Automated MicroPlastic Detector

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What are Microplastics?

- Plastic pieces between 1 um – 5mm
- Insoluble in water
- Typically invisible to the eye
- Health impacts are being actively researched

According to a 2019 study:

The Average American ingests more than **70,000 MPs per year** in their drinking water supply...

...or a **credit card** every week.

"Public health is at risk from microplastic content in our drinking water!"

Existing Solutions

Tap Score
Sample Testing
$579

EXPENSIVE
COMPLEX
INEFFICIENT

Raman/FT-Infrared
Spectroscopy
$10,000+

https://mytapscore.com/products/microplastics-water-test
https://www.sciencedirect.com/science/article/abs/pii/S0043135418304421

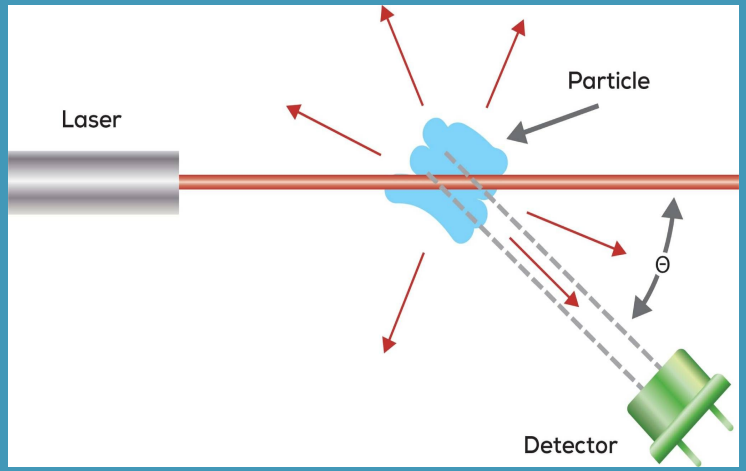
Value Proposition

Our solution (AMP'D) will provide a system to test for microplastics at home.

