Near-Infrared Light and OpenCV as Components for Low-Cost Airborne Microplastic Detection Machine

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Abstract

Microplastic, resulting from the breakdown of larger plastic objects, poses substantial threats to ecosystems and human health. This research addresses the escalating environmental concern of airborne microplastics by developing a low-cost detection machine employing infrared sensors. The near-infrared light is attached to the machine for detection using the sensors. Different types of microplastic, specifically less than 5mm, are used. There are 3 types of plastics used for detection, 30 pieces each of polyethylene, polystyrene, and polyester microplastics. Each type of microplastic is tested for detection in different time frames, 1, 2, 3, 4, and 5 minutes each, and the three types of plastics are combined randomly for the last detection with the same number of minutes. Because of the final results, it can determine the effectiveness of the sensor in detecting airborne microplastics in terms of the number of correctly detected microplastics. In conclusion, this research advances our capacity to detect airborne microplastics, contributing to environmental conservation and public health protection. The detection machine's development and the insights gained from the study have broader implications for standardizing methodologies, advancing technology, and fostering collaborative efforts in addressing the challenges posed by airborne microplastics.

1. Introduction

In recent times, microplastics have gained the status of a serious environmental challenge as scientists from around the globe have given these items a high degree of attention. The nano-sized plastic particles that undergo decomposition from the large suspended plastic particles are the ones crossing through several ecosystems, causing major threats to environmental sustainability as well as human health (National Geographic, 2022). The common fear at the outset revolved around microplastics in the aquatic environments; while the investigators of late are turning their attention towards the presence of this pollution in the air. There is, therefore, a need to do more research into the scope, effects, and mitigation strategies for airborne microplastic contamination (Sridharan et al., 2021).

Minuscule non-solid microplastics deemed to be airborne by low altitude and the slightness of their gravitational force, are carried off by winds to distances that become almost boundless. The importance of microscopic ambient particles/air, which is considered one of the factors of breathing illnesses by researchers, has become an issue that is widely questioned (Prata, 2018). Several studies indicate that in the case of microplastic inhalation, respiratory diseases may occur. However, in the cause of assessment, individual characteristics and particle characteristics may come into play to determine the extent of the impact of health risks (Prata, 2018).

Along with inhaling contaminated air, microplastics may also enter our bodies through the consumption of food and drink which are contaminated, and thus the problem aggravates. Studies showed that people don't knowingly eat an impressively high amount of microplastic particles per year (Armstrong, 2021). Among other complications created by these hydrophobic and large-surface-operation phenomena, the presence of various environmental contaminants, such as Industrial chemicals or insecticides, in their surroundings is facilitated (Akhbarizadeh et al., 2012).
Microplastics to be found in the human body are reported to aggravate some illnesses. Complications in the treatment of microplastic inhalation from the air environment may include oxidative stress, inflammation, and even potential health struggles (Shao, Li et al., 2021). In this way, these particles also act as viral vectors which not only expose our respiratory system to contaminated material but are the pathways through which infective agents can be transitioned (Ordonez, 2022). Moreover, during the process of fragmentation of plastic, it can release heavy metals, and the concentration will be higher (Santana-Viera et al., 2021; Wright & Kelly, 2017).

Any impact that these pollutants have on human health and climate warrants further investigation. Indirectly determining such weather conditions as precipitation and temperature through advice on atmospheric transport and cloud formation has been recognized (Jones, 2023).

Research into microplastics in the air is in a state of development utilizing gaining more and more knowledge about the reality of their wide presence. Studies have established the presence of microplastic umbrellas in the air across different environments, from urbanized settings to remote locations (Campanale et al., 2020). Although these advances have been tremendous, the obstacles persist. The most challenging aspect is the development of standardized methods of data acquisition and calculating airborne microplastic a reason to compare different sets of studies (Sarathana & Winijkul, 2023). On top of that, the issue of human health impact from inhalable microplastic particles is intricate and difficult to tackle (Ivleva, 2021). The discussion of chemical analysis and microplastics/nanoplastics is still an ongoing research area for the scope of research (Ivleva, 2021). Research, therefore, underscores the value of evaluating microplastic pollution data to use it to guide remediation strategies (Jenkins et al., 2022). Micropollution studies in the air tend to overcome a set of obstacles that hinder investigating sources, eliminating micro-fragments, measuring their distribution, and inferring impacts; thereby, the field seeks to remain proactive on the above (Chieh Kun et al., 2022).

