AMP’D: Automated MicroPlastic Detector

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Table of Contents

1 Abstract

Public health is at risk from increased microplastic content in drinking water, which so far can only be reliably measured through expensive professional laboratory testing. The Automated MicroPlastic Detector (AMP'D) team has developed a system for rapid detection of microplastics in water. The system provides both a visual and quantitative analysis, allowing users to assess the quality of their water at home and compare microplastic concentrations in household, tap, and bottled water against safety standards. AMP'D proves that it is possible to create a low-cost, intuitive, and accessible system to test for microplastics.

The AMP'D device allows a user to monitor the presence of microplastics in their water supply using two unique methods of detection: an optical approach, which looks at scattered light, and an impedance approach, which detects a change in impedance compared to pure water. Utilizing a 3D printed tube to house both methods, a pump then runs a water sample through the tubing. The experiment flow is controlled by software on a Raspberry Pi where the user can change parameters and receive feedback on the status and results. It first takes analog voltage measurements from two repurposed total dissolved solids (TSD) probes, paired with electrodes, which transmit and receive signals from either a low or high frequency square wave. Then, it captures images by a CMOS camera of light scattered from a 650 nm wavelength laser due to the microplastics. The user can use the analysis buttons on the GUI to determine the estimated amount of plastic. The impedance analysis calculates the average impedance, capacitance, and resistance from the voltage data. It compares these values to determine what concentration (ppm) of contaminants are present. The camera analysis calculates the average amount of scattered light across all of the images by looking at pixels that are significantly red. Both methods use experimentally determined Lagrange correlation to estimate the amount of plastic in the sample.

For system validation, polyvinyl chloride (PVC) microplastic samples in the order of 400 microns were run through the device at different concentrations. Cross-correlation of the impedance data amongst differing concentrations of microplastic, as well as images provided by a CMOS camera, makes for an accurate depiction of the microplastic content in a given sample. Further research into detecting non-potable water ensures public health awareness and environmental sustainability by enabling the identification of microplastic contamination in diverse water sources, ultimately aiding in pollution mitigation efforts. Proof of concept has indicated that the AMP'D device is successful in detecting plastic content in a typical sample of water, in which plastics might not be visible to the human eye.

2 Introduction

The presence of microplastics has recently emerged as a pressing issue with the advancement of detection methods for solids and liquids. Microplastics are classified as plastic pieces smaller than 5 millimeters in size, whereas pieces smaller than 1 micrometer are nanoplastics. Three of the most common types of microplastics are polyethylene (PE), polypropylene (PP), and polyester (PET), with an abundance found in different oceanographic campaigns of 54.5%, 16.5%, and 9.7%, respectively [1]. Exposure can occur through two primary avenues: inhalation and ingestion. Each year, it is estimated that the average American ingests more than 70,000 microplastics from their drinking water supply. The origin of these microplastics stems from multiple sources, including littering, stormwater runoff, and poor wastewater management [2].

As a result, microplastics have even been found in the human bloodstream. In a 2022 study, around 77% of the people tested were found to have microplastic content in their bloodstream. There are theories concerning the results of this discovery, including the possibility of microplastics acting as endocrine disruptors and contributing to cancer [3]. However, the implications of microplastics for human health are still largely unknown, but animal studies suggest that an accumulation of microplastics internally can induce an immune response. In addition, biofilm was found to grow on microplastics, which are a source of microbial pathogens, further risking one's health. Ensuring safe drinking water is now a prioritized issue on the agenda of public health agencies worldwide [4].

3 Problem Formulation

Current detection methods for microplastics are not standardized. There exist numerous approaches varying in accuracy, precision, and complexity. One such approach is carried out by sending a water sample to a lab that carries out optical microscopy using Nile Red staining and polarized light microscopy. The results include the detection of microplastic concentrations down to 1 micron, but will not indicate the plastic type. In addition to the upfront cost of $569, it takes 12 days to carry out the process, and the customer must take and ship the sample using a provided kit [5]. Another approach is through spectroscopy, which is the study of absorption and emission of radiation by matter. Two primary types of spectroscopy can be used, which are Fourier Transform Infrared (FTIR) and Raman. FTIR spectroscopy occurs through using an IR source to generate radiation from the sample, which is then measured using an appropriate detector. On the other hand, Raman spectroscopy occurs through using a laser source to generate a scattering of light from the sample, which is consequently measured using an appropriate detector. Both of these techniques require highly expensive equipment, upwards of $10,000, and training to get accurate [6]. It becomes clear that existing methods are expensive, inconvenient, and inaccessible for the average customer to find out the microplastic concentration in their drinking water.

4 Analysis

The AMP'D team has successfully developed a product that solves the problems in the Problem Formation section, being able to detect microplastic concentration in a less expensive, convenient, and accessible way. It uses two methods being impedance with TDS modules, and scattering with CMOS camera, to ensure accuracy.

The product is significantly less expensive than the cheapest alternative, of $569 testing kit. In total, our product costs us under $200 to make, and in addition, costs are able to be further reduced via ordering parts in bulk.

Additionally, our product is very convenient to use and hosts features that make the process more streamlined and intuitive. The user just needs to pour water into the water container, press a few analysis buttons on our touchscreen device, and they are able to view the concentration of microplastics. They are also able to view other information, such as imaging of the actual microplastics, and through a few other buttons, are able to effectively compare their results with those of other users or previous experiments. Our product also gives results back quickly, within a matter of minutes. This is significantly more convenient than waiting days for it to come back from a lab or getting results back from spectroscopy.

People without a great understanding of the science behind our product are still able to get readable results and comprehend when there are microplastics present in their water. We are able to forward the information to our website, which is accessible on all devices. Our screen is also adjusted at an angle, which makes interacting with it simple and comfortable.

