housing unit to be able to be opened so that the inside can be easily seen, but also that it will be easier for the user to perform any maintenance on the fish tank algae detector. Maintenance like checking to see if the tubing needs anything done with it, like cleaning the water tubing for the fish tank or replacement the water tubing. Other maintenance may be checking to make sure there is no condensation around the water tubing.

To also help with any maintenance that may be necessary in the future, there will be shelf(s) built into the housing unit. If the components are not all right on top of each other then it will be more convenient to switch out any parts later, and it will be easier to connect everything together. Since the height of our housing cube will be approximately 12 inches, there are two options, one has one shelf at approximately six inches from the bottom, and they have six inches till the top of the algae detection cube. Then there would be one shelf for most of the electrical components, and another for the optical components. Or then there is the second option that is to have three shelves, about one every four inches. Then the bottom compartment would serve as a water trap in the event of any water line breach. Since we are using a siphon, if the is a brake in the water tube and air gets in the siphon will stop, so the amount of water will be minute. Then the next four-inch compartment would be for some of the electrical components. With the last or top shelf being for the optical components. The best option would be a combination between the two, with a smaller, about one inch, compartment at the bottom of the housing unit to catch any water in the case of a leak, and two other compartments of approximately five-and-a-half-inches each. One five-and-a-half-inch compartment for some or all of the electrical components and another five-and-a-half-inch compartment for all the optical components.

Since we are planning on putting in a shelfing system and we need to make sure that the housing unit for the fish tank is as easily accessible to the inside as possible so that any maintenance that needs to be done can be done with as much ease as the design will allow. Also, having the inside of the housing easily accessible will mean that putting all the components in will be easier for use to keep all of the components organized.

The first thought for the housing unit was to have the top only opens, with the four sides glued together at 90° angles and bottom being glued to normal surface of the four sides. The top would be attached be a pair of henges and secured with some type of closer like a latch. But then the shelves on the bottom and middle would be difficult to access if necessary.

Then the next idea was to only have the front open, much like how a cabinet works, with three of the sides glued together at 90° angles to each surface and the top and bottom glued to those three sides to be normal to those three sides, so that the front is open. With the front door being attached with two hinges and a clasp or latch to keep it secure.

The third idea of how the design of the housing should be was a combination of the first two. Three of the sides seem glued together at 90° angles to each other and then glued to be normal to the surface of the bottom. Making a cube missing two sides, then the top would be connected to the side opposite of where the missing side is, connected using two hinges. Then the front would be attached to the bottom using two hinges, so that when it is closed it will make the entire structure a cube. There will then be a clasp or latch put so that it will be caped close completely.

3.5.2 Glue to Hold the Sides of the Housing Together

The material that we chose is Black ABS Plastic Sheet made by Zuvas, with the dimensions being 12 inches by 16 inches by 0.06 inches. Since the material is so thin, being 0.06 inches, we will need a strong adhesive to hole the sides together since the it is too thin to use screws to hold it together. We want our housing to be as strong as possible, so it is extremely important that our connections are strong. So, the adhesive that we select needs to make a strong bond with our ABS sheeting.

For the glue needed to hold the sides of the Black ABS Plastic Sheet made by Zuvas container together our first thought was to use silicon. Silicon is commonly used in the construction of fish tanks. The silicon is used to glue the sides of the glass together since it is quite a stable material, and it is non-toxic. It also comes in black so it would not stand out from the Black ABS Plastic Sheet made by Zuvas. There is a multitude of adhesives out there that will work for ABS Plastic Sheets, see the table of comparison of different adhesives is below.

Housing Adhesive Comparison				
Product	Does it bond to ABS?	Amount in Container	Colors Available	Price
Water Resistant In 30 minutes, Premium Exterior/Interior Window, Door, and Siding Silicone Sealant By Dap	Yes	Come in 10.1 oz	-Almond -Black -Brown -Clear -Gray -White	$9.78 for a single tube
Maximum Strength, Premium Window, Door and Siding Silicone Sealant By Dap	Yes	Come in 10.1 oz	-Almond -Black -Brown -Clear -Gray -White	$9.78 for a single tube
Long Lasting, All-Purpose Acrylic Latex Caulk Plus Silicone By Dap	Yes	Come in 10.1 oz	-Almond -Antiqued White -Black -Brown -Cedar Tan -Clear -Crystal Clear	$3.18 for a single tube

			-Dark Bronze -Gray -Slate Gray -White	
Clear Exterior/Interior Silicone Window, Door, Siding Sealant 100% Silicone By Dap	Yes	Come in 10.1 oz	-Almond -Black -Bronze -Clear -Aluminum Gray -White	$20.79 for a single tube
Advanced Silicone Clear Kitchen and Bath Caulk By GE	Yes	Come in 10.1 oz	- Almond -Clear -White	$8.79 for a single tube
Silicone Clear All Purpose Caulk By GE	Yes	Come in 10.1 oz	-Clear -White	$6.98 for a single tube
Advanced Silicone Clear Exterior/Interior Window and Door Sealant By GE	Yes	Come in 10.1 oz	-Almond -Black -Brown -Clear -Light Gray -White	$8.78 for a single tube
100% Silicone Sealant By Gorilla Glue	Yes	Come in 10.1 oz	-White only	$9.98 for a single tube
PL Premium Polyurethane Construction Adhesive By Lock-Tite	Yes	Come in 10 oz	-Gray	$6.18 for a single tube

Power Grab Express Heavy Duty Construction Adhesive By Lock-Tite	yes	Come in 9 fl. oz	-White	$5.98 for a single tube
Ultra-Gel Control Super Glue By Lock-Tite	Yes	Come in 0.14 fl. oz.	-Clear	$5.28 for a single tube
Two-Component Epoxies By Gorilla Glue	Yes	Come in 0.85 oz	-Clear	$6.47 for a set of tubes
Twin Tube Kwik Weld Two-Component Epoxies By J-B Weld	Yes	Comes in 1oz	-Mat Clear	$6.28 for a set of tubes
Heavy Duty Steel Bond Epoxy Gorilla Weld By Gorilla Glue	Yes	Come in 1oz	-Mat Clear	$6.28 for a set of tubes
Clear Weld Quick-Set Epoxy Syringe By J-B Weld	Yes	Come in 0.85 oz	-Clear	$6.98 for a set of tubes
Clear Weld Pro By J-B Weld	Yes	Come in 8 oz	-Clear	$20.28 for a set of tubes
Twin Tube Cold Weld By	Yes	Come in 1oz	-Clear	$6.28 for a set of tubes

J-B Weld				
Structural Acrylics- 600 FAST DRY ACRYLIC WHITE CONTRACTOR PACK By Tower Pro	Yes	Come in 10.1 fl. oz	-White	$39.73 for a 12 tube
Polyurethanes Heavy Duty Construction Adhesive By Gorilla Glue	Yes	Come in 9 oz	-White	$8.97 for a single tube
Heavy Duty Construction Adhesive By Liquid Nails	Yes	Come in 10 oz	-White	$3.28 for a single tube

Table 27 Housing Adhesive Comparison

The type of adhesive that is required is one that bonds well to Black ABS Plastic Sheet made by Zuvas, and is in a color that will go well with the material. Meaning, since the Black ABS Plastic Sheet made by Zuvas is black we will need an adhesive that is also black or clear as to not to cause significant contrast making the project look as though it is not will made. The other main criteria that were taken into consideration while going through the different adhesives on the market was the price of the adhesive, since we are trying to keep the budget as small as possible.

The types of adhesives that bound well to ABS plastic are ones like' "Cyanoacrylates, two component epoxies, Structural Acrylics and Polyurethanes are suitable for bonding ABS" [Research 13]. That being said, silicon does make a quit strong bond to ABS plastic sheets. The only difference between silicon and Cyanoacrylates, two component epoxies, Structural Acrylics and Polyurethanes is that silicon is not a permanent bond. Much like how a fish tank held together with silicon caulking can be taken apart by peeling a scaping off the silicon with a razor blade, the same can be done with almost anything that is held together with silicon caulking. But that does not mean that it makes a weak bond to the surfaces that it is used on.

The best adhesive for the housing of our project would be the one highlighted in yellow above and also in the picture above, the Water Resistant In 30 minutes, Premium Exterior/Interior Window, Door, and Siding Silicone Sealant made by Dap. It says that it is water resistant, and it works for ABS plastic. It is also on the cheaper side, being $9.78 for a 10.1 oz (about 286.33 g) tube, and 10.1oz (about 298.69 ml) should be more than enough to make the entire housing unit. It also comes in black or clear so it will not stand out from our black ABS material which will help give the fish tank algae detector a more professional look.

Figure 25 Water Resistant In 30 minutes, Premium Exterior/Interior Window, Door, and Siding Silicone Sealant made by Dap that we are going with [Research 14].

If for some reason this adhesive, Water Resistant In 30 minutes, Premium Exterior/Interior Window, Door and Siding Silicone Sealant by Dap, is out of stock then the second option would be Long Lasting, All-Purpose Acrylic Latex Caulk Plus Silicone by Dap. And if once it is constructed and we don't think silicon is not strong enough then a two-part epoxy like Clear Weld Quick-Set Epoxy Syringe by J-B Weld, will be used.

4. Constraints

The main constraints of this project are as follows in the table.

Our Main design Constraint	
Economical	We are trying to keep the budget less than or equal to $1,000
Time	Almost all team members do not have much free time to get together. The Project must be completed in two semesters.
Environmental	The device is being made with minimal components.
Ethical	Our device is going to be contained in a case to ensure that the fish in the tank will be all right.
Health and Safety	The laser emitting diode will be enclosed, so that its light cannot cause harm to the user.
Manufacturability	All the parts required are available to be purchased.
Sustainability	The product is sustainable, since people in the future will most likely want to still own fish tanks, and the design is so streamlined that it would be difficult to do the exact same thing for a the same amount of money with a different design.

Table 28 Constraints8

This table has our main constraints in a general form, but these constraints can be broken out into their own components.

4.1.1 Economic Constraints

Economic constraints are a type of external constraint. Economic constraints are the constraints that arise due to self-imposed financial restriction. For our group we are trying to keep all the costs less than or equal to $1,000, or approximately $250 per person. some members of the group are trying to save money, that is why this value was chosen.

For the economic constraints there are many factors that can cause difficulties in keeping things within our self-imposed budget.

The factor that can cause budget to increase	
The Pandemic	Causing the cost of fuel to crease. Causing labor shortages. Causing delays in importation of goods.
The War in Ukraine	Causing the cost of fuel to crease.

Table 29 Budget increase factors9

In The U.S. there is a 40 year high in inflation on everything, this is also causing the cost of our components to increase, and there in the cost of our project to have to increase as well. For example, the cost of our beam splitter has increased from approximately $300 to approximately $390. These external forces will increase the difficulty in keeping the costs low for our project and also the availability of parts that can be purchased.

4.1.2 Environmental

The environmental constraints are similar to the economic constraints in that they are external constraints that cause limitations on the project. In our case these constraints manifest themselves as:

Environmental Constraints	
Humidity	Since our project is a fish tank algae finding system it is going to sitting on top of the fish tank exposed to a great deal of humidity.

Heat	Since it will be on top of the fish tank it will be exposed to some heat coming off of the fish tank lights.

Table 30 Environmental Constraints10

4.1.3 Manufacturability

The manufacturability refers to whether or not the project that has been proposed can be made with already existing parts. This affects the design aspect by limiting what we can do and how we can make it our device by what is available on the market. In some cases, this requires going back to the drawing board in order to have the device do the same task with different components.

For our algae detection in a fish tank device, we looked at our features and objectives that we had chosen to do. For the optical components of the device the self-imposed constraints from the features and objectives section, we knew that the entire optical system had to lie within in 12 inches by 12 inches by 12 inches. for instance focal length, the size that the finished device was to be as big as or smaller than 12 inches by 12 inches by 12 inches.

4.2 Laser pointer Standards

The laser pointer that we have selected is in the wavelength of 450nm meaning that it is in the blue spectrum of light. When working with laser pointer or any light source when it is in the visible spectrum it is particularly harmful to humans or any creature that has light receptors, cones, in that wavelength of light. It is particularly harmful because the lens of the eye focuses the light onto the retina where the fovea is. The fovea is where the light receptors called cones are. If the light is at a high level of power, then when it is incident on the fovea it could cause the cone cells to rupture. Leading to hemorrhaging in the eye. If this accrues this will lead to permanent damage to the eye. Even if the laser pointer is at a moderate power, it can still cause damage to the eye, that is one of the reasons why we are placing a housing unit around our laser pointer optical system. We will also be running our laser pointer at a low power to make the system as safe as possible so that any risk of injury is minute.

The voltage that the laser pointer is starting off at from the manufacturer is 1.5V battery, with the current being 500 mA. The power can then be calculated using the equation [46]:

Watts=(Amperes) X (Volts)
Power = (Current) X (Voltage)
Power= (500 mA) X (1.5V)
Power=0.75 Watts

Or
Power= 750 milli Watts

So, this means that the power we are running the laser pointer at is 0.75 Watts or 750 milli Watts when it is operation normally. But to increase the safety of our fish tank algae detection optical system we are going to cut the input power by half. This will drastically decrease the risk of injury to anyone using or working on the device.

Reducing the power into our laser pointer will have no ill effect on the output results of algae detection. It will have no effect on the output results because in our optical design the light is coming out of the laser pointer and going directly through a fifty-fifty beam splitter. This fifty-fifty beam splitter will split the optical power by fifty presents in each direction. Meaning when a beam of light is incident onto the fifty-fifty beam splitter, the light passing through gets split into two separate beams at a forty-five-degree angle from each other, each having fifty percent of what its original beam had.

So, when the collimated light leaves the laser pointer and it falls incident onto the beam splitter with everything lined up properly, the fifty-fifty beam splitter will send fifty presents passing through to a photo diode. The other fifty present passing through the fifty-fifty beam slitter from the laser pointer the light will pass through to a collimation lens, then onto the water sample, then another lens to focus and collect the light, until it finally reaches the other photo diode.

The system then takes the intensity reading in real time of the second photo diode, the one that went through the fifty-fifty beam splitter and then was passed through a lens to the water sample to another lens and then to its photodiode. And then divides first photo diode, the one that only went through the fifty-fifty beam splitter. The value of this ratio is less than one for when there is any kind of sample in the system.

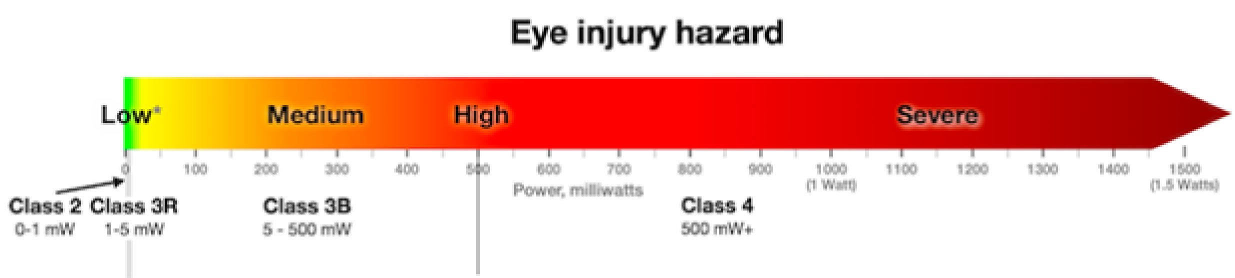


Figure 26. illustrates the injury hazard of different classes of laser pointers [Optical Research 47]

Looking at the figure above, it illustrates the injury hazard of different classes of laser pointers at different power levels. As stated before even a higher-class laser can be made less hazardous to work with and be around when the power is turned down. The figure above shows how even a class three laser when it is turned down in terms of power can have its eye injury hazard risk turned down from high to a low medium.

Recalling that our laser pointer is normally a class three B laser pointer running at 750 milli Watts it would fall in the category of high eye injury hazard risk. This would mean that our laser pointer would be closer to a class four laser pointer than a class three B according to the above chart.

With all of this being this being taken into account and the fact that our optical system ability to detect algae would not be affected, we decided to cut the power in half. By cutting the power in half from 750 milli Watts, that takes our laser pointer from a class three B laser pointer approaching a class four laser pointer, to a laser pointer at 375 milli Watts. With our laser pointer at 375 milli Watts, it is directly in the section of class three B laser pointers. The class three B laser pointer it is at the upper side of the medium eye injury Hazard. This significantly increases the safety of our optical system, both for us building it and for any user of our fish tank algae detection device.

