The Utilization of Chitosan and Arduino Interface in Making a Microplastic Filter

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Abstract: Microplastics have emerged as a major issue of concern globally due to their effect on marine life, human health, and biodiversity as well as their presence in water sources. Removal of microplastic particles, which are generated from industrial waste, synthetic textiles, and plastic trash, is nearly impossible and their removal using standard filtration techniques is even more complicated. Furthermore, their presence in drinking water is increasingly becoming a global concern that poses a considerable threat of toxic chemicals and bioaccumulation through the food chain. In addition, the problem of controlling microplastic pollution is only a decade worse due to the exponential growth in the production of plastics. This study utilized the quantitative method and experimental design to solve the problem by creating a microplastic filtration device based on biopolymer chitosan filter and is enabled by an Arduino interface to improve detection and automated filtration process. The effectiveness of the device was evaluated by conducting experiments using different concentrations of microplastics for detection and removal and quantitatively measuring the results of the experiment. The Microplastic Filter demonstrated 100% detection accuracy across low, medium, and high concentrations of microplastics, and consistently extracted an average of 8.33 grams per liter from a 10-gram per liter solution within 44.33 seconds. Furthermore, the filter effectively removed microplastics of varying sizes, achieving an average extraction of 8 grams for 1-2 millimeters particles and 9.33 grams for 2-5 millimeters particles creating a stable and efficient operation. This study underscores the effectiveness of the Microplastic Filter as a filtration medium for water. This filter demonstrated reliable performances in detecting and filtering microplastics, with high detection rates as well as high efficiency in removing the microplastics. The findings illustrate that the system provides an effective and scalable application for microplastic pollution removal with the capability for real-time monitoring and self-adjusting filtration. Recommendations: It is recommended to optimize the design of the filter by enhancing the filtration properties of materials, and improving its applications toward more universal solutions for water treatments.

Keywords: *Arduino Interface; Chitosan, Microplastic Filtration; Water Treatment; Water Quality Management*.

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I. INTRODUCTION

The widespread presence of microplastic contamination poses a significant concern for human health. Microplastics, defined as plastic particles measuring less than five millimeters, manifest in diverse forms and dimensions. These microplastics are present due to the fragmentation of bigger plastics (Osman et al., 2023). When significant objects degrade into microplastics, the amount of debris increases, rendering small plastics more prone to ingestion, especially by smaller organisms. As predators consume contaminated smaller organisms, microplastics can accumulate in their bodies, eventually reaching human consumption from eating seafood. Nevertheless, eliminating plastic particles from the environment may intensify due to the difficulty of manually extracting small plastic particles (Shim & Thompson, 2015).

Coastal areas in the Middle East, facing intense wave action and intense sunlight, undergo substantial degradation of plastic waste into microscopic particles, making them difficult to detect. Exposure to sunlight can break broader plastic items into smaller pieces through photodegradation, as ultraviolet (UV) radiation weakens the molecular bonds of plastics (Lusher et al., 2015). These changes directly affect the distribution patterns, adsorption processes, and ecological effects of microplastic particles in aquatic ecosystems (Ma et al., 2024).

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The bioavailability of microplastics can increase due to flocculation with marine particles, resulting in aggregates that reach the food chain. In turn, detritivorous species can consume fecal remnants containing microplastics. On the other hand, microplastics are absorbed by marine zooplankton, as well as the transfer of microplastic particles from mesozooplankton to macrozooplankton, indicating a grave risk of microplastics entering marine food webs (Ugwu et al., 2021). Commercial and ecologically vital fish collected from diverse habitats in the Arabian Gulf reveal a high prevalence of ingested microplastics, attributed to the reported abundance of floating microplastics in these fish (Baalkhuyur et al., 2020).

Microplastics (MPs) have been detected in drinking and tap water in different parts of the world, potentially impacting human health. A study examining 159 tap water samples from 15 countries found high levels of microplastics, averaging 5.45 particles/L (Kosuth et al., 2018). Microplastic contamination in bottled drinking water often stems from its packaging materials (Hossain et al., 2023). The mechanical actions during the bottling process, such as the use of high-speed machinery, can cause the shedding of microplastic particles into the water. Bottles and caps are typically made from polymers like polyethylene terephthalate (PET) and polypropylene. Wear and tear, as well as interactions between the water and these materials can lead to the release of microplastics (Mason et al., 2018). Upon ingestion, microplastics resist breakdown in the human digestive system, potentially causing inflammation in stomach cells or the intestinal lining. Given the essential role of drinking water in daily life, exposure to microplastics is inevitable, posing health risks associated with their physical and chemical properties (Brancaleone et al., 2024).