5 Design

5.1 Mechanical

5.1.1 Experiment Housing

The housing for the experiment allowed for our product to be portable. We had a few important features and requirements for our design:

1. Make sure that each component can't move so that the laser and probes won't get misaligned
2. Water has to remain in the specified enclosure and flow properly to fill the entire experiment tube. If there are air pockets, our data would be dramatically skewed.

To get each component locked into place, we created mounts and precise holes so everything fit together and locked into place.

We mounted the tube where our experiments are run at an angle so that air bubbles wouldn't form and had our outlet above our inlet so that the entire tube had to be filled with water before water could leave the enclosure.

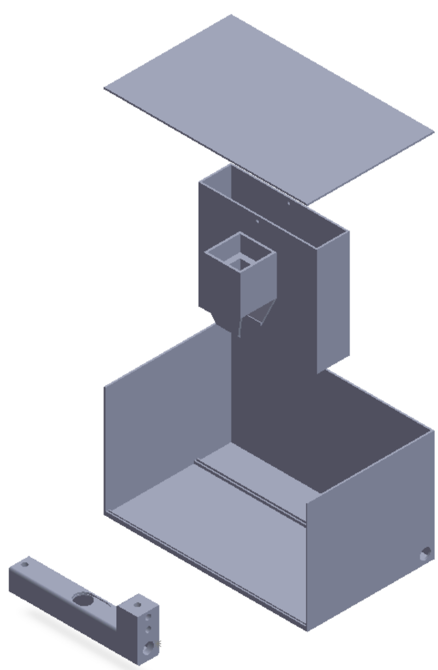


Figure 1: SolidWorks diagram of device housing

5.1.2 Electronic Housing

This housing is separate from the experimental housing, which allows for the electronic components to be connected without fear of being damaged in case of water spillage. It also mounts the touchscreen display in place, which will allow the user to interact with it. This housing case is then mounted at an adjustable angle for the user's convenience.

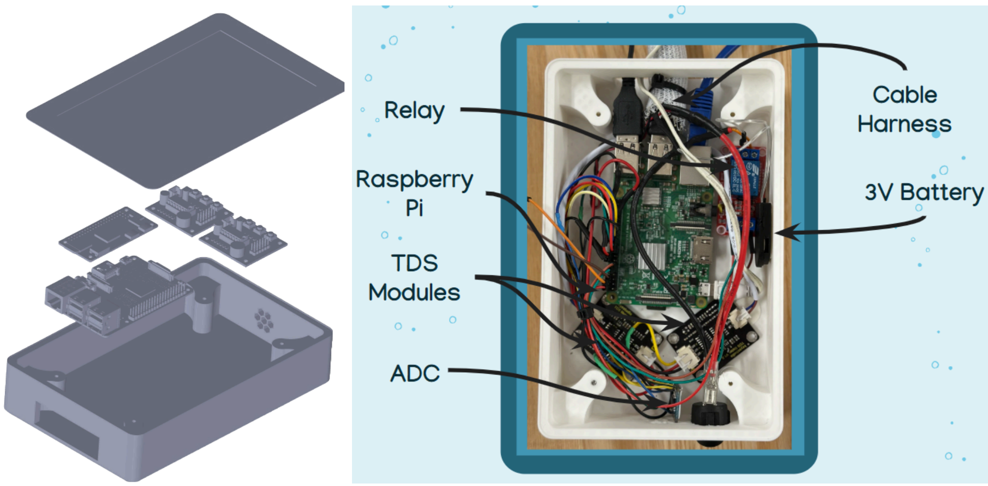


Figure 2: SolidWorks diagram (left) and image (right) of electrical housing

5.2 Electrical

All electronics, besides those directly interfacing with the water sample, are held in the electrical housing. The Raspberry Pi is the brain of the operation, managing all other components. GPIO pins on the Pi are used to toggle the relay for the laser and water pump, as well as the TDS modules. Additionally, the Pi provides power and interfaces with the touchscreen, camera, and ADC. Pictures below show the probe and laser placement and the electrical flow diagram.