ANSI and IEC laser classification	**Class 1**		**Class 2**		**Class 3**		**Class 4**	**Notes**
Sub-class	**Class 1**	**Class 1M**	**Class 2**	**Class 2M**	**Class 3R**	**Class 3B**	**Class 4**	
U.S. FDA laser classification	Class I	No special FDA class	Class II	No special FDA class	Class IIIa (definition is different but results are similar)	Class IIIb	Class IV	Newer ANSI/IEC number classes are now preferred over older FDA Roman numeral classes
Human-accessible laser power (for visible light)	For visible light, emits beam less than 0.39 milliwatts, or beam of any power is inside device and is not accessible during operation.		Emits visible beam of less than 1 milliwatt.		For visible light, emits beam between 1 and 4.99 milliwatts.	For visible light, emits beam between Class 3R limit (e.g. 5 milliwatts) and 499.9 milliwatts	For visible light, emits beam of 500 milliwatts (1/2 Watt) or more	Non-visible lasers emitting infrared or ultraviolet are not included in this chart. Only visible lasers are discussed.
Caution/warning indication	No special caution/ warning indication		No special caution/ warning indication		**CAUTION**	**WARNING**	**DANGER**	
Label descriptive text		DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS	DO NOT STARE INTO BEAM	DO NOT STARE INTO BEAM OR EXPOSE USERS OF TELESCOPIC OPTICS	AVOID DIRECT EYE EXPOSURE	AVOID EXPOSURE TO BEAM	AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION	For visible-light lasers, the word "light" can be used instead of "radiation". The latter is more accurate for lasers emitting infrared and ultraviolet radiation.
EYE AND SKIN HAZARDS								
Eye hazard for intraocular exposure (having a direct or reflected beam enter the eye)	Safe, even for long-term intentional viewing. For visible light, usually applies when the laser is enclosed inside a device (ex: CD or DVD player) with no human access to laser light.	Safe for unaided eye exposure. May be hazardous if viewed with optical instruments such as binoculars or eye loupe.	Safe for unintentional exposure less than 1/4 second. Do not stare into beam.	Safe for unintentional (< 1/4 sec) unaided eye exposure. May be hazardous if viewed with optical instruments such as binoculars or eye loupe.	Unintentional or accidental exposure to direct or reflected beam has a low risk. Avoid intentional exposure to direct or reflected beam.	Eye hazard; avoid exposure to direct or reflected beam.	Severe eye hazard; avoid exposure to direct or reflected beam.	
Maximum or typical Nominal Ocular Hazard Distance (for 1 milliradian beam, exposure time less than 1/4 second)	Not an eye hazard -- does not apply	Consult an LSO as described in the Technical Note below	**NOHD of 0.99 mW beam:** 23 ft (7 m)	Consult an LSO as described in the Technical Note below	**NOHD of 4.99 mW beam:** 52 ft (16 m)	**NOHD of 499.9 mW beam:** 520 ft (160 m)	**NOHD of 1000 mW (1 Watt) beam:** 733 ft (224 m). **NOHD of 10 W beam:** 2320 ft (710 m)	Avoid eye exposure to a direct or reflected laser beam, within the NOHD. The closer you are to the laser, the greater the chance of hazard and the more serious the injury potential.
Eye hazard for diffuse reflection exposure (looking at the laser "dot" scattered off a surface)	None	Consult an LSO	None	Consult an LSO	None	Generally safe. Avoid staring at the laser "dot" on a surface for many seconds at close range.	To avoid injury, do not stare at laser "dot" on a surface. The light is too bright if you see a sustained afterimage, lasting more than about 10 seconds.	
Skin burn hazard	None	Consult an LSO	None	Consult an LSO	None	Can heat skin if beam is held long enough on skin at close range	Can instantly burn skin. Avoid direct exposure to the beam.	
Materials burn hazard	None	Consult an LSO	None	Consult an LSO	None	Can burn materials if beam is held long enough on substance at close range	Can instantly burn materials. Avoid direct exposure to the beam, for materials susceptible to burning.	Dark materials which absorb heat, and lightweight materials such as paper and fabric, are most easily burned by visible laser light.
VISUAL INTERFERENCE DISTANCES								
Maximum or typical flashblindness distance (FAA 100 μW/cm², for 1 milliradian beam, 555 nm green light)	Not applicable; beam is usually contained inside a device such as a CD or DVD player	Consult an LSO	**For a 0.99 mW beam:** 117 ft 36 m	Consult an LSO	**For a 4.99 mW beam:** 261 ft 80 m	**For a 499 mW beam:** 2.614 ft (1/2 mile) 797 m (0.8 km)	**For a 1 Watt beam:** 3,696 ft (0.7 mile) 1,127 m (1.1 km) **For a 10 W beam:** 11,689 ft (2.2 miles) 3,563 m (3.5 km)	Value given is for 555 nm, the green wavelength that appears brightest to the light-adapted human eye. This gives the longest hazard distance. To approximate for red laser light, divide the distance by about 5; for blue, divide by 20.
Maximum or typical glare distance (FAA 5 μW/cm², for 1 milliradian beam, 555 nm green light)	See above	Consult an LSO	523 ft 159 m	Consult an LSO	1,169 ft 356 m	11,689 ft (2.2 miles) 3,563 m (3.5 km)	**For a 1 Watt beam:** 16,531 ft (3.1 miles) 5,039 m (5 km) **For a 10 W beam:** 52,275 ft (9.9 miles) 15,933 m (16 km)	See above
Maximum or typical distraction distance (FAA 0.05 μW/cm² or 50 nanowatts/cm², for 1 milliradian beam, 555 nm green light)	See above	Consult an LSO	5,227 ft (1 mile) 1,593 m (1.6 km)	Consult an LSO	11,689 ft (2.2 miles) 3,563 m (3.5 km)	116,890 ft (22 miles) 35,628 m (35.6 km)	**For a 1 Watt beam:** 165,307 ft (31 miles) 50,386 m (50 km) **For a 10 W beam:** 522,746 ft (99 miles) 159,333 m (160 km)	See above

Technical Notes	For a 1/4 second exposure to accessible visible-light beams, Class 1 limits are the same as Class 2, and such lasers are usually labeled as Class 2.	We are unaware of any Class 1M laser devices intended for consumer use. If you do have such a laser, consult a qualified Laser Safety Officer for more detailed analysis.	Class 2 (and 2M) only applies to visible lasers. Infrared and ultraviolet lasers cannot be Class 2 (or 2M).	We are unaware of any Class 2M laser devices intended for consumer use. If you do have such a laser, consult a qualified Laser Safety Officer for more detailed analysis.	Class 3R is either: (1) From 1 to 4.99 mW into a 7mm aperture (e.g., pupil of the eye) or (2) five times the Class 2 limit of 2.5 mW/cm^2, which works out to be 12.5 mW/cm^2. The second method is used by LaserSafetyFacts to determine NOHD.		
	Class 1	**Class 1M**	**Class 2**	**Class 2M**	**Class 3R**	**Class 3B**	**Class 4**
	Class 1		**Class 2**		**Class 3**		**Class 4**

Table 31 courtesy of [Optical Research 47]

The above table gives all the different ANSI classifications for different laser pointers in the visible light spectrum across the top, gives the risks and hazards for those different laser pointers. So, looking at the class three, class three B column, it can be seen that the laser pointer carries the cautionary level of “Warning”. With the caution level of warning, it is advised to avoid exposure to the eye with the beam. This hazard will be taken care of by the housing we are building for the system. For eye hazard the laser printer carries the “avoid exposure to direct or reflected beam,” this too will be taken care of by the housing and the lenses we are purchasing we have anti reflective coting on them, [Optical Research 47]. The table goes on to give examples of a laser pointer that is much more power full than ours at different distances that the beam from the laser pointer can still pose harm to the skin and eye, it also goes on to give the distances that the glare from the laser pointer would still be pose a risk of being harmful, but as stated before our optical system will be enclosed in a housing unit so the light from the laser pointer will pose no harm to anyone or anything outside of the housing unit.

4.3 Software Testing Standards

The standard, ISO/IEC/IEEE 29119, is a combination of software testing standards. This standard is in place in order to define an internationally-agreed set of standards for software testing that can be used by any organization when performing any form of software testing. It helps to ensure proper testing processes, techniques and documentation of software. This series of international standards can support testing in many different contexts. This will be used with our project due to the software element of the application and the software aspect of the hardware. There are five different parts in this standard that will be followed for this project and outlined below.

One of the main concepts that will be used is software testing. Software testing is necessary because it provides information on the quality characteristics of the test items. The items being tested does not always do what it is expected to do. The test item being tested needs to be verified. The item also needs to be verified. This evaluation of the test item needs to be processed throughout the software and system development life cycle.

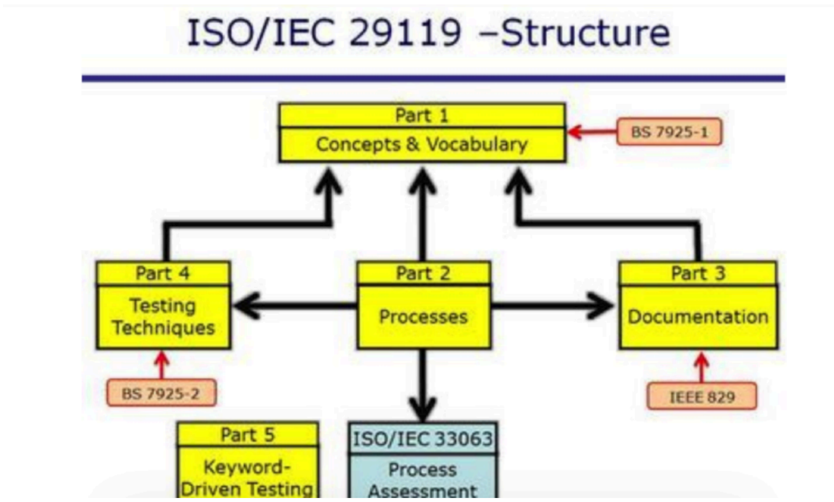


Figure 27: Structure of ISO.IEC 29119

5. Product Design

Based on our research, the following design has been created to align with our goals from our House of Quality Matrix. The Fish Tank Assistant is going to require the integration of the chosen components from the design research. The device specifications such as required voltage and current will determine if additional components will be needed for the system to operate. Once sensors and other accessories are successfully configured, they need to be programmed and calibrated to detect the presence of harmful blue green algae. After extensive testing the final design can be constructed and prepared for presentations.

The design is broken down into 3 sections: Hardware Design, Optic Design, and Software Design. Each covers the required components of the respective category, for instance, any lenses or lasers used in this system will be found in the Optic Design section 5.2. The programing language will be discussed in the Software Design and will be determined by the software supported by the selected microcontroller and the type of display. After all the components are selected and tested the housing can be constructed and fixed with custom 3D printed casings.

5.1 Hardware Design

The following hardware design is based on the previous research in section 3. Hardware is going to include any physical component being integrated into the system. Our device is going to require a microcontroller that will be programed to detect changes in light intensity and a laser that will be diffracted with 1 beam interacting with a water sample and the other acting as a reference. The beams will be focused and angled to be read by the chosen photodiodes that will relay the analog data back to the microcontroller. A liquid crystal display (LCD) will be coded to display the calibrated digital output. A thermal camera will be used to monitor the temperature of the water sample as it passes through a siphon. All optic components will be mounted via custom 3D printed casings that can be fastened to the constructed waterproof housing. A separate printed circuit board (PCB) is going to be developed to interface with the liquid crystal display and regulate current. Our design is based off our House of Quality Matrix with a focus on cost and user experience.

5.1.1 Microcontroller

Arduino offers an open-source platform focused on electronics with easy-to-use hardware and software that is intended for inexperienced designers. They manufacture microcontroller boards and sell development kits that can be used to follow along with online projects. These boards can read inputs from devices such as light sensors or buttons and turn them into outputs activating another component like a motor or LED. The systems are easily programed through the Arduino Software (IDE) and can be run on Linux and Macintosh as well as Windows.

The Arduino Uno is the most documented board in the entire Arduino family on the open-source platform. There are hundreds of datasheets, tutorials and guides available to get started with. Interactive schematics are available and can be opened in a program called Eagle where the design can be tested, and the printed circuit board can be constructed. The PCB will interface with the liquid crystal display and allow the user to view specific data and power on and off the system. These low-cost microcontroller boards can be found for an even lower cost by other manufacturers.

5.1.1.1 Development Kit

Miuzei Pro is an online resource that offers discounted components as well as development kits for Arduino Uno and Raspberry Pi. The Arduino Uno starter kit contains over 160 components including a bread board, jumper wires and a LCD1602 display for testing and only costs 5 dollars more than a true Arduino Uno. This made the Arduino Uno the superior microcontroller for our design. This starter kit allowed us to procure the accessories needed to test the optic system at a minimal cost.

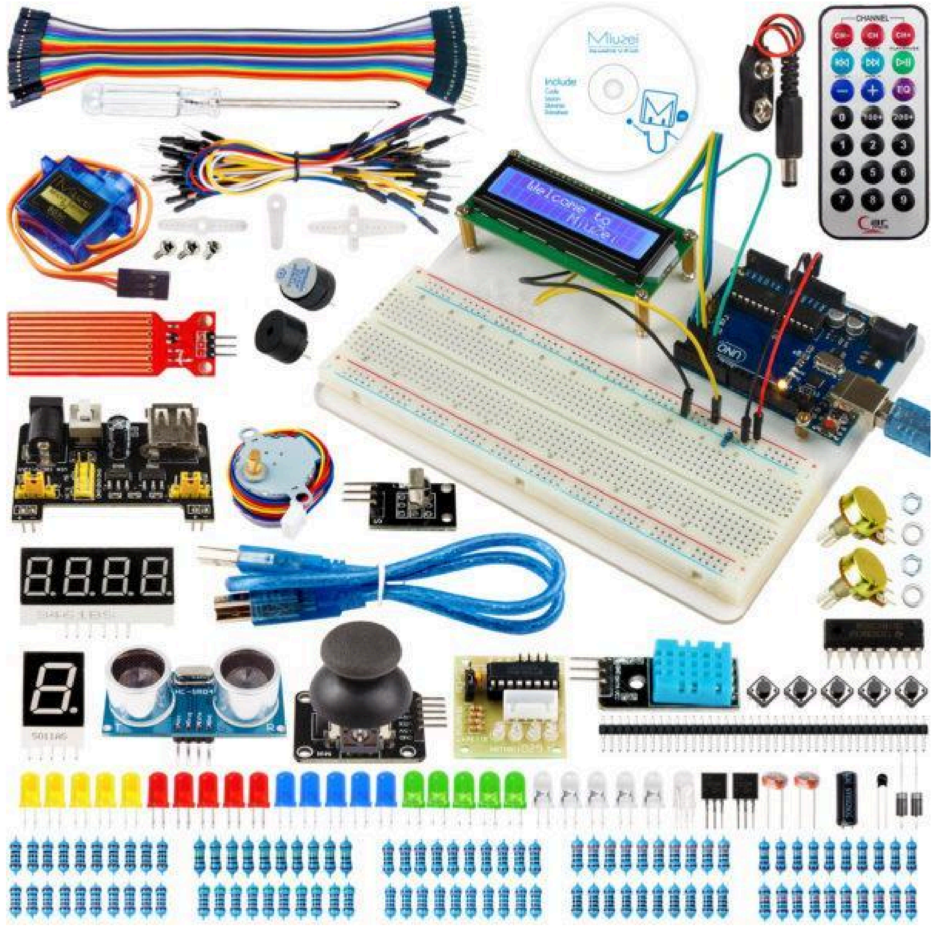


Figure 28: Miuzei Starter Kit (Courtesy of MiuzeiPro.com)

5.1.1.2 Specifications

The Miuzei starter kit includes a number of components that will be useful in the testing section. Typically, microcontrollers are purchased as a single board with a USB power cord and any additional wires, resistors, and displays must be purchased separately. The kit comes with a range of resistors and wires that can be easily integrated on the 830 tie-points breadboard with other components such as the LCD1602 module. Purchasing all of the components separately can get expensive fast, especially with shipping, for just a few more dollars we were able to purchase the microcontroller with the shown modules and smaller components.

Board	Name	Arduino Uno R3
	SKU	A000066
Microcontroller	ATmega328P (Removeable)	
USB Connector	USB-B	

Pins	Built-in LED Pin	13
	Digital I/O Pins	14
	Analog Input Pins	6
	PWM Pins	6
Communication	UART, I2C, SPI	
Power	I/O Voltage	5V
	Input Voltage (nominal)	7V-12V
	DC Current per I/O Pin	20 mA
	Power Supply Connector	Barrel Plug
Clock Speed	Main Processor	ATmega328P 16 MHz
	USB-Serial Processor	ATmega16U2 16 MHz
Memory	ATmega328P	2KB SRAM, 32KB FLASH, 1KB EEPROM
Dimensions	Weight	25g
	Width	53.4mm
	Length	68.6mm

Table 32 Arduino Uno Specifications

5.1.2 Power Supply

The Arduino Uno has 3 main power options: USB cable, barrel connector, and Vin pin. The Fish Tank Assistant will use a wall adapter plugged into the barrel connector to provide 9V to the AC-DC power adapter. Barrel connectors, also known as coaxial power connectors, are used to attach external electricity to extra low voltage devices such as microcontrollers. These cables are made up of a copper core surrounded by a dielectric insulator, woven copper shield, and plastic sheath, in that order, and come in a variety of sizes with a range of inside and outside plug diameters.

FlickerStar offers a low cost 2.1mm x 5.5mm barrel cable that accepts a voltage range of 100V-240V AC with a 9V DC output. Model B07ZM46WKF meets the Arduino Uno's in put voltage range, 7V-12V DC and will fit the mounted jack socket. While the other wall adapters had similar specifications, the FlickerStar came with a smart chip that protects against short circuits, dangerous temperatures, and multiple overages including current and voltage.

Figure 29: FlickerStar B07ZM46WKF 9-volt AC Adapter (Courtesy of Amazon)

5.1.2.2 Specifications

Based off the product specifications the FlickerStar 9V adapter would be able to support our design. In order for the system to continuously monitor the water conditions with little to no interruptions the wall adapter needs to be secured to a powered wall outlet or power strip. The 120VAC input from the wall goes from the two-prong plug connected to the primary coils of a transformer, then a secondary transformer is connected to a full bridge diode rectifier followed by a capacitor and center positive output jack.

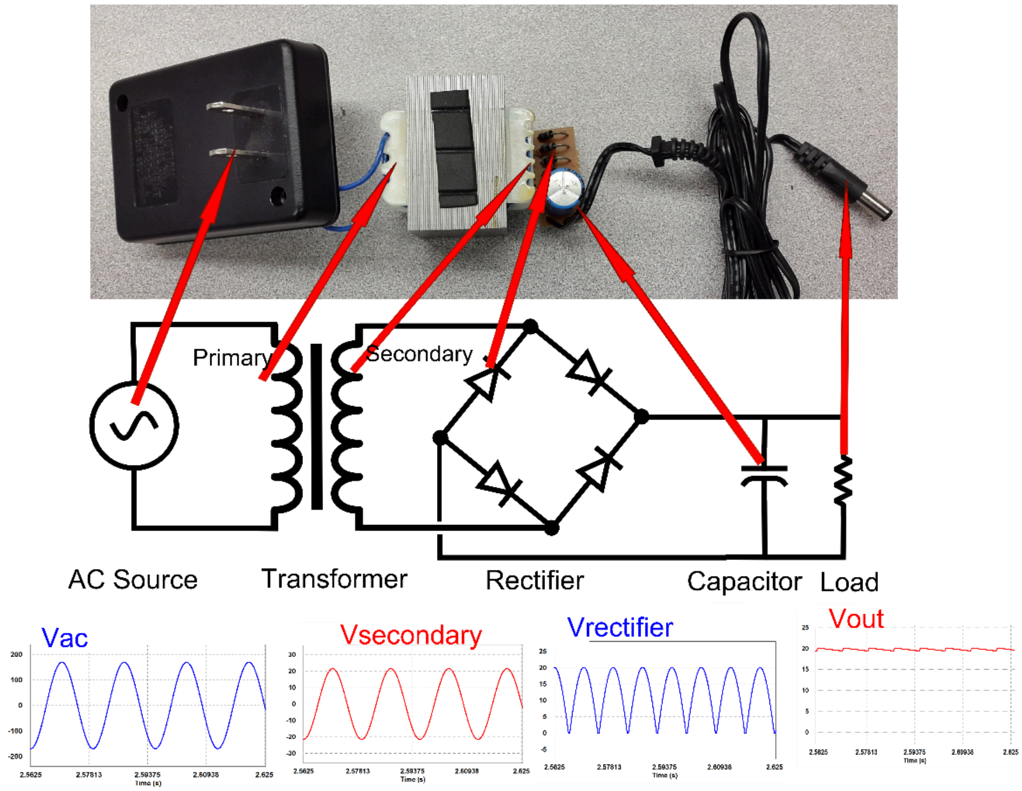


Figure 30 AC Adaptor, Schematic and Voltages (Courtesy of AllAboutCircuits.com)

Type	FlickerStar
Input Voltage Range	100-240V AC , 50-60 Hz
Output Voltage Range	9V DC
Output Amps	1000mA
Plug Polarity	Inner Positive (+), Outer Negative (-)
Cable Length	6.6 feet (200 cm)
Manufacturer Part Number	B07ZM46WKF
Size	2.1mm x 5.5 mm
Price	10.98
Customer Rating	4.4 out of 5

Table 33 FlickerStar B07ZM46WKF 9-volt AC Adapter Technical Specifications

5.1.3 Display

System displays come in a variety of shapes, sizes, and formats. Displays can be as simple as 7 segment displays that produce a single number output or dot matrixes that allow for limited outputs based on the dimensions. Liquid Crystal Displays evolved from Cathode Ray Tubes and offer products in applications such as televisions, tablets and system displays. LCDs have become more popular over time due to the development of capacitive and resistive touch screens. These are commonly used in tablets, smartphones, and other touch enabled devices.