This study used Chitosan and the Arduino Interface. Chitosan, a naturally occurring, flexible biopolymer derived from the N-deacetylation of chitin, plays a crucial role in treating wastewater (Rhazi et al., 2002). Chitin, found in the cell walls of certain invertebrates, fungi, insects, and crustaceans, provides the raw material for chitosan (Pellis et al., 2022). Storing chitosan in sealed containers at low temperatures of 2–8 °C is essential due to its sensitivity to environmental conditions. Ambient relative humidity (RH) greatly affects the presence and distribution of moisture in chitosan material. (Szymańska & Winnicka, 2015). Chitosan retains its chelating property for at least six months regardless of its storage form (Cruz-Filho et al., 2017). Due to its high absorption capacity, chitosan has proven effective in filtering microplastics and nanoplastics. Shells are composed primarily of chemically stable calcium carbonate ($CaCO_3$), which makes their decomposition difficult without any treatment (Topić Popović et al., 2023). This study extracted chitosan from the shells of commonly consumed crabs and shrimp.

A previous study used chitosan as a natural flocculant to remove microplastics from water through a coagulation-flocculation process, focusing on finding the optimal chitosan concentration for effective remediation (Putranto et al., 2023). The study explored the interactions between chitosan and microplastic particles in different experimental setups aimed at improving the efficiency of the natural flocculant in microplastic cleaning applications. However, the study did not explore the scalability of applying this method to larger volumes of water and the integration of technologies like Arduino. Identically, another study utilized chitosan, specifically chitosan-glutaraldehyde nanofiber sponge, also known as chitosan NF sponge (Risch & Adlhart, 2021). This sponge, made up of chitosan nanofibers crosslinked with glutaraldehyde, forms a porous and absorbent structure with unique properties. The study developed a filtration system inspired by oysters, using the chitosan nanofiber sponge as a vital component. The product emphasizes a filtration system over a detection system. With this, the study did not utilize an interface, specifically an Arduino, for its operations on microplastic detection. Additionally, the study incurred significant expenses and required considerable time to develop the nanofiber sponge.

The Arduino, also known as the Arduino Integrated Development Environment, is a user-friendly platform for electronics, combining a small programmable circuit board and software to write code and control devices like sensors, lights, and motors. Its adaptable technology has fostered the creation of automated systems by enabling devices to operate independently based on sensor data, resulting in the automatic operation of external devices, a critical advancement in public health and safety protocols. Previous studies utilized Arduino Interface and successfully programmed to create an Air Ionizer-Purifier and Ion Generators (Patil et al., 2022; Real, 2023).

This study aimed to create a microplastic filter. The mechanism detects and extracts microplastics, with specific functionalities designed for this purpose. Additionally, the microplastic filter is programmed using the Arduino interface. The turbidity sensor is connected to the Arduino to enable the mechanism to detect microplastics. An extraction feature is also integrated into the system, utilizing chitosan to filter out microplastics from the water.

This study can introduce methods for extracting microplastics using chitosan. Bottled drinks and plastic containers are common sources of microplastics found in Qatar, which pose potential hazards. This knowledge can greatly benefit the country, as it enables the provision of higher-quality and less hazardous supplies of water for everyone about the potential of repurposing waste materials to create environmentally friendly solutions, such as microplastic filters and detectors.

Furthermore, this study's findings, information, and data can serve as a reference for future researchers conducting studies related to microplastic filters and detectors. Future researchers can utilize the findings of this study to validate the accuracy of other research, aiding in resolving issues in their investigations. Additionally, they can adopt similar components and techniques to develop higher-quality frameworks.