Machine development that succeeds in taking care of the large-scale collection and detection of airborne microplastics is of significant importance concerning microplastic research. The main reason behind building such technology is to improve the efficiency, repeatability, and scalability of data gathering which is highly required when you are attempting to obtain in-depth information about the ubiquitous problem of microplastic pollution. The ultra-sensitive sensor for airborne microplastic detection can provide more comprehensive and consistent datasets, thus allowing ecologists to evaluate more thoroughly microplastic distribution, source investigation, and potential implications for ecosystems and human life. Therefore, this technology not only simplifies the scientific investigation process but also lends itself to replication of methodologies thus enabling unprecedented comparisons cross-visits, and the intricate dynamics of microplastics are unveiled. Finally, the development of such devices is a good move in the scientific field to deal with the difficulties of microplastic contamination and provides methods for making decisions and strategies to mitigate these problems well.

Moreover, the development of a low-cost detection machine utilizing near-infrared light and OpenCV for airborne microplastic detection signifies a groundbreaking application of geospatial technologies in environmental science. This innovative technology plays a crucial role in advancing environmental conservation and safeguarding public health by facilitating efficient data collection on airborne microplastics, aiding in assessing their impacts on ecosystems and human health, guiding remediation efforts, and informing policy decisions to combat microplastic pollution. Moreover, by standardizing methodologies and enabling comparisons across studies and regions, this machine contributes significantly to advancing knowledge and developing effective solutions in the realm of airborne microplastic research. Additionally, its accessibility fosters collaborative efforts globally, promoting knowledge sharing, interdisciplinary synergies, and a unified approach towards addressing the pervasive challenge of airborne microplastics.

2. Review of Related Literature

Plastics have attracted a growing concern in present times mainly because an estimated 8 million tons of waste from these are dumped into oceanic habitats. In addition to ecosystems, this plastic pollutes human health. This review aims to give first and foremost the reader as a whole comprehension of what we know about airborne microplastics which includes their presence and concentrations, their origins, and the consequences. The literature review will encompass studies on the presence of microplastic particles in the opening to the atmosphere, their characteristics, possible health hazards, and the mechanisms behind the particles' dispersion.

Living organisms and animals without exception are impacted by microplastics (MPs) and nanoplastics (NPs), which are the categories of upcoming pollutants with high occurrence in the air. Because of a size of fewer than 0.3 micrometers, differing shapes, a wide variety of polymeric nature, applied coatings, as well as the large surface area that draws chemical and microbial sorbates, they are difficult to detect, identify, and quantify them in environmental matrices and biota. This mini-review focuses on the benefits and disadvantages of analytical approaches used commonly for MP and NP measurement. These methods of analysis can be broadly classified as mass spectrometry techniques, such as matrix-assisted laser desorption/ionization time-of-flight analysis (Adhikari et al., 2021), or pyrolysis gas chromatography, as well as liquid chromatography coupled to tandem mass spectrometry, stereoscopic microscopy, scanning electron microscopy

Over the past decade, both the scientific society and media increased their focus on the decrease of environment caused by microplastics (MPs) via articles and television (Beaurepaire et al., 2021; Ramkumar et al., 2021). The range of materials composed of several different elements, including nitrogen, carbon, hydrogen, oxygen, chlorine, and sulfur, belongs to the group of "plastics" (Li et al., 2020).