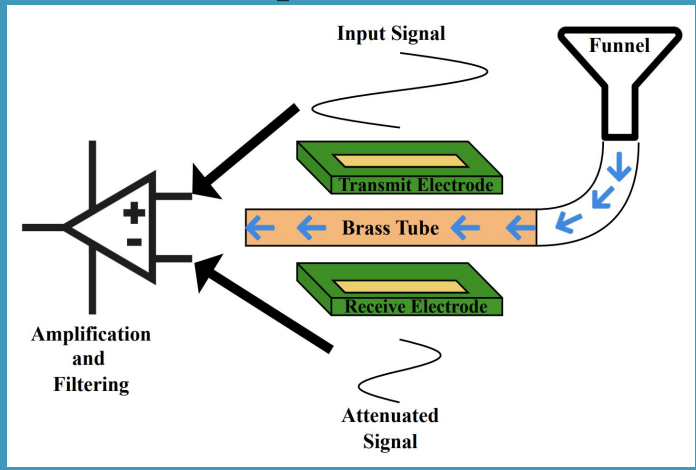
Project Development Journey

Preliminary Research

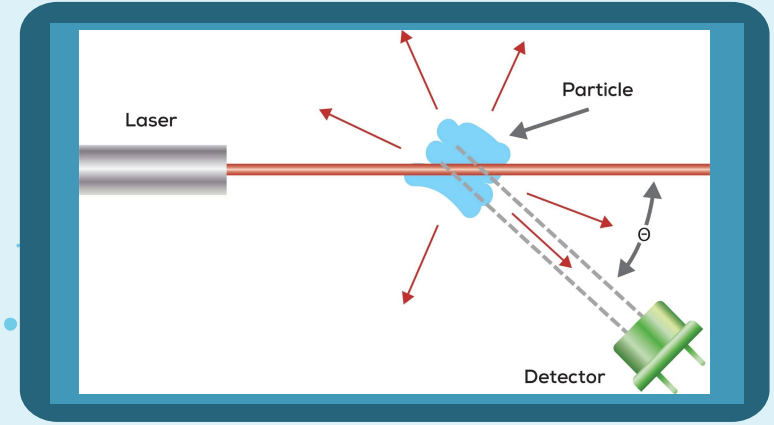
Optics

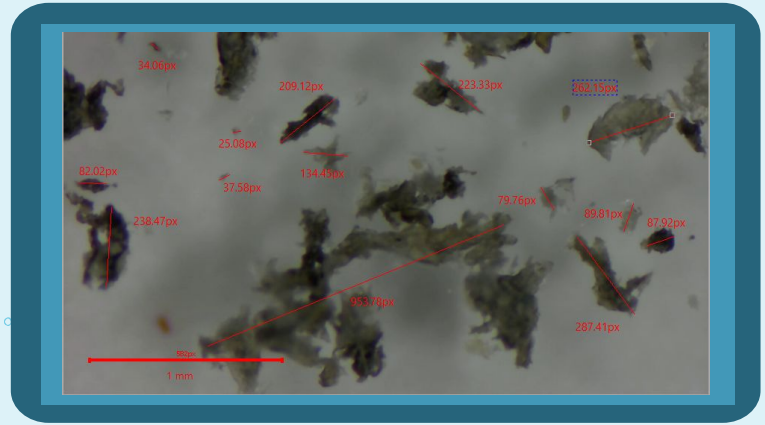


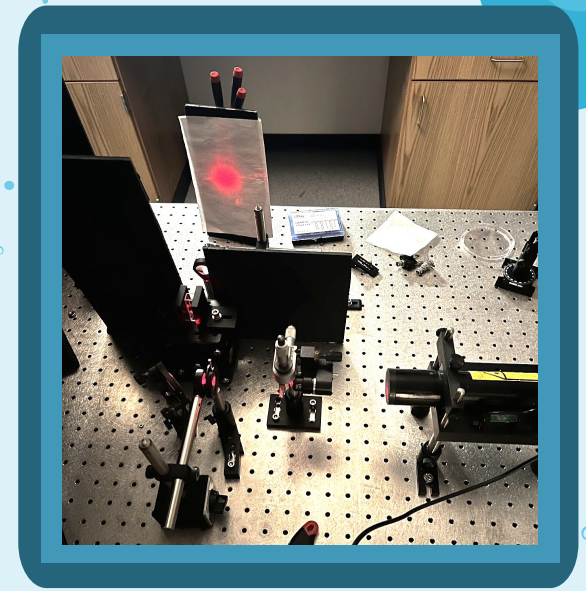
Impedanc



Refraction

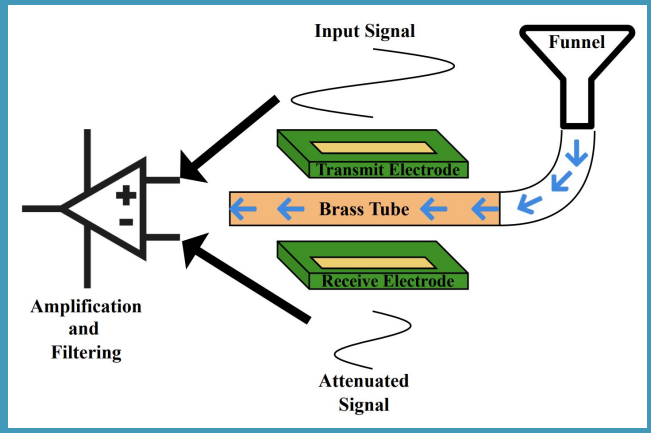


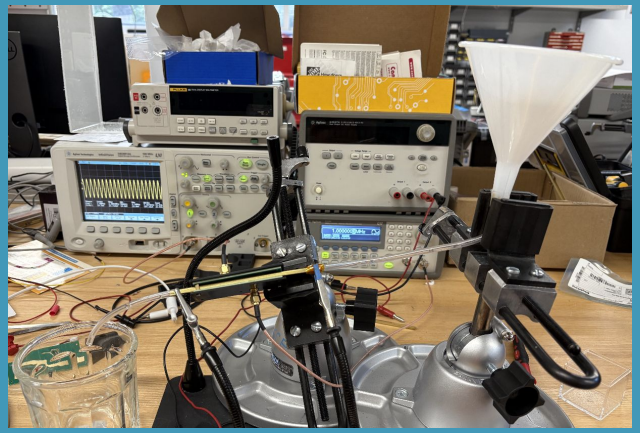


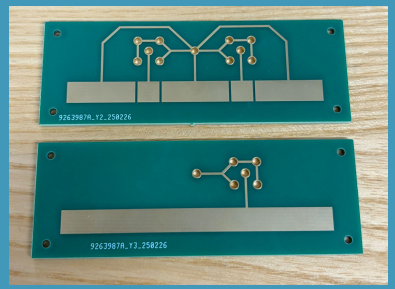


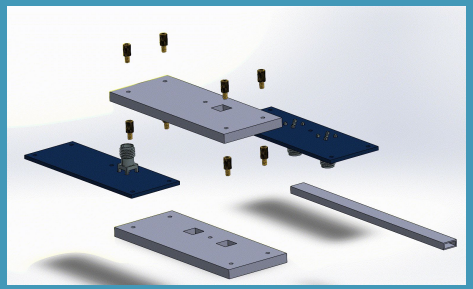
- Utilizes optical principles; refraction indices
- Equipment is expensive and sensitive

Impedance Plates









- Detects microplastics through impedance spikes
- Experienced low signal-to-noise ratio

How can we utilize this research in a capstone project?

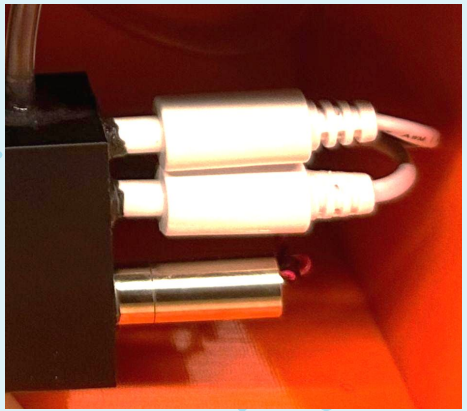
Goals: Affordable, Intuitive, Rapid

Final Decision: Dual-Method Solution

Part 1: Impedance with TDS Modules

Modification of flow cells

- Uses multiple Total Dissolved Solids module to check for changes in conductivity caused by plastics



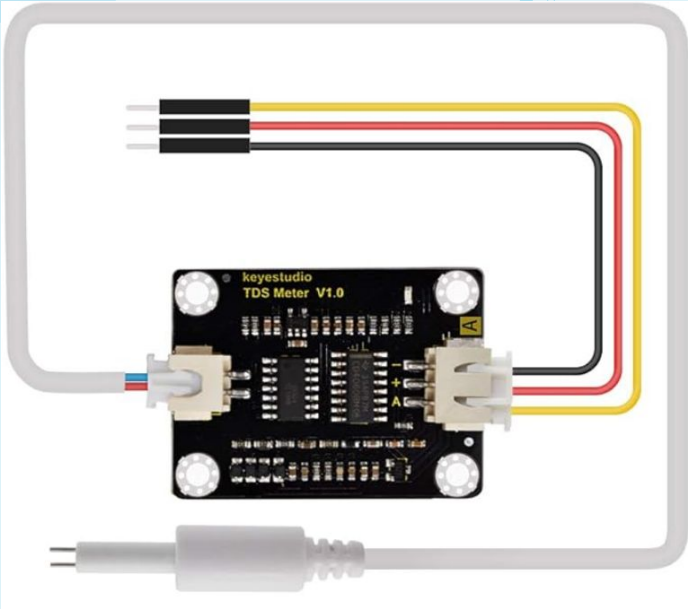
Part 2: Scattering with CMOS Camera

Modification of refraction

- Uses a camera to detect refracted beams from the presence of plastics in the water

