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Automated Optical Detection of Potential Microplastic Particles in Water

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Abstract: ***Microplastic contamination in drinking water has become an increasing environmental and health concern due to the widespread use and degradation of plastic materials. Conventional techniques such as Fourier Transform Infrared Spectroscopy (FTIR), Raman Spectroscopy, and Scanning Electron Microscopy (SEM) provide accurate identification, but they require expensive laboratory equipment, trained personnel, and considerable time, making them unsuitable for routine monitoring. This paper presents an automated optical detection and monitoring architecture for potential microplastic particles in water using microscopic imaging and computer vision. A water sample is pumped through a micro-filtration setup (20–50 µm membrane) using a peristaltic pump monitored by a flow sensor for precise volume measurement. The retained particles are imaged under a digital microscope with LED back-illumination, and the captured images are processed using a fine-tuned YOLOv8n object detection model. Real-time diagnostics, particle counts per liter, and confidence scores are presented on a local display and synchronized to a web platform dashboard (built with React.js and Node.js). A literature review shows that existing systems lack low-cost edge deployment with high-throughput filtration and web analytics, motivating the proposed design. The paper presents the problem definition, objectives, system architecture, methodology, expected benefits, and experimental results.***

Keywords: microplastics detection, computer vision, YOLOv8n, microscopic imaging, water quality monitoring, edge AI, Node.js, React.js

I. INTRODUCTION

Access to clean, potable water is an urgent global priority, as drinking water supplies increasingly face micro-pollutants and microplastic intrusion from synthetic textiles, degradation of packaging, and industrial runoffs. Conventional drinking water treatment plants often fail to retain microscopic particles below 1 mm, leading to potential ingestion and associated bioaccumulation risks. Standard identification methods rely heavily on laboratory-bound analytical tools such as FTIR spectroscopy, Raman spectroscopy, and SEM. While these methods yield high chemical specificity, their operational complexity, prolonged turnaround time, and high capital costs render them impractical for point-of-use or continuous field monitoring.

To address these limitations, this paper presents an automated, low-cost optical microplastic detection system combining embedded fluidic sampling, high-magnification digital microscopy, and deep learning-based computer vision. The system routes a measured volume of water through a micro-membrane filter via a peristaltic pump and flow sensor. Trapped particles are imaged in an integrated chamber under controlled LED/UV back-illumination and analyzed by a YOLOv8n object detection model. Quantitative detection results and confidence scores are displayed locally and transmitted to a cloud-based web application for spatial and temporal analytics.

The contributions of this paper are:

1) A systematic review of existing optical and AI-driven microplastic detection techniques highlighting gaps in low-cost field deployment.
2) An integrated architecture combining volume-controlled micro-filtration, digital microscopic imaging, and YOLO-based real-time detection.
3) An end-to-end processing methodology linking hardware acquisition with a web dashboard.

II. RELATED WORK

Research on microplastic detection spans laboratory spectroscopy, optical microscopy, machine learning, and IoT-based monitoring networks.

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A. Deep Learning and Computer Vision Models

Chen and Liu [1] proposed a CNN model achieving 97% accuracy on microscopic water particle images; however, high computational demands hinder direct deployment on resource-constrained platforms. Park et al. [3] implemented a YOLOv5 model achieving 89% accuracy for real-time localization, but noted substantial computational and dataset overheads. Li et al. [5] utilized MobileNetV2 transfer learning, reaching 90% classification accuracy on specific polymers, while Teng et al. [6] used SVM on handcrafted shape/texture features for classification

B. Optical and Staining Techniques

Bhagat et al. [2] and Stanton et al. [12] demonstrated high-sensitivity microplastic detection using Nile Red fluorescent staining under UV light and HSV color thresholding; however, chemical preparation adds complexity and limits field usability. Acharya et al. [9] proposed a low-cost LED photodetector optical sensor for particle concentration estimation, though it lacked particle shape/size resolution. Automated microscopic stages proposed by Biber et al. [10] improved throughput but significantly increased hardware costs.

C. Portable and Edge Implementations

Kumar and Nair [8] built a portable analyzer using a Raspberry Pi camera and Otsu thresholding with 78% accuracy, though performance degraded at high particle densities. Gupta et al. [7] validated TensorFlow Lite on Raspberry Pi for edge environmental monitoring. OpenCV-based image processing pipelines using thresholding and contour detection were analyzed by Zhang et al. [11].