Microplastic, which is currently one of the greatest concerns, has attracted considerable attention mainly because of the extensive air discharge which consequently leads to loss of biodiversity and ultimately ecosystems. From the following sources including automobile tires, brake pads, industrial processes, to waste incineration are the main sources of microplastics in the outdoors. Besides, amazingly, the sizes of these particles can be found around the globe- from the Pyrenees Mountains of Spain to the Polar Regions, at the rate of 154,000 particles per liter to the minimum of 0.3 particles per liter. Amazingly, though, indoor air environments may also be polluted by dust mites more and may even record up to 9900 particles per day. The deteriorating components of indoor ceilings and walls, along with other synthetic materials such as textiles and furniture finishes, are the main sources of microplastics (IUPAC). These particles can display distinct actions in the air like attachment (or adhesion), suspension, resuspension, and spontaneous settling. They can also interact with other chemicals, microbes, and microplastics. Microplastics also become more noticeable through airborne deposition, especially during heavy rains. In open settings and because they operate by the power of sunlight, they can be spread to far distances by the trade winds. The electrostatic links and the hydrogen bonds, which are like two legs of the same stool, are what make the complicated interplay between airborne microplastics possible.

During the last 70 years, plastic production has gone up as much as the world demand, from 1.7 to 360 million tons yearly, and this has encouraged several uses such as the construction, packaging, and automotive sectors that depend on plastic products. According to Plastics Europe (2020), the most often used polymers are polypropylene (19.4%), polyethylene (low density: 17.4% of the total, 10.5% for high-density polyethylene, 10% for polyvinyl chloride, 7.9% for polyurethane, and 7.9% for polyethylene terephthalate.

The fact that some MPs have just been detected both in the Arctic and Antarctic (Brahney et al., 2021; Can-Güven, 2021; Qian et al., 2021; Szewc et al., 2021) brings attention to the possibility of a transport mechanism for MPs through the atmosphere (Bergmann et al., Lebreton and Andrady (2019) argue that the amount of plastic discharge into the ecosystems will increase as a result of the predicted three-fold growth of plastic waste to be generated worldwide by 2060 which would rise from half a billion tons yearly between 2015 and 2030 to 265 million tons.

With airborne microplastics, the effect on human health is not the only concern. Their influence on animals and plants is also a subject of discussion. Having been exposed to microplastics airborne most of the time has shed light on the health effects such as developmental problems, oxidative stress, inflammatory reactions, and, ultimately, the point of having increased risk for human cancer. Moreover, these particles have got negative effects on the ecosystems as they cause the inhibition of the plants and retard in the seedling. The good thing is that there are mitigation strategies in place directly or indirectly that contribute to reducing airborne microplastics. This can be through regulatory measures, source reduction strategies, the use of biodegradable materials, or air conditioning filters. We still need more scientific research to help us advance beyond

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our current knowledge of airborne microplastic pollution which largely focuses only on marine, freshwater, and terrestrial environments. The shortage of the scope of the current research can be seen by a review of only 140 research papers published during the last 10 years (Zhao et al., 2022).

In traveling to the site, MPs can fly over considerable distances with an enormous height of approximately 95 kilometers, according to Allen et al. (2019). In the long run, they will contaminate the hydrosphere and the terrestrial surfaces through precipitation deposition- both for wet and dry forms (Li et al., 2020). As Khalid et al. (2020) indicate, the MPs become reactive with the environment by releasing their intrinsic chemical components such as flame retardants, antibacterial agents, plasticizers, and BPA. The sorption of MPs' full spectrum of chemicals involves organochlorine pesticides (OCPs) such as dichlorophenyldichloroethane (DDT), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) (Akhbarizadeh et al., 2021; Jiménez-Skrzypek et al., 2021).

It can be said that the anxiety level relating to microplastics (MPs) and the threat the environment faces from human activities must have worryingly increased to the max over the last decade. However, the legislators have evolved into algalites and become real stratigraphic indicators of the epoch of the Anthropocene. Yet recent findings indicate that the atmosphere is a vast resource where short-range invisible microplastics carry huge distances over the ocean and alpine reaches. However, the lack of uniform procedures for the monitoring and measurement of atmospheric microplastics was an obstacle to profound studies even though it is a matter of great concern; of course, it is not due to the prevalence of soil and water pollution monitoring. This paper reviews thoroughly the literature on what MPs are and the current techniques used for sampling, identification, and extraction of them are highlighted. This sample assessment covers "passive" and "active" sampling procedures, visual recognition, and separation by density which will mark the base of further research. A high-level classification, sources, transport mechanisms, short and long-term distribution patterns, and ecological impact have been provided across the article proceeding with the profound analysis of these numerous physical, and chemical properties.

