Detection of Algae in Fish Tanks Using Optical Absorption

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***Abstract* — With many people owning fish tanks nowadays the issue of trying to keep the water in them clear becomes 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. An algae bloom can also be an indicator that the lights on the fish tank need changing. Our Device seeks to assist fish tank owners in knowing what is going on in their fish tank. Fish tank assistant 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 assistant is also helpful for a fish tank owner to know when they need to clean their tank based on the amount 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.**

***Index Terms* — Ceramics, coaxial resonators, delay filters, delay-lines, power amplifiers.**

I. Introduction

Fish Tank Assistant, it 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.

II. Overview of the Digest

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.

III. 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.

According to a 2019/2020 study, fish are the 3rd most popular house pet with 11.5 million households in the U.S owning freshwater fish. It's not a surprise that Goldfish are the most common freshwater fish to own as a pet. It's tradition to win them at events and purchasing certain varieties can be of low cost. While acquiring a pet fish is fairly simple, keeping them alive doesn't 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. 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 through the use of optical components specifically designed for detecting the presence of algae in a water sample.

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 for blue-green algae in to use a test kit such as API Fresh Water Aquarium Master Test Kit. These kits consist of test tubes, test drops and a color card for manual testing.

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IV. Components

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. In order 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 programed to produce to desired output.

A. Microcontroller

A microcontroller is a small computer that can be integrated and programed 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, codes can be written to for systems like the Fish Tank Assistant.

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.

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 synced across devices. The Arduino IDE 1.8 should be used for projects based on this version. All tools use a programing language based on C++ with additional functions and offer extensive built-in example codes to assist new users.

B. 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.

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.

C. 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.

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.

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.

G. PCB

Our design will require a printed circuit board to be designed and implemented in the final system. Our circuit will need to regulate the voltage being supplied from the Arduino Uno to the various temperature and optical components. For instance, while the Nextion Liquid Crystal Display and the Temperature sensor both require 5V the photodiodes need 1V and the laser needs 3V. In order to power all the components via the Arduino Uno a voltage regulator needed to be designed. Our system requires three different voltages that can be achieved through using two variable voltage regulators in series. LM317 is a common variable voltage regulator that only requires 2 capacitors and 2 resistors to operate.

V. Optical Components

A. Laser

The light source for the system is laser pointers that do not exceed a maximum optical power of 5mW. Laser pointers were chosen for their simplicity and their beam collimation as they do not require a collimator which would be required for LEDs. The initial wavelength we wanted to use was 450nm as this wavelength is absorbed the most by Chlorophyll a. However, later we decided to use the test laser pointers we had purchased for our preliminary testing and repurpose them for wavelength dependent sensitivity calibrations. We were able to purchase a laser pointer operating at 450nm with a maximum optical power of 5mW from Alpec [3] which met all of our specifications. The test laser pointers were purchased from an Amazon store that no longer exists, but these laser pointers are the basic three pack of laser pointers that are sold on amazon where the optical power is 5mW and the wavelengths are 405nm, 532nm, and 650nm. We used the green 532nm and the red 650nm wavelengths for our sensitivity calibrations whereas the 405nm wavelength laser was used for testing how to integrate the lasers into the system properly. By using the 405nm wavelength in this way we hoped to eliminate the possibility of damaging the expensive Alpec laser pointer which we would need for our final system as we believed this wavelength would produce the most sensitive results. The system can detect algae through the green pigment

Chlorophyll-a which is present in all targeted algae. Chlorophyll-a's absorbs mostly blue wavelengths but also absorbs to a lesser extent red wavelength on the other hand Chlorophyll-a reflects green wavelengths and based off these absorption and reflection characteristics we have selected the previously mentioned wavelengths for our system where the comparison between the wavelengths is addressed in the demonstration.

B. Beam splitter

The beam splitter is a calibration optic whose purpose is to split the beam into two beams of identical optical power before transmitting through the water. The purpose of doing this is to record the input or initial optical power for the system while the other beam is used to transmit through the water. When the beam passes though the water that contains algae the beam should lose optical power due to the absorption or reflection of the light. Finally, this output power will be read and the differences between the two readings if algae is present will indicate the amount of optical power absorbed. The beam splitter chosen for the system is the Thorlabs BSW10 [5] this beam splitter has a 50:50 split ratio which will give the desired optical power split while positioned 45 degrees to the incident beam path. As stated, before the beam splitter is an optic used for calibration purposes and in a finished marketable product would not necessarily require the beam splitter or the second photodiode. Instead, a marketable product would only require a laser pointer, a water tube, a focusing lens, and a photodiode. The system would have more complex software to run more robust tests and save more data from those tests.

