Optical Chlorine Concentration Analyzer

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Motivation and Background

- The high cost of existing chlorine analyzers presents a significant barrier for many users, particularly in resource-limited settings or small-scale operations.

- Our senior design project aims to address this issue by developing a cost-effective chlorine analyzer that leverages photodiodes and lasers.

- Chlorine is widely used as a disinfectant in water treatment due to its ability to eliminate harmful pathogens. Accurate measurement of chlorine concentration is crucial in maintaining the efficacy of disinfection processes and ensuring the safety of skin contact with water.

Goals for the OCCA

Basic Goals

1. Design an optical system that can detect and accurately report the amount of chlorine content in water in ppm.
2. Develop a mobile application for android phones that displays concentration of chlorine in the system.
3. Achieve an accuracy rating >88%

Advanced Goals

1. Achieve an accuracy rating >95%
2. Create a database for every unique user and system.

Stretch Goals

1. Expand the system to be able to test more than one water source at the same time and expand the application accordingly to give updates without impeding the understanding of the user.
2. Create a cross-platform mobile application accessible on both Android and iOS devices.

Objectives for the OCCA

Basic Objectives:

1. Research spectroscopy and laser attenuation methods and compare.

2. Using knowledge of objective 1, decide on how much water will be tested for our water sample.

3. Use the results of the previous objectives to design the layout of the optical system for detecting chlorine, as well as take note of the full power requirements of the optics system.

4. Integrate electrical components into optical system and ensure there is no conflict between the major sections.

5. Order parts and create the prototype of the design we've developed, then tweak the system to fulfill our basic goals (Accurate detection of free chlorine in water sample).

6. Design housing of project with consideration to size of components in Solidworks and 3D print sections, then assemble.

7. Develop a mobile application in the form of an APK (file usable by android mobile devices) that can accurately display our detected chlorine content from the prototype, as well as communicate with the user through email.

Requirements Specifications

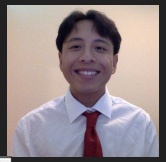
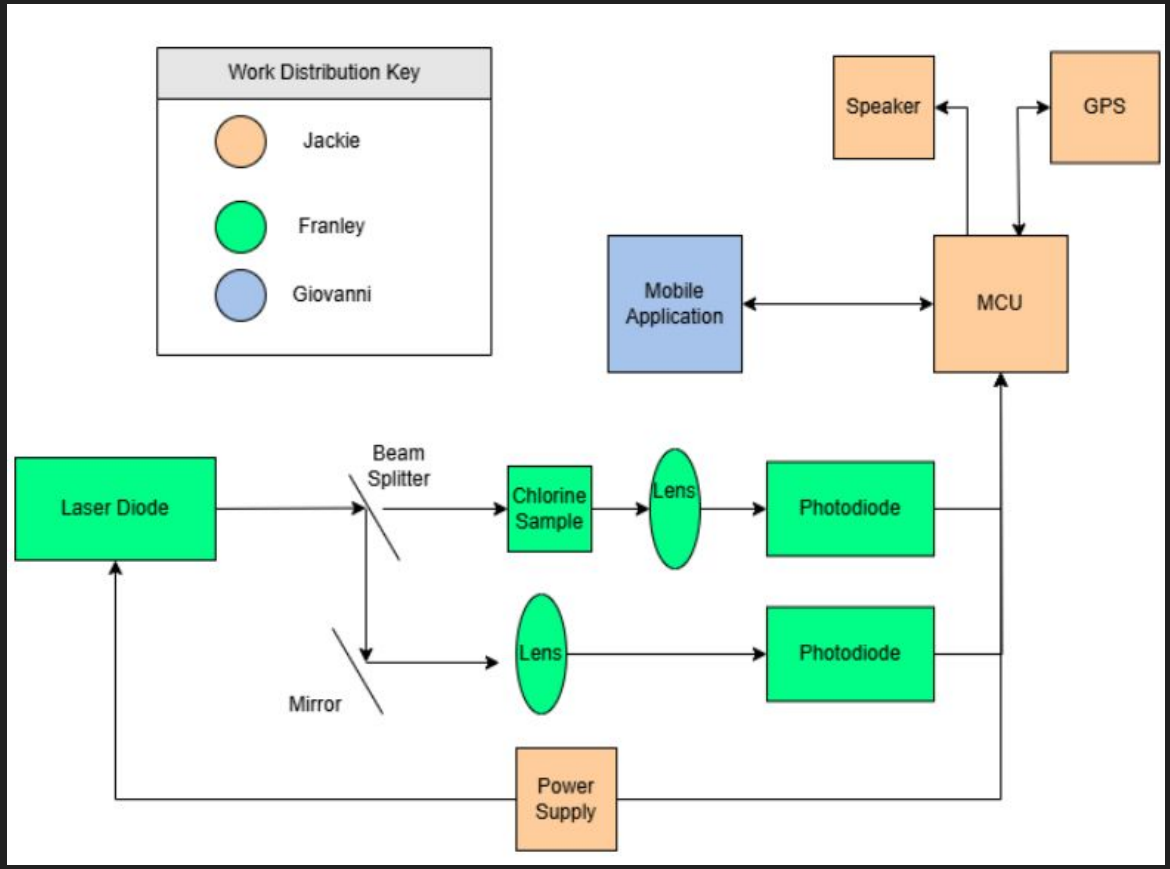