Capacitive touchscreens were invented 10 years before the first resistive touch screen and become popular after Apple used it 2007. It contains an X and Y matrix of transparent electrodes separated by a layer of insulation. When a conductive material such as the human body makes contact with the screen a capacitance coupling happens which changes the electrostatic capacitance between the X and Y electrodes which allows the controller to detect the change. These screens come with excellent clarity, sensitivity, and can be made of scratch resistant materials such as gorilla glass.

Resistive touchscreens consist of a glass and film substrate both coated with a transparent conductive layer then separated by spacer dots that allow for small air gaps. When the screen is touched the air gap is filled and the conductive layers make contact and allow the controller to calculate the touch position. Compared to capacitive touchscreens, resistive touch screens have low power consumption, are significantly cheaper and can be easily activated by any material as long as pressure is applied.

Nextion manufactures various sizes of TFT LCD touch screens with the smallest at 2.4 inches and the largest being 10.1. They focus on combining their Editor software with memory touch displays and on board processors. They offer the NX3224T024 from their basic series, a 2.4-inch resistive touch screen with a required input of 5V. Based off the product specifications, customer reviews, and additional internet resources it was found that this display would meet the requirements for the system while remaining under budget.

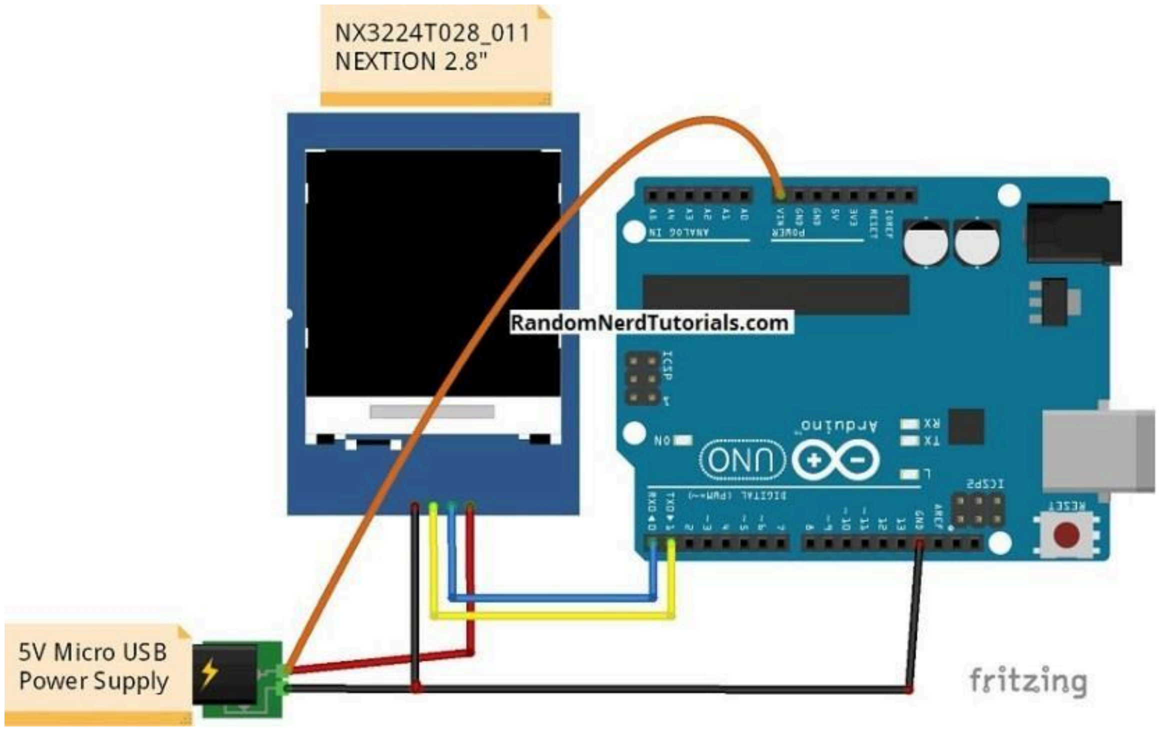


Figure 31 Wire Diagram of Nextion Liquid Crystal Display with Arduino Uno (Courtest of randomnerdtutorials.com)

5.1.3.1 Specifications

Manufacturer	Nextion
Part Number	NX3224T024
Resolution	320 x 240 pixel
Colors	64k
Flash	16MB
Diagonal Size	2.4”
Connection	8 Digital GPIO
Outline Dimension	66.4mm x 96.7mm
Active Area	60.26mm x 42.72mm
Touch Panel	Resistive
Backlight Color	LED
Power Supply	4.75V - 7V
Supply Current for LCM	90mA (Vdd=5V)
Operating Temperature	-20℃~70℃
Cost	$29.98
Customer Rating	4.6 out of 5

Table 34 Nextion NX3224T024 Specifications

5.1.4 Communication

Our design is going to communicate via WiFi with the help of a ESP8266. MakerFocus manufactures open-source hardware compatible with Arduino modules. The ESP8266 has an input power of 3.6V max 1MB memory that can be connected directly to the Arduino Uno 3.3V pin. Tutorials are available online to configure, code, and connect your device. By integrating a self-contained WiFi networking system we will be able to share the sensor outputs via a web application.

5.2 Optical Design

5.2.1 Why Use Beer's Law Method instead of Spectrometer for Optical System to Detect Algae

Spectrometer Pros and cons
Pros

- Would get more hands-on experience with diffraction grating.

Cons

- Less user friendly
  - Set up is not as streamline as Beer's law approach.
- If it needs to be taken apart for cleaning it has more fragile components that could be scratched and damaged.
  - ~3 lenses
  - 1 Light
  - 1 Diffraction grating
  - 1 Camera
  - Total of 6 components
- Total cost of components is higher
- More errors could arise with the spectrometer method
  - The camera could get fogged up by humidity could cause it to give the wrong information.
  - The diffraction grating could get scratched during cleaning causing errors to arise.

Beer's Law Pros and cons

Pros

- More user friendly
  - It is a verry streamed line set up
- If it needs to be taken apart for cleaning it has less components to be cleaned.
  - 2 Photodiodes

  - 1 Light source
  - 1 Beam splitter
  - 1 Lens
  - Total of 5 components
- The total cost of components is lower than the spectrometer

Cons

- Optical alignment must be prosses for incident light to hit the photodiode.

The ratio of pros to cons for the beer's law utilizing system is better than it is for the spectrometer since there is fewer cons than pros, so we have chosen to go with the Beer's law approach.

5.2.2 Selection of Laser Emitting Diode's wavelength

For Selecting a light source, we first need to look at either the emission spectrum of algae, or the absorption spectrum of algae. For the emission spectrum we want the wavelength that dips the deepest or has the deepest trough. The converse can be said for the absorption spectrum, there the highest peak is wanted because it is where the most light is absorbed. But, there are approximately fifteen types of algae that are commonly found in fish tanks [5]. There was not any wavelength that would be perfect for all fifteen. So, looking at the makeup of those algae, all of them contained a significant amount of chlorophyll a. A study done in lakes with diverse types of environmental conditions showed that in a Hypereutrophic environment, like what it is in a fish tank, the part per billion of algae are quite high, see below [42].

A hypereutrophic environment is one that is nutrient rich. These nutrients can take the form of phosphates, nitrites, nitrates, etc. These nutrients come about by overfeeding fish in the tank. The overfeeding causes both the access nutrients to break down and also the added food leads to the fish producing more waste. this can then lead to an algae bloom.

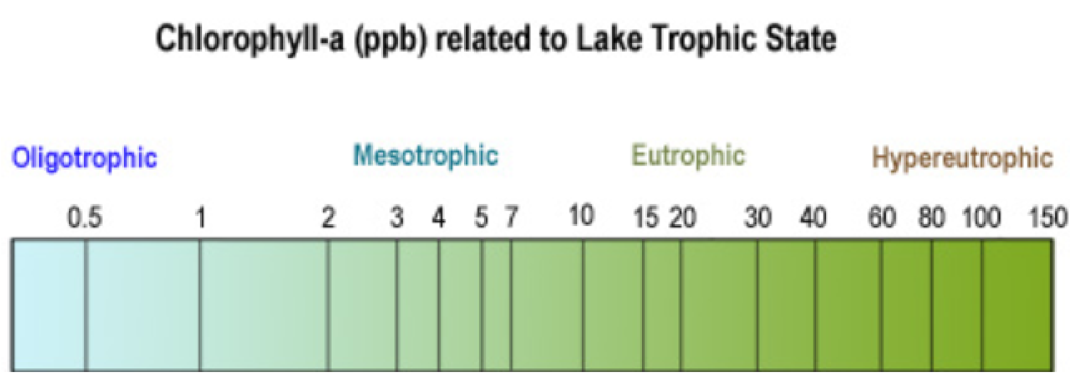


Figure 32: Amounts of Chlorophyll A of Varying Types of Algae in Different Environments (Courtesy of [42] Copyright approval pending)

Part per billion is compatible to ug/L or micro grams per later. Taking into account the figure above of the amount of chlorophyl a in a Hypertrophic environment the choice to use chlorophyl a as the way to find algae in a water sample is the right one.

Looking at the spectrum of chlorophyll a from the Optical Design section, it peaks at 450nm, and has a width going from 425nm to 475nm meaning that $\Delta\lambda \approx 450$nm, so that is the wavelength that is needed for the laser pointer so that the optimal amount of light is absorbed by the chlorophyll a in the algae giving the largest amount of contrast in the optical system.

5.2.3 3D Printed Optical Mount Designs

We decided to design 3D printed optical mounts to save us funds and keep the overall weight lightweight. The 3D prints also eliminate the need for a rail system to mount the beamsplitter in the Thorlabs beamsplitter mount. The Thorlabs mount is called C45P, which is the part number. By designing our optical mounts, ourselves, we also can create them to any specifications we desire, allowing for customizable placement and adjustability. We decided to use FreeCad as our modeling software for the design process of the mounts as it is accessible to all users and does not require licensing and is familiar to our team members. We decided to start with the bi-convex focusing lens mount as this would be the most difficult to design because of the lens curvature on both sides. Before modeling the mounts, we started importing the Thorlabs step files from their website for the bi-convex lens and the beam splitter.

After importing the files, we began designing the mounts in two separate parts that would come together, housing each of the optics using nuts and bolts to secure the pieces together. We then wanted the optic housing to slide into a base mount which would be attached to the physical housing of the system. The optics window was designed to be a few millimeters more significant than the actual optic. The design was intended to allow the optics to safely sit inside the mount without causing damage such as scratches to occur while assembling. To secure the optic into the mount, we designed a small lip situated inside the window to keep the optic from falling out. To counteract any printing errors, we plan to use hot glue to fill in any gaps and provide extra security. However, the optics themselves will not be glued into the mounts as we want to have the ability to remove and clean them as need be while aligning. Instead, the hot glue will be placed inside the mounts without the optic and allowed to dry. After drying, the excess hot glue will be scraped out of the mount, and the optic will then be placed inside. The process of removing the excess glue will leave enough material inside the mount to fill any gaps created by the printing process allowing for a more accurate fit. We made similar mounts for the other components, where each 3D print would have a base to attach to the physical housing of the system. The following figures display the current design of each mount and the orientation of the optical system.

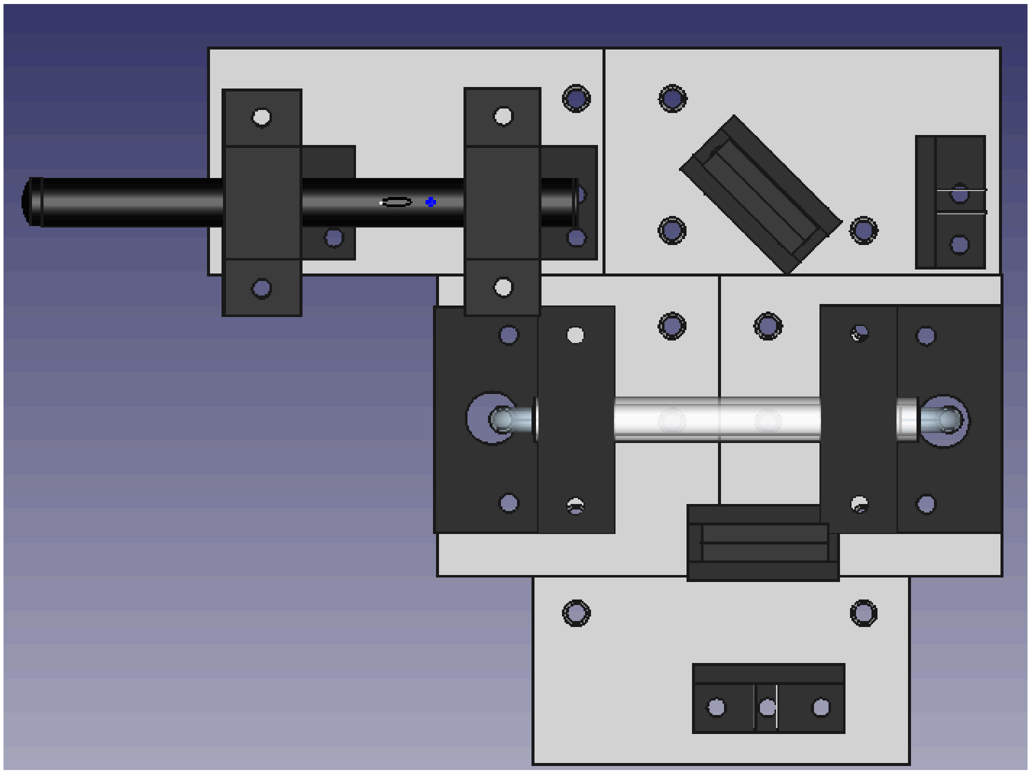


Figure 33: FreeCAD Optic Mounts Frontal View

We provided two images of the optical system because the overhead image does not prominently display the designs of the mounts. However, the frontal image does not adequately show the distance or the optical system's separate paths that the beam will take. We also decided to leave visual measurements out of the FreeCAD model as they would overlap and be confusing to view. Instead, we decided to tabulate the distances between the components for more accessible references and later access.

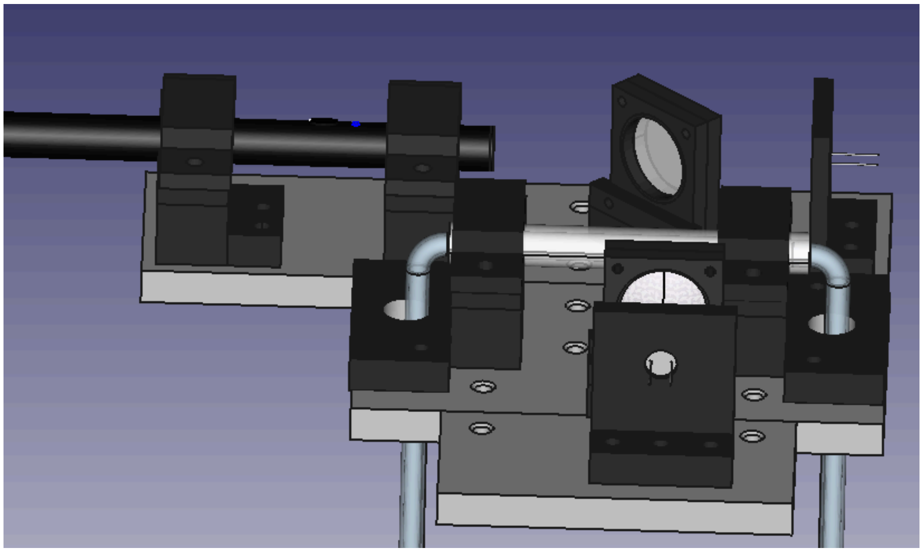


Figure 34: FreeCAD Optic Mounts Frontal View

Optical Path	Path 1	Path 2
Laser pointer to beamsplitter	5 centimeters	5 centimeters
Beamsplitter to photodiode 1	3 centimeters	NA
Beamsplitter to water tube	NA	5 centimeters
Water tube to focus lens	NA	2.4 centimeters
Focus lens to photodiode 2	NA	3 centimeters

Table 35 Beam Splitter Path Comparison

5.2.4 Breadboard Design

The breadboard is essential for the overall system as we need a component that each of the 3D mounts can attach to inside the system. We began by considering a manufactured stainless-steel breadboard from Thorlabs. Still, we realized early on that a stainless-steel component would add a lot of weight to the system, which may cause stress to a fish tank's structure and poses a potential risk of stressing the physical systems housing from the weight. Therefore, for the reasons described above, we decided to design our breadboards to 3D print instead, which will provide a lightweight and cheap solution. We plan to connect each board using structural pieces to ensure that the panels will line up with each other.

5.3 Software Design

There are two aspects to consider while working on the software design of this project. There is the Hardware programming which is programming the microcontroller, as well as the sensors and buttons to operate as intended above. The second aspect is what our stretch goal is for the software design and that is developing a simple app that is user friendly that allows the user to monitor and interact with the device through a smart device.

5.3.1 Hardware Programming

In this section, we have to take into consideration the IDE that will be used and will best work with the language we decided to go with.

5.3.1.1 Arduino IDE C/C++

Since we decided to go with C/C++ libraries and language to code the microcontroller, we chose Arduino IDE as it is compatible with both the language and the microcontroller we will be using. Arduino offers an open-source platform focused on electronics with easy-to-use hardware and software that is intended for inexperienced designers.

Advantages:

1. Inexpensive
2. Open source in hardware
3. Don't need to external programmer (burner)
4. Programming ease
5. Open source in software
6. IDE software operate on any operating system

Programs written using Arduino Software (IDE) are called sketches. These sketches are written in the text editor and are saved with the file extension .ino. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom righthand corner of the window displays the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches, and open the serial monitor.

Libraries:

Libraries provide extra functionality for use in sketches, e.g. working with hardware or manipulating data. To use a library in a sketch, select it from the **Sketch > Import Library** menu. This will insert one or more **#include** statements at the top of the sketch and compile the library with your sketch. Because libraries are uploaded to the board with your sketch, they increase the amount of space it takes up. If a sketch no longer needs a library, simply delete its **#include** statements from the top of your code.

Robotics
Libraries for controlling servo and stepper motors.

- Servo - for controlling servo motors.
- Stepper - for controlling stepper motors.

Communication

Libraries for using the SPI, I2C and UART protocols.

- SPI - for communicating with devices using the Serial Peripheral Interface (SPI) Bus.
- Wire - Two Wire Interface (TWI/I2C) for sending and receiving data over a net of devices or sensors.
- SoftwareSerial - for serial communication on any digital pins.

Connectivity

Libraries to access radio modules on different IoT boards (Wi-Fi, Bluetooth®, LoRa®, GSM, NB-IoT, Sigfox).