C. Lens

The system requires a focusing lens to refocus any divergence the beam may experience due to transmitting through the water onto the output photodiode to ensure the decrease in optical power is from the presence of the algae in the system. The lens chosen is a biconvex lens manufactured by Thorlabs referred to as LB1757-A [5]. This is of course the last element of the system that ensures the optical power decrease is from the algae as the first is the system's setup procedure in which the system can be run with clean water to confirm that there is not any optical power loss due to the beam traveling through the clean water sample. This specific lens was chosen for its antireflective coating in the visible range of 350nm to 700nm, a one-inch diameter, and a focal length of 30 mm (about 1.18 in). The focal length was chosen prior to deciding to change the water tube design, however, the selection was determined to work for the redesigned water tube after a few adjustments to the position of the water tube and the lens with respect to each other. As for the shape of the lens being a biconvex, we chose this specific shape due to its ability to focus diverging beams back to a point which is where the photodiode will be positioned to receive the focused beam.

VI. Hardware

A. 3D Models

The 3D models were designed in Free CAD with the intention of replacing and of the optomechanical parts that could normally be purchased through Thorlabs. The 3D models are used for the mounts for lens mount, beam splitter mount, laser pointer holder, photodiode mount, sample water tube for sample water ends, and platforms to hold the mounts. The 3D printed parts are made of PLA plastic 3D printer filament. We felt that by printing the 3D mounts we needed we could reduce the weight of the overall system that metal mounts and breadboards would possess as well as reduce the cost of the overall system as we were able to make all of the prints for an estimated equivalent price of a single optic mount from Thorlabs.

B. Siphon

For the siphon component of the system, we are using a STAR Water Systems Thermoplastic Transfer Pump. This transfer pump can move approximately 3.5 gallons per minute. The pump will be attached to the sample tube that we constructed out of plexiglass and 3D printed parts by the rubber tubing that is on the pump.

C. Water tube

The Water tube was initial going to be a cylindrical tube of borosilicate glass with an inner diameter of 6 mm and an outer diameter of 12 mm. After some preliminary testing we found that the optical path inside the water tube was too short, so we had to move on and design a water tube ourselves. We decided to use a rectangular tube design to increase the optical path length and to simplify the beam behavior when incident onto the water tube. The flat surface of the water tube should make transmission through the tube simpler while the increased optical path length makes the system more sensitive by allowing the beam the chance to interact with more algae and thereby have the chance to experience more absorption by Chlorophyll a than it would with the shorter optical path length.

VII. Software

A. Liquid Crystal interface

Using Nextion Program, we were able to simulate the interface on the LCD as well as program the different functions of the buttons. Our main goal is to make the user interface on the screen to make it as intuitive and as user friendly as possible so that the user would easily be able to control the device without having to look at any type of guidance or manual. Using Nextion, it allowed us to program the user interface by placing buttons and text as well as a measurement reader that would work coercively with our Arduino code.

B. Microcontroller

We chose Arduino Uno microchip to program in order to achieve the goals of this device and make it

$$n = \frac{\#\,of\ grams\ being\ used}{molar\ mass} = \frac{5g}{893.51g/mol} = 0.0055959082718716\ \text{mol}$$

operational ad functional. Our choice was based on functionality, ease of use, resources and cost and those were the main factors that lead us to Arduino Uno as it preforms exponentially well for the purpose of this project while maintain a reasonable cost as well as providing an excellent IDE that allows us to easily code the microchip to make the different parts of the device functional. Using the Arduino code we were able to make the buttons on the screen functional and that allowed the screen to be responsive to the commands given by a touch interface

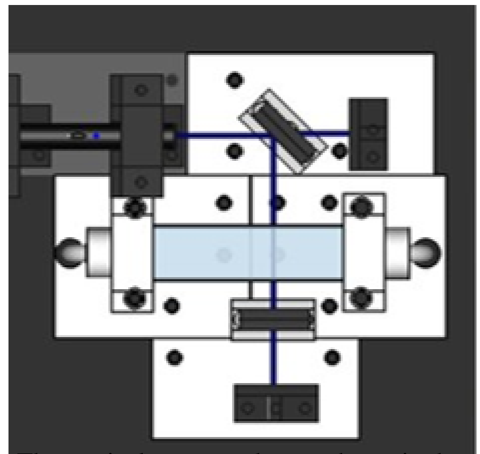
C. Photodiodes

To be able to measure the initial optical intensity of the beam, called control and the intensity of beam through the water sample, called test we were able to utilize the photodiodes by using a bread board and making the necessary connections to calibrate it with the code we devised on Arduino IDE as it is connected to the microchip, and we successfully were able to program them to be able to detect the control and test. The photodiodes are an essential part of the system as they are the optical receivers that measure the intensities for the calculation of light absorption due to the presence of algae in the system.