Table 1. Requirements Specifications

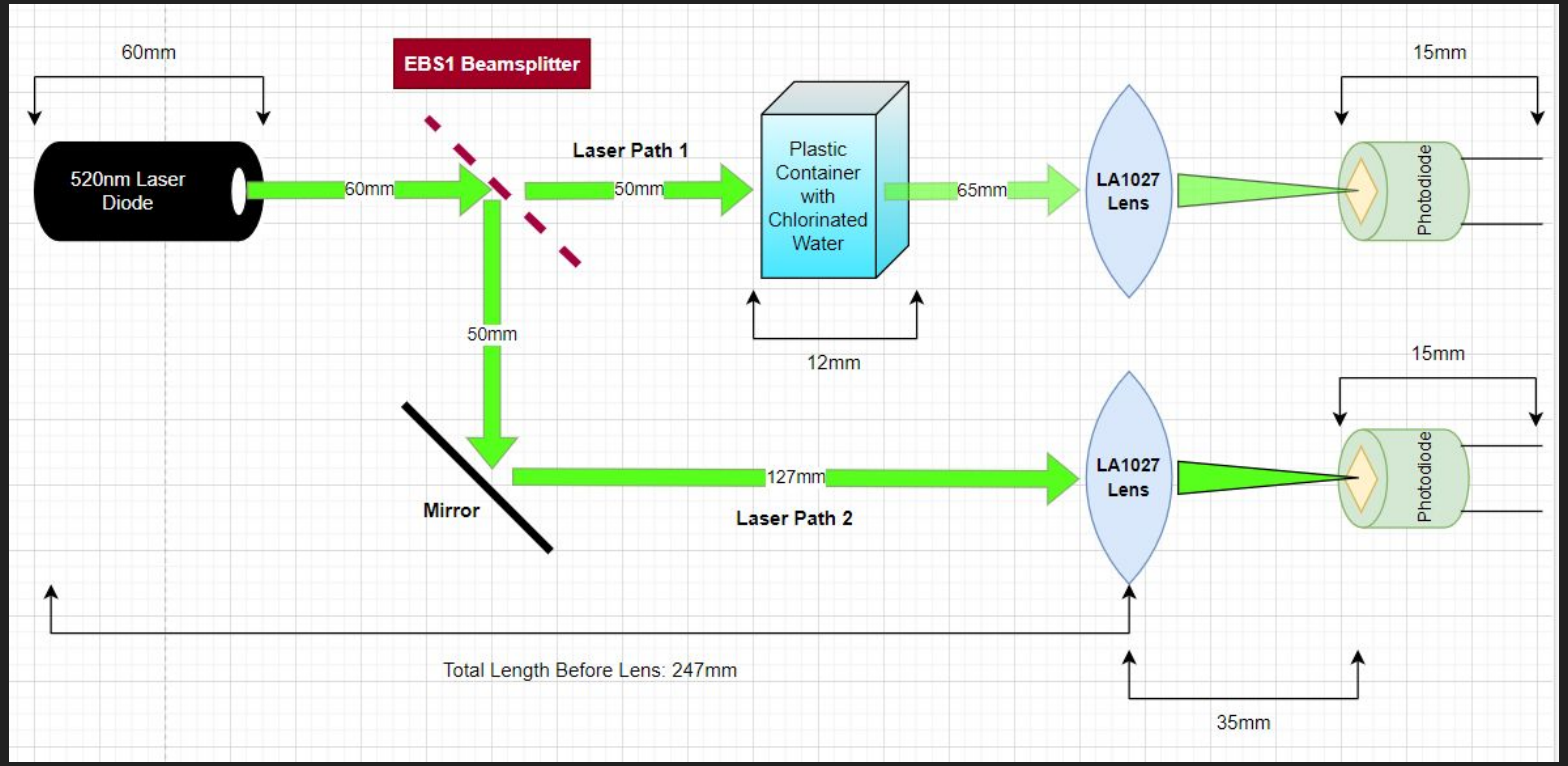
Requirements	Parameter	Description	Specification
Chlorine in Water Detection Range	Detection Sensitivity	The Optical Chlorine Analyzer should be able to detect chlorine concentrations.	0.5ppm - 10ppm
Response Time	Speed	The detector should be able to report results on the app within a minute of the initial data collection.	< 1 minute
Accuracy	Reliability	The Optical Chlorine Analyzer should give an accurate reading of the current concentration present in the water.	> 88%
Environmental Conditions	Temperature Resistance	There should be a defined operating temperature and pH for the detector. We also want to identify any environmental conditions that could affect the detector.	Room Temperature (~293 K) pH between 6.5 to 7.5
Photodetector Sensitivity	Input Sensitivity	Have our photodetector be sensitive enough to record a discernible difference in power to determine chlorine concentration	Dependent on laser power
Laser Diode Specifications	Wavelength Required	The laser diodes wavelength should be that it matches with the absorption spectrum of the DPD so that we achieve a readable signal in our Photodiode	520 nm
Power Consumption	Power Required	Define an acceptable power consumption for the sensor if it is deployed at a remote location.	5W-10W
Cost Constraints	Budget	We want to make sure the project does not exceed $1,000.	< $1,000
Dimensions	Size	It should be less than 1x1x1(m) to ensure the system is portable and easy to set up in a lab setting.	< 1x1x1(M)
Maintainability	Durability	The Optical Chlorine Analyzer should be able to run for an extended period without maintenance or supervision.	> 1 year

- The rows highlighted in blue are the demonstrable specifications.
- Our basic goals strive to fulfill at minimum the demonstrable specifications.
- Once the demonstrable specifications are fulfilled, advanced and stretch goals will be considered.

Project Hardware Block Diagram

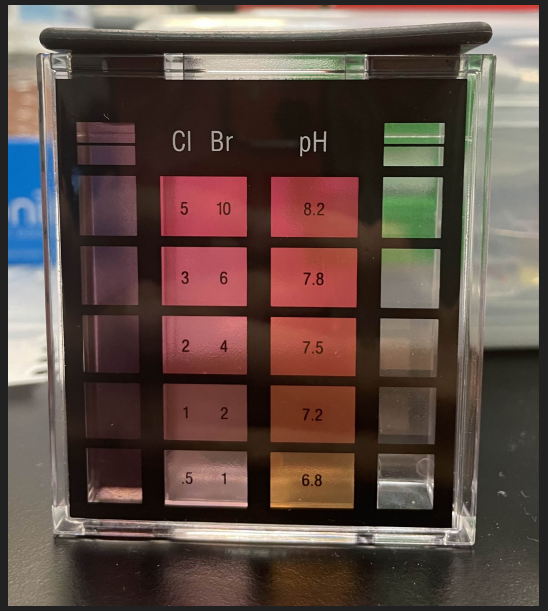


Complete Layout of Optical System



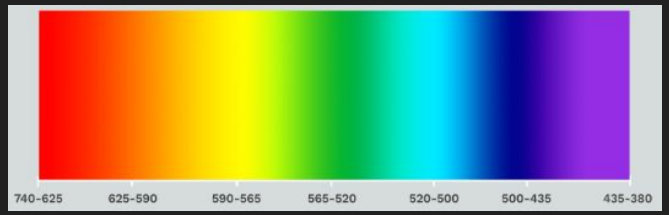
- Created with consideration to component sizes and LA1027 EFFL (35mm).
- Gives information needed to simulate lenses and ensure best performance in Zemax.