- ArduinoIoTCloud - This library allows to connect to the Arduino IoT Cloud service. .
- ArduinoBLE - library to use the Bluetooth® Low Energy on a selection of boards.
- Ethernet - for connecting to the Internet via Ethernet.
- GSM - for connecting to a GSM/GRPS network with the GSM shield.
- MKRWAN - library for MKR WAN 1300/1310, for connecting to LoRaWAN® networks.
- MKRGSM - library for MKR GSM 1400, for connecting to GSM/GPRS networks.
- MKRNB - library for MKR NB 1500, for connecting to NB-IoT / Cat M1 networks.
- SigFox - library for MKR FOX 1200, for connecting to the Sigfox network.
- WiFi - library for the WiFi shield, for Internet connections via Wi-Fi.
- WiFi101 - library for the MKR 1000 WiFi and WiFi101 shield, for Internet connections via Wi-Fi.
- WiFiNINA - library for boards with a Wi-Fi NINA module, for Internet connections via Wi-Fi.

Nano Family Libraries

Libraries designed for embedded sensors on various Nano boards.

- ArduinoAPDS9960 - library to use the gesture sensor APDS9960; it senses gesture, color, ambience illumination and proximity.
- Arduino_LSM6DS3 - library to use the LSM6DS3 6 axis IMU available on the Arduino Nano 33 IoT and the Arduino UNO WiFi Rev. 2.
- Arduino_LSM9DS1 - library to use the LSM9DS1 9 axis IMU available on the Arduino Nano 33 BLE and the Arduino Nano 33 BLE Sense.
- Arduino_LSM6DSOX - library to use LSM6DSOX 6 axis IMU available on the Arduino Nano RP2040 Connect.
- ArduinoLPS22HB - library to use the barometer and temperature sensor LPS22; it is an ultra-compact sensor which functions as a digital output barometer.
- ArduinoHTS221 - library to use the HTS221 relative humidity & temperature sensor.
- PDM - library to use the digital microphone MP34DT05 (Nano BLE Sense and Nano RP2040 Connect).

Memory

Libraries for memory management and data storage.

- EEPROM - reading and writing to "permanent" storage.
- SD - for reading and writing SD cards.

Display

Libraries for controlling different displays.

- LiquidCrystal - for controlling liquid crystal displays (LCDs).
- TFT - for drawing text , images, and shapes on the Arduino TFT screen.

MKR Family Libraries

Libraries listed below are specifically designed to work with Arduino MKR Family products.

- Scheduler - manage multiple non-blocking tasks (also works with the Arduino Due).
- RTCZero - Real Time Clock to schedule events.
- ArduinoMKRGPS - library to be used with the Arduino MKR GPS Shield.
- ArduinoMKRRGB - library to be used with the Arduino MKR RGB Shield.
- ArduinoGraphics - library with graphic primitives, works also with the Arduino MKR RGB Shield.
- ArduinoRS485 - library that implements RS485 on the Arduino MKR RS485 shield.

- ArduinoMKRENV - library to read all MKR ENV Shield sensors.
- ArduinoMKRTHERM - library to read the sensors connected to the Arduino MKR THERM Shield.
- MKRIMU - library to read the acceleration, gyroscope, magnetic field and euler angles from the IMU on your MKR IMU shield
- ArduinoMotorCarrier - library for controlling the MKR / Nano Motor Carriers.
- Arduino_MKRIoTCarrier - library for controlling the MKR IoT Carrier

Audio

Libraries for audio sampling and playback.

- AudioFrequencyMeter - library to sample an audio signal and get its frequency back.
- AudioZero - library to play audio files from a SD card.
- ArduinoSound - simple way to play and analyze audio data.
- Audio - allows playing audio files from an SD card. For Arduino DUE only.
- I2S - library for using the I2S protocol on SAMD21 (included in SAMD platform).

USB

Libraries for using your Arduino as either a USB host or device.

- USBHost - communicate with USB peripherals like mice and keyboards.
- Keyboard - send keystrokes to an attached computer.

Mouse - control cursor movement on a connected computer.

5.3.2 Software Programming/ App development

In this section, we must take into consideration the IDE that will be used and will best work with the language we decided to go with.

5.3.2.1 Swift

Swift is developed in the open at Swift.org, with source code, a bug tracker, forums, and regular development builds available for everyone. This broad community of developers, both inside Apple as well as hundreds of outside contributors, work together to make Swift even more amazing. There is an even broader range of blogs, podcasts, conferences and meetups where developers in the community share their experiences of how to realize Swift's great potential.

Swift has many other features to make your code more expressive:

1. Generics that are powerful and simple to use

2. Protocol extensions that make writing generic code even easier
3. First class functions and a lightweight closure syntax
4. Fast and concise iteration over a range or collection
5. Tuples and multiple return values
6. Structs that support methods, extensions, and protocols
7. Enums can have payloads and support pattern matching
8. Functional programming patterns, e.g., map and filter
9. Native error handling using try / catch / throw

Libraries:

- Fundamental data types such as Int, Double, and String
- Common data structures such as Array, Dictionary, and Set
- Global functions such as print(_:separator:terminator:) and abs(_:)
- Protocols, such as Collection and Equatable, that describe common abstractions.
- Protocols, such as CustomDebugStringConvertible and CustomReflectable, that you use to customize operations that are available to all types.
- Protocols, such as OptionSet, that you use to provide implementations that would otherwise require boilerplate code.

<Animation UI>

1. Spring: A library to simplify iOS animations in Swift.
2. Material: An animation and graphics framework that is used to create beautiful applications
3. RazzleDazzle: A simple keyframe-based animation framework for iOS, written in Swift. Perfect for scrolling app intros
4. Stellar: A fantastic Physical animation library for swift
5. Macaw: Powerful and easy-to-use vector graphics Swift library with SVG support

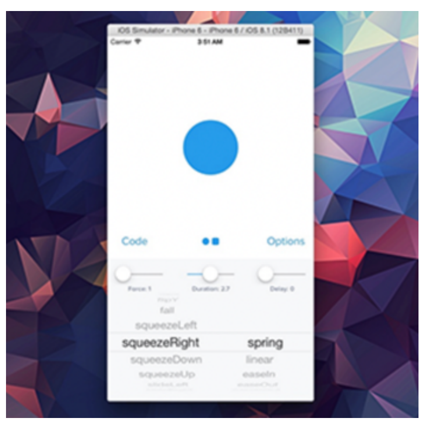


Figure 35: Animation controller library

<Transition UI>

1. PagingMenuController: Paging view controller with customizable menu in Swift
2. PreviewTransition: A simple preview gallery controller
3. PinterestSwift: Transition like Pinterest in Swift
4. YouTube Transition: Watch a video on the right corner like Youtube iOS app, written in Swift 3
5. Twicket Segmented Control: Custom UISegmentedControl replacement for iOS, written in Swift

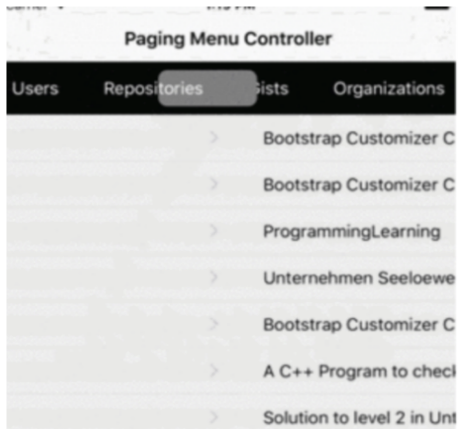


Figure 36: Transition menu

<Pop up UI>

1. SCLAlertView-Swift: Beautiful animated Alert View written in Swift
2. SwiftMessages: Very flexible alert messages written in Swift.
3. XLActionController: Fully customizable and extensible action sheet controller written in Swift 3
4. Popover: Balloon pop up library like Facebook app, written in pure swift.
5. Presentr: Wrapper for custom ViewController presentations

Figure 37: Pop-ups

<Feed UI>

1. FoldingCell: An expanding content cell inspired by folding paper material
2. ExpandingCollection: A card peek/pop controller
3. DGElasticPullToRefresh: Elastic pull to refresh component written in Swift
4. Persei: Animated top menu for UITableView / UICollectionView / UIScrollView written in Swift
5. IGListKit: A data-driven UICollectionView framework for building fast and flexible lists — Instagram Engineering.
6. PullToMakeSoup: Custom animated pull-to-refresh that can be easily added to UIScrollView

Figure 38: Notification and feed

<Onboarding UI>
1. DZNEmptyDataSet: Empty State UI Library
2. Instructions: Create walkthroughs and guided tours in Swift.
3. Presentation: Make tutorials, release notes and animated pages

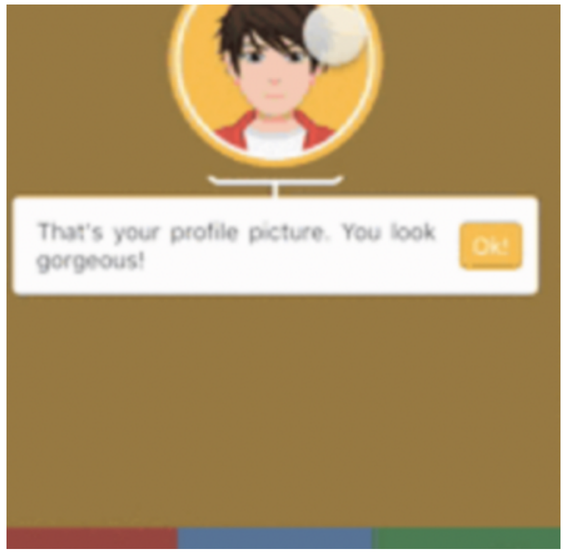


Figure 39: Intro and step-by-step guide

<Color UI>
1. Chameleon: Flat Color Framework for Swift Developers
2. Hue: All-in-one coloring utility that you'll ever need to write in Swift
3. DynamicColor: Extension to manipulate colors easily in Swift
4. FaceAware: An extension that gives UIImageView the ability to focus on faces within an image when using AspectFill
5. ComplimentaryGradientView: Create complementary gradients generated from dominant and prominent colors in supplied image

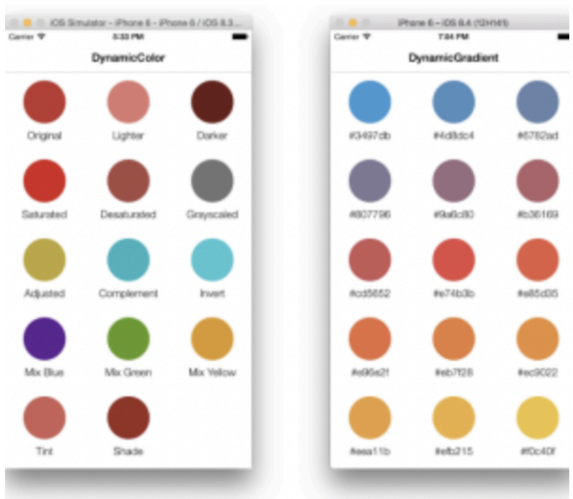


Figure 40: Colors

<Image UI>

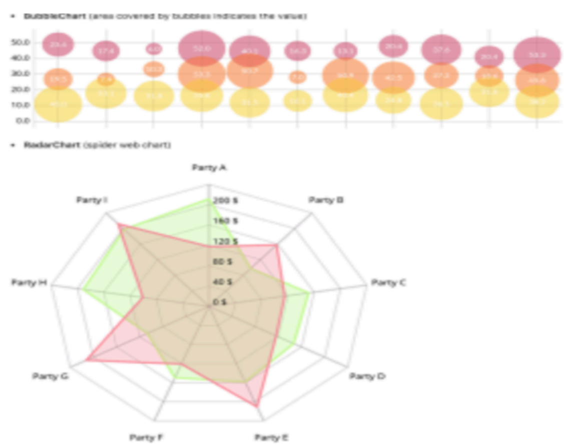
1. FaceAware: An extension that gives UIImageView the ability to focus on faces within an image when using AspectFill

2. ComplimentaryGradientView: Create complementary gradients generated from dominant and prominent colors in supplied image

Figure 41: adding images and graphics

<Graph UI>

1. Charts: Beautiful charts for iOS built in Swift



. . .

Figure 42: Graphs and illustrations

2. Scrollable-GraphView: An adaptive scrollable graph view for iOS to visualize simple discrete datasets.

<Icon UI>

1. Paper Switch: RAMPaperSwitch is a Swift module which paints over the parent view when the switch is turned on.
2. Circle Menu: A simple, elegant menu with a circular layout

<Schedule UI>

1. JTAppleCalendar: The Unofficial Swift Apple Calendar Library. View. Control. for iOS & tvOS

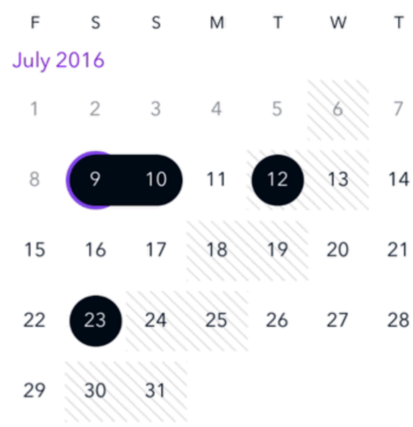


Figure 43: Calendar scheduling

2. DateTimePicker: A nicer iOS UI component for picking date and time

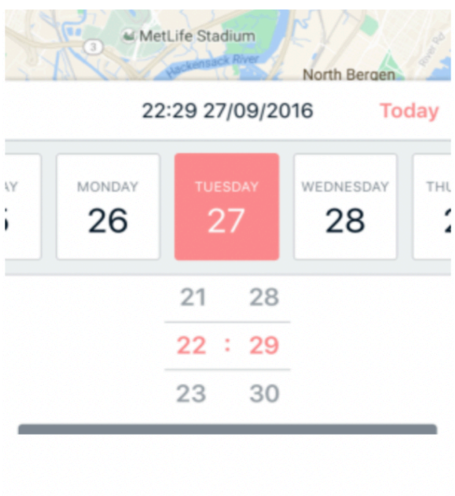


Figure 44: Calendar Scheduling

<Form UI>
Eureka: Elegant iOS form builder in Swift

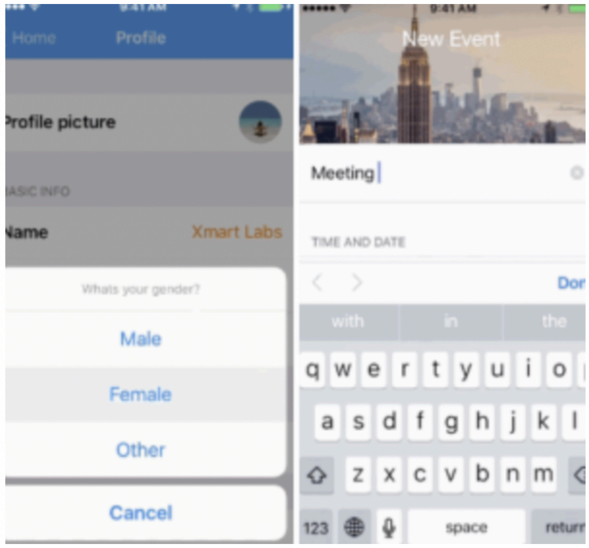


Figure 45: Forms

<Layout UI>
Neon: A powerful Swift programmatic UI layout framework for iPhone & iPad

Figure 46: Layout between iOS devices

<Message UI>
NMessenger: A fast, lightweight messenger component built on AsyncDisplaykit and written in Swift
<Search UI>

Reel-search: A search controller that allows you to choose options from a list

Cross platform:

Swift already supports all Apple platforms and Linux, with community members actively working to port to even more platforms. With SourceKit-LSP, the community is also working to integrate Swift support into a wide-variety of developer tools. We're excited to see more ways in which Swift makes software safer and faster, while also making programming more fun. Due to the fact that most of the team members own an iPhone, we decided to work with swift as it is a great platform to build an app with.

Swift for server:

While Swift powers many new apps on Apple platforms, it's also being used for a new class of modern server applications. Swift is perfect for use in server apps that need runtime safety, compiled performance and a small memory footprint. To steer the direction of Swift for developing and deploying server applications, the community formed the Swift Server work group. The first product of this effort was SwiftNIO, a cross-platform asynchronous event-driven network application framework for high performance protocol servers and clients. It serves as the foundation for building additional server-oriented tools and technologies, including logging, metrics and database drivers which are all in active development.

5.3.2 User Interface

5.3.2.1 The different types of applications

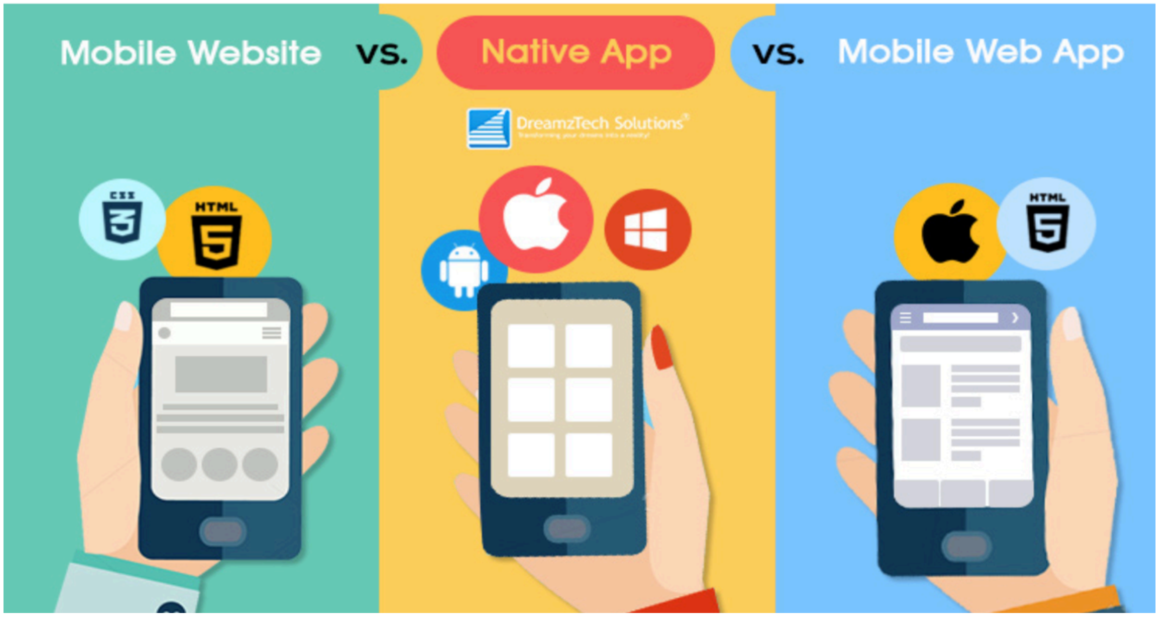


Figure 47: Difference between Mobile website vs. native app vs. mobile web app

Mobile Website

Theoretically, a mobile website is pretty much the same as any other website - it uses browser-based HTML pages that can be accessed by handheld devices and tablets. Unlike a website built for viewing on a desktop, the mobile site is designed to appear on a much smaller handheld display. It is a customized version of a regular website that is used specifically for mobile. Many companies today use responsive website designs in which their website is created to function on multiple platforms and screens. It is a versatile option that makes the most out of any given design.