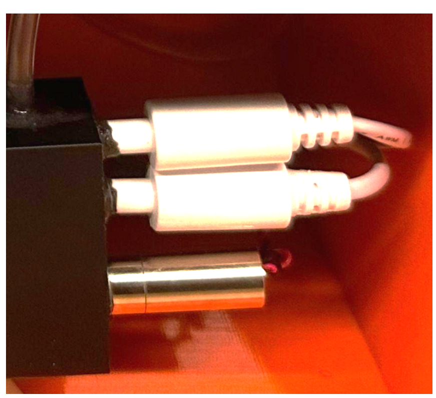


Figure 3: TDS Probes and Laser embedded in 3D printed tube

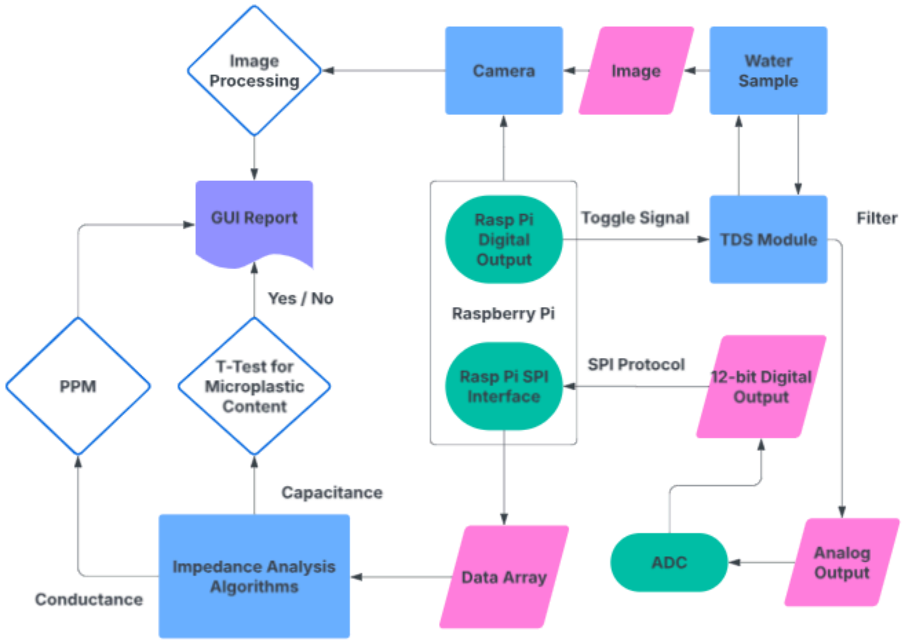


Figure 4: Flowchart of AMP'D experiment

5.3 Software

5.3.1 Software Overview

The implementation of our software running on the Raspberry Pi was done entirely through Python. This software was easy to work with, and we had experience using it prior. We implemented a model-view-controller design pattern. This architecture offers several key advantages, particularly in improving code organization and maintainability. By separating the application into three distinct components, the model (data and business logic), the view (user interface), and the controller (input handling and coordination). MVC allows developers to work on each component independently. This modularity makes the codebase easier to understand, test, and scale. It also enhances flexibility, as changes to the user interface can be made without altering the back-end logic.

In addition, this was paired with a website, where the local program had "upload" capabilities. The idea was to build out the functionality of the product as it would be used by real users, with features such as viewing data history and comparing samples to each other. Separating this out into a website takes advantage of some of the features of web development modules that already exist, which include easy creation of intuitive and well-organized visual components.

6 Parts and Implementation

6.1 Full System Housing

The experimental and electrical housing was designed using SolidWorks CAD software, then printed with PLA filament on PrusaSlicer 3D printers with its affiliated software (PrusaSlicer v2.x.x). A stark color palette (black, white, and orange) was chosen when fabricating each part so that major components of the system can be easily distinguished from an onlooker's perspective. Two separate housings were made to enclose the experimental and electrical setup, mostly to keep the water systems in the former away from the sensitive electronics in the latter.

Figure 5: Picture of entire AMP'D Device running

6.2 Water Compartment and Tubing

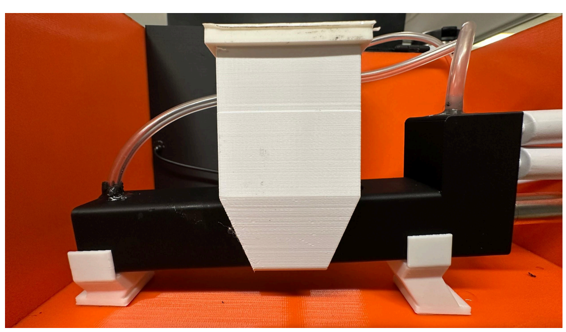


Figure 6: Water tube and camera housing

6.2.1 Main Water Chamber

The water chamber was the most intricately designed component due to being the central piece of the experimental setup. A black filament was used to print the main tube to simulate completely dark conditions, which will contrast against any illuminated microplastics in the flowing water when the system is running. This was done to simplify the image processing needed to digitally detect any foreign bodies dissolved in the water via the CMOS camera.

Holes were intentionally printed at a lower diameter than the actual size of the TDS probes + laser to be inserted at the sides and the clear tubing at the top of the left and right ends of the chamber. These holes were then carefully adjusted with a Dremel until a snug fit of the respective component was established. The tubings at the top were also sealed to the water chamber with an epoxy mixture to ensure waterproofness.

Two angled mounts, where one is taller than the other, were also designed so that the chamber could be suspended and canted at an approximate 5-degree angle. This was done not only to facilitate the movement of water throughout the chamber, but also to reduce the formation of water bubbles, which could be detrimental to the integrity of collected data.

A separate enclosure for the CMOS camera was also affixed atop the medial section of the chamber using velcro strips for convenient removal. This part was designed to block any external light from entering the system, which was another factor that was considered to potentially interfere with our data collection. The independent housing was also necessary to keep the camera secured in place, as inconsistent positioning of the captured video feed could also contribute to erroneous data.

6.2.2 Water Reservoir and Tubing

A simple box was designed and placed behind the main water chamber to hold the water sample. An elevated rectangular wall section was included in the main enclosure to form a dedicated compartment for the reservoir. The water tank holds about 350 mL of liquid, which is a generous amount, as the minimum amount required for the experimental system to run is only the volume required to fill the main water chamber, which is about 60 mL. Additional holes were drilled into the side of the water tank to allow clearance for tubing and wiring and sealed with an epoxy mixture to prevent leakages.

Vinyl material tubing was used due to its high durability and flexibility at an affordable cost, all of which meets the needs of our experimental setup. The transparency of the material is also a plus, as visualizing the flow of water through the tubing is useful for testing and troubleshooting. Only two tube segments were needed to build the setup – one to input water from the reservoir to the main chamber and another to feed it back into the reservoir.

6.2.3 Water Pump

One of the few electrical components inside the experimental setup is the water pump module, which is affixed to the bottom interior of the water reservoir. When powered, it will continuously circulate water to and from the main water chamber, therefore allowing for microplastic content data to be collected for as long as the system is running. The pump is powered using a battery rather than the Raspberry Pi due to its high current draw and electromagnetic signal interference. To isolate the pump from the sensing electronics, a 5V relay inside the electrical compartment was used, closing the pump's circuit when a dedicated Raspberry Pi GPIO pin connected to the relay control pin is set to high. This allows the runtime program to synchronize water flow with the optical and impedance measurements without EMI noise present.