D. Environmental Occurrence and Health Impact

Selvam et al. [4] confirmed microplastic presence across tap water in five Indian cities using FTIR and SEM, emphasizing urban contamination. Pivokonsky et al. [16] documented microplastics in raw and treated drinking water, while Mintenig et al. [17] analyzed wastewater effluents. The WHO
[18] and Eerkes-Medrano et al. [19] stressed the need for standardized, accessible monitoring. Serranti et al. [20] demonstrated hyperspectral imaging for polymer classification, though cost remains prohibitive.

E. Research Gap

Table I compares representative systems with the proposed approach. Existing works fail to integrate low-cost automated sample filtration, microscopic optical imaging, YOLO-based object detection, and web-based dashboard analytics into a single unit

TABLE I .Key Features and Limitation

Ref.	Key feature	Limitation
[1]	CNN for microscopic particle analysis (97% accuracy)	High computational demand; no field unit
[2]	Nile Red fluorescence microscopy	Requires chemical staining
[3]	Real-time YOLOv5 detection (89% accuracy)	High resource consumption
[8]	Raspberry Pi + Otsu thresholding (78% accuracy)	Fails with overlapping particles
[9]	Low-cost LED-photodetector sensor	No shape/size classification
[10]	Automated microscopy for high throughput	High hardware cost
[20]	Hyperspectral imaging for polymer sorting	Prohibitive equipment cost

III. PROBLEM IDENTIFICATION AND OBJECTIVES

A. *Problem Identification*

1) Microplastics (<5 mm) in drinking water are invisible to the naked eye and difficult to track continuously.
2) Laboratory methods (FTIR, SEM, Raman) are expensive, time-consuming, and unsuitable for rapid field screening.
3) Manual microscopic counting is tedious, slow, and prone to subjective human error.
4) Traditional image thresholding struggles with particle overlap and non-uniform background noise

B. *Objectives*

The objectives of this work are to:
1) Design a low-cost, portable optical microplastic detection system using digital microscopy and embedded fluidics.
2) Implement a micro-filtration setup (20–50 µm membrane) with peristaltic pumping and flow sensing for volume quantification.
3) Train a fine-tuned YOLOv8n deep learning model to automatically locate, bound, and count potential microplastic particles.
4) Develop a Node.js backend and React.js frontend web interface for seamless image upload, particle count estimation per liter, and analytics

IV. PROPOSED SYSTEM ARCHITECTURE

A. *Fluidic and Sampling Stack*

The physical sampling line consists of a water sample inlet connected via silicone tubing and hose fittings. A 12V peristaltic pump transfers the liquid through a YF-S201 flow sensor to measure precise sample volume. The sample passes through a 20–50 µm membrane filter that retains potential microplastic fragments and fibers.

B. *Optical Imaging Chamber*

The retained filter slide is transferred to an illuminated imaging chamber featuring an adjustable USB digital microscope with controlled LED/UV back-illumination, capturing magnified high-contrast particle images.

C. *AI Detection and Software Stack*

Captured microscopic images are annotated using Roboflow and used to train a YOLOv8n object detection model. The backend, built on Node.js and Express.js, processes API requests, runs inference, and returns bounding boxes with confidence scores. The React.js frontend displays original vs. detected images, total particle count, and confidence metrics.

D. *Block Diagram*

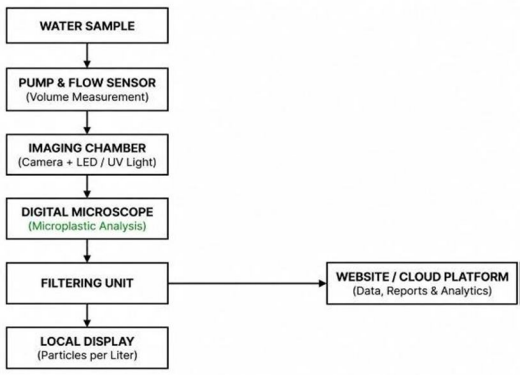


Fig 1. Block diagram

The Fig 1. Represents the block diagram of the proposed microplastic detection system.
It shows the process of collecting the water sample and filtering it to trap potential microplastic particles.
The trapped particles are captured as microscopic images using a USB digital microscope.
These images are processed using the YOLOv8n model to identify and localize potential microplastic particles.
Finally, the detection results are displayed through the Node.js backend and React.js web application.