Reagent Comparisons

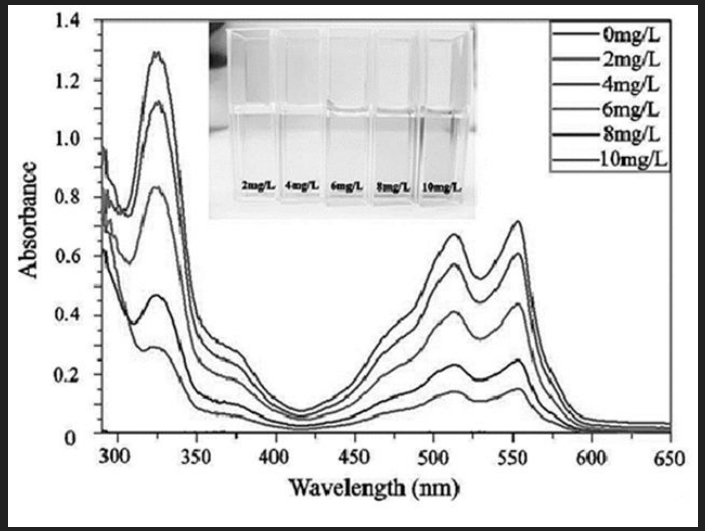


- DPD Reagent and its reaction based on concentration

	OTO	DPD	FAS-DPS
Chemistry Levels Tested	Total Chlorine	Free Chlorine & Total Chlorine	Free Chlorine & Combined Chlorine
Potential of “Bleach out”	No	Yes, after 10 ppm	No
Reliable Chlorine Readings	0.5 - 5ppm	0.5 - 5ppm	0.2 - 20ppm
Color	Yellow	Pink	Pink

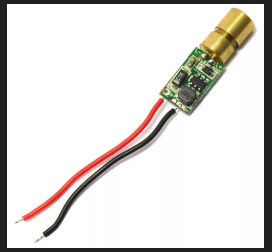


Optical Parts Selection: Laser Diode



Laser Diode	Wavelength	Price	Power	Connection Type	Additional Components Required?
Apinex Laser Diode Module	520nm	$39.50	5mW	Positive and negative wiring	✗
Q-BAIHE Laser Diode	520nm	$16.66	5mW	Positive and negative wiring	✗
Berlin Lasers Laser Diode Module	520nm	$150 + $57.50	5mW	DC Output Cable	✓

- Above graph illustrates absorption spectrum of DPD and Free Chlorine.
- Aiming for laser sources at 520 nm to reach peak.



Q-BAIHE Laser Diode

Apinex Laser Diode Module

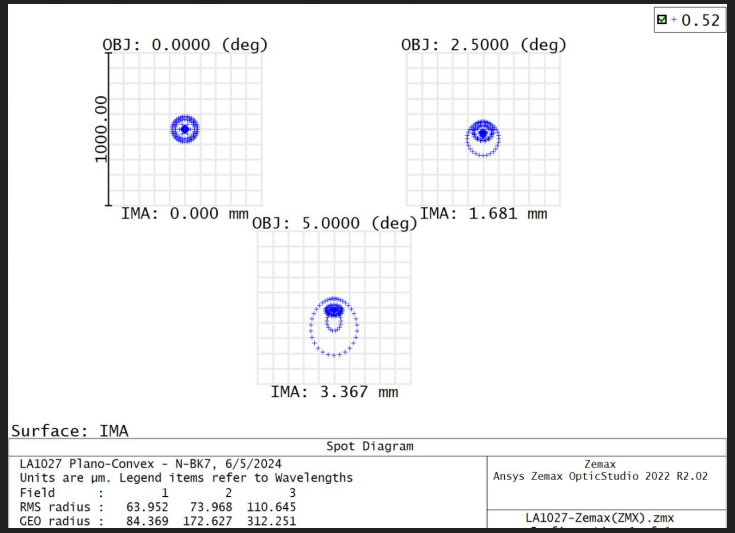
Optical Parts Selection: Beamsplitter

Beamsplitter	Price	Surface Diameter	Shape	Glass Thickness	Power Split Ratio at 520nm
Edmund Optics #13-399	$47.00	12.5mm^2	Rectangular Plate	1mm	45R:55T
EMF Corp BS-5050-125D	$30.00	12.5mm	Circular Plate	1mm	50R:50T ±5
Knight Optical BAE0906	$17.82	9mm^2	Rectangular Plate	1.1mm	49R:51T
Thorlabs EBS1	$38.32	25.4mm	Circular Plate	1mm	49R:47.5T

- Beam spot size is 4mmx5.5mm, desire beam splitter with minimum double the size for easy system setup.
- It is preferred to have as close to 50:50 split as possible.

Optical Design for Selection of Lens

- 12 lenses from Thorlabs and 7 from Newport were considered and modeled using Zemax.
- The best focus we were able to attain was a ⅛ of the smallest spot diagram seen on the right, using the Newport KPX022.
- KPX022 was not selected due to small diameter, only 6.35mm.
- Compromised spot size for larger lens with solid performance, which is the LA1027 lens seen on the right, with a similar focal length to the KPX022.

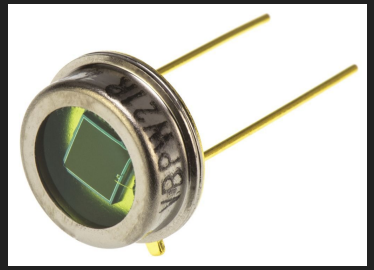


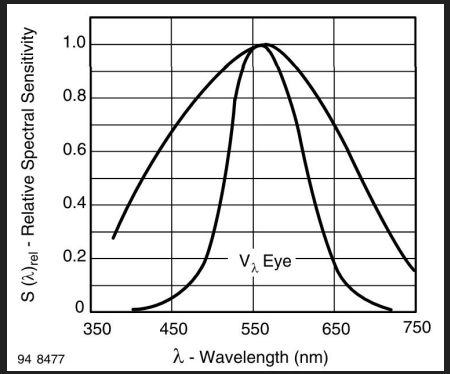
Thorlabs LA1027 Plano-convex Lens

- 25.4mm diameter
- 35mm focal length, ensures enough space for photodiode.

Optical Parts Selection: Photodiode

Photodiode	Price	Responsivity at 520 nm Laser Light	Active Area	In Stock
Vishay BPW21R	$12.30	93%	7.5mm^2	✓
Marktech MTD5052N	$7.54	~100%	0.57mm^2	✓
EPIGAP EOPD-525-1-0-0.9-1	$3.10	~100%	0.73mm^2	✓

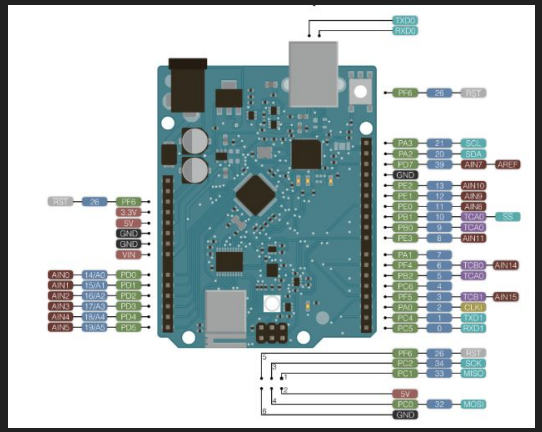




- At least 4 photodiodes are purchased, 2 used and 2 for backup.
- Active area is considered more valuable than responsivity due to most considered photodiodes responding well to our laser diode wavelength.