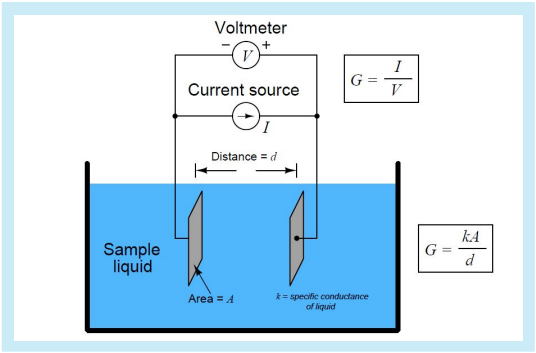
AMP'D
Product Design

Impedance Probes

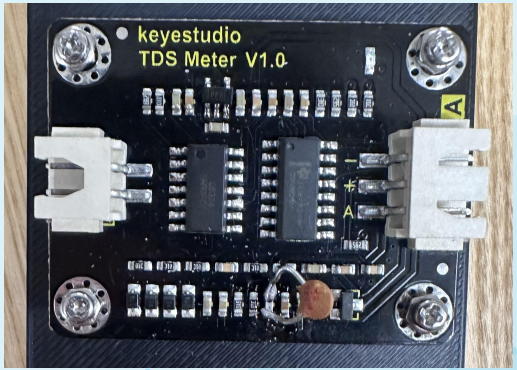


Two Total Dissolved Solids (TDS) Modules

Measuring Conductance

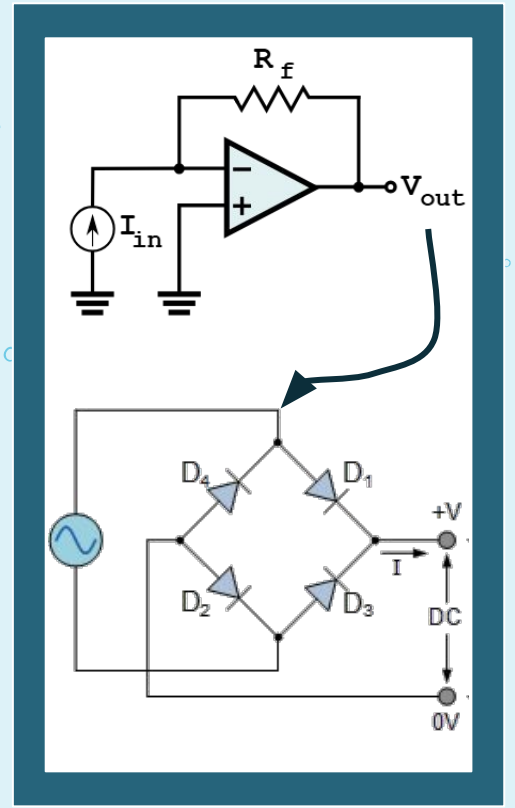


Modified Capacitor for Alternative Frequency



Electrical Post Processing

TDS Module Circuitry



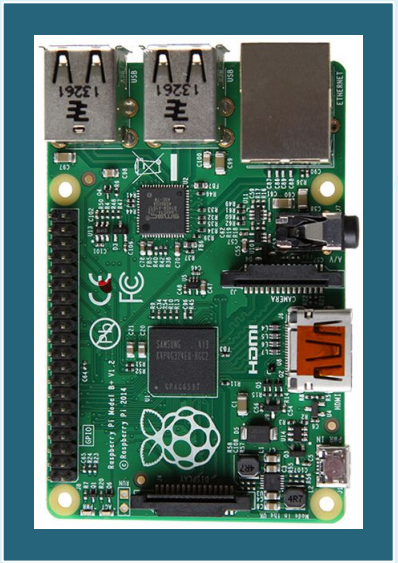
DC Voltage

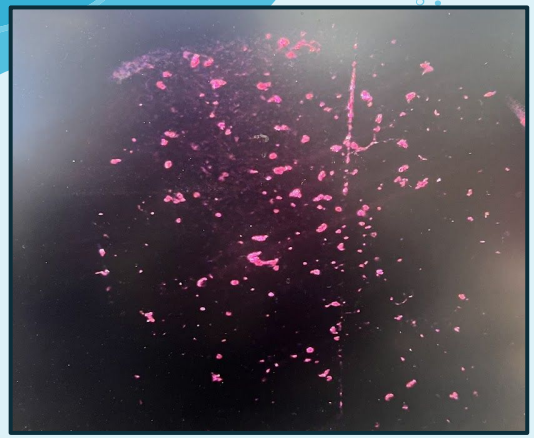
Rectifier & Low Pass Smoothing

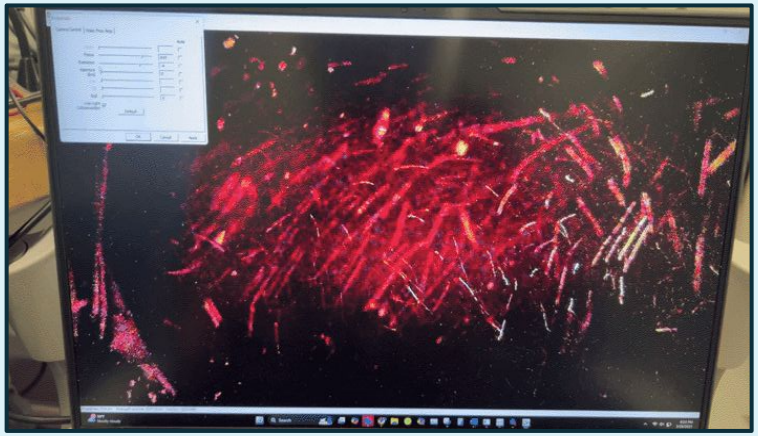
ADC Breakout Board

SPI

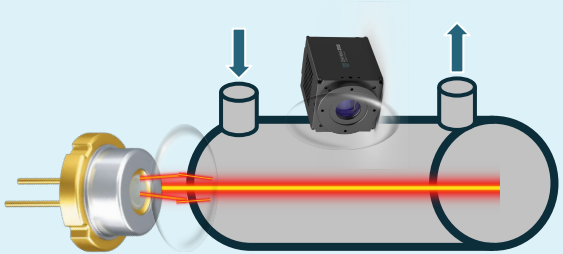
Raspberry Pi 3







Optics



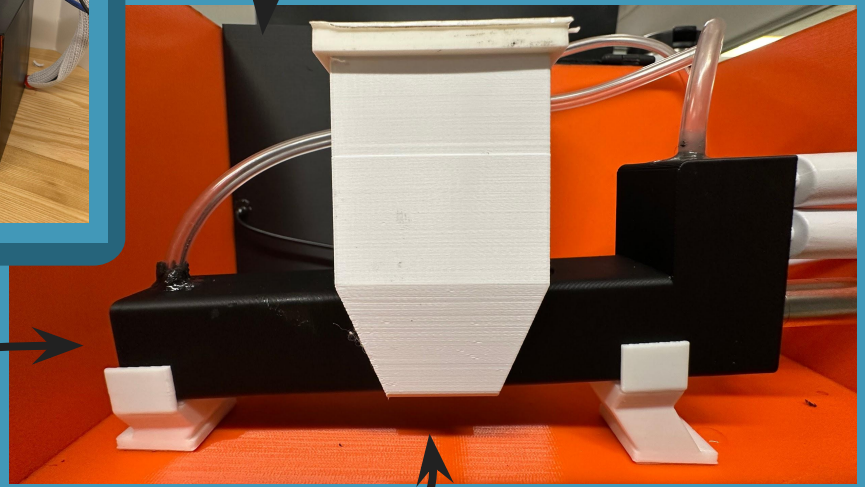
- CMOS Camera perpendicular to direction of the laser
- As water flows, microplastics scatter the collimated beam into the camera