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II. METHODOLOGY

This study employed an experimental research design, which examined the outcome of the independent variable's interaction on the dependent variable (Creswell, 2009). The independent variables in this study are the Arduino interface and the Chitosan extract, while the dependent variable is the microplastic filter used for detection and extraction. Additionally, the researchers utilized the quantitative method to confirm, understand, and analyze experiment outcomes using numerical data (Sardana et al., 2022). This method is necessary as it enables control over variables affecting outcomes and facilitates the production of reliable, consistent, and precise results.

III. RESULTS

This section presents the results and interpretations of the data that was collected during the testing procedure in relation to the research questions. The Chitosan-based Arduino-enhanced filter evaluates the filter's accuracy in detecting microplastics at certain concentrations, its effectiveness in extracting them from water, the average time it takes to filter out the microplastics in water, and its efficacy in removing different microplastic sizes.

A. Accuracy of the Microplastic Filter in Detecting Microplastics in Various Concentrations

Table 1 Accuracy of the Microplastic Detector in Various Concentrations

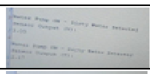
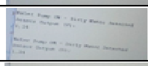
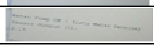
Concentration level	Trial 1 (Detected or not)	Trial 2 (Detected or not)	Trial 3 (Detected or not)	Photos
6 g/L	Detected	Detected	Detected	
10 g/L	Detected	Detected	Detected	
20 g/L	Detected	Detected	Detected	

Table 1 shows the Microplastic Filter's detection accuracy at three specific concentration levels of microplastics in water: 6 grams (low), 10 grams (medium), and 20 grams (high) per liter. The results showed that for 6 g/L, all trials yielded "Detected" outcomes, resulting in an average detection accuracy of 100%. Similarly, for 10 g/L, all trials yielded "Detected," with an average of 100%. Lastly, for 20 g/L, all trials also yielded "Detected," maintaining an average detection accuracy of 100%. These results demonstrate the Microplastic Filter's exceptional and consistent detection performance across all tested concentration levels.

The consistent detection accuracy of the Microplastic Filter across all tested concentrations aligns with the advancements in microplastic detection technologies, such as the development of portable, reagent-free sensors aimed at enhancing detection efficiency in environmental water samples (Environmental Protection Agency, 2023). Additionally, the use of spectroscopic techniques, like Fourier Transform Infrared (FTIR) and Raman spectroscopy, has been instrumental in identifying and quantifying microplastics in water, contributing to more accurate assessments of microplastic pollution levels.

Accurate microplastic detection is essential as it poses a risk in marine life contamination. Marine life, including fish, seabirds, and marine mammals, face grave dangers as they mistake MPs for food or inadvertently ingest them while feeding (Singh et al., 2024). Consumption can cause animals to suffer from physical harm, chemical exposure, provoke inflammatory responses and can undergo behavioral modifications (Jeong et al., 2024). This shows that microplastic detection can significantly help improve the overall well-being of marine animals.

Furthermore, it also poses a threat in human consumption as drinking water has become a route for MPs to enter the human body (Maliwan et al., 2025). Through time it can accumulate in the body that can cause respiratory disorders such as lung cancer, asthma, and hypersensitivity pneumonitis (Winiarska et al., 2024). This further highlights the adverse effects of failure in detecting MPs in drinking water.

B. Effectiveness of the Microplastic filter in Extracting Microplastics from water

Table 2 Effectiveness of the Microplastic Filter In Extracting Microplastics

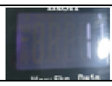
Trial	1st	2nd	3rd	Average
Photos				
Weight of Extracted Microplastics (in grams)	7 grams	10 grams	8 grams	8.33 grams

Table 2 shows the effectiveness of the Microplastic Filter in extracting microplastics at a constant concentration of 10 grams per liter. A set of three trials was conducted to evaluate this part of the experiment. In each trial, water with an initial concentration of 10 grams per liter passed through the filter. After the filtration process, the remaining microplastics in the water were gathered and weighed using a digital scale. To determine the exact mass of microplastics removed by the filter, the initial weight of the chitosan filter (3 grams) was subtracted from the total weight recorded after filtration. This procedure accurately identified the weight of microplastics extracted by the filter. The collected data from

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the three trials was used to calculate the average mass of microplastics removed, providing an objective measure of the filter's extraction capability at a set contamination level. The chitosan as a natural flocculant for microplastic remediation has demonstrated the effectiveness of removing microplastics from contaminated water at 68.3% removal efficiency at a concentration of 30 ppm (Liang et al., 2023). This aligns with experimental findings where chitosan-based filters extracted an average of 8.33 grams of microplastics per liter, highlighting their effectiveness.