Microcontroller Comparisons

- The Arduino Uno WiFi Rev2 has built in WiFi connectivity.
- Arduinos have many compatible over the counter sensors and hardware.
- Arduinos are easy to use and setup with the Arduino IDE.



Comparison Features	Arduino Uno WiFi Rev2	Arduino Nano ESP32	Raspberry Pi 4	Raspberry Pi Zero 2W
Processor	ATmega4809	Xtensa dual-core (or single-core) 32-bit LX6 microprocessor	Broadcom BCM2711	Broadcom BCM2710A1
Operating Voltage	5V	3.3V	5.1V	5V
Operating Temperature (°C)	-25 to 70	-25 to 70	0 to 50	-20 to 70
Digital I/O Pins	14	14	40	40
PWM Digital I/O pins	5	All pins (5 simultaneously)	40	40

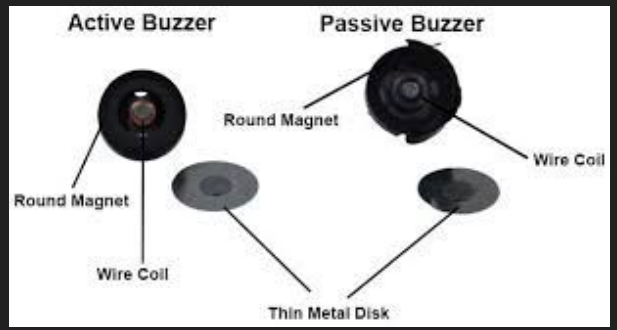
GPS Module Comparisons

- The Adafruit Ultimate GPS Shield is designed to be compatible with Arduino Uno boards.
- The MKR GPS Shield and NEO GPS module requires additional configuration and setup.

Feature	MKR GPS Shield	Adafruit Ultimate GPS	NEO GPS Module
Compatibility	Designed for Arduino MKR series	Compatible with Arduino Uno WiFi Rev2 in shield form	Compatible with most Arduinos
Libraries	MKR GPS Libraries	Adafruit GPS Library	TinyGPS++
Update Rate	Up to 5Hz	Up to 10Hz	Up to 10Hz
Accuracy	1.5m CEP	1.8m CEP	2.5m CEP
Ease of Use	Easy with Arduino MKR Boards	Easy with Arduino Uno boards	Moderate, additional setup and configuration

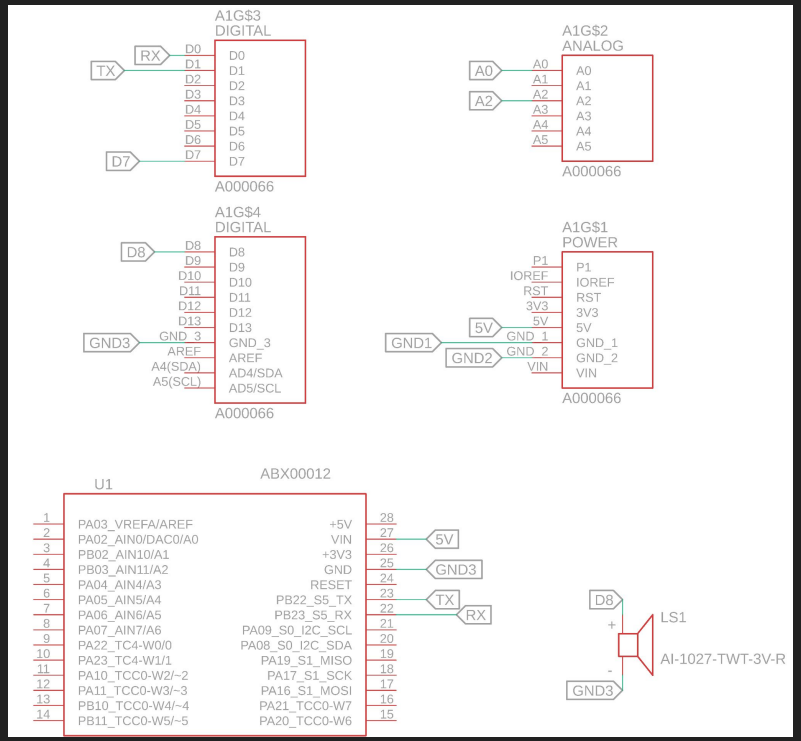
Speaker Comparisons

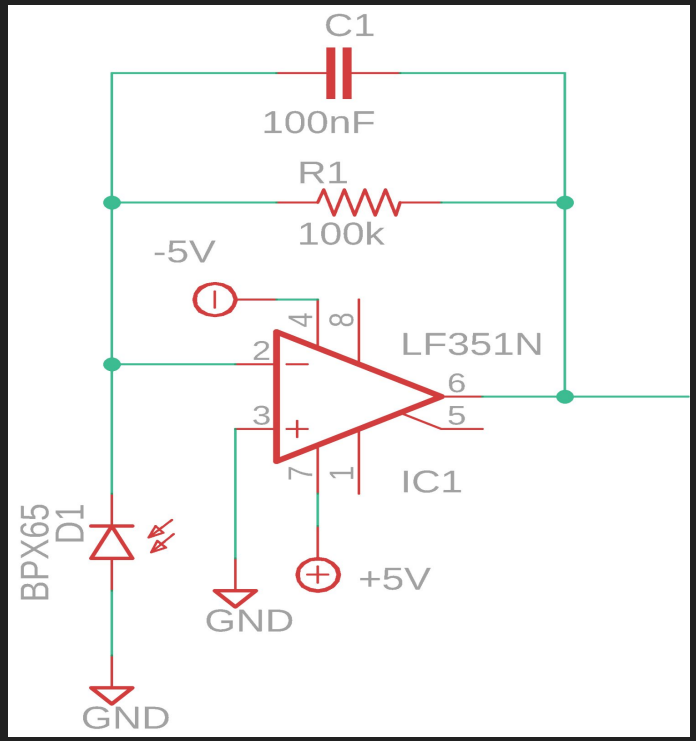
- The Passive Piezo speaker allows customizing the alarm's pitch, tone, and volume.
- An Active Piezo Speaker only has one sound that is not configurable and the MP3 Player requires additional setup and parts such as an SD card.