V. METHODOLOGY

1) Sample Pumping & Volume Measurement: The peristaltic pump draws the water sample through the flow sensor to record volume.
2) Filtration: Water passes through the membrane filter, trapping particles down to 20 µm.
3) Microscopic Image Acquisition: High-magnification images are taken via the USB digital microscope.
4) AI Detection & Analysis: Images uploaded to the web app are processed by YOLOv8n to locate particles, generate bounding boxes, and compute confidence scores.
5) Analytics & Local/Cloud Display: Particle concentration (particles/liter) is displayed locally and stored on the cloud dashboard\

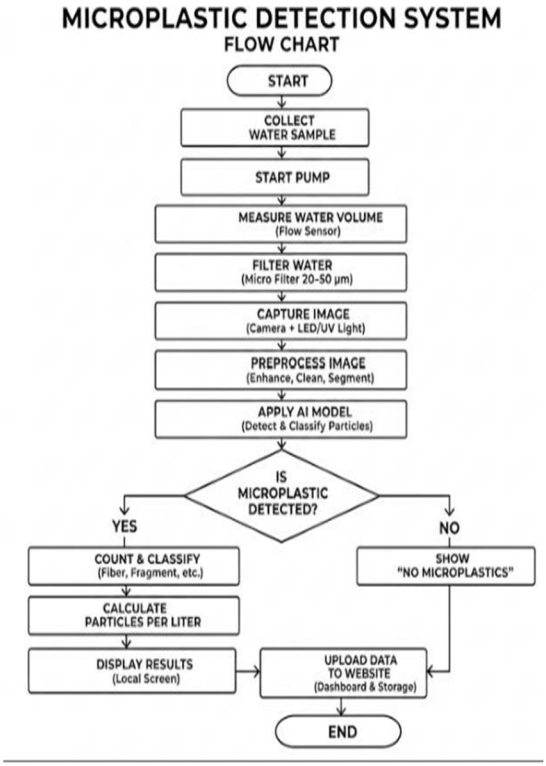


Fig. 2. Flowchart of the control methodology .

The Fig 2. illustrates the flowchart of the proposed microplastic detection system. First, the water sample is collected and passed through the filtration setup, where potential microplastic particles are trapped on the membrane filter .The filtered membrane is then placed under the USB digital microscope, and microscopic images containing potential microplastic particles are captured. These images are collected and prepared as a dataset for further processing.

VI. RESULTS

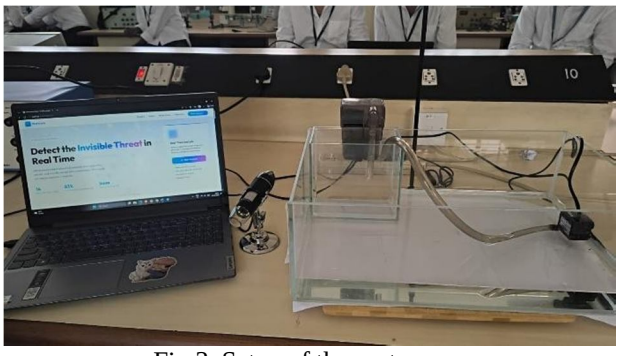


Fig 3. Setup of the system

Fig 3 represents a compact lab prototype for detecting microplastics in water. A submersible pump circulates water from the glass tank through tubing into a filtration unit, where a membrane filter traps suspended particles. The captured particles are then imaged using a USB digital microscope connected to a laptop. The images are uploaded to MicroLens, a web based analysis platform that uses computer vision to detect, count, and classify microplastics by type and size. The system offers a low-cost, fast, and automated alternative to manual particle counting, making water quality monitoring more accessible and efficient.