Mechanical Housing

Custom screen enclosure houses electrical

Movable screen with mount

Water Tank with pump

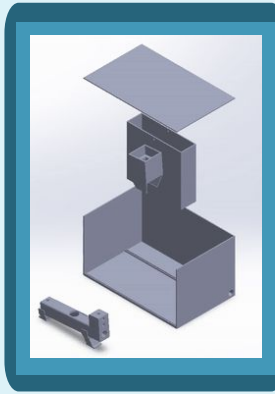


Probes

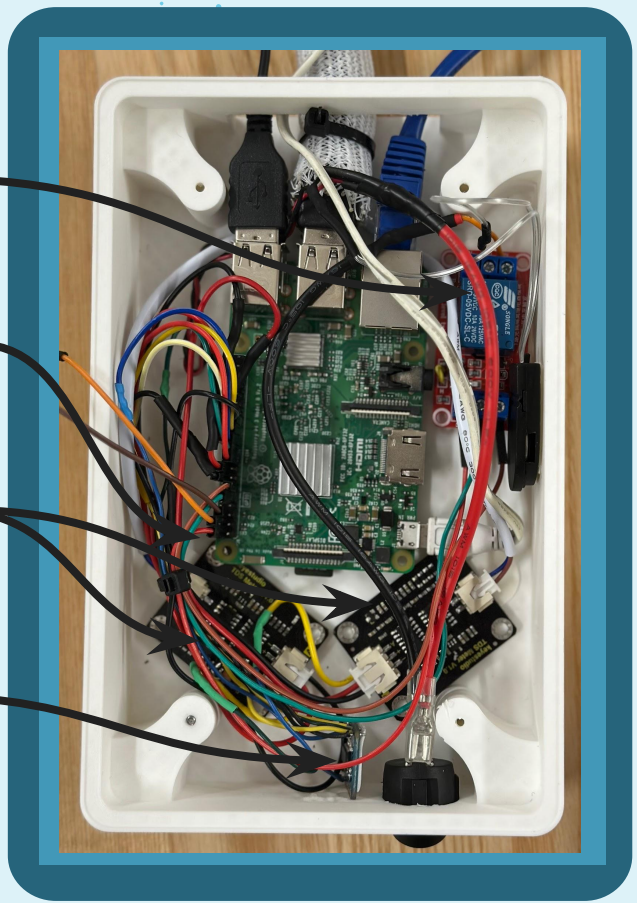
Laser

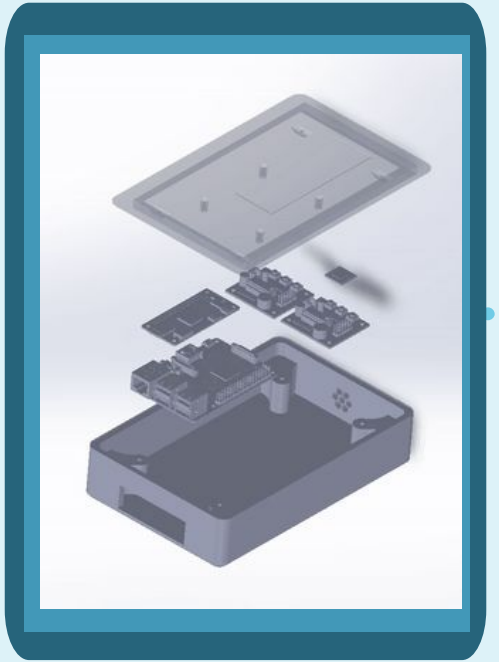
Slanted tube to remove air pockets

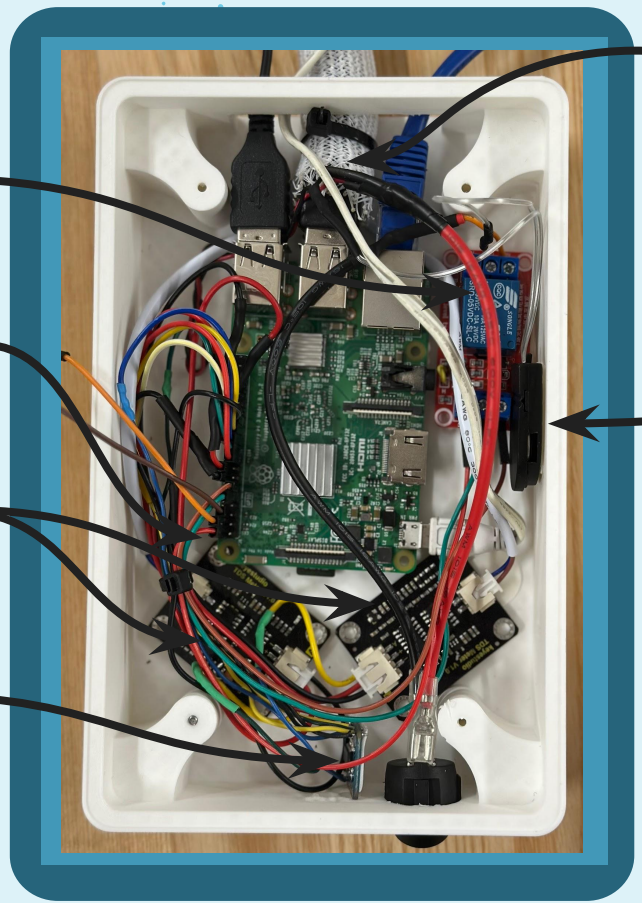
Camera Mount blocks external light



Electrical Housing






Relay
Raspberry Pi
TDS Modules
ADC
Cable Harness
3V Battery

Software

Changeable Variables

Status/Monitoring

Testing Controls

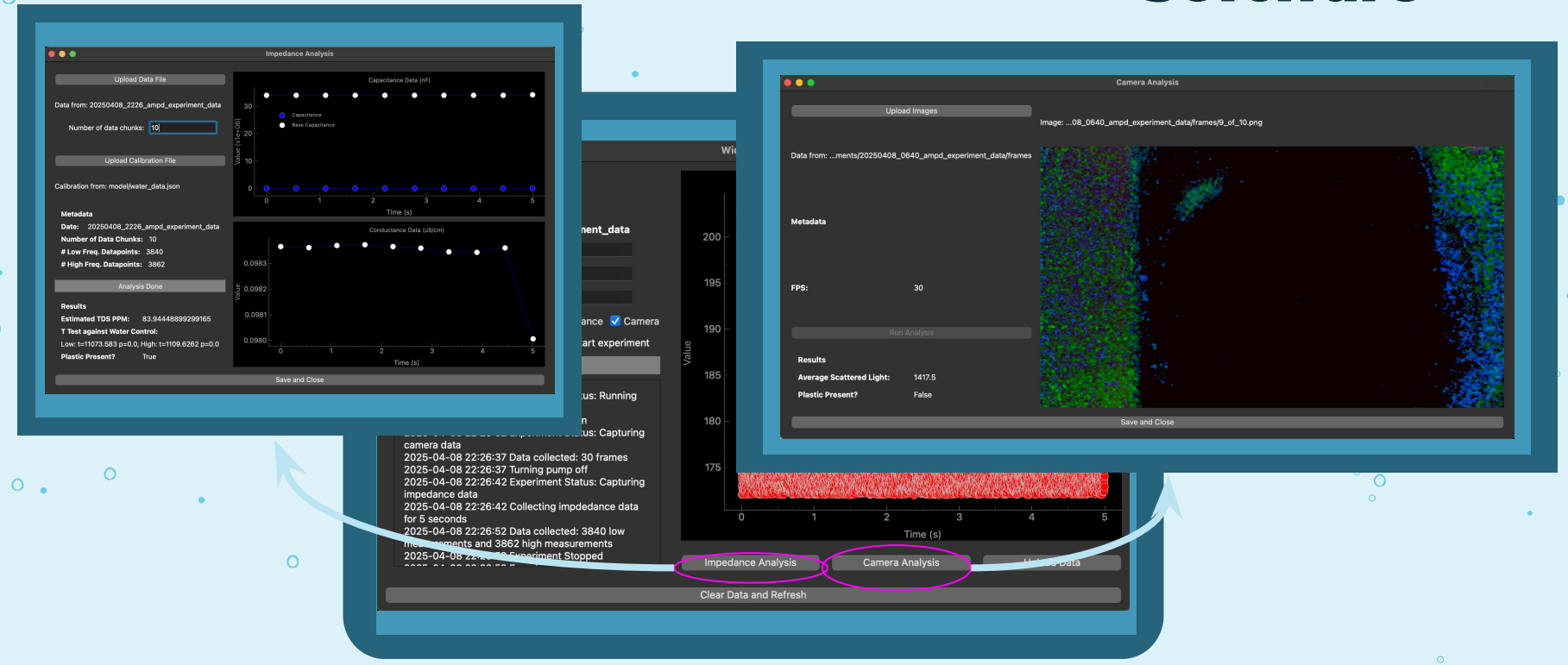
Progress Logs

Graph of collected raw data

Upload Data Online

Data Analysis

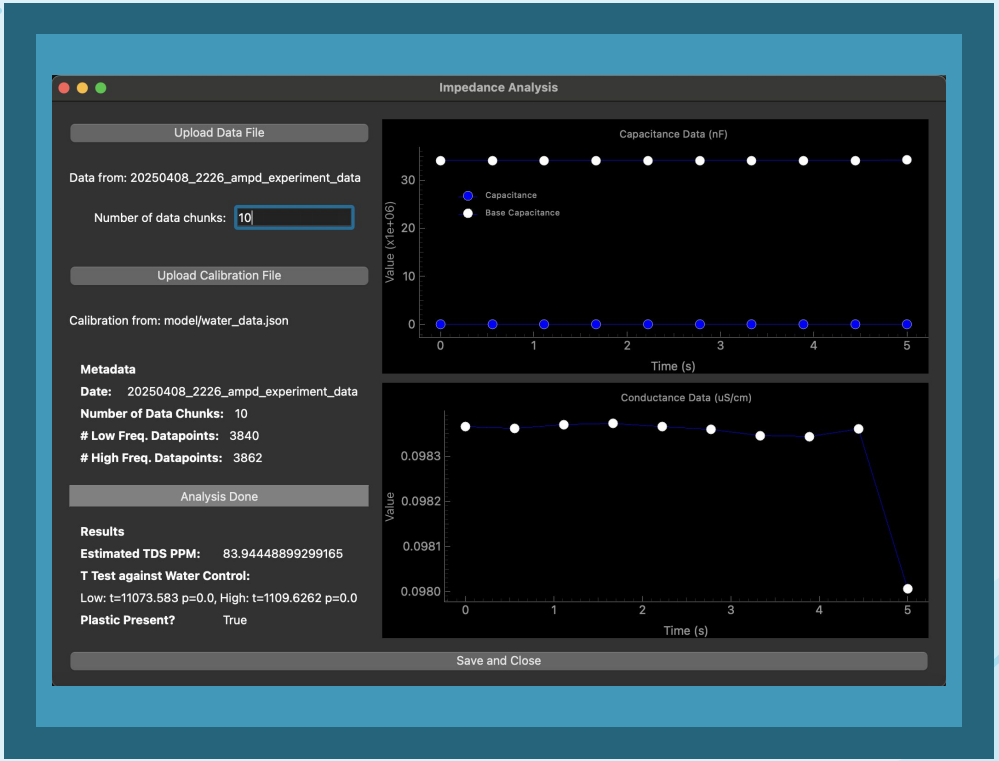
Software


Impedance Analysis
Upload Data File
Data from: 20250408_2226_ampd_experiment_data
Number of data chunks: 10
Upload Calibration File
Calibration from: model/water_data.json
Metadata
Date: 20250408_2226_ampd_experiment_data
Number of Data Chunks: 10
Low Freq. Datapoints: 3840
High Freq. Datapoints: 3862
Analysis Done
Results
Estimated TDS PPM: 83.94448899299165
T Test against Water Control:
Low: t=11073.583 p=0.0, High: t=1109.6262 p=0.0
Plastic Present? True
Save and Close
Capacitance Data (nF)
Capacitance
Base Capacitance
Value (X1e+06)
Time (s)
Conductance Data (uS/cm)
Value
Time (s)
Camera Analysis
Upload Images
Image: ...08_0640_ampd_experiment_data/frames/9_of_10.png
Data from: ...ments/20250408_0640_ampd_experiment_data/frames
Metadata
FPS: 30
Run Analysis
Results
Average Scattered Light: 1417.5
Plastic Present? False
Save and Close
Camera
art experiment
Value
Time (s)
camera data
2025-04-08 22:26:37 Data collected: 30 frames
2025-04-08 22:26:37 Turning pump off
2025-04-08 22:26:42 Experiment Status: Capturing impedance data
2025-04-08 22:26:42 Collecting impdedance data for 5 seconds
2025-04-08 22:26:52 Data collected: 3840 low
and 3862 high measurements
Impedance Analysis
Camera Analysis
Clear Data and Refresh