VIII. Pre Testing

A. Software: User Interface on LCD Screen

B. Testing Optical System



The optical system shown above it the system that was tested. The system was tested using a sample of Hair algae. The sample will be at a concentration of 5 grams per letter. The theoretical value for the transmitted light was calculated using the equation for Beer's Law, shown below, this value was used to test the optical system to ensure that it is functioning properly.

$$A = \varepsilon c l$$

A	Absorbance	
ε	Molar absorption coefficient	$M^{-1}cm^{-1}$
c	Molar concentration	M
l	optical path length	cm

chlorophyll a in Hair algae is and the malar mass of Chlorophyll a. The Molar concentration, C, was calculated by first calculating the molar number, n, as shown below.

Once the molar number, n, was calculated then the Molar Concentration, C, was calculated using the formula below.

Then taking into account that the amount of chlorophyll a in algae goes from 0.1% to 9.7%, with hair algae on average being 1.42042%. Finally putting all the calculated components into the equation for beer's law, we get the table below.

Table 1

Expected Values for 5 Grams per letter of water concentration

Molar absorption coefficient	1.261E+05 M-1*cm-1
Molar concentration	0.005595908271871M
Optical Path length	2.5 cm
Expected Absorption	1241.964
Expected Transmitters	70.20246%

IX. Testing

A. Preliminary system test

The preliminary system test was performed using both the 650nm red wavelength laser and the 450nm blue wavelength lasers along with the photodiodes for detecting the blue wavelength's intensity, and phototransistors

$$C = \frac{Molar\ Number}{Volume} = \frac{n}{v} = \frac{0.0055959082718716\ mol}{1\ Leter} = 0.0055959082718716\ \text{mol/L or}\ 0.0055959082718716\ M$$

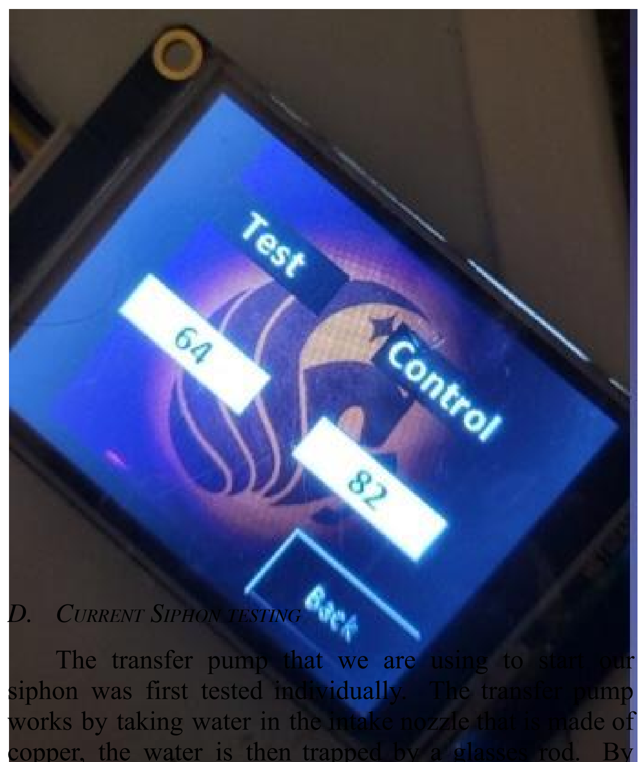
obtained through the CREOL undergraduate lab courtesy of Dr. Mhibik for detecting the red wavelength's intensity as the photodiodes were chosen primarily for the blue wavelength during the infancy stages of the project. However, once it was decided to compare three different wavelengths for the calibrations the photodiodes were confirmed to be capable of detecting green wavelengths as well as the blue. Unfortunately, the photodiodes were unable to detect the red wavelength, leading us to contact Dr. Mhibik to obtain the photodiodes, however, we were unable to locate any photodiodes in the lab and therefore decided to try to implement phototransistors for the calibration testing. The system at this stage was operating via a breadboard powered by an Arduino Uno. ()

The optical components were integrated into the Arduino Uno and tested via a bread board and small LED screen. The photodiodes were aligned in series with a current limiting resistor for the initial testing. The LCD screen was able to tap into the 5V supplied by the Arduino Uno.