Native App

As for native apps, they are downloaded applications - from Apple's App Store, Android Apps on Google Play, etc. - that are installed on a mobile device and can't be accessed within a browser. (Note: the name is derived from the fact that these apps are written in the language of the operating system of the device they are installed on.) Apps are a separate entity from a company's website, but are often used to supplement the brand in some way. Perhaps there is a game associated with your company, or you can provide your services to individuals through a smaller platform, rather than requiring them to go through your website.

Mobile Web App

Mobile web apps appear similar to the native app, but they differ in the manner in which they are built and rendered. These apps are viewed through a mobile web browser and are built in HTML/CSS. They are real websites that look, feel, and function like any other application. The main difference is through their implementation on the back end.

5.3.2.2 Mobile Website

Advantages:

Building a mobile website is pretty similar to building a website designed for the desktop. If you want to make your website mobile-friendly, in 95% of cases, a mobile website will accomplish your goals. This may take time, and resources, to accomplish, but it will increase the versatility of your brand by making it easily accessible for your audience on any given platform.

Challenges:

The need for speed. Even the best mobile website design is at the mercy of the networks being used to access it. Often the network access, quality, and speed varies from location to location. Compounding the speed issue is the fact that mobile users are much more demanding than those coming to your site on a desktop because they're usually on the go and looking for a quick answer. A desktop user at home will not be put off by an extra click here and there when a usability issue is encountered. A mobile user will leave your mobile website if the loading process is sloppy, or if it takes too long. *If you don't optimize a site's functionality on mobile devices and end up making visitors work and wait too long for information, they're gone. You will lose their attention almost immediately.*

5.3.2.3 Mobile Web app

Figure 48: native vs. mobile

Advantages:

The planning and launch of a mobile web app is similar to the average custom designed website, and ultimately produces a look and feel just like the more expensive and time-consuming native app. For the most part, it performs and functions just like a native app, only different in that it is rendered through a mobile browser. Once a mobile web app is launched, it's also easy to make edits and changes that are immediately available to the user. They do not need to update the app in a way that native apps require whenever changes and improvements are made.

Disadvantages:

While a mobile web app is usually the best cost-efficient option for most businesses, there are some drawbacks to consider. Mobile web apps, like mobile websites, can only be accessed when there is a good network connection and/or WiFi available. They also don't run well on old devices and browsers, so you better hope your visits are coming from people with the latest smartphone/tablet technology. The fact that the technology industry is constantly changing is something that people have grown accustomed to, however it results in businesses and audiences alike finding the need to keep up.

5.3.2.4 Native App

Advantages:

The native app can interface with the device's features, information, and hardware (camera, GPS-location, etc.). Native apps can run without an Internet connection and generally have a more friendly UX design than mobile web apps. They are made specifically for mobile audiences from the very beginning, rather than being redesigned in order to fit that platform.

Disadvantages:

The native app is costly and can take a good deal of time to develop. You'll also have to create the same app several times for each operating system because each app must use the native programming language of the device: Java (Android), Objective-C (iOS), and Visual C++ (Windows Mobile). This can be a tedious process, and you can receive a lot of pushback from audiences who are frustrated if they can't yet access your app on their particular device. Other long-term drawbacks include the app store process. Designed to assure user quality and safety, every update must be reviewed and approved. The manual downloading and installation of the app also means that many users will be operating on different versions. Also, any changes in functionality or design that are made to the app require the user to update them manually rather than automatically.

Conclusion:

Due to budget restriction as well as time constraints we decided to build a native app for the user to interact with the product and control it.

6. Prototype Construction and Testing

6.1 Project Housing

For the housing it will be constructed using Black ABS Plastic Sheet made by Zuvas, held together with either Water Resistant In 30 minutes, Premium Exterior/Interior Window, Door and Siding Silicone Sealant by Dap or some type of super glue or two-component-epoxy. The design will be a cube that is 12 inches by 12 inches by 12 inches. The cube will have a door that opens on the top and another that folds down on the front. The housing unit will also have shelves in it. The housing unit will also have shelves in it. One shelf to hold some or all of the electrical components and another to hold the optical components.

6.1.1 Project Enclosure

The project enclosure or housing will first have a mockup made of it made. This mockup will be made of cardboard or cord stock. The mockup will be used to ensure that the design is stable enough to be made in the Black ABS Plastic Sheet made by Zuvas. If it is stable then it will be made in the Black ABS Plastic Sheet made by Zuvas. If it is not stable in the cardboard or cord stock model than the design will be altered to ensure that it is. These alterations will most likely come in the form of having the top be glued to the sides of the housing, so that there is only one door on the front. So that the housing unit looks like a cabinet.

This prototype made of cardboard or cord stock will be tested by gluing the necessary sides together, that is the three of the sides and the bottom, and temporarily attaching the hinges so that the box can be closed. The prototype will then be opened and closed in rapid succession. It will also be picked up and put down, both with the two doors open and with the two doors shut, to see how sturdy it appears and feels. This will also help to determine if the structure will have any warping that will happen if it is picked up with the doors open. And how strong the design is once the doors are closed, to help determine structural integrity.

6.1.1.2 Project Enclosure Testing

If the mockup made of cardboard or cord stock passes its testing, then the housing unit will be made of the Black ABS Plastic Sheet made by Zuvas. The project enclosure or housing unit made of Black ABS Plastic Sheet made by Zuvas will be tested by first gluing three of the sides to the bottom. Then the hinges for the top doors will be connected to the back middle side. Then the hinges for the front door will be connected to the bottom of the housing unit. The doors will be opened and closed repeatedly to ensure that they are connected securely. If it passes that test, then the latch will be attached.

Then the housing unit will be picked up and down with the doors closed and latched shut. This will be to check that the structure will be stable in transit. The doors will then be opened. The housing unit will be picked up and moved around again to ensure that the housing unit is stable, and the sides were glued on properly. If the housing unit passes all of these then it is ready to have the shelves and optical and electrical components put in.

6.1.2 Holder

For all the holders used in our design, they were designed using Free CAD and then 3D printed. The holders were done this way because holders for optical components are usually quite expensive. The holders that were required are two top and bottom pieces for the laser pointer, two top and bottom pieces for the water tube, for each lens one lens mount holder, the front and back for the lens mount, and a mount for each of the photo diodes.

6.2 Printed Circuit Board

Our system will integrate a custom printed circuit board designed to regulate the voltage supplied to the optic components. The laser and photodiodes require voltages lower than the 5V supplied by the Arduino pins. Our system will initially be designed on a breadboard physically and then built electronically via a program called Eagle. The breadboard will allow for simple component plug and play until a final design can be determined. Once the schematic is created it can be converted into a board file where components are placed, and trace lines are identified and routed.

6.2.1 PCB Design

The printed circuit board was designed with 2 LM317T variable voltage regulators. Our system requires 3 different voltages, 5V, 3.1V, and 1.2V for the varies components. The LM317T is a small 3-legged component consisting of an input, output, and adjust pin. The adjust pin is used connected between two resistors to influence the output of the regulator. This regulator has an output range of 1.2V to 37V which can be manipulated through adjusting R2. By setting R1 to 220 ohms we can use the formula provided in the datasheet to determine 3.3 ohms would be sufficient for 1.2V and 330 ohms for 3.1V.

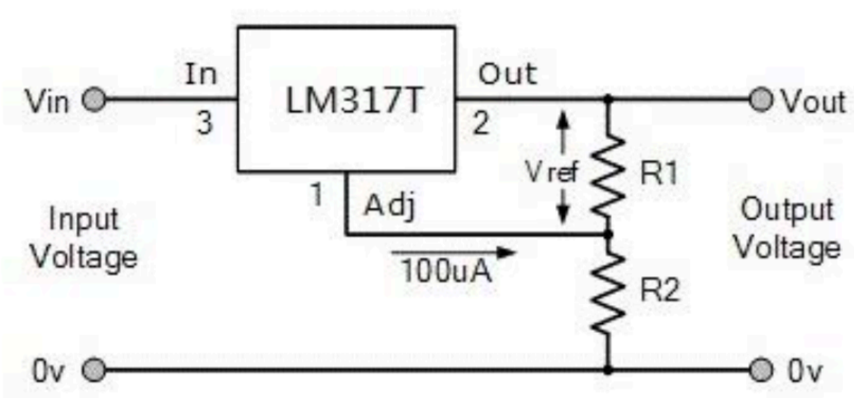


Figure 13 LM317T Schematic (Courtesy of Apogeeweb.net)

Once the voltage regulator has been selected the design can be constructed as a schematic in Eagle. Below is the original design for the voltage regulator. Initially the two regulators were going to be tied in series and accept 5V from the 5V pin. After further research and development, it was decided that the regulators should have independent voltage sources in order to allow for push button operation of the laser while unaffecting the other components.

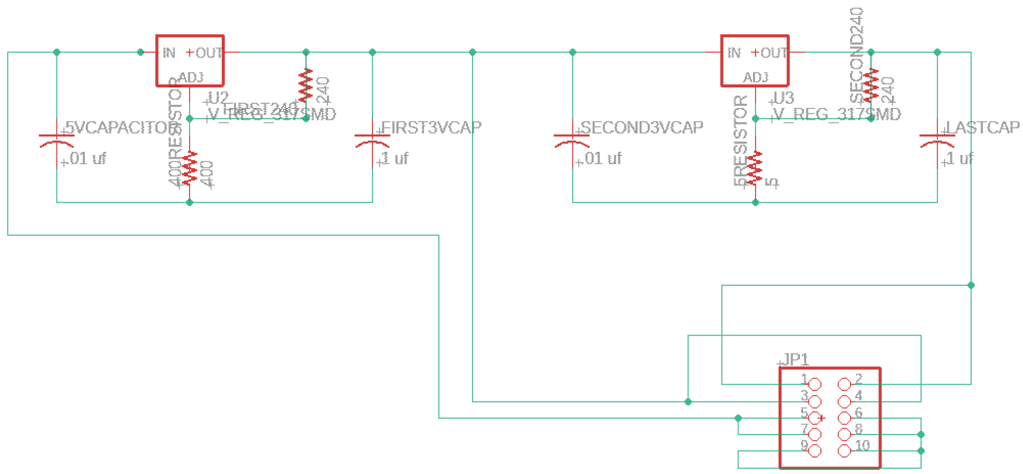


Figure 14 First draft PCB design (Eagle Schematic)

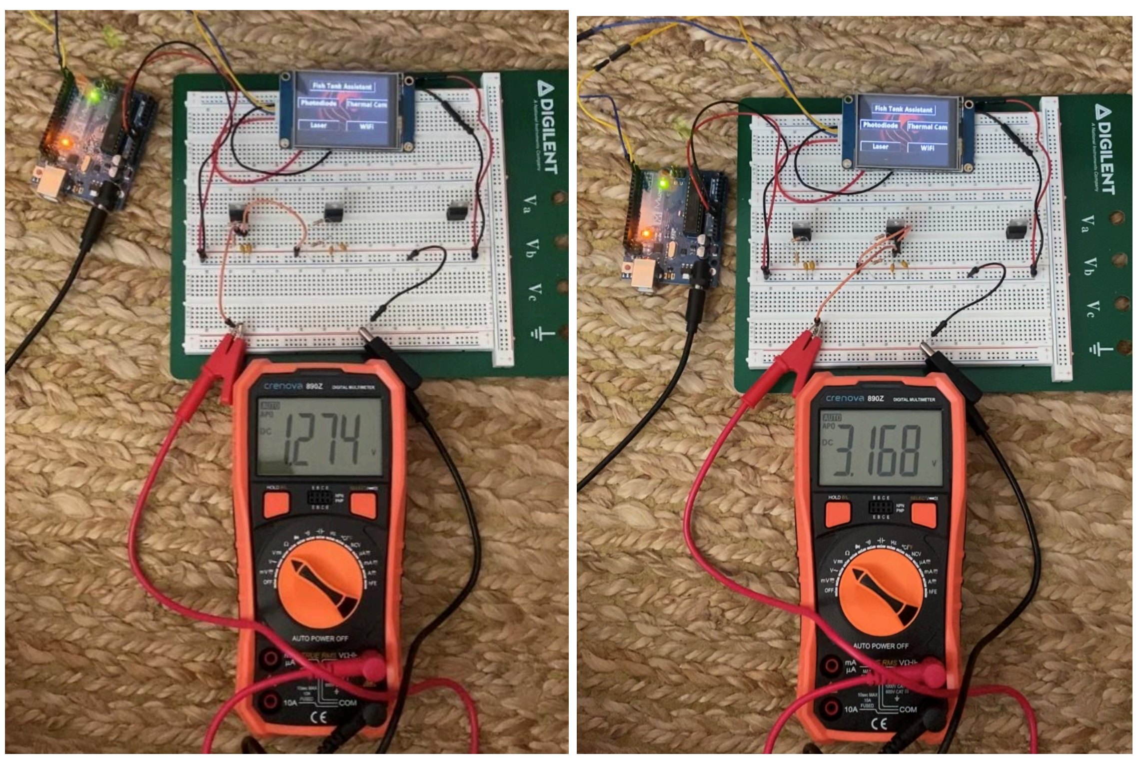


Figure 15 LM317T 1.2V and 3.1V testing via breadboard

The initial voltage regulator tests were a success showing 1.2V and 3.1V respectively. By connecting the multimeter to the middle leg of the voltage regulator and ground we are able to display the desired voltage. Here we are still using the single 5V pin to power the liquid crystal display as well as both voltage regulators. In our final design the printed circuit board will have a separate voltage input per regulator.

6.2.2 PCB Fabrication

Due to the structure of our design team, we were able to get a vector board approved for our final design. This allowed the team to gain useful experience in soldering through hole components. The original design was created in Eagle to be prefabricated by a third party. By soldering the components on a vector board, the design needed to be updated with 2 additional 10 pin header sockets to avoid interference.

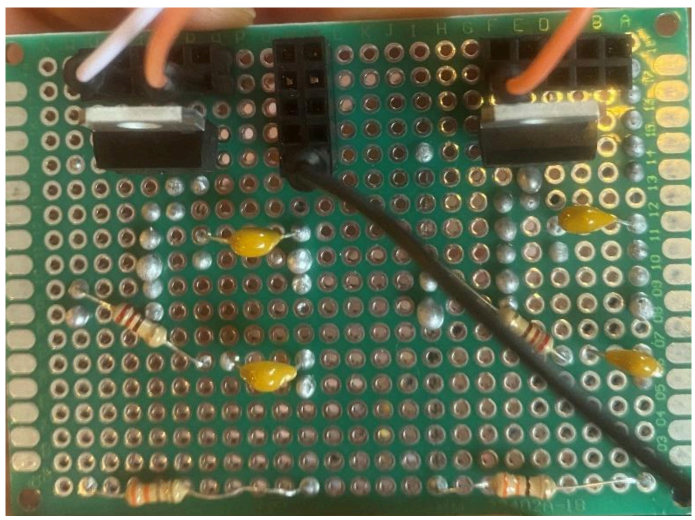


Figure 16 Soldered PCB Front

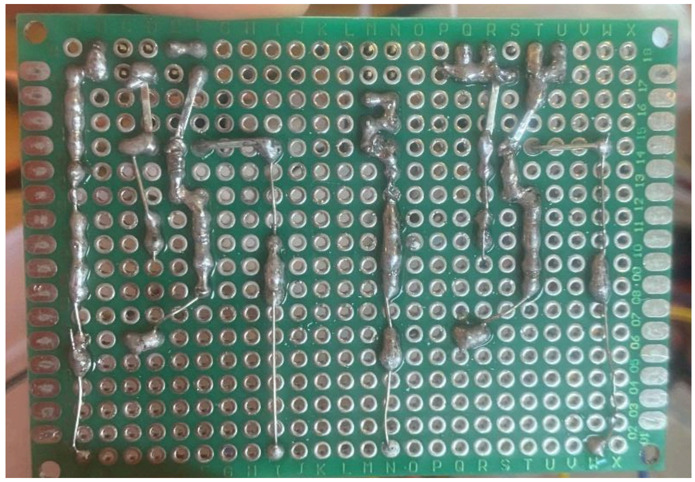


Figure 17 Solder PCB Back

6.2.3 PCB Board Testing

The vector board containing 2 independent LM317T voltage regulator circuits can be seen below. The 1.27V output can be found in the next figure with the circuit on the left being tested. The following figure shows the 3.18V output from the regulator on the right. It was important to separate these circuits because the laser should be turned on and off via a button on the liquid crystal display and that would require a digital pin connection instead of the 5V pin we have been using for the LCD screen and photodiodes that can receive constant power.

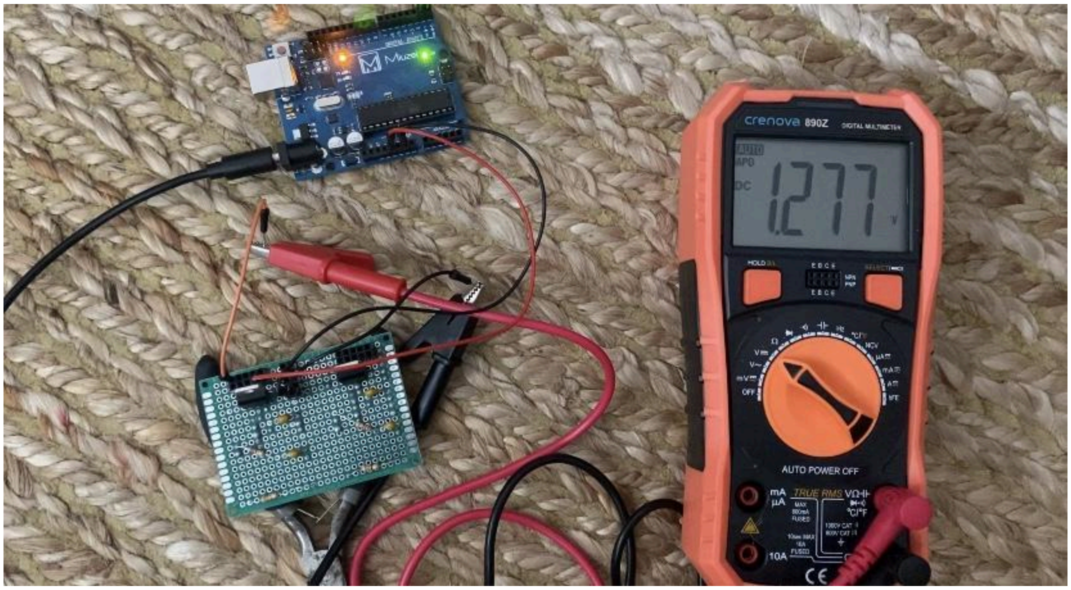


Figure 18 PCB Testing 1.2V Regulator

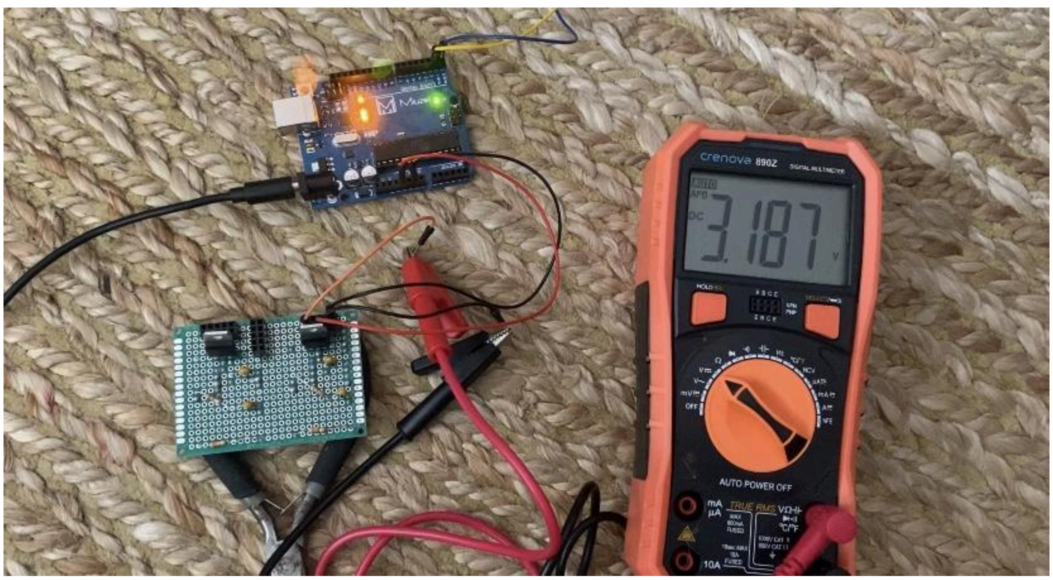


Figure 19 PCB Testing 1.2V Regulator

6.4 Optical Testing

The optical testing will consist of several tests being run on all optical components including the photodiode, laser, and lenses. The photodiode will read the intensity of the light being emitted from the laser and the lens will help focus the beam after it has traveled through a water sample.