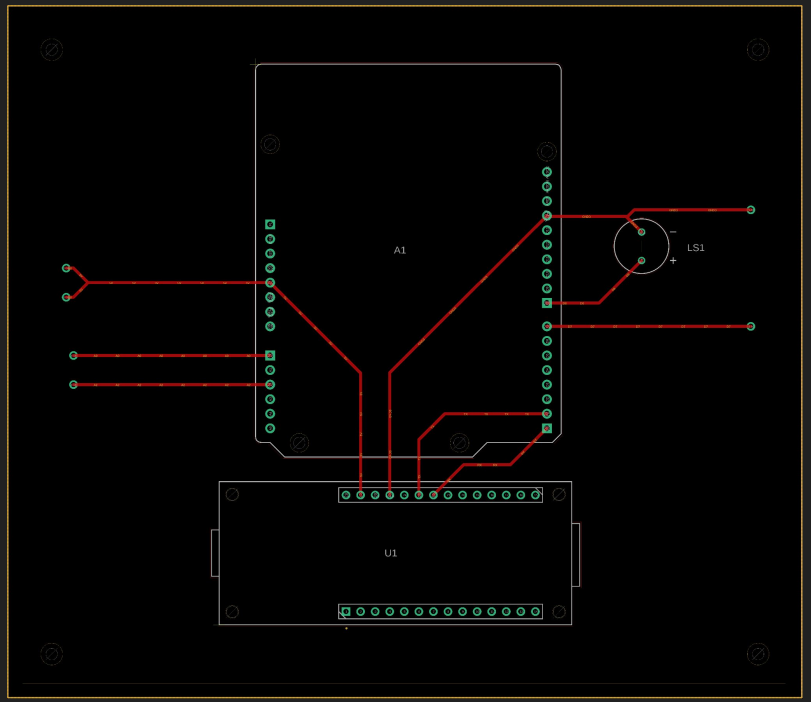
Feature	Passive Piezo Speaker	Active Piezo Speaker	MP3 Player
Power Consumption	Low	Low	High
Complexity	Moderate	Low	High
Control	PWM Signals	Digital Write On/Off	Arduino MP3 Library
Size	Small	Small	Moderate
Cost	Low	Low	Moderate
Flexibility	High	Low	High

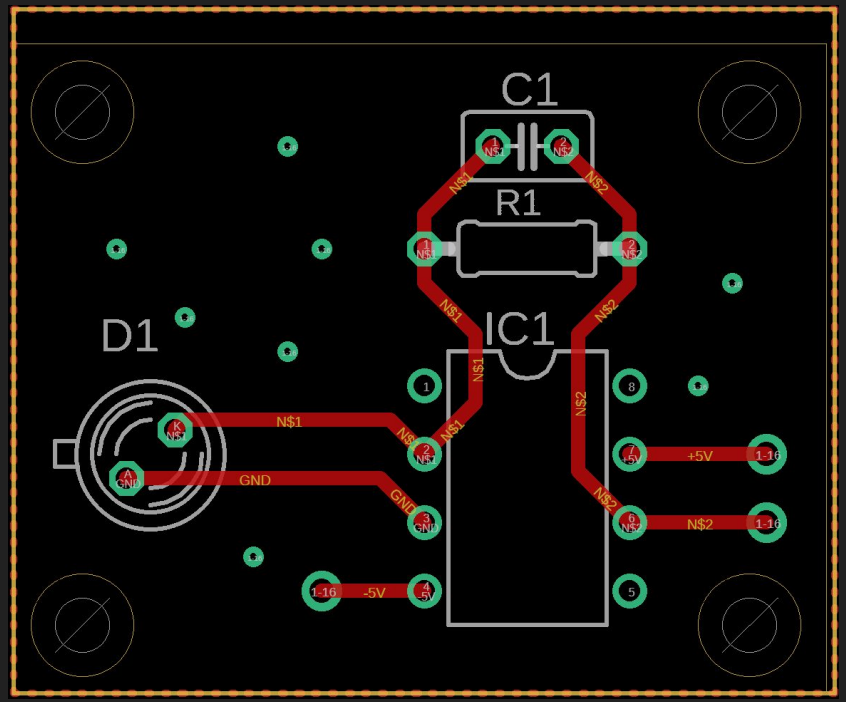
PCB Schematic

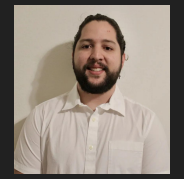




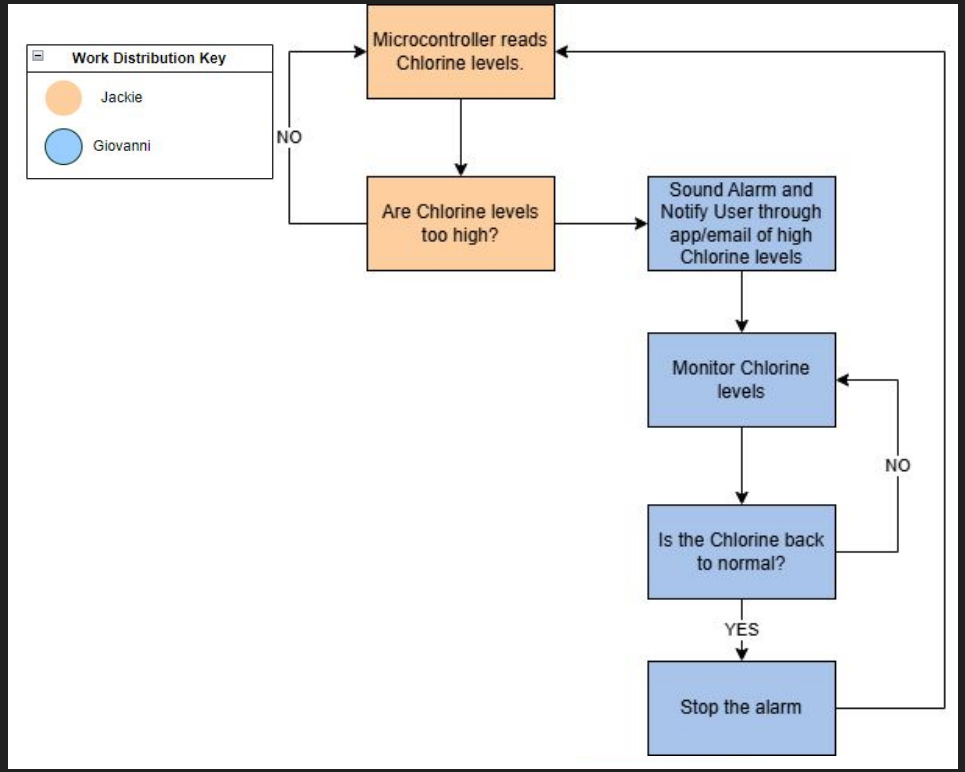
PCB Board Layout





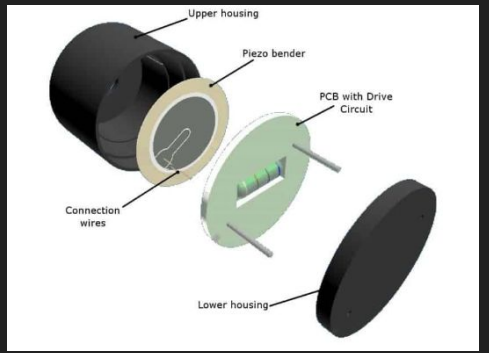


Software Block Diagram



Warning System

- The warning system will be comprised of the GPS module, Piezo speaker, the mobile application, and Google API.
    - The GPS will provide the location of the body of water with high chlorine content.
    - The Piezo speaker will sound an alarm to warn the user.
    - The software application will use Google API to send emails to alert the users of high chlorine levels.