Moreover, efforts to study the potential harmful exposures of inhalable MPs should be stepped up. Certified and standardized protocols and methods need to be developed to advance our knowledge about airborne microplastics and to stop detriment to the environment and human health. It is imperative that sampling becomes a constant thing since the circulation of the airborne MPs is everywhere present as showcased by the pollutants and the contaminants. Forward research studies should clarify microplastic involvement and their applications across the lithosphere, hydrothermosphere, and atmosphere (Shao et al., 2022).

3. Methodology

This study is aimed at assessing the performance of the detection machine and its elements for catching airborne microplastics. This is a usability research design that emphasizes the impacts of the machine's design on various types of airborne plastic particle detection to locate substantial detection differences for different periods. The quantitative approach was chosen and used to reveal the cause-and-effect relationships as well. The utilized statistical tool was the Analysis of Variance (ANOVA) for the analysis.

The OnShape computer-aided design service served as a basis for building up the general structure of the machine. The acrylic board of the machine body came to us from a nearby glazing shop, and the hardware supplies were all from different hardware stores. LEDs, resistors, switches, and a webcam were bought from an electronics supplies store nearby and one of the researchers had provided the webcam herself.

The acrylic sheet was precisely cut to obtain the various desired sizes, and the dimensions were set to match the design. Once the material was cut, the pieces were sanded with emery paper and spray-painted black. The paint reduces the emittance of light. The hand drill was used to fasten the wheels along with the main body of the machine by drilling holes in it. Pressed metal parts with rivets and screws were used for assembly, and the main electrical equipment was put at the back of the vending machine and fastened with screws.

Each piece of electronics was wired and soldered to a perfboard to make electrical connections. Wires were attached to the perfboard as the components were secured. The main power unit was connected to start supplying the power to the electronic components, and the electronic parts were isolated after they had been installed to prevent power disconnection issues.

The camera module was then mounted on top of the camera stand using the nuts and bolts. Afterward, modification on the lens was undertaken such that the lens had a precise field of view. The apparatus was then aligned to the center to take the testing size.

The machine was programmed with the Python programming language as the underlying programming language, and PyCharm is the integrated development environment in which the entire program development process was done. The OpenCV library and its contour-detection feature were installed and used in the program after certain optimization algorithms were considered.

The main power module was supplied with power at that time, which triggered the activation of the machine, and the loaded program was run to start the process. After that, the machine was started for a 30-minute run, a type of sequencing process, to carefully check for any electrical connection issues. Following this, the program was additionally tested completely for errors, and the machine was turned off till the demand for data was there to be obtained.

Filtering and thresholding techniques are employed to isolate the desired output. Filtering methods like median filtering is used to help remove noise and enhance the signal-to-noise ratio, crucial for the accurate detection of microplastics in the air. Otsu's thresholding method was also applied to segment the signal and identify regions of interest, aiding in the precise detection of microplastics based on their unique spectral characteristics in the near-infrared spectrum. The researchers employed Fourier transform analysis to decompose the near-infrared (NIR) signal into its constituent frequency components, enabling them to isolate and identify specific regions of interest that corresponded to the unique spectral signatures of airborne microplastics.

The process of collecting data was done by switching the machine on followed by the initiation phase and the samples brought in for testing were the last step. The results of data processing by the machine were delivered through the system dialog also an additional CSV file intended for the researchers' and data analysis purposes. Next, each sample was tested and the device was deactivated and put in storage.

To analyze data the investigators used the software IBM SPSS version 26. A one-way ANOVA manner was presented to indicate the mean of three or more independent groups which might be different from each other. Consequently, the statistical analysis would check for a valid outcome, and then would Tukey's and Scheffe's post-hoc tests be used to evaluate the distinctness between various groups' mean values. Now in addition to testing the effectiveness of the machine, the researchers used a sensitivity test to make sure the percent accuracy was the same.

The summation of this study applied the sophisticated research design, and the methodology to measure whether some specific components of the detection machine are the most effective for finding the airborne microplastics. Utilization of a usability research design, quantitative methods with ANOVA, Tukey's, and Scheffe posthoc tests, as well as a sensitivity test during the data research, has yielded strong, in-depth, and vivid results.