6.3 Optics and Imaging

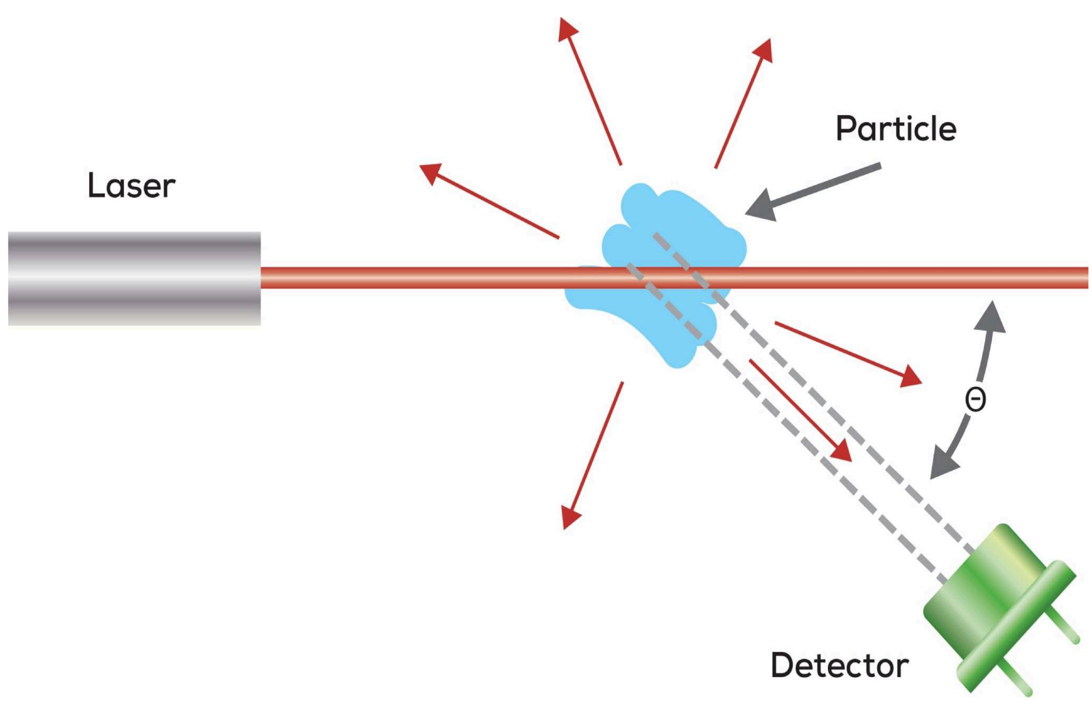


Figure 7: Diagram of optical scattering from microplastics

6.3.1 Laser Scattering Methodology

The basis of our optical detection method is centered around the principles of laser light scattering, a phenomenon in which a coherent beam of light interacts with particles suspended in some sort of medium. By shining a collimated laser beam through a sample of water containing various sizes and shapes of microplastics, the light will encounter discontinuities in the water's usual refractive index, indicating the presence of suspended plastics. As a result, scattered light at various angles is produced and can be analyzed to determine the content of a sample.

This angular deflection is quantified as the scattering angle, which is defined as the angle between the incident and scattered beams of light. By analyzing the intensity and angular distribution of scattered light, we can approximate the size, shape, and concentration of microplastics suspended in water. This method enables accurate detection as well as characterization of suspended particles, however, it is typically expensive and impractical for routine analysis in the real world. Laser scattering is largely limited to laboratory settings, where precise alignment, sensitive detectors, and controlled environmental conditions all play a factor.

6.3.2 CMOS Camera Imaging

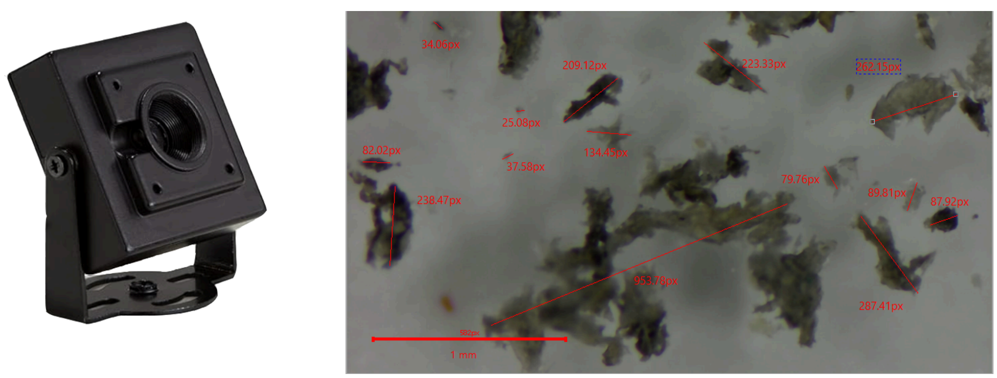


Figure 8: CMOS camera used (left) and image of microplastics under the microscope with their size (right)

To address the high cost and impracticality of measuring laser scattering, we transition to a much more accessible and cost-effective alternative using a CMOS camera. Instead of measuring a precise scattering angle, such as what we would do in a lab, we use imaging-based detection to confirm the presence of microplastic particles in a sample. This method involves a very similar setup to a laser scattering method, where we illuminate a water sample using a laser source. However, in this approach, rather than measuring the angle of scattered deflections, a CMOS camera, positioned perpendicular to the beam, captures images of any microplastics as they pass through the optical housing.