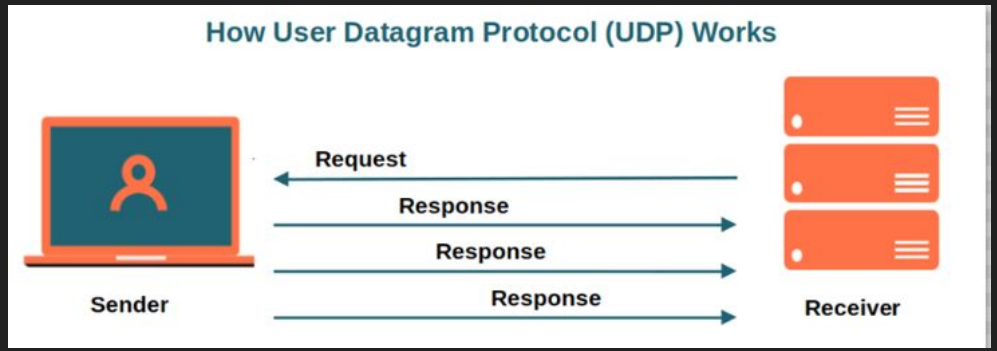
Hardware Communication Protocol Comparison

- Simple to implement and configure.
- GPS module is the only hardware that requires a communication protocol, Arduino Ultimate GPS Shield supports UART.

Feature	SPI	I2C	UART	USB	Bluetooth
Wires	3-4 (MOSI, MISO, SCLK, CS)	2(SDA, SCL)	2(TX, RX)	4+(Power, Ground, Data+)	Varies
Speed	Fastest	Slow-Moderate	Slow-Moderate	Fast	Moderate
Duplex Mode	Full Duplex	Half Duplex	Full Duplex	Full Duplex	Full Duplex
Addressing	Master-Slave	Multi-Master	Point-Point	Device-Host	Device Addressing
Complexity	Simple	Moderate	Simple	Complex	Moderate
Typical Use	Internal communication between chips and PCB	Low-power communication between sensors and microcontroller	Serial communication between devices	Peripheral connections	Wireless communication between devices

Software Communication Protocol Comparisons

- UDP is connectionless and does not require a handshake which reduces latency.
- UDP is ideal for applications where real-time communication is crucial.
- UDP is simple to implement.



Feature	UDP	TCP	SSL/TLS	HTTP/HTTPS
Type	Transport Layer	Transport Layer	Security	Application Layer
Connection Oriented	No	Yes	No, relies on TCP for connection	Yes
Reliability	No, packets can be lost, out of order, or duplicated	Yes, guarantees in-order delivery	Not by itself, relies on TCP mechanisms for reliable data delivery	Yes, same as TCP
Error Correction	No	Yes	Not by itself, relies on TCP mechanisms for error correction	Yes, same as TCP
Encryption	No	No	Yes	Yes
Authentication	No	No	Yes	Yes
Typical Use Cases	Real-time applications	File transfers, web browsing, email	Securing communication channels	Transferring web pages and data between web servers and browsers
Port Numbers	Varies	Vaies	Varies, usually 443	80 (HTTP), 443 (HTTPS)

Development Platform

- Flutter is compatible across multiples operating systems using one code base.
- Hot Reload feature for faster development.
- It has built-in widget for easier UI development.

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

Tech Stack

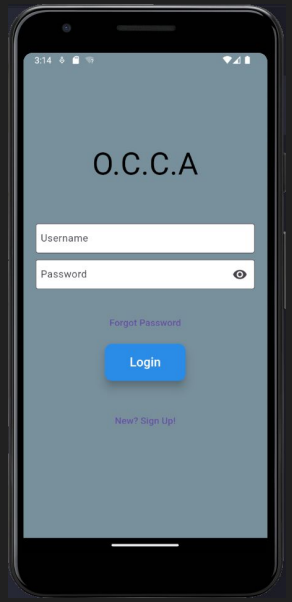
- MERN stack use a single programming language (JavaScript) for the entire stack.
- It use MongoDB that its a noSQL database. Node.js and Express as the backend API runtime environment.
- It has libraries, tool, and frameworks that help the development of the application.

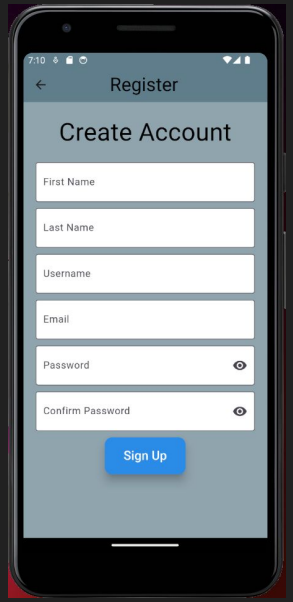
Comparison Features	LAMP	MERN	MEAN
Components	Linux, Apache, MySQL, PHP/Python	MongoDB, Express.js, React.js, Node.js	MongoDB, Express.js, React.js, Node.js
Server-side Backend	PHP/Python	Node.js	Node.js
Database	MySQL	MongoDB	MongoDB
Programming Language	JavaScript, Python	JavaScript	JavaScript
Scripting/Style Sheet Language	HTML, CSS, PHP, MySQL	N/A	N/A
Cost	Open-Source	Free version/ Paid version	Free version/ Paid version
Web Server	Apache	Express.js	Express.js
Frontend	N/A	React.js	Angular