4. Results

Trial	Count	Sum	Mean	Variance
1st	12	260.43	21.70	0.07
2nd	12	251.47	20.96	0.54
3rd	12	234.60	19.55	0.02

Table 1. The number of polyester microplastics detected

Table 1 illustrates the varying number of polyester microplastic across three trials. Notably, the first trial has the highest average number of detected polyester microplastics (Mean = 21.70).

Trial	Count	Sum	Mean	Variance
1st	12	201.09	16.76	0.06
2nd	12	199.77	16.65	0.29
3rd	12	191.40	15.95	0.21

Table 1. Number of polyethylene microplastics detected

Table 2 illustrates the varying number of polyethylene microplastic across three trials. Notably, the first trial has the highest average number of detected polyethylene microplastics (Mean = 16.76).

Trial	Count	Sum	Mean	Variance
1st	12	256.01	21.33	0.02
2nd	12	313.68	26.14	0.01
3rd	12	281.06	23.42	0.01

Table 2. Number of polystyrene microplastics detected

Table 3 illustrates the varying number of polystyrene microplastics across three trials. Notably, the second trial has the highest average number of detected polyester microplastics (Mean = 26.14).

Time (Seconds)	Mean		
	Polyester	Polyethylene	Polystyrene
5	20.48	16.43	23.64
10	20.72	16.39	23.57
15	20.53	16.13	23.64
20	20.93	16.53	23.59
25	20.97	16.15	23.50
30	21.39	16.93	23.60
35	20.48	16.28	23.63
40	20.69	16.69	23.70
45	20.56	16.59	23.64
50	20.86	16.59	23.71
55	20.72	16.41	23.69
60	20.49	16.30	23.69

Table 3. Mean of three trials per microplastic type against time

Table 4 shows the mean of every three trials per microplastic type. This mean was then put up against their respective time (seconds). Notably, the polystyrene group has the highest number of recorded microplastic, followed by the polyester group, and lastly, by the polyethylene group

Source of Variation	SS	df	MS	F	P-value
Between Groups	286.378	2	143.189	304.440	0.05
Within Groups	15.521	33	.470		
Total	301.899	35			

Table 4. Analysis of variance between microplastics detected based on the type

A one-way ANOVA shows that there is a significant difference between the three groups – polyester, polyethylene, and polystyrene terms of the detected number of microplastics; $F(2,33) = 304.440$, $p > 0.05$.

Therefore, the null hypothesis - there is no significant difference between the capability of the machine in sensing different kinds of airborne microplastics between the groups: polyester, polyethylene, and polystyrene – is rejected.

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Microplastic Type (I)	Microplastic Type (J)	Mean Difference $(\bar{x}-\bar{x})^2$	Std. Error	Significance
Polyester	Polyethylene	4.28	0.28	0.00
	Polystyrene	-2.90	0.28	0.00
Polyethylene	Polyester	-4.28	0.28	0.00
	Polystyrene	-7.18	0.28	0.00
Polystyrene	Polyester	2.90	0.28	0.00
	Polyethylene	7.18	0.28	0.00

Table 6. Tukey’s posthoc test of detected microplastic based on the type

The findings show why the null hypothesis was rejected. There is a significant difference between the number of airborne microplastics detected all across the pairs, specifically in the pairs of Polyester and Polyethylene, Polyester and Polystyrene, as well as Polyethylene and Polystyrene – since $p < 0.05$.

Timeframe	Counts	Mean	Std. Deviation	Minimum	Maximum
1 Minute	12	15.87	.07013	15.70	15.95
2 Minutes	24	16.13	.44778	15.41	17.65
3 Minutes	36	16.14	.41048	14.40	16.68
4 Minutes	48	16.39	.24529	15.20	16.79
5 Minutes	60	16.56	.24189	15.89	16.98
Total	180	16.33	.37447	14.40	17.65

Table 5. Means of combined microplastics detected based on different timeframes

Table 7 illustrates the overall mean of detected combined microplastics across different time frames – 1 minute, 2 minutes, 3 minutes, 4 minutes, and 5 minutes. Notably, the 5-minute group shows the highest number of microplastics detected as indicated by the mean (Mean = 16.56).