6.4.1 Pretesting

Optical testing started with initial testing of the water tubes purchased for the light to propagate through to confirm the theorized beam behavior when exiting the tube. Next, we bought testing laser pointers of similar optical power and wavelength. These test laser pointers were affordable compared to our final project's proper laser pointer. In addition, the test laser pointers served another purpose for our system, allowing for the electrical circuits needed for the appropriate laser pointer to operate remotely. Using these test laser pointers, we minimized the possibility of the more expensive proper laser pointer being damaged by testing the designed circuit with the inexpensive ones first. This testing system enables the detection of errors in the design while securing the safety of the planned laser pointer. The setup of the pretest was straightforward, without any stabilizing mounts. The laser pointer wrapped an everyday rubber band around it to keep the activation button pressed down, allowing continuous wave propagation. We filled the tube with clean water, plugged both sides, and positioned the incident surface of the tube six centimeters away from the test source.

After the six centimeters, we changed the position to ten centimeters from the test source. The chosen test distances were based on simplistic estimations for the locations of the optical elements in the designed system. Based on the housing specifications of the system would allow for the ten-centimeter distance between the source and the incident surface of the tube. This distance was estimated based on the probable optical design at the time. We theorized the beam would travel five centimeters before being incident on a beamsplitter, splitting the beam into two equally powered beams traveling perpendicular. The beam traveling through the tube would be the 90° reflected beam from the beamsplitter and would travel another five centimeters before being incident onto the tube. As expected from our geometrical calculations, the beam exiting the tube behaved with a mainly vertical diverging beam when the orientation of the tube was horizontal. We then tested with the opposite tube orientation resulting in primarily horizontal beam divergence. Due to the beam divergence theorized in our research, we confirmed the need for a focusing element after leaving the tube. We used very large distances to observe the extremes of the beam divergence where the minimum distance from the tube to the target was four feet.

Figure 49 & 50: Pretest Laser Propagation and Beam Divergence Orientation to Tube Orientation

After the pretest using the substitution laser pointer, we switched to our next testing phase to verify our calculations with the Alpec laser pointer and used an uncoated substitute focusing lens from Newport with a half-inch diameter and 38.1 mm focal length that was available to us from the CREOL senior design lab.

Figure 51: Substitute Test Lens KBX031 (Courtesy of Newport Copyright approval pending [43])

We used this lens as it was the closest match to our lens specifications that we could find. For our initial testing, our objective was to confirm our lens choice and to observe and record the testing results, including the beam behavior. Our testing setup was simple, with the source positioned ten centimeters away from the first surface of the water tube. The reason for this was to imitate the beam path length for the final system where it would be incident on the beam-splitter, which would be oriented at a 45° angle to the source, positioned five centimeters from the source. Half of the beam would transmit through, and the other half would reflect then travel another five centimeters before being incident on the first surface of the water tube. We then positioned the substitute focus lens 2.4 centimeters from the exiting surface of the water tube as we would for the final system.

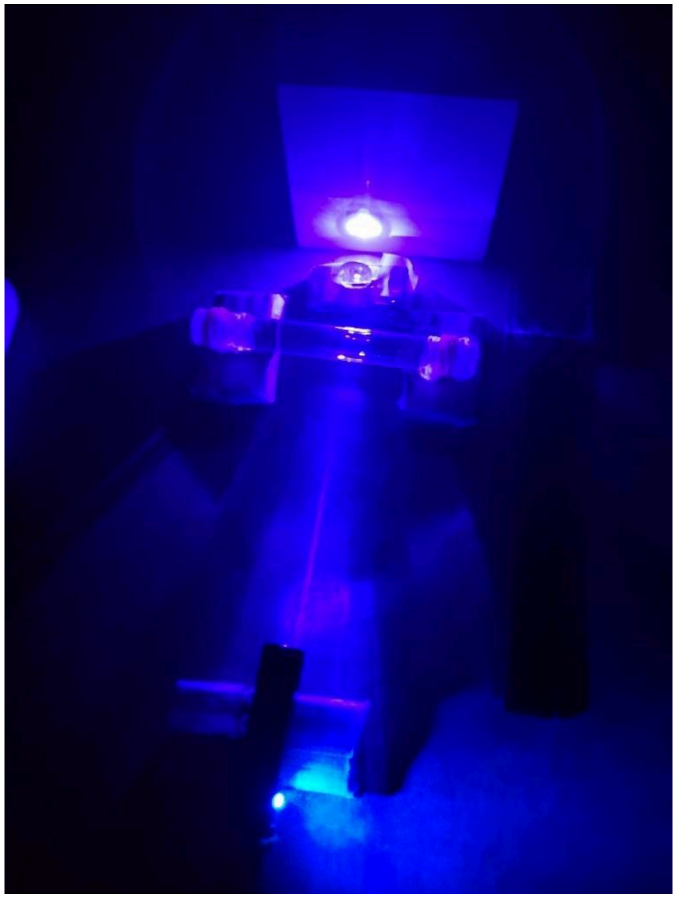


Figure 52: Pretest Setup

In our test, the beam shape and size captured in our image were not the actual size or shape, as the glare from the beam was exaggerated. We could not show the actual beam size; however, we measured it at 2 mm^2. We decided to take an image of what the beam shape looked like at a much further distance of at least 25 centimeters from the lens's focal length onto the wall.

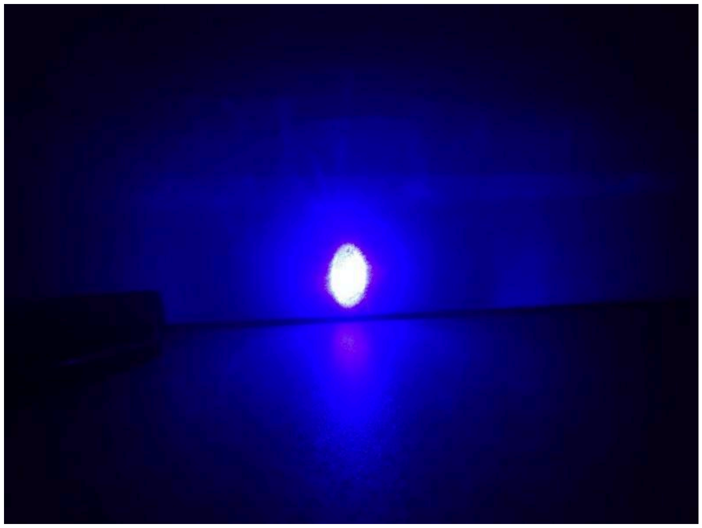


Figure 53: Pretest Beam Shape at Large Distances

It is evident from the extra distance that the beam shape still diverges slightly in a more vertical orientation than horizontal, which we confirmed would be apparent in the prior beam testing using the substitution laser pointer. The vertical divergence was explained in our research when we investigated the geometric side of the optical designing process. We determined, however, that the beam shape would not interfere with our result in the final system as we confirmed the output beam shape of the source is slightly elliptical, in which case the beam incident onto both photodiodes will be similar if not the same.

6.4.2 Optical Component Testing

We decided to do component testing for our photodiodes and our laser pointer to confirm their typical operating characteristics. To measure the responsivity of the photodiodes, we would need to obtain a light source with a verified optical power, in which case we had two options. The first option was to utilize any available light sources in the CREOL senior design lab to measure the photocurrent produced by the photodiode when the light source was incident onto it, and a reverse voltage was applied to the photodiode. Our second option was to authenticate our laser pointer's optical power before employing the same approach as our first option. For the sake of the project's reproducibility, we decided to test our light source and measure the optical power and the peak wavelength. We plan to use a diffraction grating to find the operating wavelength while using an available power meter to obtain the optical power from the laser pointer. To find the operating wavelength, we will be using $\lambda = \frac{d \cdot y}{x}$ courtesy of Instructables [44]. This equation is derived from Young's double-slit experiment equation $d\, sin\theta = m\lambda$ where d, y, and x are for the following distances.

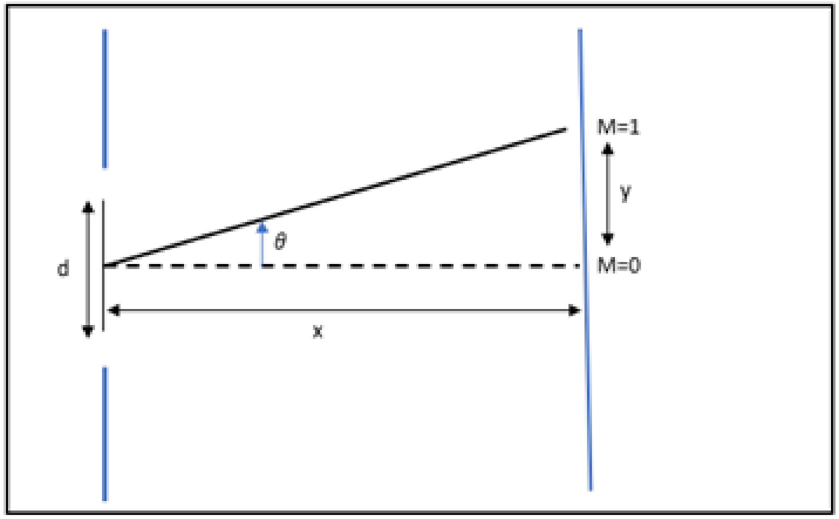


Figure 54: Diffraction Grating Calculation

Using supplies in the CREOL senior design lab, we could perform our testing without needing to purchase anything else. These supplies included everything shown in the figures below, such as the diffraction grating and mounting pole.

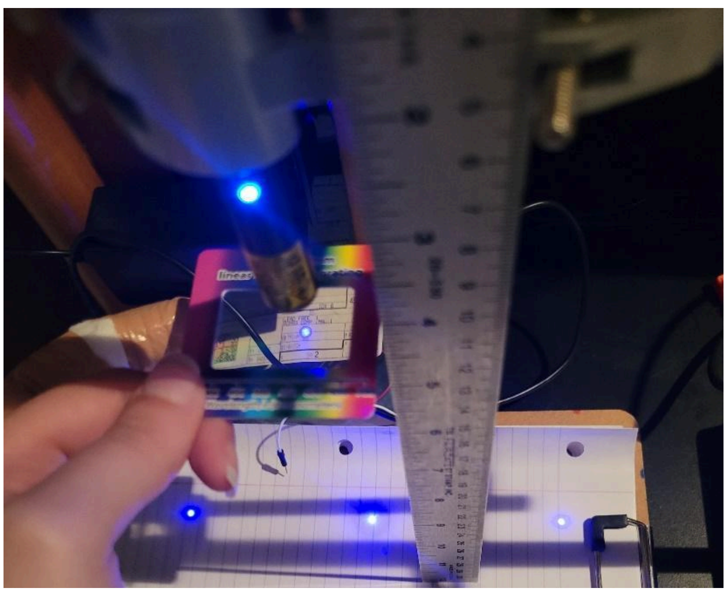


Figure 55: Diffraction Grating Wavelength Testing Procedure

We positioned the target roughly 17.7 centimeters from the diffraction grating, which is the x in our equation for the test. We then measured the distance between the center fringe and one of the second fringes, which was measured to be 80 centimeters, the "y" in our equation. Lastly, the distance between slits in the diffraction grating was calculated by dividing one millimeter by the number of slits in the diffraction grating, which was 1000 slits per one millimeter. The distance between slits was calculated to be one micrometer, giving us all of the values needed to calculate the wavelength. We confirmed the wavelength of 450 nanometers from our calculations, which was our desired wavelength for the system.

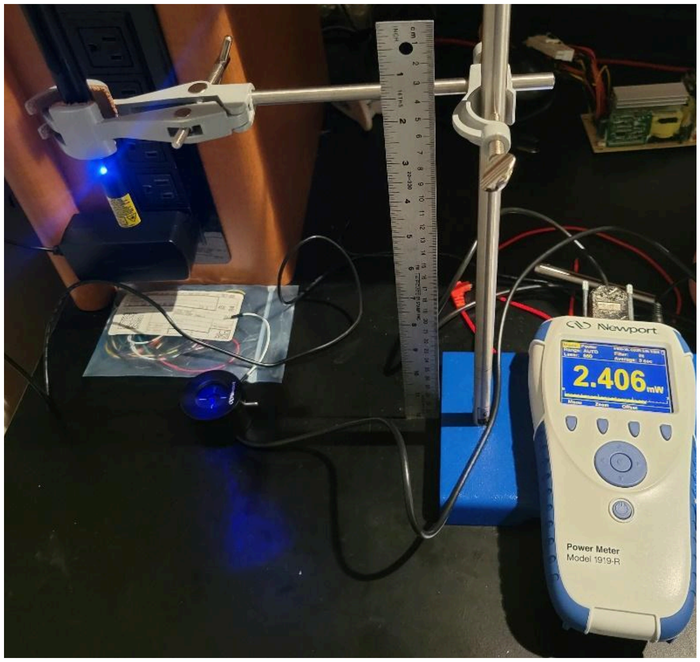


Figure 56: Power Meter Optical Power Testing

Our component testing was done in the following way where the results of the power meter test were a little lower than the maximum five milliwatts reaching roughly 2.4 milliwatts; however, we believe this should be enough power through the system as 1.2 milliwatts should still be enough to see the difference in the absorption of the water and algae.

6.4.3 Photodiode Intensity Testing

The photodiode testing is the most important in our optical testing as this will give us references for our results. Therefore, the initial test will be to find the photocurrent or, more accurately, the dark current when no incident light is present on the sensor. The dark current is paramount for a few reasons: the dark current is an essential measurement for the accuracy of measuring the photocurrent when there is incident light present. The second reason is relative to the environment experienced by the photodiodes when enclosed in the system housing. Finally, it will be necessary to measure the ambient lighting inside the system as we plan to use system housing with the capability of eliminating most outside lighting. After finding the dark current, we will move on to finding the split power intensity from the beamsplitter for use in our calculations. After measuring the intensity, which we will refer to as the incident intensity, we will then measure intensity through the sampling side of the system. These measurements will be essential for data comparison and comparing the potentially different levels of algae present in the tank.

6.4.3.1 Photodiode System Integration

The BPQ21R is a silicon PN photodiode that will be used to detect the intensity change in our laser through the water sample. A beam splitter will be used to divert 1 beam to a control photodiode and the other through a glass enclosure containing the sample to a second photodiode. The microcontroller will then be programed to compare the two intensities and tell the user when the environment is becoming dangerous. The final design will have the laser, photodiodes, and water sample attached to the housing via custom 3D printed casings. During testing a bread board will be used to demonstrate components functionality.

A main reason we chose Arduino as our microcontroller was for its wide variety of project resources from tutorials with sample code to forums where you can get your questions answered in real time by other coders. Arduino has a basic workshop on how to connect a photodiode along with the basic code required. Based off our research and our datasheet each photodiode is going to require 50 mA and 1-1.3V to work properly. The Arduino Uno has a 3.3V and 5V pin available, for testing we will be using the 5V pin. In order to drop the voltage two resistors are connected in parallel to create the appropriate pulldown resistance. In our case we wanted the resistors to drop the voltage 4V to allow for a safe 1-1.3V to pass through the photodiode. We divide 4V by 50mA to find that we need a 80 ohm resistor. A 330-ohm resistor and 100-ohm resistor were used in parallel for testing.

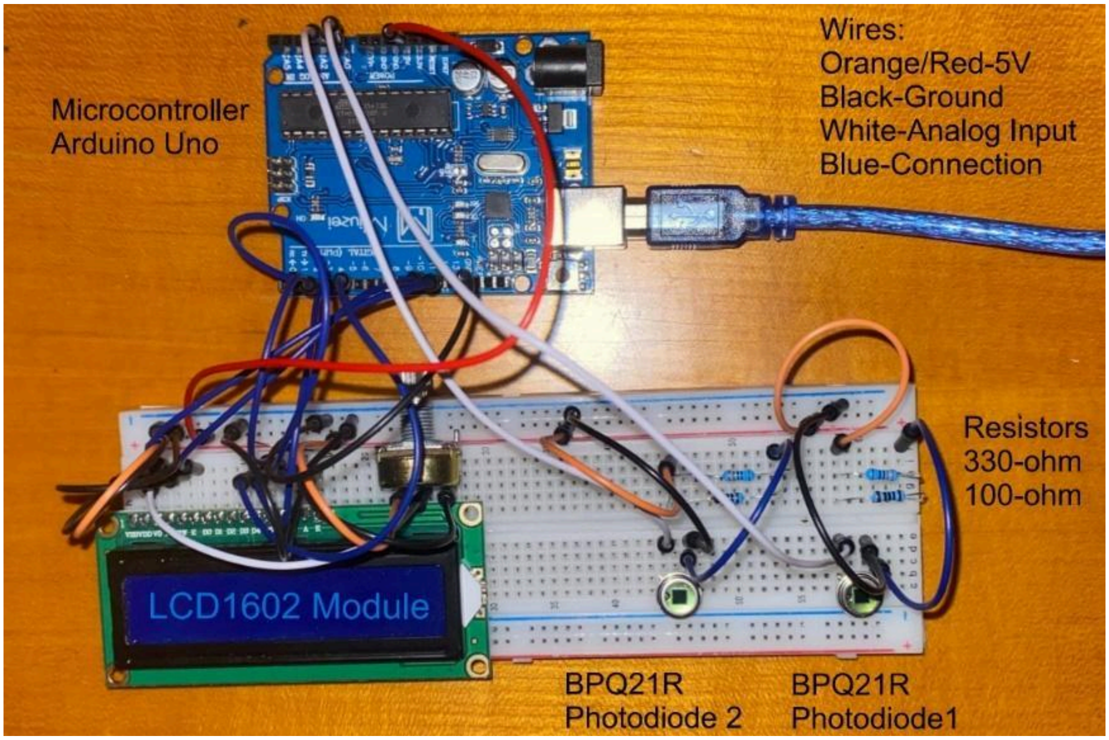


Figure 57 Photodiode Testing Configuration

The photodiode has a simple system integration with a positive pin for outputting analog data and a negative pin for supplying power. Once the needed resistance is found and the system has been organized properly then the microcontroller can be programed. Sample codes can be found online and modified for project needs. A simple sensor reading code has been modified to read inputs from A0 and A1 and display them as intensity outputs on a liquid crystal display.