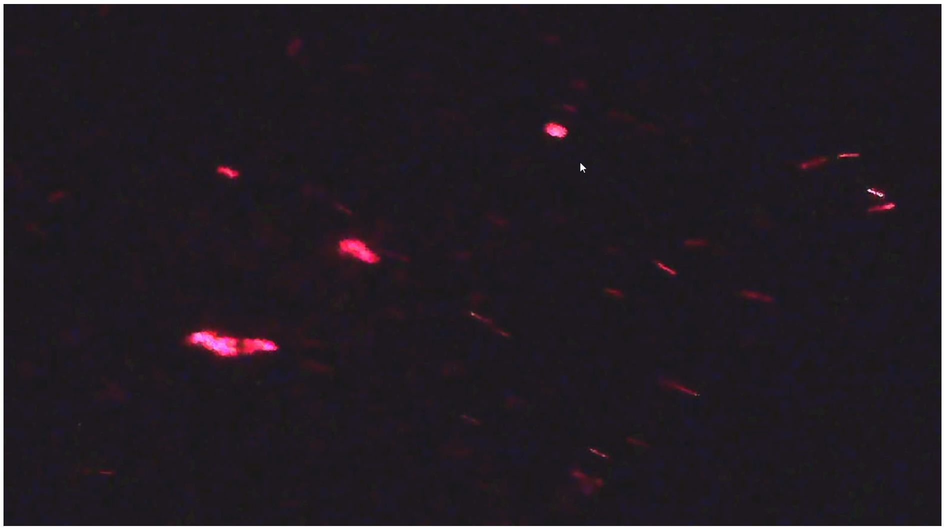


Figure 9: Scattering picked up by the CMOS camera from plastics

The presence of microplastics causes light to scatter away from the usual beam path, which can be captured by the CMOS camera as visible specks, flares, or other diffused patterns. By analyzing these deviations, we can determine whether scattering due to the presence of microplastics is occurring, as well as approximate how many particles are present in the given sample. This method falls short in terms of accuracy, as it does not offer the same level of precision in characterizing particle size and/or concentration; however, for the purposes of this project, using CMOS camera-based imaging provides a sufficiently effective alternative that is low-cost, quick, and intuitive for most at-home solutions.

6.4 Impedance Measurement

6.4.1 TDS Probes

Two total dissolved solids (TDS) probes were inserted near the exit of the main water chamber. The probes each have a transmit and receive electrode. The transmit electrode sends an alternating current signal, which passes through the medium (sample water in this case). The receive electrode picks up the signal, proportional to the admittance of the medium between the electrodes. The probes used are shown in the figure below. Each TDS probe was connected to a respective TDS Module, the KS0429 Keyestudio TDS Meter V1.0 (shown below).

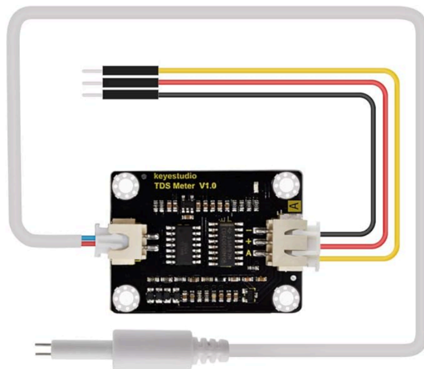


Figure 10: KS0429 Keyestudio TDS Meter V1.0

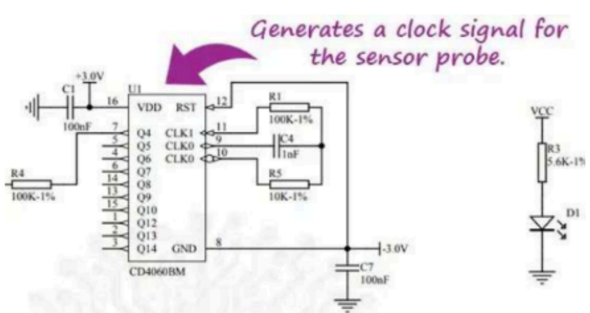
6.4.2 TDS Modules

Each TDS probe was connected to a respective TDS Module (shown above). Both modules are powered via the Raspberry Pi using 3.3V GPIO pins, so they can be toggled separately, preventing their signals from interfering. The default oscillator onboard the module creates a 408 mV peak-to-peak square wave at 2.403 kHz. One module was modified by soldering a 2.14 nF capacitor in parallel with C4 to change the oscillation frequency to 765 Hz. The derivation for this is shown below.

TDS Module Signal:

The TDS Module outputs a 408 mV peak-to-peak (204 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:

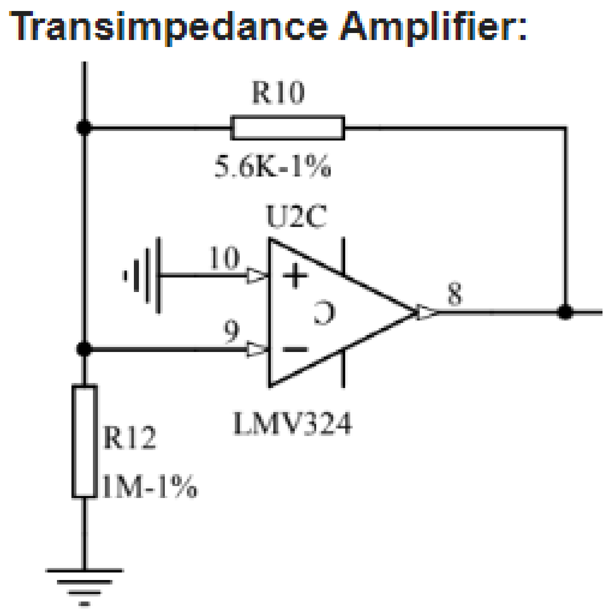
$$f_H = \frac{1}{0.602 \cdot 2\pi(R_1 + R_5)C_4} = \frac{1}{0.602 \cdot 2\pi(100\text{K} + 10\text{K})1\text{n}} = \frac{1}{0.00013244\pi} = 2.403\,\text{kHz}$$

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

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

Figure 11: TDS Module Frequency Calculations

The connector from the receive probe passes the input signal through a transimpedance amplifier with a -5600 V/A gain, as shown below.