Source of Variation	SS	df	MS	F	P-value
Between Groups	8.26	4.00	2.06	21.45	.000
Within Groups	16.84	175.00	0.10		
Total	25.10	179.00			

Table 6. Analysis of variance between combined microplastic based on different timeframe

A one-way ANOVA shows that there is a significant difference between the five groups – 1 minute, 2 minutes, 3 minutes, 4 minutes, and 5 minutes timeframes; $F(4, 175) = 21.45$, $p < 0.05$. Therefore, the null hypothesis - there is no significant difference between the number of airborne microplastics detected within the group: 1 minute, 2 minutes, 3 minutes, 4 minutes, and 5 minutes – is rejected.

Microplastic Type (I)	Microplastic Type (J)	Mean Difference $(\bar{x}-\bar{x})^2$	Std. Error	Significance
1 Minute	2 Minutes	-0.26	0.11	0.13
	3 Minutes	-0.27	0.10	0.07
	4 Minutes	-0.52	0.10	0.00
	5 Minutes	-0.70	0.10	0.00
2 Minutes	1 Minute	0.26	0.11	0.13
	3 Minutes	-0.01	0.08	1.00
	4 Minutes	-0.26	0.08	0.01
	5 Minutes	-0.43	0.07	0.00
3 Minutes	1 Minute	0.27	0.10	0.07
	2 Minutes	0.01	0.08	1.00
	4 Minutes	-0.25	0.07	0.00
	5 Minutes	-0.42	0.07	0.00
4 Minutes	1 Minute	0.52	0.10	0.00
	2 Minutes	0.26	0.08	0.01
	3 Minutes	0.25	0.07	0.00
	5 Minutes	-0.17	0.06	0.04
5 Minutes	1 Minute	0.70	0.10	0.00
	2 Minutes	0.43	0.07	0.00
	3 Minutes	0.42	0.07	0.00
	4 Minutes	0.17	0.06	0.04

Table 9. Scheffe Post-hoc Test of Detected Microplastics Based on Different Timeframes

The findings show why the null hypothesis was rejected. There is a significant difference between the number of airborne microplastic detected all across the pairs, specifically in the pairs of 1 minute and 4 minutes, 1 minute and 5 minutes, 2 minutes and 4 minutes, 2 minutes and 5 minutes, 3 minute and 4 minutes, 3 minute and 5 minutes – since $p < 0.05$.

	Polyester	Polyethylene	Polystyrene
Mean Percentage	69.12	54.84	78.77

Table 7. Mean percentage of correct number of microplastic detected based on average values between three trials

Table 10 presents the percentage of a correct number of microplastics detected between three trials. The average percentage of the correct number of microplastics detected over the total number of samples is calculated for each type. For Polyester, the average percentage is approximately 69.12%, for Polyethylene it is around 54.84%, and for Polystyrene, it is about 78.77%. These values indicate the accuracy of the machine in detecting microplastics of different types, with the highest accuracy observed for Polystyrene and the lowest for Polyethylene.

5. Conclusion

The work by Lorenzo-Navarro et al. (2020) summarizes the innovative Computer Vision-enabled system for unbiased plastic microfiber enumeration by displaying ultra-high caliber in the classification of particles. The research highlights the ability of image processing algorithms to change the detection of microplastics and enables the biologists to cover a much larger area and thus, can provide more data than could be monitored manually.

Also, the study shed some light on the role of time frames in the microplastic detection process. Several patterns were observed in the detection of microplastics from polyester, polyethylene, and polystyrene, across different trials and time durations among which only polyethylene exhibited a significant pattern The findings stress that detection techniques need to be more specific to improve the accuracy and reliability and the case study of the polystyrene is the highest compared with other types of microplastic.

What is more, the aspect of research not only furthers microplastic studies but also supports vital environmental problems through this procedure of constructing cheap airborne microplastic detection machines with infrared rays. The findings of the research have far-reaching implications for the conservation of the environment, health protection, advancement of technology, education, and policy-making drawing the line of the fact that more needs to be done, and the technologies have to be more refined and remarkable in fighting the microplastic pollution and saving ecosystems and human health.

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