The results from the test outlined the effectiveness of the Microplastic Filter in removing microplastics at a constant concentration of 10 grams per liter. The trials yielded results of 7 grams, 10 grams, and 8 grams of extracted microplastics, respectively, after accounting for the initial weight of the chitosan filter. This resulted in an average removal effectiveness of 8.33 grams of microplastics per liter, showcasing the filter's high and consistent extraction capability.

Mass concentration of total microplastics (MPs) in the influent water was 26.23 mg/L. After being filtered through the water treatment, 24.48 mg/L was filtered out. Indicating that the product filtered 93.3% of the initial concentration. (Xu et al, 2023). This supports the effectiveness of the device's capability to successfully filter out microplastic of the same concentration.

Sand filtration with alum as a coagulant removed 70% of MPs, while granular activated carbon (GAC) filtration added 28%, achieving a 98% cumulative removal efficiency (Velasco et al., 2023). These findings align with Xu et al. (2023), further reinforcing the effectiveness of filtration methods in significantly reducing MPs in water.

The efficiency of chicken eggshells and chitosan as coagulants was tested. They found that adding 8.5g of chicken eggshells removed 89.14% of contaminants, while 10g of chitosan removed 75.67% (Liemin et al., 2023). This shows that chitosan is effective in water treatment, similar to the microplastic filter in our study, which consistently removed 8.33 grams of microplastics per liter.

C. The Average time for the Microplastics to be Filtered using the Microplastic filter

Table 3 Average Time of the Microplastic Filter In Filtering

Trial	1st	2nd	3rd	Average
Photos				
Time (in seconds)	44 seconds	42 seconds	47 seconds	44.33 seconds

Table 3 presents the average time for the Microplastic Filter to effectively remove microplastics at a constant concentration of 10 grams per liter, chosen to represent an average level of microplastic contamination for a high-concentration level. A stopwatch was utilized to precisely measure the duration of the microplastic filter's process of removing microplastics. Three trials were executed using water samples with the specified concentration. The duration of the filtering process was measured using a stopwatch, starting when the filter is activated and ending when all water has gone down the filter. To ensure data reliability, the average filtration duration was calculated by determining the average time recorded across the three trials.

Table 3 Reveals the average time for the Microplastic Filter to effectively remove microplastics at a constant concentration of 10 grams per liter. The results outlined the following: 44 seconds, 42 seconds, 47 seconds, respectively. With the average of the device taking 44.33 seconds to filter the given samples.

Furthermore, standardized protocols from the National Oceanic and Atmospheric Administration (NOAA) highlight that an ideal microplastic filtration method should provide consistent removal times across trials to ensure accuracy and reliability (Masura, et al, 2015). Since the device yielded a deviation of only 2.05 seconds, this proves that the microplastic filter operates within acceptable range of variability, confirming its reliability.

D. Effectiveness of the Microplastic filter in Removing Microplastics of Different Sizes

Table 4 Efficacy of the Microplastic Filter in Various Sizes

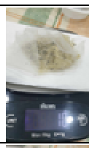
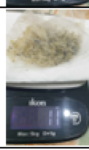
Size Category	Trial 1 (in grams)	Trial 2 (in grams)	Trial 3 (in grams)	Average	Photos
1-2 mm	7 grams	9 grams	8 grams	8 grams	
2-5 mm	10 grams	8 grams	10 grams	9.3 grams	

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Table 4 exhibits the performance of the Microplastic Filter in extracting microplastics of two distinct sizes: 1-2 mm (medium) and 2-5 mm (large) (Chen, 2022). Each size category underwent three separate trials, all conducted at a consistent concentration of 10 grams per liter. The microplastics of each size were separated using mesh nets with the specified sizes and then mixed into the water. Following filtration, the retained microplastics were weighed using a digital scale. To ensure accurate results, the initial weight of the chitosan filter (3 grams) was subtracted from the recorded weights to determine the net weight of microplastics extracted by the filter. The average weight of retained microplastics was calculated by taking the mean weight across the three trials for each size category. A study highlighted the efficiency of microplastic removal in wastewater treatment plants, which is influenced by the size of the particles. Primary treatment processes can achieve removal efficiencies ranging from 78% to 98% for MPs, with smaller particles often being more challenging to eliminate (Cristaldi et al., 2020).