Transimpedance gain A is given by:

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

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

Figure 12: TDS Module Transimpedance Amplifier

After this, the amplified signal goes through a full-bridge rectifier and a low-smoothing filter, creating an analog output voltage proportional to the admittance of the sampled medium. The analog output of each module was connected to a separate input channel on the ADC.

6.4.3 Analog-to-Digital Converter

The MCP3008 analog-to-digital converter was used to deliver the TDS module outputs to the Raspberry Pi through the breakout board shown below. The MCP3008 has eight input channels (two were used), a maximum sample rate of 200 thousand samples per second (experimentally, this rate was significantly lower), and interfaces with the Raspberry Pi using the SPI interface.

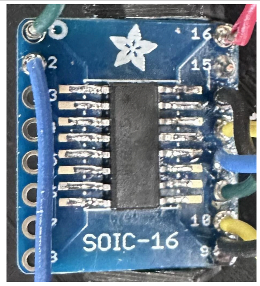


Figure 13: MCP3008 ADC on the Breakout Board

6.4.4 Water Quality Calculations

Based on the voltage read by the ADC, it is possible to calculate the sample's impedance based on the equation below.

Calculating Water Impedance based on V_{out}:

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

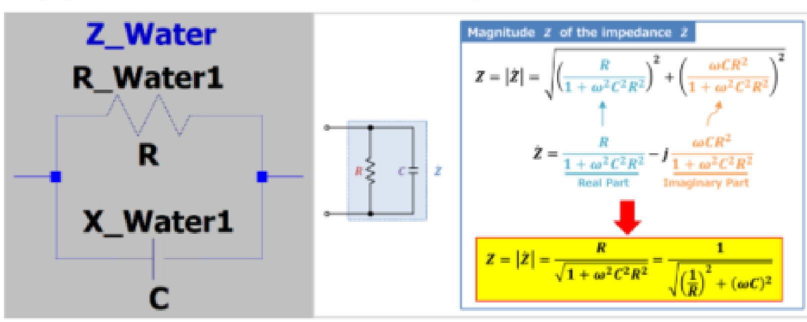
$$V_{in} = I_{in}|Z_{water}| = \frac{V_{ADC}}{|A|}|Z_{water}|$$

$|Z_{water}| = \frac{|A| V_{in}}{V_{ADC}} = \frac{5600 \cdot 204}{V_{ADC}}$, where V_{ADC} is read in mV and $|Z_{water}|$ is given in Ω.

Water Impedance Formula

The water sample was electrically modeled as a resistive element in parallel with a capacitive element, as shown below.

Approximate Water Impedance Model:



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

Figure 14: Approximate Water Impedance Model

Using the impedance values obtained at two different frequencies, it was possible to calculate the water sample's capacitance, resistance, conductivity, and approximate parts per million using functions within the ImpedanceAnalysis class. These calculations are shown below.

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.

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

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

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

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

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

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

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

Figure 15: Water RC Constant Calculation

Calculating Water Resistance based on RC Constant:

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

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

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

Calculating Water Conductivity based on Resistance

$$G_{water} = \frac{1}{R_{water}}$$

The electrodes are 1/8" = 0.3175 cm apart.

$$\sigma_{water} = \frac{3149606.299}{R_{water}}\ \mu\text{S/cm}$$

Calculating Water Capacitance based on Resistance:

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

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

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

Figure 16: Water Resistance, Conductivity, and Capacitance Calculations

Calculating PPM based on Output Voltage:

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

Can be linearized for normal tap water:

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

Figure 17: Water PPM Calculation using High Frequency Measurement

6.5 Software

6.5.1 User Interface

The user interface on the Raspberry Pi is displayed on the connected LCD touch screen using Python and PyQt6. We utilized PyQt6 as our graphic user interface (GUI) of choice due to its advantages in large, complex GUI applications and access to multiple widget tools. This gave us full control over the features and appearance of the GUI and allowed us to take advantage of PyQt Threads in order to run our experiment without disrupting the flow of the GUI. Another advantage is that we were easily able to bridge the numpy and pyqtgraph modules to include graphs in our interface, which helped track the distribution and quantity of microplastics in water over time, and display it to the user. We used button and label widgets to connect the interfaces to the backend to conform to the MVC pattern. Almost all inputs that the user could change were data validated, or formatted as a button or toggle in order to ensure that unnecessary errors wouldn't be caught. In addition, a logging system was created where any thread that was running from the main GUI and the GUI itself would be able to access and update the user with the status of the experiment. This brought many of the features of the GUI up to industry standards for Python interfaces with hardware.

Another design decision that was made was to have both the analysis screens and the upload screen separate from the experiment, and initiated when the user pressed a button. Paired with this was the automatic saving of any experiment data that was run to a default file name determined by the date. The result was that analysis could be performed asynchronously from the experiment, and users could choose to analyze or upload samples at any time. The upload functionality required an internet connection, which for the project was done through Ethernet.