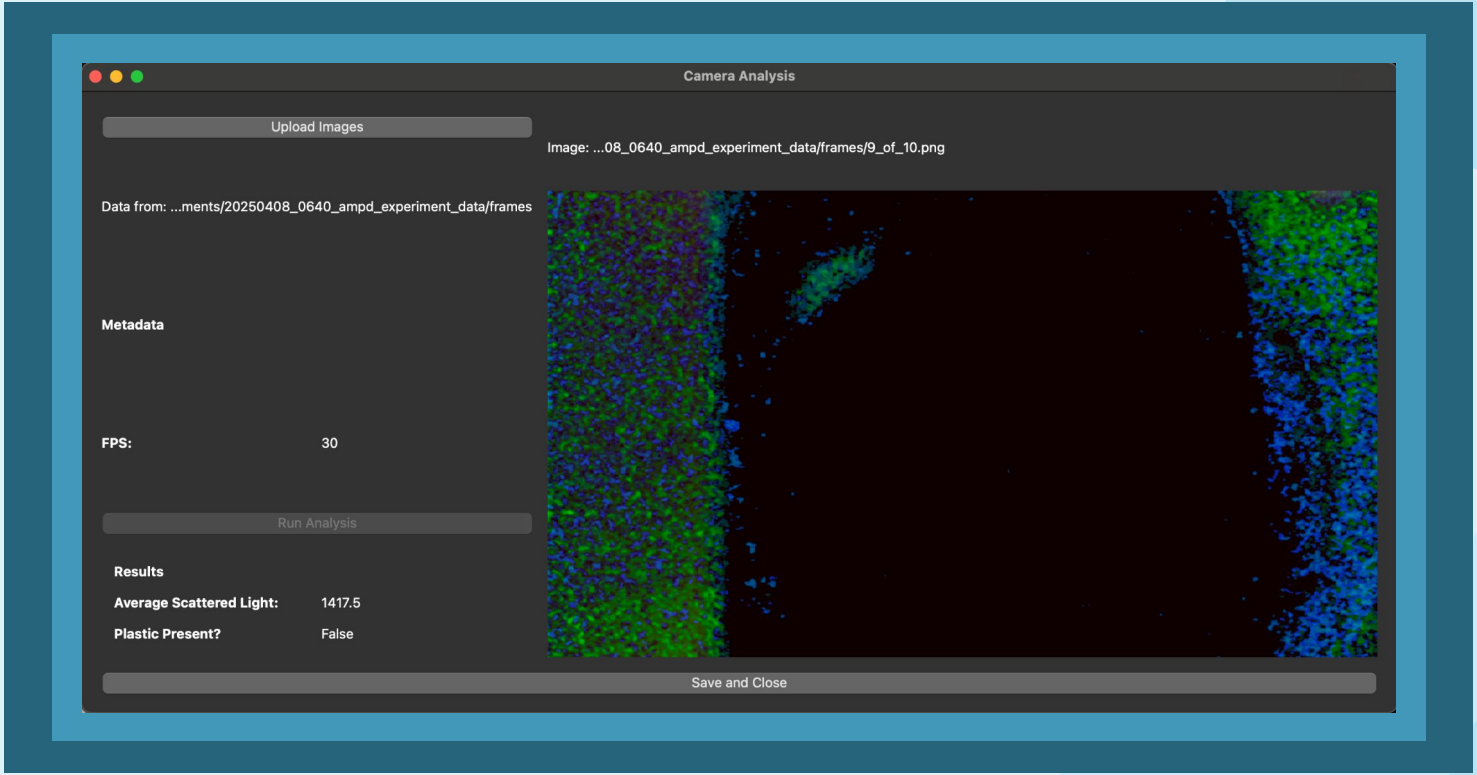
Impedance Analysis

- Measuring water's impedance at multiple frequencies allows us to calculate:
  - Capacitance
  - Conductivity
  - PPM

- Gives a detailed look into the water's contents
  - Metals and minerals increase conductance
  - Microplastics decrease capacitance