The results for the medium-sized microplastics (1-2 mm) yielded weights of 7 grams, 9 grams, and 8 grams in trials 1, 2, and 3, respectively, with an average of 8 grams after subtracting the filter's initial weight. For large-sized microplastics (2-5 mm), trials 1, 2, and 3 produced weights of 10 grams, 8 grams, and 10 grams, resulting in an average of 9.33 grams. The microplastic removal efficiency varies based on particle size, with smaller microplastics often being filtered more effectively than larger ones. Research on wastewater treatment found that smaller polyamide particles had a maximum removal rate of 74.7%, while larger polyethylene particles had a significantly lower removal rate of 1.39% (Azizi et al., 2023). This highlights the importance of considering the role of particle size in filtration effectiveness.

Microplastics may vary in size, and microplastics below 5 mm are known to be challenging to filter out (Acarer, 2023). However, the Microplastic Filter efficiently removed approximately 80-93% of the microplastics on average, demonstrating its efficiency in handling various sizes.

IV. DISCUSSION

The Microplastic Filter exhibited 100% accuracy in detecting microplastic, as it successfully identified 6 grams, 10 grams, and 20 grams per liter of water. Its capability aligns with advanced technologies such as Fourier Transform Infrared (FTIR) and Raman spectroscopy, which are known for their remarkable detection capabilities. These findings highlight the device’s effectiveness in microplastic detection, indicating that the Arduino interface can serve as an alternative for this purpose.

In addition, the device demonstrated consistent and high efficiency in removing microplastics from water, as reflected in its ability to detect and extract microplastics across all tested concentrations and sizes. Using a chitosan-based filtration medium it proved effective in separating microplastics, with extracted weights consistently aligning with expected outcomes across all trials. By subtracting the initial weight of the chitosan filter (3 grams) from the measured post-filtration weights, precise quantification of extracted microplastics was achieved, showcasing the filter's accuracy.

These findings align with previous research highlighting chitosan's potential as a sustainable and biodegradable adsorbent for water treatment applications (Chen, 2022). Chitosan's chemical structure facilitates the adsorption and entrapment of microplastic particles, enhancing its suitability for filtration systems. Chitosan-based adsorbents exhibits reputable adsorption qualities to numerous pollutants (Omer et al., 2022). The filter's ability to consistently remove microplastics of varying sizes, including challenging smaller particles, further emphasizes its versatility and applicability for addressing microplastic pollution.

The filter's performance across size categories (1–2 mm and 2–5 mm) demonstrated its adaptability, achieving average removal rates of 80-93%. This adaptability is crucial for addressing the diverse nature of microplastic contaminants in real-world scenarios. The consistent detection and extraction rates at a fixed concentration of 10 grams per liter underscore the filter's reliability, highlighting its potential for application in both domestic and industrial water treatment systems. These findings contribute to the growing body of evidence supporting the use of chitosan as an effective, eco-friendly solution for mitigating microplastic contamination in aquatic environments.

The abundance, non-toxic, anti-bacterial, biocompatible, and hydrophilic properties of chitosan proves its promising applicability to address the growing presence of pollutants in water (Janaína Oliveira Gonçalves et al., 2024). Chitosan is a biodegradable material that has a high absorption rate; but over time, its ability to trap microplastics will decrease as the material gets more saturated. Moreover, the chitosan filter can degrade over time when exposed to water with fluctuating pH levels and high temperatures (Xu, et. al, 2015). Prolonged exposure may weaken the chitosan matrix, leading to reduced filtration efficiency. The chitosan filter is designed to specifically extract microplastics. However, it does not target and address other pollutants such as metals, organic contaminants, and microbial pathogens. Additional water treatment systems may be incorporated to ensure purification of water.

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