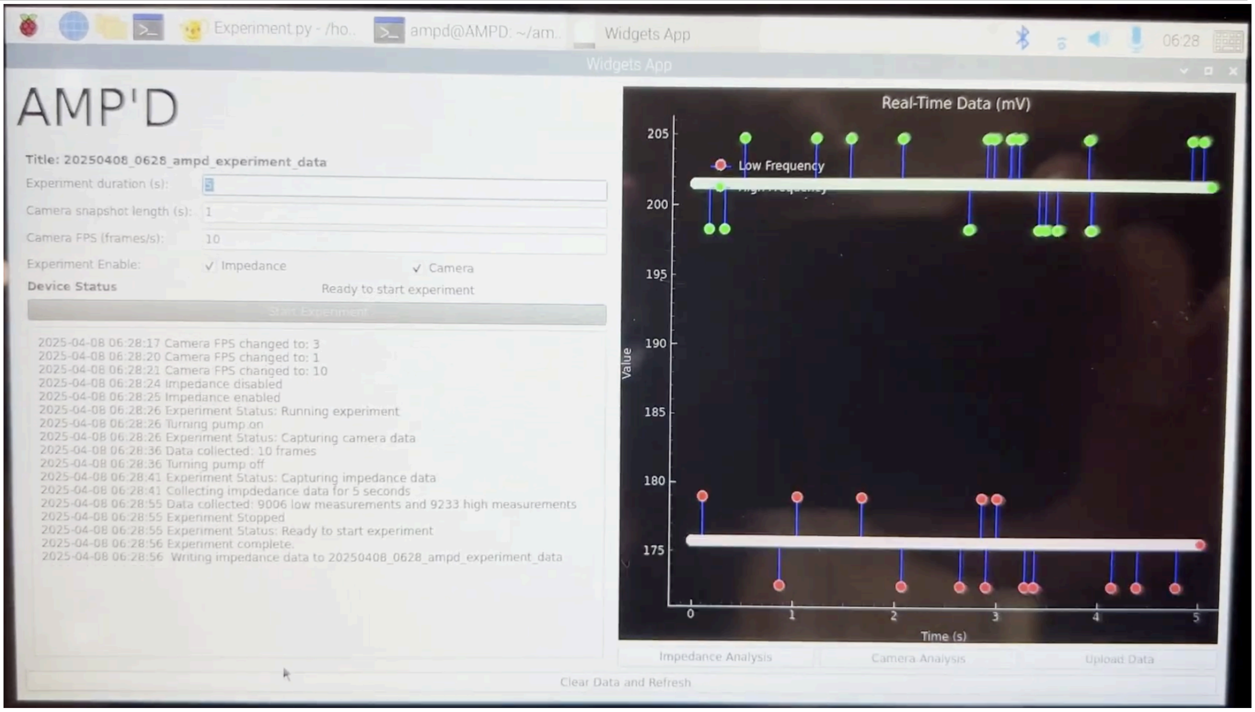


Figure 18: Screenshot of GUI running on Raspberry Pi, displayed on LCD Screen

6.5.2 Website

The website, hosted on Render, utilizes React.js and TypeScript to build the application. We had prior experience using React, which is a powerful tool to build modern web applications. It allows our application to be cross-platform and its component-based architecture aligned with our design patterns. We also used Firebase as a database to store our analysis information to display on the website. To combine our local software with the webpages we used modules in the GUI on the upload window to send data to our database which our website could extract data from. From the GUI to the database to the website, all data was handled as JSON files, which was a decision made for the ease of parsing and storage across both software implementations.

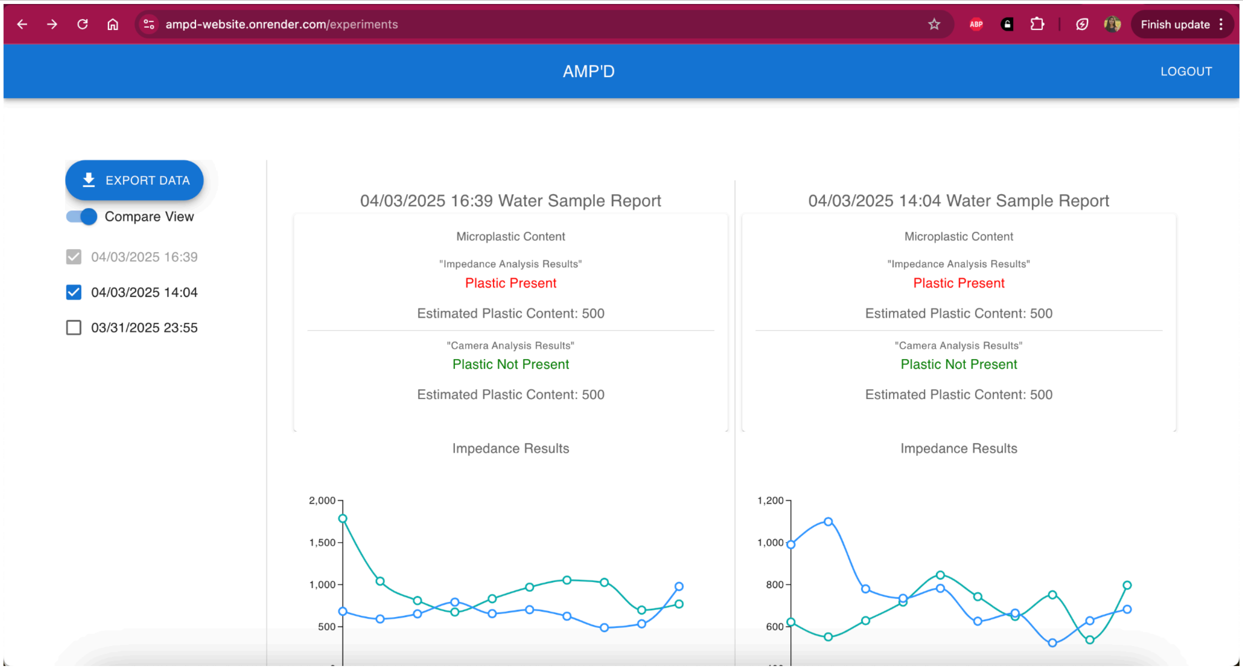


Figure 19: Screenshot of the website utilizing the compare view

6.6 Testing and Results

To test our device, we prepared samples of various plastic types, using both deionized and tap water. These were done in the optics lab of Prof. Fuentes. Due to the changing nature of polarity in plastic types and their varying hydrophobic properties, we tested both PLA (non-polar) and PVC (polar). To create the samples, plastic was shaved using a file or sandpaper, collected, and placed into glass vials. In a few instances, we utilized a 400-micron mesh filter to strain out larger pieces of plastic and test if our detection was sensitive on a smaller scale. Water was then added to the dry plastic and mixed around, before being added to the water tank for testing. Many of the earlier design choices, such as using a water pump, were made because of how the plastic reacted with the water and our desire to get a uniformly mixed sample.