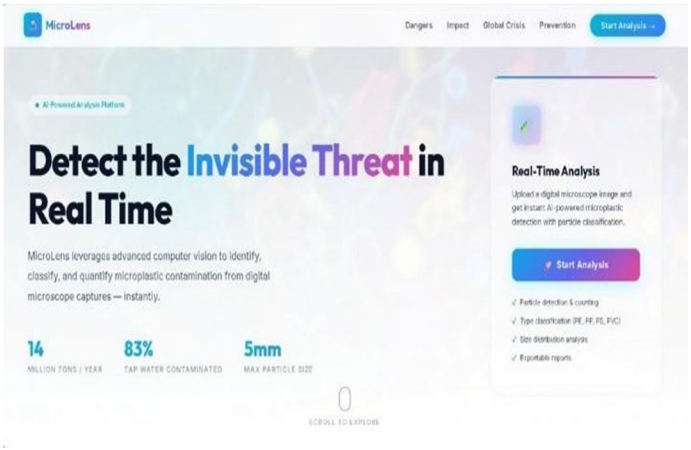


Fig 4 .Home page of web application

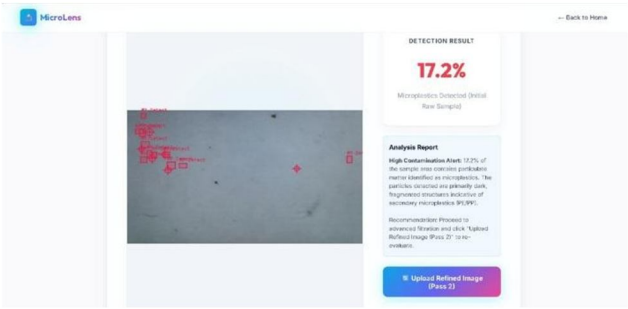


Fig 5. Initial Raw Sample Analysis

Pass 1: Initial Raw Sample Analysis

Fig 5. Represents the Initial Raw Sample Analysis. The first analysis was run on a microscope image of the raw, unfiltered sample . The model detected microplastic particles and marked each one with a red bounding box and crosshair labelled “MP-Detect”. Most detections cluster in the left region of the frame, with a few isolated detections elsewhere. The system reported a contamination level of 17.2**%**, meaning that fraction of the analysed sample area was identified as microplastic particulate.

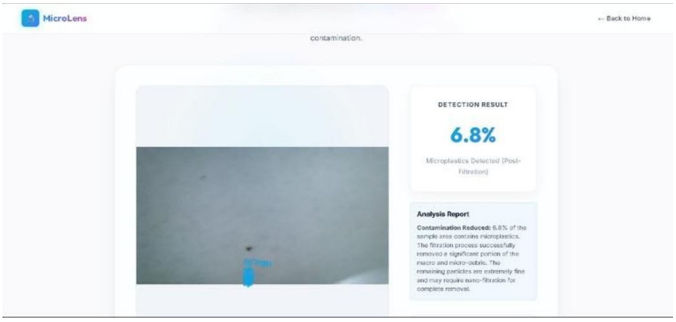


Fig 6. Post-Filtration Analysis

Pass 2: Post-Filtration Analysis

Fig 6. Represents the Post-filtration Analysis. After filtration, an image of the refined sample was uploaded for a second pass The detected contamination fell to 6.8%. The microscope view is visibly cleaner, with only a small number of fine particles remaining and far fewer detection markers than in Pass 1.

The report classified this as Contamination Reduced, noting that filtration removed a significant portion of the macro-particles and micro-debris. It also noted that the remaining particles are extremely fine and may need nano-filtration for complete removal.

VII. EXPECTED BENEFITS AND LIMITATIONS

A. Expected Benefits

An automated microplastic detection system delivers real-time, high-accuracy quantification and chemical profiling of waterborne synthetic pollutants. By automating light spectrum analysis and digital microscopy, it removes the need for slow, costly laboratory testing, dramatically reducing sample processing time from days to minutes. Its compact inline design allows for continuous, decentralized water quality monitoring directly at municipal treatment plants, industrial discharge outlets, and marine research buoys. This immediate data stream enables water managers to identify contamination spikes instantly, evaluate filtration efficiency, and safeguard ecosystems and public drinking supplies while offering a scalable, cost-effective framework for global microplastic mapping and regulatory compliance

TABLE II. Design Comparison

Aspect	Existing Methods	New approach
Equipment Cost	Very High (Spectrometers/SEM)	Low (Digital Microscope + AI Edge/Web)
Portability	Fixed Laboratory	Portable Field Unit
Turnaround Time	Hours to Days	Near Real-Time (Seconds)
Operation	Specialized Technician	Automated User-Friendly Web Interface
Equipment Cost	Very High (Spectrometers/SEM)	Low (Digital Microscope + AI Edge/Web)

B. Limitations and Future Work

Current identification relies on optical geometry and morphology rather than chemical composition. Future work includes:
Expanding training datasets across diverse polymer matrices;
Integrating edge-AI hardware for offline field deployment; and
Incorporating multi-spectral fluorescence for higher accuracy.