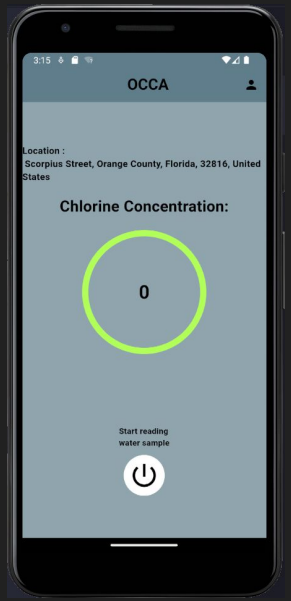
Mobile Application Design

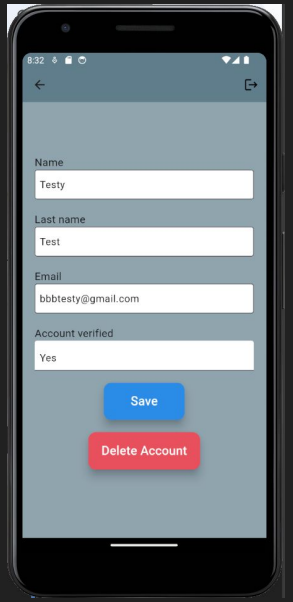
- There will be four pages

- Login
- Sign up
- Landing page
- Profile page

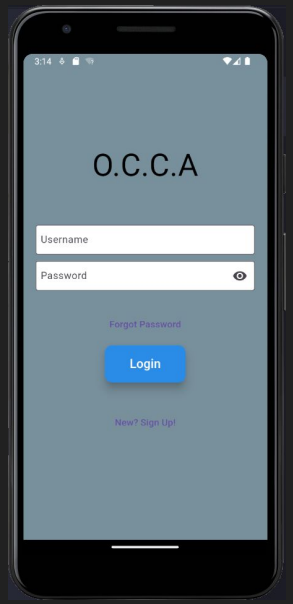


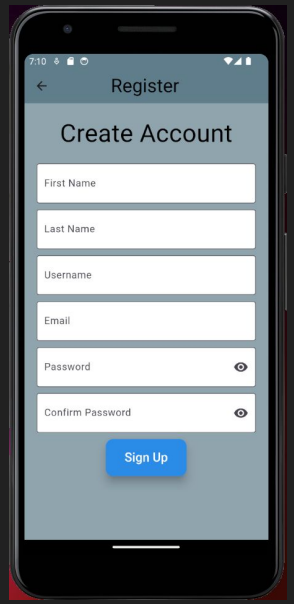


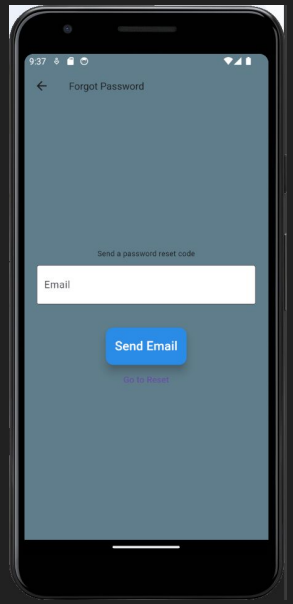




Application Design



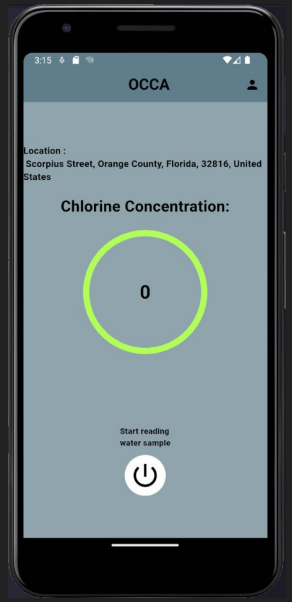


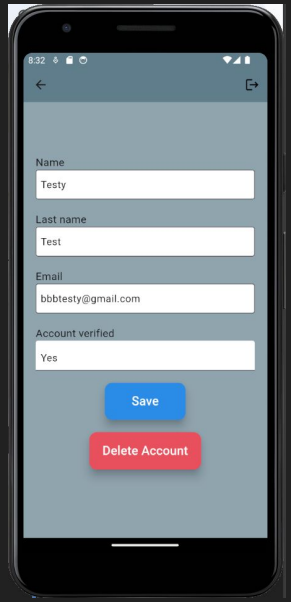


Login/Signup

- First Name, Last Name, Username, Email, password is stored in the database.
- User confirm email address after account is created.
- Reset Password

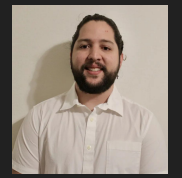
Application Design





Landing page

- Display the Chlorine Concentration.
- Display the current location of the system.
- Start/Stop the analysis of the water sample.
- Send email to user when the sample pass the 5 ppm threshold.
- Send email when the sample ppm goes back down to normal
- Profile page for updating user credentials.
- Deletion of account.

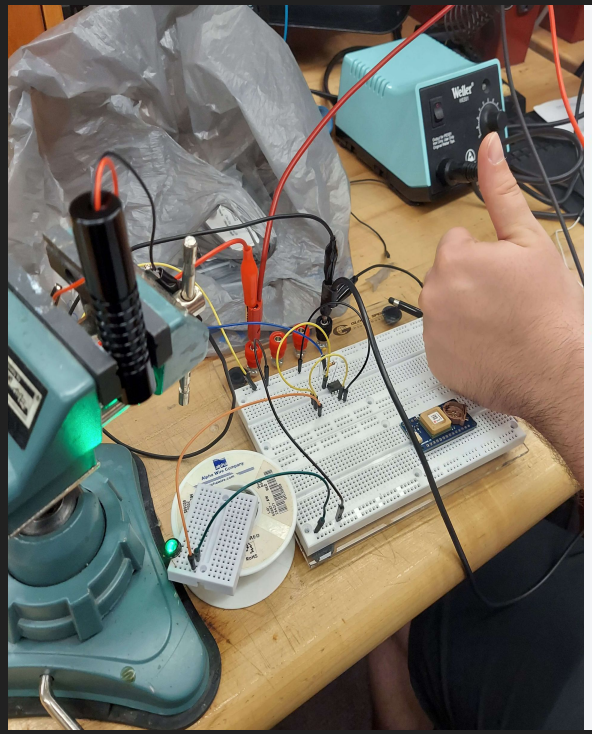


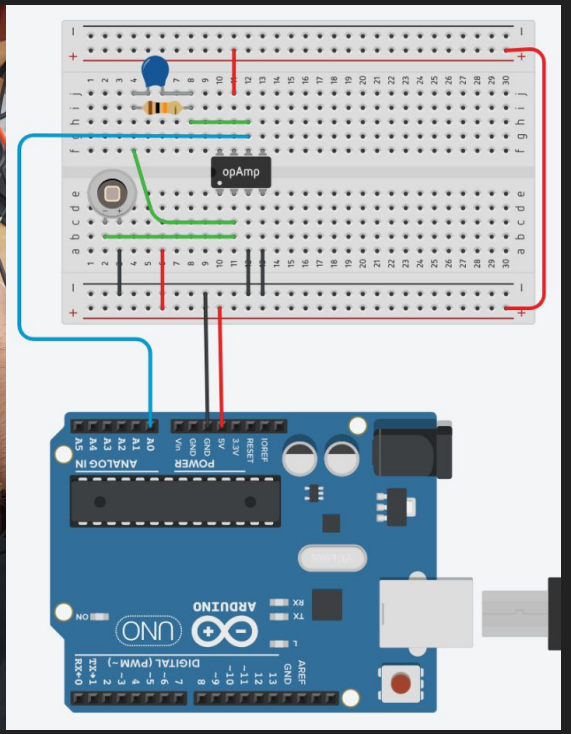
Bill of Materials

Components	Quantity	Unit Cost	Total
Laser Diode	1	$40.00	$40.00
Reagents	1	$40.00	$40.00
Arduino Uno Wi-Fi REV2	1	$53.80	$53.80
Piezo Speaker	1	$7.99	$7.99
GPS Module	1	$40.10	$40.10
Power Supply Adapter	1	$7.99	$7.99
Photodiode	2	$12.00	$24.00
Beam Splitter	1	$38.32	$38.32
Lenses	2	$25.81	$51.62
PCB	5	$3.00	$15.00
Total			$318.82

Prototype Schematic

- The prototype built on a breadboard is working as expected.
- Our current prototype includes the speaker, photodiode, and laser.
- We used a 100k Ohm resistor, 100nF capacitor, and an LF351 JFET Op Amp.
- The final version of the prototype will include a GPS module with UDP communication with the mobile application.