Due to the varying nature of polarity, plastic shapes, and a small amount of plastic, it became difficult to determine exactly how much we had, and whether the device was picking up on a change in plastic content or a change in the tap water conductance. Therefore, we implemented a calibration system by which the user could upload existing calibration data, and the analysis would compare the results to that data. It did so using a two-tailed T-test, checking whether the sample means were statistically different. This helped us in multiple ways - firstly, there was no need to create an empirically established threshold value, which could change with time and would lower the accuracy of our product. Second, it was able to account for variability in ion content in tap water, which affects the base measurements from the impedance analysis. Third, the two-tailed approach meant that the polarity of plastic could be accounted for without necessarily knowing what type went in. Lastly, when comparing images, a calibration allowed us to exclude air bubbles or other debris in front of the camera when counting the amount of scattered light.

One major setback in the testing process was the inability to get solutions of microplastics with a known size and concentration, due to their cost. Therefore, this preparation of samples was our solution to being able to test the device. To not misrepresent what our data meant, we chose to display the amount of plastic present as a binary, as with our current low-cost mechanisms and lack of standard testing samples, we cannot confidently state a concentration. However, the TDS modules are able to provide a PPM measurement of any contaminants in the water that can be used in conjunction with the plastic present variable.

6.7 IEEE Standards and Constraints

6.7.1 IEEE 1451

The IEEE 1451 standard defines common interfaces between sensing and actuating transducers with other instruments, computer networks, or controllers. The purpose is to create adaptable and scalable devices and processes that are compatible. In this project, the TDS probes should include a transducer electronic data sheet that provides identification and calibration information. Additionally, keeping these standards in mind will be beneficial in case sensor probes need to be swapped or if sensors are integrated directly with the IoT.

6.7.2 IEEE 1241

The IEEE 1241 standard defines vocabulary and testing methods for analog-to-digital converters with the goal of preserving performance and accuracy. Ensuring high-fidelity signals with high signal-to-noise ratios is crucial for detecting small contaminants present in sample water. The sample rate and bit accuracy of the ADCs used in the project were tested against a calibrated DC supply to confirm they functioned properly.

7 Cost Analysis

Our final budget can be seen in the figure below. We were under the Capstone budget by $109.18. Most of our costs were on researching techniques such as optical scattering and impedance plates, which weren't used in our final design. Our final product totals less than $200, making it significantly more affordable than other products on the market.

Table 1: Budget

Glitter and Photodiode Module	$13.08
Acrylic Boxes	$8.89
Lenses	$25.18
PVC Pipe and Cap, Laser, and Mesh	$47.12
SMA Connectors	$12.31
Funnel, Vinyl Tubing, SMA Cables, and Silicon Tube	$39.05
Brass Tubes	$14.38
Sealer	$6.98
Signal Generator, ADC, and TDS Module	$36.97
Magnifying Objective	$9.99
Aluminum Bar	$33.93
Electrode Fab	$33.50
Nuts and Bolts	$25.99
CMOS Camera	$49.99
Pumps and TDS Modules	$33.95
Camera	$38.89
PVC	$5.92
PP File Box	$10.52
Acrylic Sheets	$6.99
ADC with breakout board	$28.38
CCD Camera Return	-$49.99
Touchscreen	$70.36
Jumpers	$5.49
3 TDS Probes	$14.99
PVC and Hinges	$18.74
Switch for Pump	$7.99
Coin Cell Batteries	$25.88
Wire Harness Sleeve	$8.99
Caulk	$6.36

Total Spent	$590.82
Capstone Budget	$700.00
Total Remaining	$109.18
Research Cost	$409.65
Product Cost	<$200

Additionally, we can see that the majority of our spending was on Optics and Electronics, based on the cost breakdown figure below. These were due to expensive components such as the CMOS camera and several electronic modules. The costs are similar to our original cost proposal, but slightly over due to the inclusion of housing materials and testing materials such as glitter.

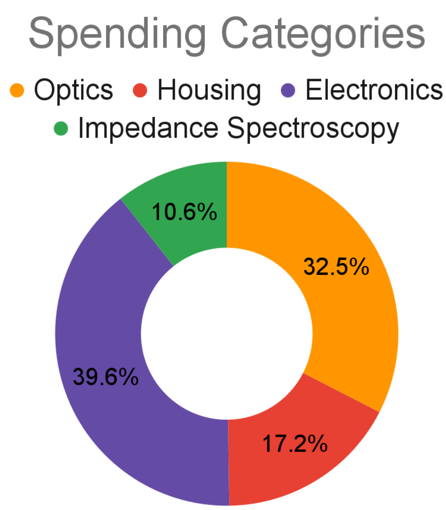


Figure 20: Budget spending categories

8 Conclusion

Overall, our design and implementation allowed for AMP'D to successfully detect microplastics at the cheapest cost. Utilizing two detection methods allowed us to improve accuracy and user experience. Showing the user visual and scientific evidence of microplastics boosts confidence in the results. By providing the average person an affordable, convenient way to detect microplastics, we hope to promote healthier lifestyles, improve research by allowing users to track where and when microplastics are present, and promote regulation to reduce plastic pollution.

9 Final Project Links

Github for GUI: https://github.com/AnanyaT129/ampd-gui

Website: https://ampd-website.onrender.com/ (logging in with email capstone@neu.edu and password 123456 will show some of the results from testing)

Github for Website: https://github.com/AnanyaT129/ampd-website

PowerPoint Presentation: AMP'D Capstone Presentation

Demo Video: AMPD_Demo_Final_Final.mp4

**Please also see the Shared Drive for an extended demo video.*

Poster Presentation: AMPD_Posterboard.pdf

10 References

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