VIII. CONCLUSION

This paper presented an automated optical detection system for microplastics in water, integrating peristaltic filtration, digital microscopy, YOLOv8n detection, and a React/Node web platform. The system eliminates manual counting overhead and offers an affordable, accessible approach for preliminary water quality screening.

IX. ACKNOWLEDGMENT

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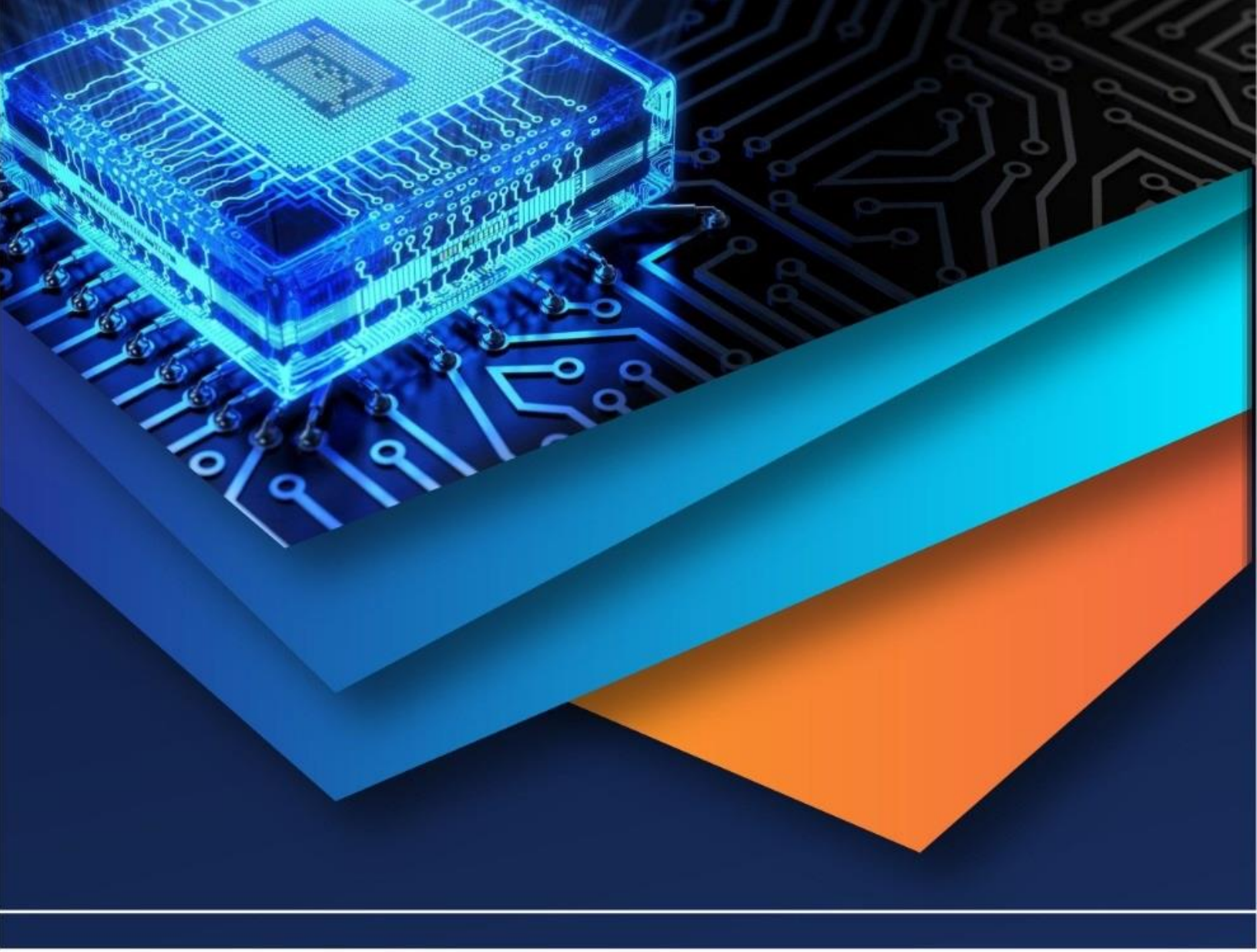
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