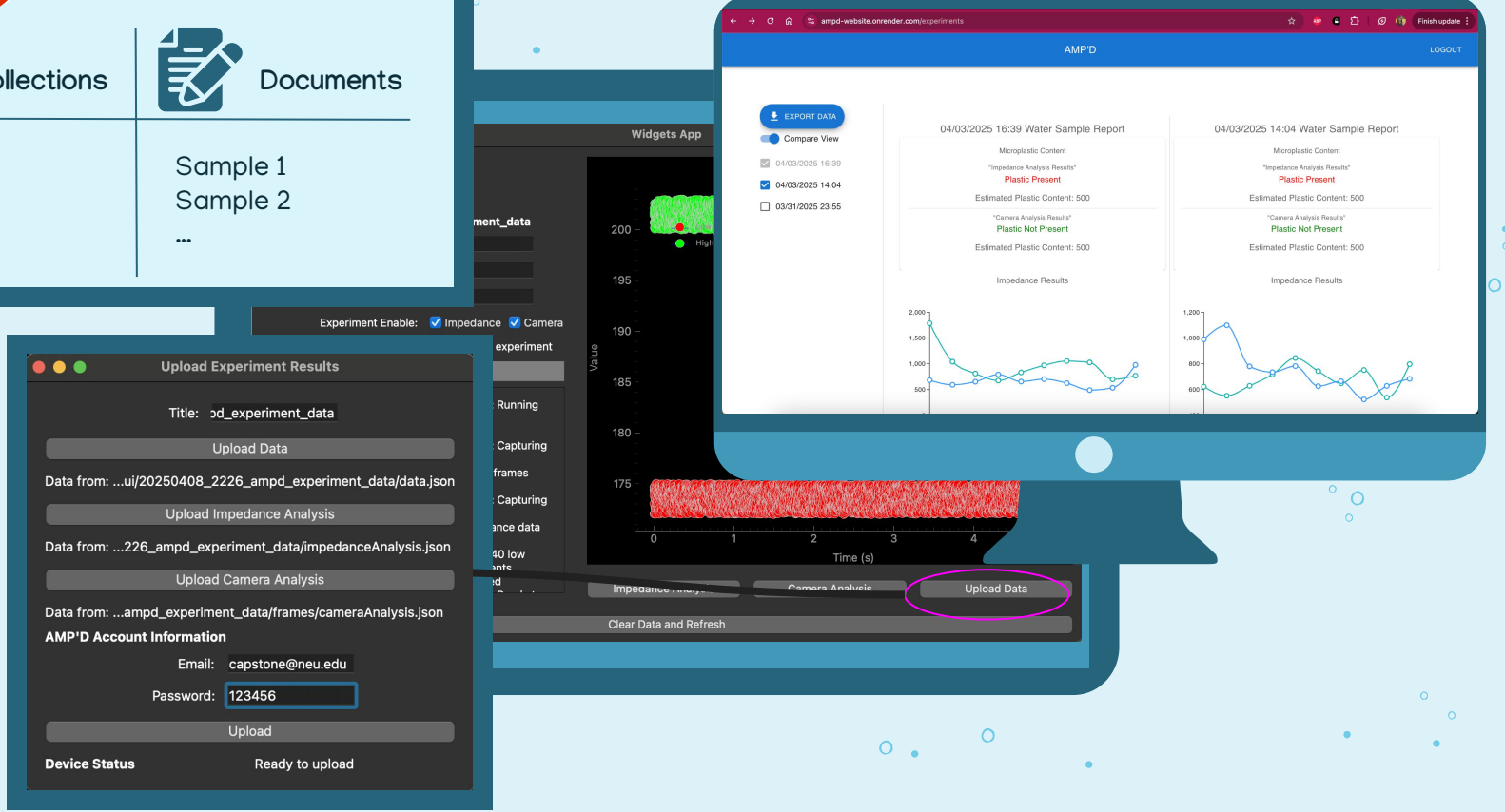
Camera Analysis



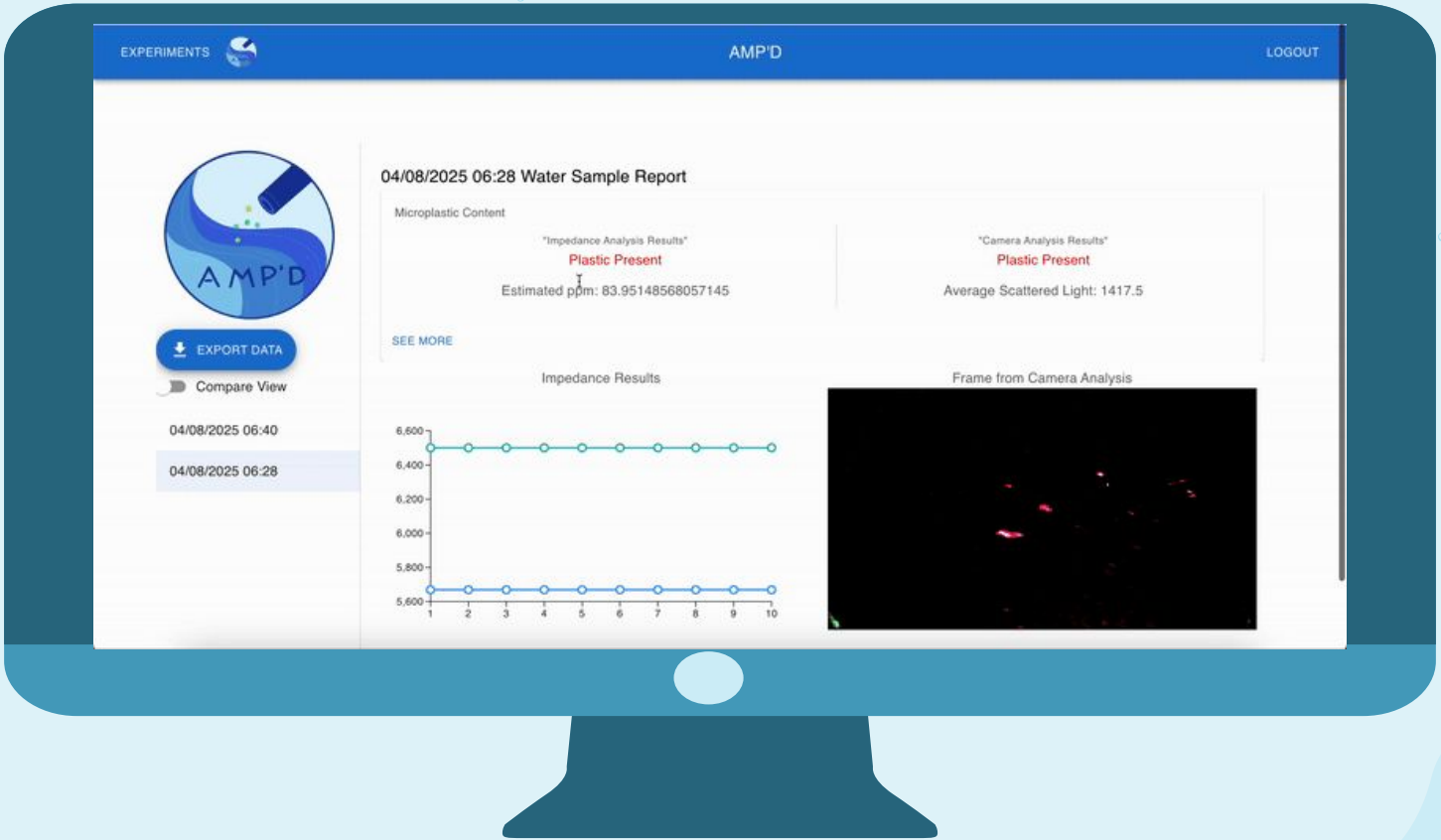
Software

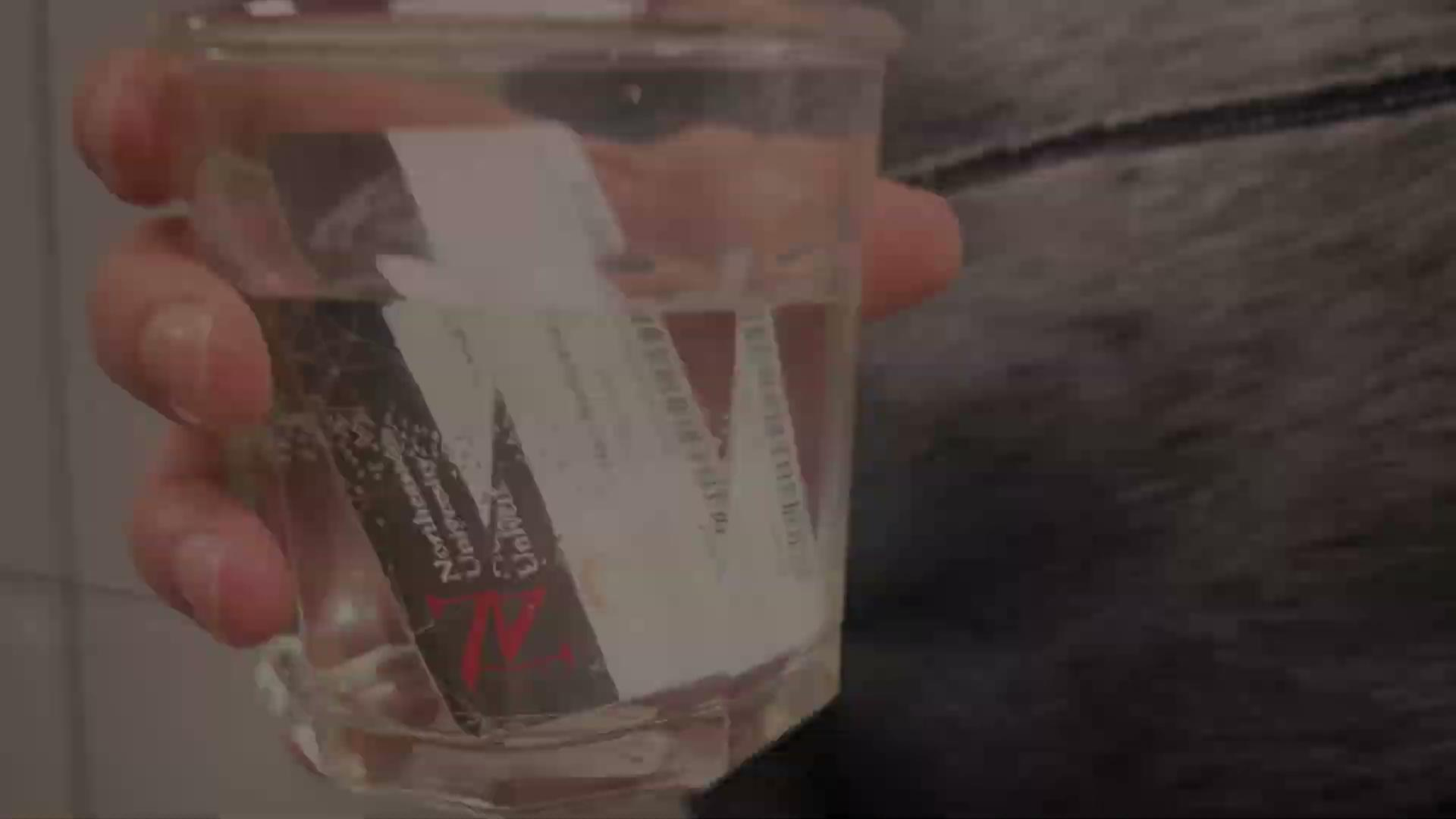
Firebase

Collections	Documents
User 1 User 2 ...	Sample 1 Sample 2 ...