We can see in the testing photos below that the two photodiodes detect similar light intensities as expected. To follow the set-up orange/red wire are used for connections power, black wires are used for connections ground, white wires are used for analog input connections, and blue wires are used for connecting components. A LCD1602 module is used for testing the photodiode outputs. Once the NX3224T024 design is configured the data will begin to be tested there.

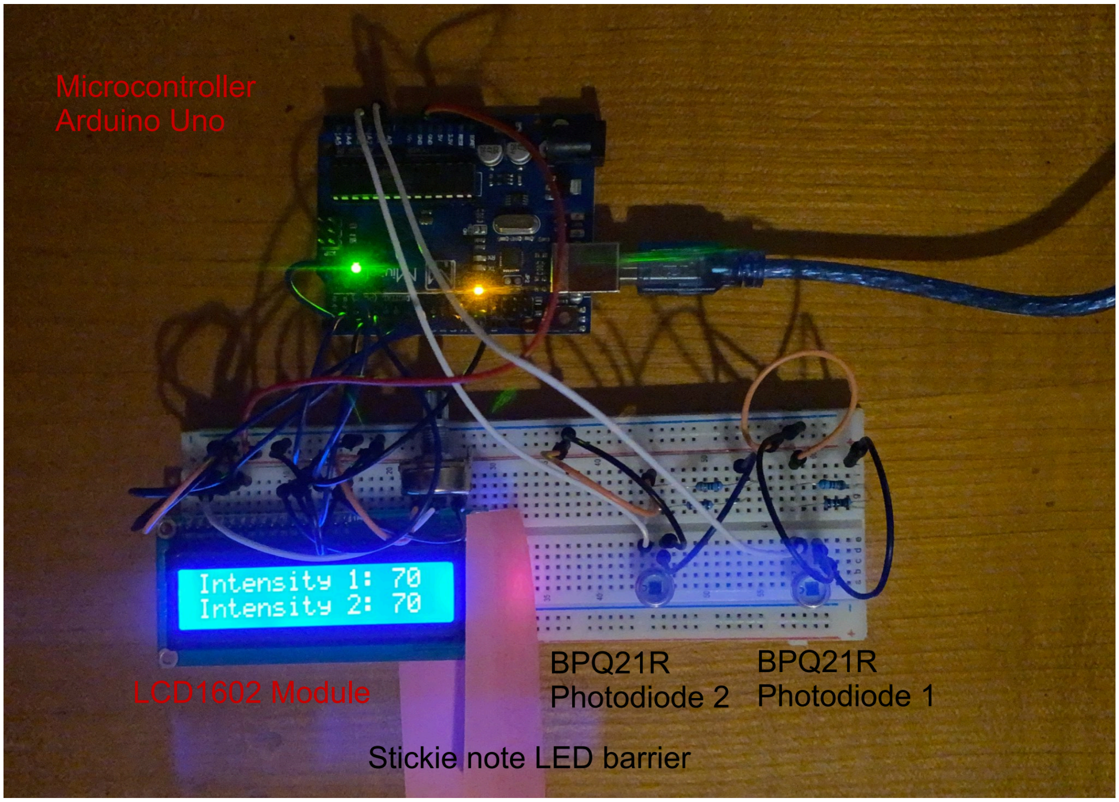


Figure 58 Photodiode Intensity Testing

Three test lasers were used to show the increased intensity on both BPQ21R silicon photodiodes. A red, blue, and green laser are shown below driving the intensity as high as 138. A blue laser pointer operating at 5mW and transmitting at 450nm from Alpec will be integrated into our final design after testing.

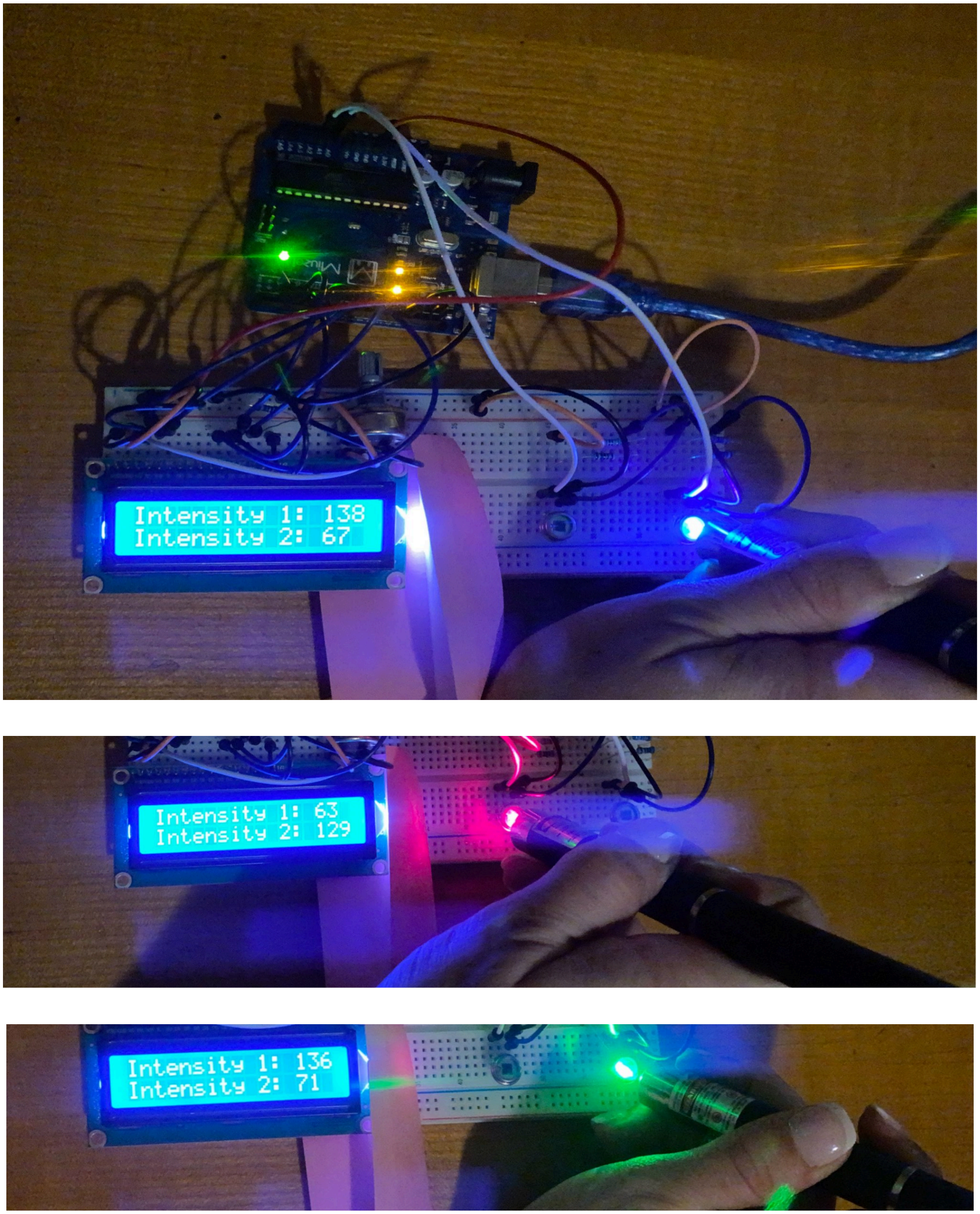


Figure 59 Laser Intensity Testing

The code is simple, first we have to include the crystal display library and define the parameters. Then we start the code and have it read the analog input from pins A0 and A1 and store them appropriately. Next, we print text on the screen identifying the specific outputs followed by their associated detected digital output. In our final design these inputs will be analyzed by the microcontroller and will notify the user via the NX3224T024 when the environment is becoming potentially dangerous.

```
Senior_Code §
#include <LiquidCrystal.h>

int SensorValue1 = 0;
int SensorValue2 = 0;
int SensorPin1= A0;
int SensorPin2= A1;

LiquidCrystal lcd(12, 11, 5, 4, 3, 2);

void setup() {
  lcd.begin(16,2);
Serial.begin(9600);
  pinMode(SensorPin1, INPUT);
  pinMode(SensorPin2, INPUT);

}

void loop(void) {
   SensorValue1 = analogRead(SensorPin1);
   Serial.println(SensorValue1);
   SensorValue2 = analogRead(SensorPin2);
  Serial.println(SensorValue2);
lcd.print("Intensity 1: ");
lcd.print(SensorValue1);
lcd.setCursor(0,2);
lcd.print("Intensity 2: ");
lcd.print(SensorValue2);

delay(500);
lcd.clear();
}
```

Figure 60 Screenshot of Testing Code

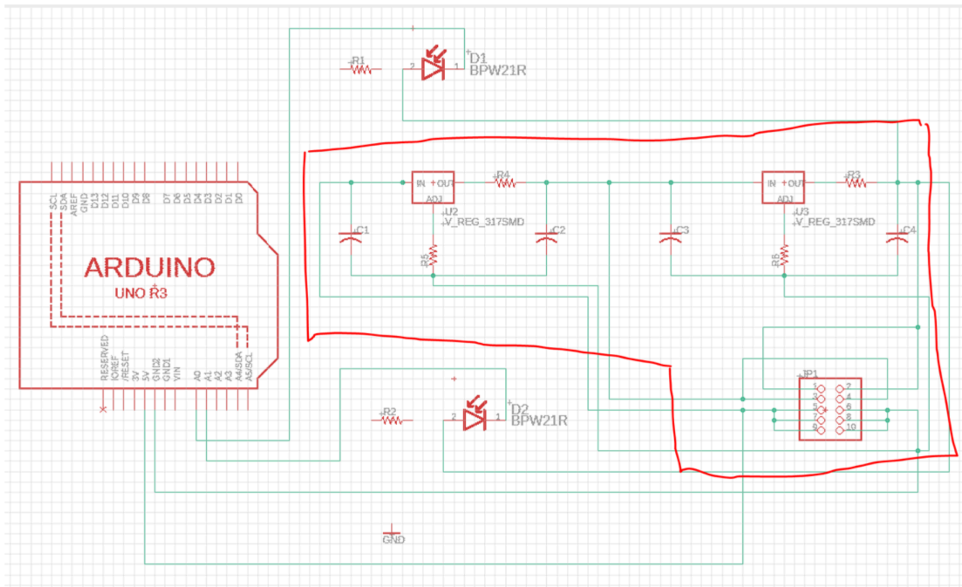


Figure 61 Overall Schematic Without Laser Pointer

Here we have the overall schematic without the laser pointer to show how the system is mean to connect between the components.

6.4.4 Algae Detection Sensitivity Test

We would like to measure the algae detection sensitivity of our system. However, we are considering two different options to do this potentially.

Option 1:

Purchase algae commonly found in fish tanks and separate it into different water sample sizes. Option one requires added expenses. While likely to be within our budget, our overall system costs will increase. The delivery time will also need to be considered as our time constraints for the project completion are tight. However, this option is favorable because most of the cultures purchasable have been measured for research purposes. Another consideration would be choosing the type of algae to use for the testing, which would lead us to purchase different common fish tank algae species for comparison testing between each algae species.

Option 2:

Obtain fresh and algae present water from a team member's fish tank. This option does not require any purchases or delivery time. Using this option, we will need to take measurements of the initial sample taken from the fish tank; then, we will need to move to dilute the sample into separate parts and strengths to compare how much of the algae is detectable. This method does not have any given measurements of the amount per sample. However, we plan to use visual references for how the fish tank appears for the sample before obtaining it.

We decided to choose option two as most fish owners are not concerned with the exact amount of algae in their fish tank but instead with taking care of it before it gets to the point where it is exceptionally noticeable.; the reason for this is primarily fish tank algae are not always harmful to the fish and is instead an annoyance because they are unable to see their fish properly. We decided the fish tank we would obtain the dirty water from would need to be at an extreme, so we allowed the algae to build up. We did this so we would be able to dilute the water by different amounts to test the sensitivity of our system for detecting algae in the fish tanks. The following figure is of the fish tank at an extreme for the reasons above.

Figure 62 Fish Tank Algae Reference

6.4.5 Standard Water Absorption Test

The standard water absorption test measures the typical absorption and or reflection of the light passing through water. The test is straightforward and only involves measuring the intensity of the output light, which is the light incident on the second photodiode. This test is essential for the system to have accurate readings of what normal fish tank water reflects and absorbs when comparing measurements taken when algae are detectable to our system. The results of our initial test were tabulated for reference.

Light onto Photodiode	Intensity in	Differences	Percentage of Transmitted Light	Percentage of Absorbed Light
Ambient Light	78 to 79	NA	NA	NA
Incident Light	124	46 to 45	NA	NA
Clean Water Incident Light	122 to 123	1 to 2	98.39% to 99.19%	1.61 % to 0.81%
Dirty Water Incident Light	122 to 123	1 to 2	98.39% to 99.19%	1.61 % to 0.81%

Table 36 Initial Test Results

The results pose a problem for our system as it currently does not show a difference between clean water and dirty water. We believe there are a few possibilities for the lack of differences between the samples. The first is that the water itself does not contain enough algae to make a difference in the absorption of the incident light. The next idea is that the photodiode itself is not sensitive enough using the current coding used to display the readings, and we will need to alter the operating code to include decimal places. The current photodiode circuit design does not use an amplifier to amplify the photodiode, which may be a possible cause of the lack of test data differences. Lastly, the results of this initial test may be a combination of the three possibilities described above. To resolve these issues, we plan to obtain water samples with a visually noticeable amount of algae in the sample and perform a similar test. If the new samples do not achieve the desired difference in measurements, we plan to proceed with altering the code for greater reading sensitivity. Lastly, if the first two procedures do not produce desired outcomes, we will be looking into redesigning the photodiode circuit to include amplifiers.

6.4.6 Algae Concentration Testing

As testing continued, we realized we would need a reference for the detection sensitivity for comparing future testing accuracy. Therefore, we decided we did not want to purchase any samples for testing as these would add more to the project's overall cost. Instead, we have investigated ways to measure the concentration of algae which we will then dilute into different sized water samples. Due to the lack of prior published research by outside sources for reference, we will be conducting our testing to observe how much light is absorbed by different algae concentrations. The testing will begin with measuring the algae into a high concentration and running the system for a preliminary absorption test. We will record the results and start with the second stage by dividing the sample in half and rerunning the system. After collecting the results, we will begin to stage three by diluting the divided sample into a water sample, a tenth of the volume of the algae sample. The testing will continue by increasing the amount of water and recording the results until no absorption is detected. Depending on our results, we will proceed in one of two ways. For the case of the algae being detectable in small concentrations, we will continue with moving the project testing and construction forward. On the other hand, if the system is only able to detect large concentrations of algae to the point where algae are extremely obvious to the human eye, then we will start investigating into resolving the issue by amplifying the photodiodes, extending the optical path length inside of the water samples, and potentially adding optical elements to change the beam's path inside of the water sample. The last option is unfavorable; however, if need be, we may use and design a Herriott mirror system in which the beam reflects from one mirror propagates through the water sample onto the other mirror, and reflects back into the water sample, repeating the process for a certain number of reflections before transmitting out of the mirror with the exiting hole.

6.5 Sample to Be Used for Testing

For testing we plan to make a sample at a specific concentration. For the sample hair algae is what will be used. The hair algae sample will be made by taking the hair algae out of its natural environment and drying it as much as possible. Then using a kitchen scale approximately 2 milligrams will be measured out. These algae will be broken up by hand added to a to a liter of water. Giving the concentration of 200ug/L. This is significantly higher than what the safe does is. A safe concentration of algae is 8ug/L [Optical Research 49]. With chlorophyll making up 9.7% of the algae, that would mean our sample would be at approximately 19.4ug/L of chlorophyll. Looking at the table below that would put our level at discoloration of water.

No problems evident, no water discoloration	0 - 10 ug/L
Algal scums evident, some discoloration	11 - 20 ug/L
Nuisance conditions, considerable discoloration	21 - 30 ug/L
Severe condition encountered, very deep discoloration	> 30 ug/L

Fig 63

From [optical Research 49] showing different levels of chlorophyll present in water and the effect it has on the water.

Since Beer's law is the property we are using to design our system we will need:

$$A = \varepsilon b C$$

A is the absorbents, meaning the amount of light that gets absorbed. ε is the molar absorption. which for chlorophyll a is 1.261E+05 M-1*cm-1 [50]. The b is optical path length, or the distance the laser pointer light travails through the water sample tube. This information will be used to test the optical system.

6.5.1 Syphon Testing

The syphon will be made up of a glass tube that will be fixed to two rubber tubes to keep the water in the tank. The syphon will be tested by simply getting it going, by either attaching a fish tank syphon to get it started or by using a syphon starting pump that can be purchased at any fish tank store. The syphon will be left to run for 24 to 48 hours (about 2 days) to see if it is going to leak.

6.6 Optical System Testing

The optical system will be tested by using the sample talked about in section 6.5 on the sample that will be used for the project. We plan to make different concentrations of the algae sample and we may make it with different types of algae too. If we are not getting the results that we are expecting from the equation for Beer's Law, then there are two main things that may need to be changed. One being to check the measurements of the algae to make sure they are accurate. The other is to change the optical path length. The tube we are using is quite narrow so that could cause there to not be much of a difference between input intensity and output intensity. So, it may be advantageous to increase the optical path length.

The optical path length could be increased by getting rid of the round tube design all together. A 3D printer could be used to make a part that opens up with two slots to put an entrance and exit window and could then be glued shut. This would allow us to increase the optical path length significantly to give grater difference between the initial and final intensities.

6.7 Software Testing

In senior design 2:

The code compiled successfully and was uploaded to the microchip with no errors. We were able to view the output values of both photodiodes and the light absorption equation onto the serial monitor of Arduino IDE.

6.8 PCB Testing

The PCB was successfully soldered and working with the different components.

We were able to connect it with the laser and photodiode and it worked, which shows that our connections and components are functioning correctly.

6.9 Senior Design II

6.9.1 Calibration Testing

The original system only called for using the 450nm wavelength laser, however, we decided to repurpose the laser pointers that were purchased for the preliminary testing to use for wavelength dependent calibration testing. We decided to compare the 450nm, 532nm, and the 650nm wavelengths with three different algae concentrations. The concentrations we decided to use were 0.01g/L, 0.05g/L, and 5g/L. For these three different concentrations data was taken for each of the wavelengths. The comparison for these three wavelengths at the different concentrations is depicted below in this graph where the x-axis represents the algae concentrations in grams per liter and the y-axis is the optical power loss in percentages.