Prototype Testing

- Prototype testing of the laser and photodiodes with specific chlorine ppm levels, values shown were within our expectations. The values' units are unique to an Arduino's conversion of input voltage.
  - Base values: 442-489
  - 1.5 chlorine PPM values: 120-143
  - 7PPM chlorine values: 18-30

```
Packet contents: Speaker Off
value(1): 471
value(2): 654
Packet contents: Speaker Off
value(1): 469
value(2): 642
Packet contents: Speaker Off
value(1): 445
value(2): 622
Packet contents: Speaker Off
value(1): 459
value(2): 635
Packet contents: Speaker Off
value(1): 489
value(2): 688
Packet contents: Speaker Off
value(1): 442
value(2): 609
Packet contents: Speaker Off
value(1): 449
value(2): 626
Packet contents: Speaker Off
```

```
Packet contents: Speaker Off
value(1): 139
value(2): 676
Packet contents: Speaker Off
value(1): 143
value(2): 691
Packet contents: Speaker Off
value(1): 127
value(2): 638
Packet contents: Speaker Off
value(1): 131
value(2): 658
Packet contents: Speaker Off
value(1): 122
value(2): 654
Packet contents: Speaker Off
value(1): 135
value(2): 664
Packet contents: Speaker Off
value(1): 120
value(2): 710
Packet contents: Speaker Off
```

```
Packet contents: Speaker On
value(1): 18
value(2): 643
Packet contents: Speaker On
value(1): 23
value(2): 639
Packet contents: Speaker On
value(1): 16
value(2): 699
Packet contents: Speaker On
value(1): 11
value(2): 690
Packet contents: Speaker On
value(1): 31
value(2): 689
Packet contents: Speaker On
value(1): 23
value(2): 644
Packet contents: Speaker On
value(1): 30
value(2): 619
Packet contents: Speaker On
```

Progress and Plan for Completion

Task	Start Date	Anticipated End Date	Duration
Build Prototype	5/13/24	5/21/24	8 days
Test & Redesign	5/21/24	5/31/24	10 days
Finalize Prototype	5/31/24	6/20/24	20 days
Peer Presentation	5/31/24	6/5/24	5 days
Final Report	6/10/24	7/17/24	1 month
Final Presentation	6/10/24	7/17/24	1 month

Work Distribution

Optical Design/Housing

Franley Casado

Optical Design:

- Research compatible laser wavelength and photodiode for selected reagent.
- Align system and ensure incident values on both photodiodes are approximately equal.

Project Housing:

- Design system housing in Solidworks with respect to known distances and component sizes.
- 3D print all sections, drill holes to screw in all components, and integrate them.

Software Design

Giovanni Maldonado-Velez

Development of mobile application:

- User interface, login and forgot password system, GPS output, integration with ppm interpretation code and email output data.

Jackie Zhao

Interpretation of photodiode outputs:

- Interpret photodiode outputs from Arduino into working ppm readings.

Development of mobile application:

- Interpret GPS raw data into readable longitude and latitude values.
- UDP communication between Arduino and mobile application.

Electrical Design

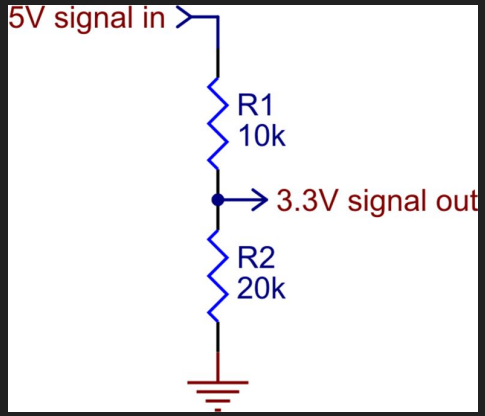
Giovanni Maldonado-Velez

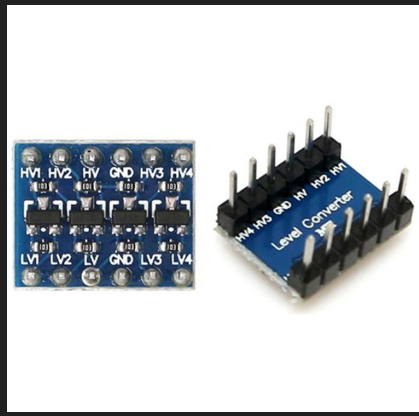
Design and testing of PCBs:

- PCB for photodiodes
- PCB for powering laser/speaker

Electrical Problems and Solutions

- [Problem] Initial electronic design did not have smooth readings.
  - [Solution] Added a 100nF capacitor and LF351 op amp.
- [Problem] Initial GPS module required 3.3V Logic, Arduino supplies 5V Logic
  - [Possible Solution] Create a voltage divider circuit to reduce 5V logic to 3.3V
  - [Possible Solution] Incorporate a bi-directional logic converter
  - [Solution] Switched to Adafruit Ultimate GPS shield





Software Problem and Solutions

- [Problem] Heroku Server did not provide an IP address to us so we could not use UDP communication.
  - [Solution] Migrated to AWS EC2 instance as our server.
- [Problem] Reverse geocoding through google is not free.
  - [Solution] Changed to nominatim API to reverse geocode the longitude and latitude to display an address.

Optical Problems and Solutions

- **[Problem]** Even after splitting the laser's power across two photodiodes, both of them oversaturate too easily.
  - **[Solution]** Introduce dark filter in front of photodiodes at set distance to reduce power incident on the photodiodes.
- **[Problem]** Designed mirror placement from 45 degree angle beam splitter isn't aligned with the rest of the system.
  - **[Solution]** Shift location of mirror about 20mm left of beamsplitter, 4mm further from beam splitter and use mirror adjustment screws to align.
- **[Problem]** Values inconsistent across photodiode despite alignment with proper focus.
  - **[Solution]** Place photodiode further away from lens to where the laser's power is distributed across the photodiode's active area.