Software


EXPERIMENTS
AMP'D
LOGOUT
AMP'D
EXPORT DATA
Compare View
04/08/2025 06:40
04/08/2025 06:28
04/08/2025 06:28 Water Sample Report
Microplastic Content
"Impedance Analysis Results"
Plastic Present
Estimated ppm: 83.95148568057145
"Camera Analysis Results"
Plastic Present
Average Scattered Light: 1417.5
SEE MORE
Impedance Results
Frame from Camera Analysis
6,600
6,400
6,200
6,000
5,800
5,600
1
2
3
4
5
6
7
8
9
10



Product Cost

Product Cost

$200

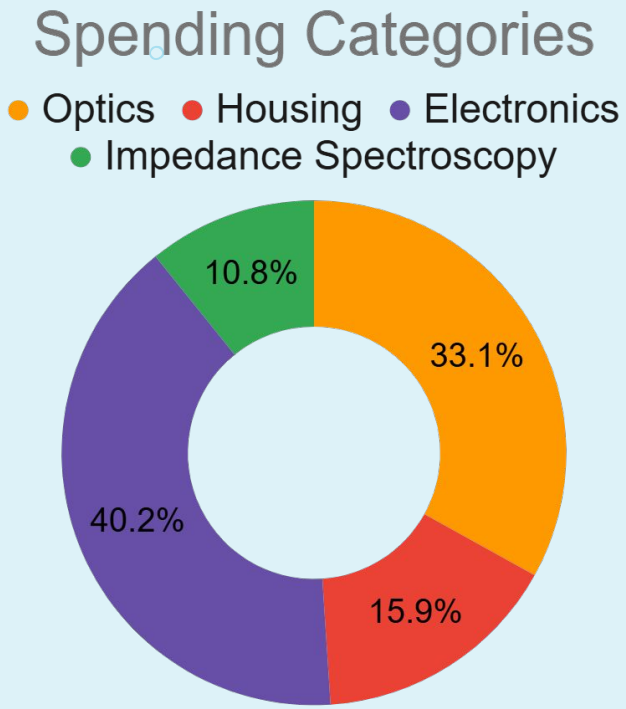
Total Spent

$575.47

Amount Under Budget

$124.53

Total Budget

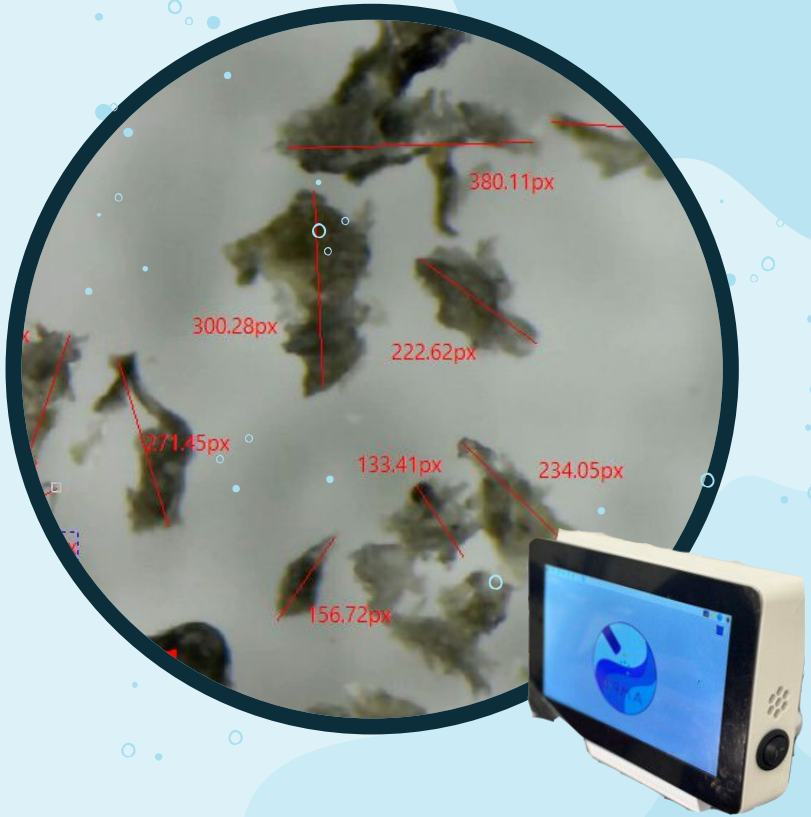


Conclusion

Results and Impact

Rapid, Accurate Microplastic Detection

- Sensitive to concentrations of PVC particles as low as **400 µm**
- Testing and analysis complete **within minutes**
- Intuitive & descriptive delivery of analysis results available through a webpage



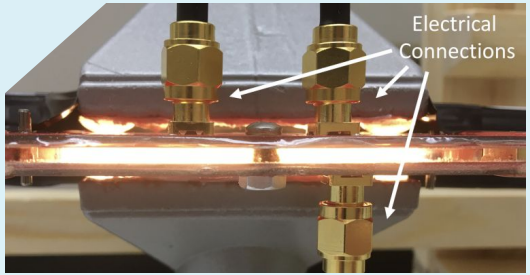
Extension of Work

Filtration & Characterization

- **Purification** of contaminated water after tested
- **Characterization** of shape, size & weight

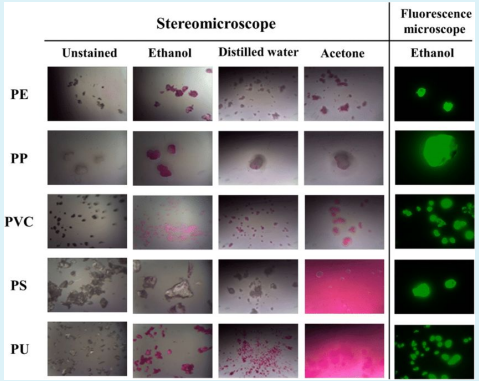
Improved Impedance Spectroscopy

- Introduce **Parallel plate electrodes** & superimposed sinusoidal input signals with different frequencies



Alternate Methods of Detection

- **Fluorescence** based detection?



A picture is worth a thousand words

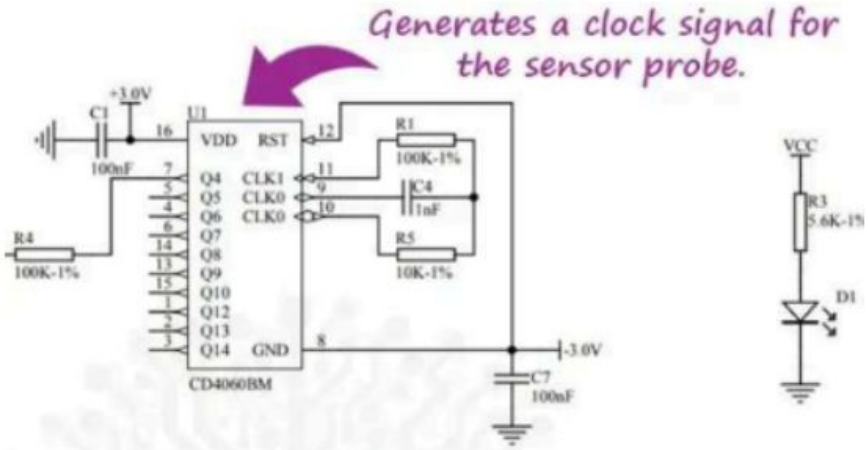
Thank you!