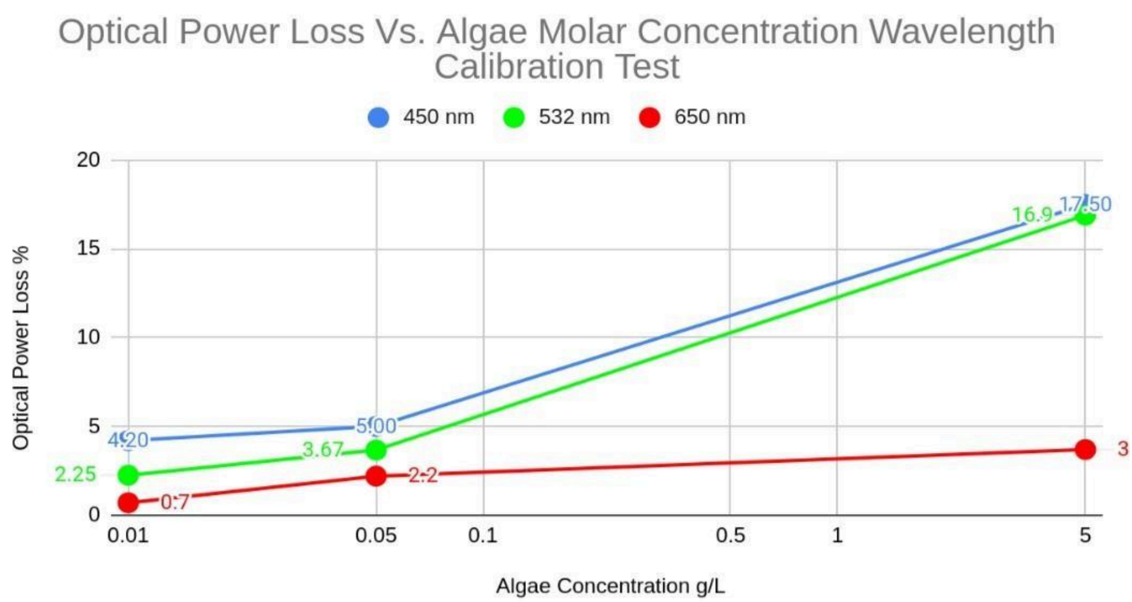


Fig 64

Wavelength Dependent Algae concentration Sensitivity Calibration

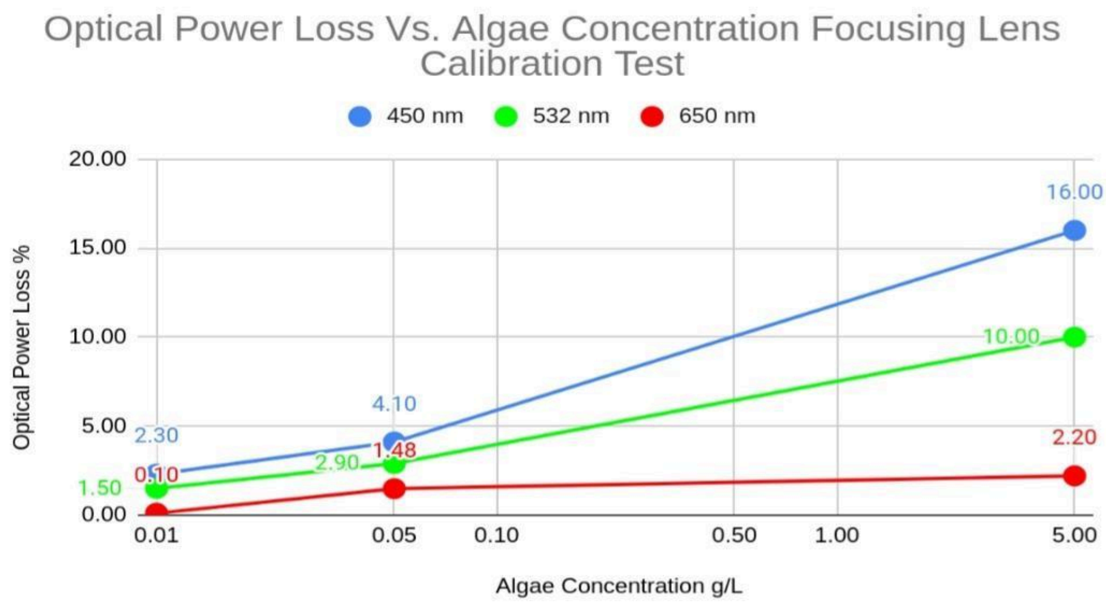


Fig 65: Wavelength Dependent Algae Concentration Focusing Lens Calibration Test

In the other calibration tests, we used the three laser pointers and the three different algae concentrations without using the focusing lens and comparing the above results with the following ones. From the results we can see that the focusing lens is necessary for the system because the system detects less absorption making it less sensitive to the presence of the algae in the system when the focusing lens is not present.

6.9.1 Thermal Camera and Wi-Fi Module

As the project progressed, we ran into many problems along with discovering some incompatibilities with a system component. The thermal camera was the component that we found out was not compatible with the microcontroller board that we had access to as the dynamic memory necessary for the thermal camera to operate was not inside of the microcontroller's limited dynamic memory space.At the time we realized the issue we were unfortunately approaching our deadlines and were unable to obtain a different microcontroller board or a different thermal camera. Due to the circumstances described the thermal camera is no longer going to be integrated into our system. The other component we planned to include was a Wi-Fi module which would allow the system to connect to a mobile app through Wi-Fi. Unfortunately, we were unable to meet this stretch goal of creating a mobile app for the system and therefore the Wi-Fi module would not serve a purpose now.

6.9.2 Goals

As the project progressed in senior design 2 there were some goals, we were unable to achieve however the goals we did achieve were not just the basic goals but also an advanced and stretch goal as well. Below is the table that lists the goals we accomplished and an explanation as to what was accomplished.

#	Type of Goal	Description	Explanations
1	Basic	Configure a spectrometer, charged coupled device (CCD) and a microcontroller in a way that will detect cyanobacteria in a water sample.	This goal was realized, however, not with a spectrometer or a CCD. Instead, it was achieved with our optical design and the principles of Beer's law.
2	Basic	Design a printed circuit board that will interface with a digital display for easy customer use.	This was achieved and demonstrated prior to LCD failure.
3	Advanced	Design and build an aesthetically appealing, lightweight, and compact holding case.	This goal was achieved through the use of black ABS sheets, gold colored hinges, and a gold colored latch.
4	Stretch	Design a system to pull water from the tank into the sample testing area.	We designed a siphon to pull water into the system through the test tube using a siphon started tube and the water test tube we designed.

Table 37 Accomplished Goals

Overall, the goals we accomplished were not simple and caused us to run into many issues along the way, however we managed to overcome the problems and issues encountered and accomplished our overall goal of creating a system capable of detecting algae in a water sample through our optical design.

6.10 Owner's Manual

The Owner's manual will instructions the owner of this algae detection system on how to properly set up the system and operate it as well as giving the proper safety instructions to ensure the safety of the owner at all times.

6.10.1 Safety

The following are safety procedures to ensure the operator and others in the vicinity remain safe at all times.

1. Confirm the system is not plugged in when moving, setting up, or opening the system.
2. Do not tamper with any components inside of the system yourself.
3. Do not remove components for any reason.
4. Confirm that the siphon has stopped and is empty before opening system or moving system.

In the unlikely event that the laser beam's reflections exit the housing do not look into beam and turn off system immediately. Contact distributor, manufacturer, or engineers directly for assistance.

6.10.2 Setup

The system setup is straightforward with a few simple steps.

1. Place the system on your fish tank making sure not to let the end of the siphon enter the water.
2. Begin the siphon by shaking the siphon starter around until siphon is started.

   Please note siphon may take a few minutes to get started. Please make sure the system's internal water tube is filled before letting the end of the siphon to fill up.

3. After Siphon is confirmed to be running close lid and secure system. Making sure that the system cannot and will not be opened during operation.
4. Plug in the power supply plug into the wall to turn the system on. Make sure not to pull hard on the plug or over-extend it as this may cause internal misalignment of the system.

6.10.3 System Operation

The LCD screen display will operate the system with a few simple buttons. All buttons will be displayed in yellow with a solid boarder while page and data display titles will be displayed in pink with a round dot boarder. Lastly all numerical data displays will be in grey with a solid boarder.

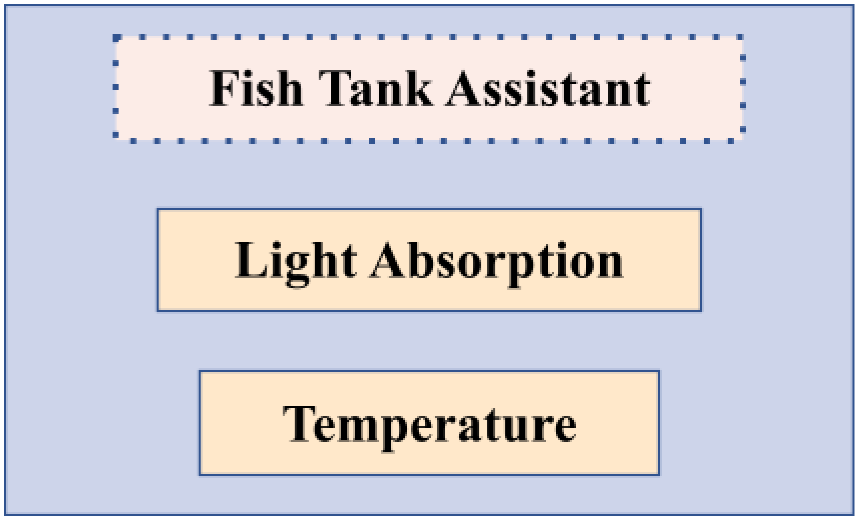


Fig 66: LCD Screen Home Screen

Here is a simple illustration of what the home screen of the LCD screen looks like. At the top of the screen is the name of the system "Fish Tank Assistant". The home screen has two buttons to make navigation simple.

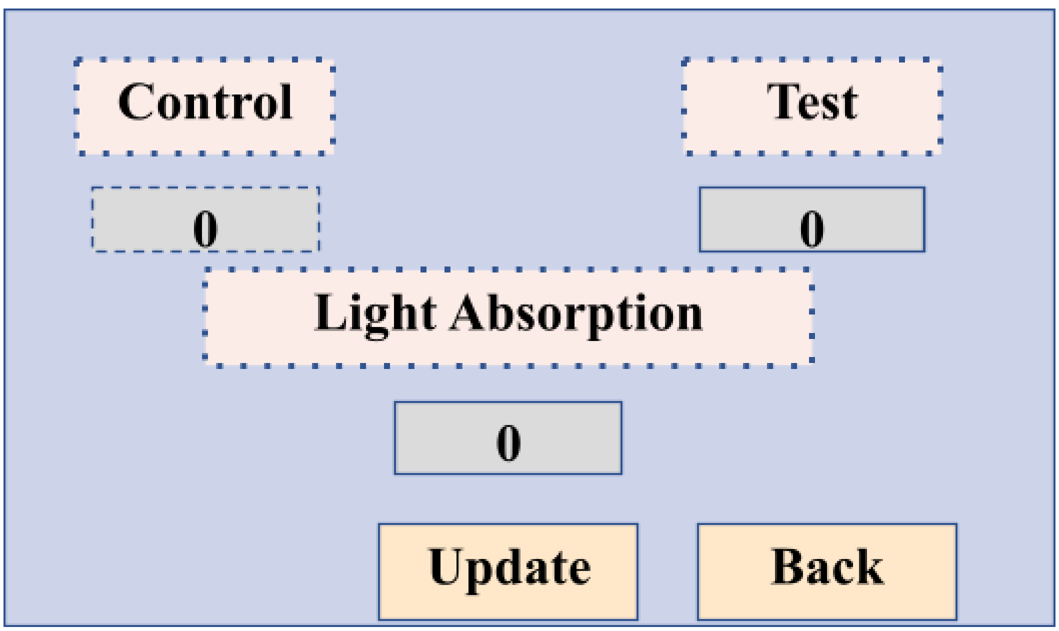


Fig 67: LCD Screen Light Absorption Button Page

By selecting the light absorption button on the home page, the page illustrated above will open. There are three data displays on this page, control, test, and light absorption. The control data display when operating will show the initial or incident intensity of the laser. The test data display when operating will show the intensity of the beam after passing through the water sample tube. The last of the data displays is the light absorption. This display when operating will show what percentage of the light was lost. There are two buttons on this page. The update button turns on and off the laser pointer. The back button returns the screen to the home page.

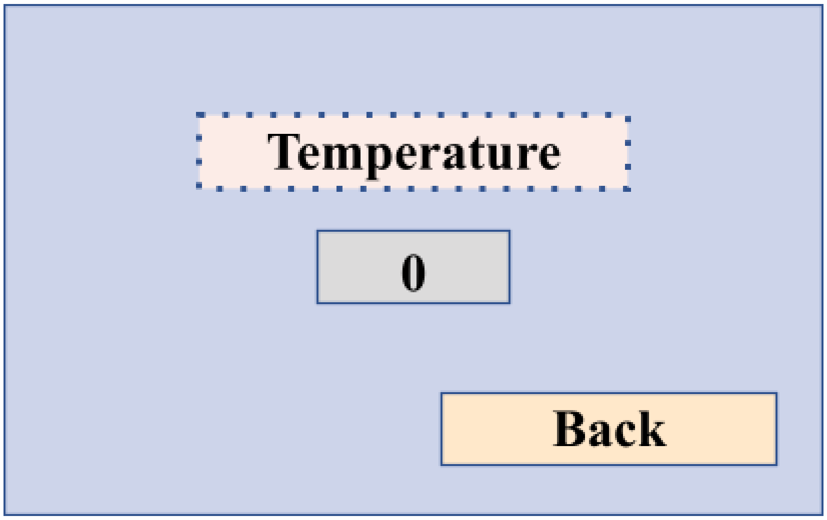


Fig 68: LCD Screen Temperature Button Page

When selecting the temperature button, the above page will be displayed. This page is simple when operating shows, the temperature inside the housing. This page only has the one back button to return to the home page.

To check if there are algae in the system the user should select the light absorption button. If the user wants to know the temperature inside of the system housing the user should select the temperature button.

7. Administrative Content

7.1 Personnel

7.1.1 Team Members

Zia McDonnold, Photonic Science Engineering
Kielan McMillan, Photonic Science Engineering
Vergin Mansour, Computer Engineering
Danielle Nastyn, Electrical Engineering

7.1.2 Individual Responsibilities

Zia McDonnold and Kielan McMillan oversee optical system design and construction.
Vergin Mansour oversees coding for the device.
Danielle Nastyn oversees the electrical system design and construction.

7.2 Project Milestones

Initial Senior Design I Milestones URC.edu

Milestone	***Target Week***	***Description***
1	2/4/2022	Divide and Conquer
2	2/18/2022	Update Divide and Conquer
3	2/25/2022*	Research Design and Specs
4	3/4/2022*	Begin Report
5	3/11/2022*	30 Page Draft
6	3/25/2022	60 Page Draft
7	4/8/2022	100 Page Draft
8	4/15/2022*	Finish Ordering and Testing Parts
9	4/26/2022	Final Document

Table 38 Senior Design 1 Milestones

Initial Senior Design II Milestones

Milestone	***Target Week***	***Description***
10	5/13/2022*	Finish Power Supply Design
11	5/27/2022*	Build Spectrometer

12	6/10/2022*	PCB
13	6/24/2022*	CCD
14	7/11/2022*	Build Prototype
15	7/8/2022*	Begin Testing and Redesign
16	7/22/2022*	Final Prototype
17	7/26/2022	Final Presentation
18	8/2/2022	Final Report

Table 39 Senior Design 2 Milestones

7.3 Budget and Financing

Bill of Material to be added*

Components	Quantity	Unit Cost	Total Cost
Optical Design Components			
Primary Laser Pointer	1	$84.99	$84.99
Photodiodes	4	$7.84	$41.70
Bi-Convex Lens	1	$39.38	$55.26
Beamsplitter	1	$106.49	$113.94
IR Camera	1	$62.50	$73.55
Test Laser Pointers	1	$14.88	$15.85
Housing & Hardware Components			
Test Water Tubes	1	$6.90	$7.35
M3 Nuts & Bolts Kit	1	$8.97	$9.55
M5 Nuts & Bolts Kit	1	$12.99	$13.83
Estimated System Housing			
3D Filament	1		
Estimated Redesigned Water Tube	1	$10 or less	$12 or less
Electronic Components			
Development Kit	1	$31.99	$31.99
Power Supply	1	$10.98	$10.98
WiFi Module	1	$12.99	$12.99

Display	1	$29.98	$29.98

Table 40 Project Cost Breakdown

Estimated project budget and financing

Item	Price Estimate
Microcontroller- (Adruino, Miuzei, etc)	$1-$30
Laser Diode (blue wavelength of light)	$90-$100
Lenses (1-2)	$30-$60
Linear array CCD or Photo diode	$4-$14 (for diode), $10-$54 (for CCD)
PCB	$100
Total (estimated range)	$392-$489 (this is just at our current state of knowing what we will need, there will dependently be more things that we will need, and the total cost will increase.

Table 41 Budget Estimate

7.3.1 Suppliers

7.3.1.1 Supplier & Manufacturer's Table

Component	Supplier Part Number	Manufacturer	Supplier

Optical Design Components			
Primary Laser Pointer	6410	Alpec	Alpec
Photodiodes	BPW21R	Vishay	TME
Bi-Convex Lens	LB1757-A	Thorlabs	Thorlabs
Beamsplitter	BSW10	Thorlabs	Thorlabs
IR Camera	1778-1231-ND	Pimoroni Ltd	Digi-key
Test Laser Pointers	NA	Jearyeng	Amazon
Housing & Hardware Components			
Test Water Tubes	NA	Innovative Crafts	Amazon
M3 Nuts & Bolts Kit	NA	Hilitchi	Amazon
M5 Nuts & Bolts Kit	NA	DYWISHKEY	Amazon
System Housing	NA	Zuvas	Amazon
3D Filament		Amazon	Amazon
Redesigned Water Tube	NA	Opix	East Hardware
Electronic Components			
Development Kit	MA05	Miuzei	Amazon
Power Supply	B07ZM46WKF	FlickerStar	Amazon
WiFi Module	SE154	MakerFocus	Amazon
Display	NX3224T024	Nextion	Amazon

Table 42 Supplier/Manufacturer Breakdown

8. Conclusion

To briefly review, our system is designed to detect the presence of algae through the optical absorption of 450 nm wavelength by the green pigment present in algae known as Chlorophyll a. The optical design is based off the properties of Beer's law to calculate the optical transmission which was then used to calculate the optical loss. The system uses the equivalent of an Arduino Mega board as a micro controller while using our designed printed circuit board to operate the system. Lastly our system is housed in a lightweight cubic foot box designed with a hinge lid for easy closure and a water siphon for transferring the water inside the fish tank to the system's water sample tube for detecting the presence of algae in the system.

9. Appendices

9.1 Index of Figures

9.2 Index of Tables

9.3 References

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(Note: The ordered glass tubes link is no longer operational. The above link is of similar glass tubes but are a little more expensive.)

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