B. Current optical testing

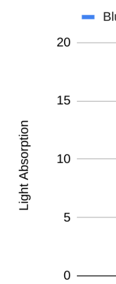
Currently we are testing all three of the wavelengths using three different algae concentration levels of 0.01g/L, 0.05g/L, and 5g/L. The 5g/L concentration is the same concentration used in the preliminary test which resulted in 20% to 30% absorption of the blue 450nm wavelength, however, for the same concentration the results of using the red 650nm wavelength and the phototransistors resulted in a much higher absorption percentage leading us to believe that the alignment may have caused the discrepancies as we would expect to see less absorption of the red wavelength than the blue.

The above is a graph of the wavelength dependent algae concentration sensitivity calibration. This data was obtained at the concentrations of 0.01g/L 0.05g/L and 5g/L at three different wave lengths.



D. Current Siphon testing

The transfer pump that we are using to start our siphon was first tested individually. The transfer pump works by taking water in the intake nozzle that is made of copper, the water is then trapped by a glasses rod. By shaking the nozzle up and down in the water suction is created that pulls water through the tube. In testing it was found that on average it takes approximately 17 seconds to



get water running through the siphon tube alone, without it connected to the water sample tube.

E. Current Software Testing

Currently, we are constantly making sure that our main code compiles with no error. Therefore, we have successfully made the touch screen operational as well as functional as the user is now able to use the buttons and there are output readings as well. Our challenge right now is getting all the components of the device to be

programmed into the microchip for it to be operational as well such as the Laser and the thermal camera. We were successful at coding and testing the photodiodes readings. However, the thermal camera has been challenging to program in order for it to read the temperature. We were successfully able to code it to make it functional.

X. System Changes

A. Optical Changes

During the first semester of designing our system we had only designed it for a singular wavelength of 450nm which we felt would result in the most sensitive detection of algae due to Chlorophyll-a absorbing the 450nm wavelength the most. However, during the beginning of the final semester, we were advised to use three different wavelengths in the system to find the wavelength with the most sensitive results. We were able to utilize the laser pointers we had previously purchased for the preliminary testing and repurpose them for these calibration tests. After using three different algae concentrations and the three different laser pointers the results were conclusive with our previous beliefs of the blue 450nm wavelength producing the most sensitive results even though the photodiodes that were purchased for the blue wavelength only had a sensitivity of 0.7 at 450nm while having its peak sensitivity at 565nm meaning that photodiodes have a higher sensitivity to the 532nm wavelength than the 450nm wavelength.

XI. 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 light weight 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.

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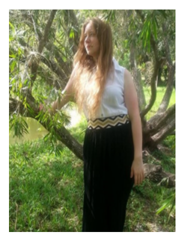
[5] https://www.thorlabs.com/thorproduct.cfm?partnumber=BSW10

IX. The engineers



Zia McDonnold
Photonics Engineer

I received a General Associate of Arts degree from The Eastern Florida State Collage in the Fall of 2019. I transferred to The University of Central Florida in the Spring of 2020 to earn a Bachelor of Science in Photonic Science and Engineering.

Kielan McMillan
Photonics Engineer

After earning my AA degree from dual enrollment at my local state college I was determined to attend UCF to earn a degree in engineering. At the time I wanted to earn a degree in civil and constructional engineering but after a semester or two, I was introduced to CREOL during an introductory engineering course. I was interested in learning how light works and how most of the everyday devices we use are dependent on photonics and optics in some way or another. This one lecture changed my entire college path and the result of that has led me to this point now where I am currently working full time as a Jr. Optical engineer at X-lumin, completing my final class, and preparing for graduation.

Danielle Nastyn
Electrical Engineer

After serving in the Navy Reserves as an Electronics Technician I knew I wanted to further my education in electronics. I am currently working for Siemens Energy in Continuous Improvement while pursuing my bachelor's in electrical engineering. I hope to pursue a career where I can continue to explore and grow in electronics.

Vergin Mansour

Computer Engineer

I will be graduating this summer with my bachelor's in computer engineering. I am currently working at Northrop Grumman as a Cyber Security System Engineer and I am excited to use the knowledge I have gained though out the 4 years of school to help assist my teammates with this project