Any Questions?

TDS Module Signal:

The TDS Module outputs a 400 mV peak-to-peak (200 mV RMS V_{in}) square wave to the probe.

The signal frequency is controller by an IC connected to an RC timing circuit as shown below:



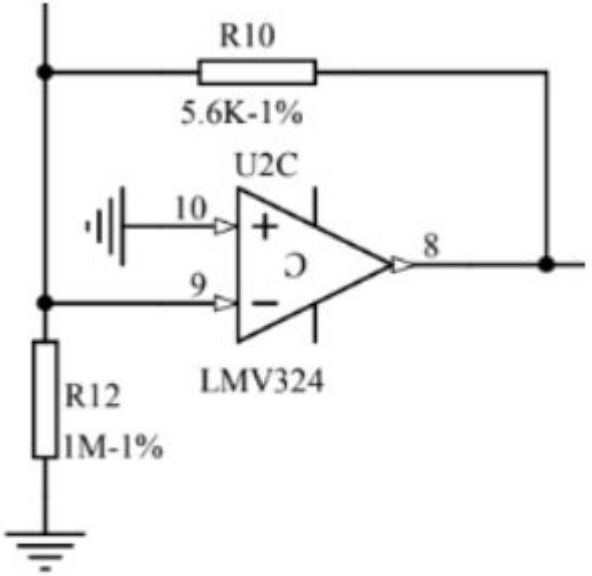
The oscillation frequency for the first (unmodified) module is given by the equation below:

$$f_H = \frac{1}{0.602 \cdot 2\pi(R_1 + R_5)C_4} = \frac{1}{0.602 \cdot 2\pi(100\text{K} + 10\text{K})1\text{n}} = \frac{1}{0.00013244\pi} = 2.403\,\text{kHz}$$

The second module has a 2.14 nF capacitor soldered in parallel with C5, an it's oscillation is given by the equation below:

$$f_L = \frac{1}{0.602 \cdot 2\pi(R_1 + R_5)(C_4 + 2.14\text{n})} = \frac{1}{0.602 \cdot 2\pi(100\text{K} + 10\text{K})(1\text{n} + 2.14\text{n})} = \frac{1}{0.0013064677\pi} = 765\ \text{Hz}$$

Transimpedance Amplifier:



Transimpedance gain A is given by:

$$V_{out} = AI_{in} = -I_{in}R_f$$

$$A = -R_f = -R_{10} = -5600 \text{ V/A}$$

$$\text{ppm} = 133.42V_{ADC}^3 - 255.86V_{ADC} + 857.39V_{ADC}$$

Can be linearized for normal tap water:

$$\text{ppm} \approx 146.6V_{ADC}$$

Calculating Water Impedance based on V_{out}:

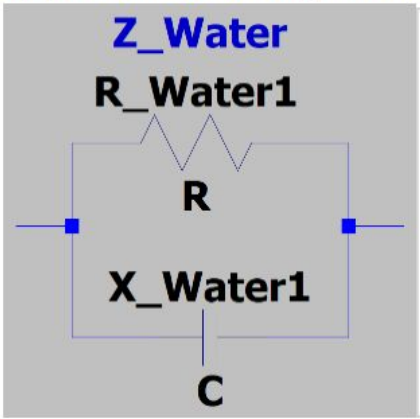
V_{out} is then passed through a rectifier and low pass filter to obtain an DC analog output signal V_{ADC}, which is read by the ADC.

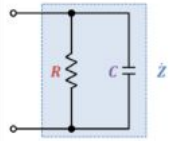
V_{ADC} is approximately given by the RMS value of V_{out}: $V_{ADC} \approx \mathrm{RMS}\{V_{out}\} = |A| I_{in}$

$$V_{in} = I_{in}|Z_{water}| = \frac{V_{ADC}}{|A|}|Z_{water}|$$

$|Z_{water}| = \frac{|A| V_{in}}{V_{ADC}} = \frac{5600 \cdot 200}{V_{ADC}}$, where V_{ADC} is read in mV and $|Z_{water}|$ is given in Ω.

Approximate Water Impedance Model:





Magnitude Z of the impedance $\dot{Z}$

$$Z = |\dot{Z}| = \sqrt{\left(\frac{R}{1+\omega^2C^2R^2}\right)^2 + \left(\frac{\omega CR^2}{1+\omega^2C^2R^2}\right)^2}$$

$$\dot{Z} = \underbrace{\frac{R}{1+\omega^2C^2R^2}}_{\text{Real Part}} - j\underbrace{\frac{\omega CR^2}{1+\omega^2C^2R^2}}_{\text{Imaginary Part}}$$

$$Z = |\dot{Z}| = \frac{R}{\sqrt{1+\omega^2C^2R^2}} = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + (\omega C)^2}}$$

$$Z_{water} \approx R_{water} \| \frac{1}{j\omega C_{water}} = \frac{R_{water}}{1 + 2\pi f R_{water} C_{water}}$$

Calculating Water RC Constant based on Impedance at Multiple Frequencies:

The water's impedance is given by Z_H for the high frequency and Z_L for the low frequency.

$$|Z_H|^2 = \frac{R_{water}^2}{1 + 4\pi^2 f_H^2 R_{water}^2 C_{water}^2} \quad \text{and} \quad |Z_L|^2 = \frac{R_{water}^2}{1 + 4\pi^2 f_L^2 R_{water}^2 C_{water}^2}$$

$$|Z_H|^2 = \frac{R_{water}^2}{1 + 4\pi^2 f_H^2 K}$$

$$|Z_H|^2(1 + 4\pi^2 f_H^2 R_{water}^2 C_{water}^2) = |Z_L|^2(1 + 4\pi^2 f_L^2 R_{water}^2 C_{water}^2)$$

$$R_{water}^2 = |Z_H|^2\left(1 + 4\pi^2 f_H^2 K\right)$$

$$|Z_H|^2 + 4|Z_H|^2\pi^2 f_H^2 R_{water}^2 C_{water}^2 = |Z_L|^2 + 4|Z_L|^2\pi^2 f_L^2 R_{water}^2 C_{water}^2$$

$$R_{water} = |Z_H|\sqrt{1 + 4\pi^2 f_H^2 K}$$

$$4|Z_H|^2\pi^2 f_H^2 R_{water}^2 C_{water}^2 - 4|Z_L|^2\pi^2 f_L^2 R_{water}^2 C_{water}^2 = |Z_L|^2 - |Z_H|^2$$

$$4\pi^2 R_{water}^2 C_{water}^2\left(|Z_H|^2 f_H^2 - |Z_L|^2 f_L^2\right) = |Z_L|^2 - |Z_H|^2$$

$$R_{water}^2 C_{water}^2 = \frac{|Z_L|^2 - |Z_H|^2}{4\pi^2\left(|Z_H|^2 f_H^2 - |Z_L|^2 f_L^2\right)} = K$$

$$|Z_H|^2 = R_{water}^2 + \frac{1}{4\pi^2 f_H{}^2 C_{water}^2}$$

$$R_{water}^2 C_{water}^2 = K$$

$$R_{water}^2 = |Z_H|^2 - \frac{1}{4\pi^2 f_H{}^2 C_{water}^2}$$

$$C_{water}^2 = \frac{K}{R_{water}^2}$$

$$R_{water} C_{water} = \frac{\sqrt{|Z_L|^2 - |Z_H|^2}}{2\pi\sqrt{|Z_H|^2 f_H^2 - |Z_L|^2 f_L^2}}$$

$$R_{water} = \sqrt{|Z_H|^2 - \frac{1}{4\pi^2 f_H{}^2 C_{water}^2}}$$

$$C_{water} = \frac{\sqrt{K}}{R_{water}}$$