



(10) Publication No: **IN202511130487 A1**

(22) Date of Filing: 23-12-2025

(43) Publication Date: 30-01-2026

Journal No: 05/2026

(19) Intellectual Property Office, India

(12) INDIAN PATENT APPLICATION

(54) Title: **Development of sensor for detection of micro plastics**

(51) International Classification: G01N 21/64, G01N 21/65, G01N 33/18, G01N 21/359 G01J 3/44 (21) Application No: 202511130487 (31) Priority Document No: -- (32) Priority Date: -- (86) International Application No: -- Filing Date: -- (87) International Publication No: -- (61) Patent of Addition to Application No: -- Filing Date: -- (62) Divisional to Application No: -- Filing Date: --	(71) Name of Applicant(s): Dronacharya College Of Engineering, (72) Name of Inventor(s): 1. Shshank Rakesh 2. Aryan Goyat 3. Sagar Sood 4. Aman Nara 5. Kunal Saini 6. Tamanna Samal 7. Prof Ashima Mehta 8. Prof Renu Narwal 9. Prof Vimmi Malhotra 10. Prof Ashwani Kumar
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(57) Abstract:

Microplastic pollution has become a critical environmental issue, threatening aquatic ecosystems and human health. Current detection techniques, such as FTIR and Raman spectroscopy, are accurate but impractical for routine field monitoring due to their high cost and complexity. This project introduces a novel solution—a low-cost, portable microplastic detection sensor that operates in real-time, designed for on-site use. The sensor utilizes a combination of optical scattering and fluorescence detection, paired with an AI/ML classifier for accurate identification of microplastic particles amidst natural waterborne materials. The system processes data on-device using TinyML for efficient, real-time analysis, while IoT connectivity facilitates remote monitoring and geo-tagging of pollution data. The sensor is designed to be field-ready, making it accessible for researchers, environmental agencies, and community groups to monitor water quality effectively. This innovation offers a scalable and cost-efficient solution for microplastic detection, supporting global marine conservation efforts and contributing to Sustainable Development Goal 14 (SDG-14).

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Microplastic pollution has become a critical environmental issue, threatening aquatic ecosystems and human health. Current detection techniques, such as FTIR and Raman spectroscopy, are accurate but impractical for routine field monitoring due to their high cost and complexity. This project introduces a novel solution—a **low-cost, portable microplastic detection sensor** that operates in real-time, designed for on-site use. The sensor utilizes a combination of **optical scattering** and **fluorescence detection**, paired with an **AI/ML classifier** for accurate identification of microplastic particles amidst natural waterborne materials. The system processes data on-device using **TinyML** for efficient, real-time analysis, while IoT connectivity facilitates remote monitoring and geo-tagging of pollution data. The sensor is designed to be field-ready, making it accessible for researchers, environmental agencies, and community groups to monitor water quality effectively. This innovation offers a scalable and cost-efficient solution for microplastic detection, supporting global marine conservation efforts and contributing to **Sustainable Development Goal 14 (SDG-14)**.

Problem Statement:

Microplastic contamination has rapidly emerged as one of the most serious environmental challenges of the modern era. These tiny plastic particles, measuring less than 5 millimetres, infiltrate water bodies such as oceans, rivers, lakes, and even drinking water, causing irreversible damage to ecosystems and potentially threatening human health. Current microplastic detection methods, including **FTIR** and **Raman spectroscopy**, are precise but come with significant drawbacks—they are **expensive, slow**, and require **laboratory settings**, making them impractical for regular field use. This gap in detection technology necessitates the development of a **portable, cost-effective solution** that enables **real-time monitoring** in natural environments.

Objective:

This project aims to create an **affordable, portable microplastic detection sensor** that can operate **in real-time** and provide immediate data on microplastic pollution levels in various water bodies. By combining **optical scattering** and **fluorescence detection** with **AI/ML-powered classification**, the system delivers accurate identification of microplastics. The sensor's integration with **IoT technology** allows for continuous monitoring and pollution mapping, making it an ideal tool for environmental agencies, researchers, and community organizations to monitor water quality effectively.

Key Features of the Microplastic Detection System:

1. Detection Mechanism:

- The sensor leverages **two complementary techniques**:
 - **Optical scattering**, where light interacts with particles and is scattered based on their size and shape.
 - **Fluorescence**, where microplastic particles emit light when exposed to UV light, which the sensor detects to differentiate between plastics and natural materials.

2. AI/ML Integration for Real-Time Classification:

- The device uses an **AI/ML classifier** to instantly process data and differentiate between microplastics and natural debris. Using **TinyML**, a version of machine learning optimized for low-power edge devices, the classifier performs analysis directly on the sensor, ensuring real-time, local processing without the need for cloud-based computing.
- 3. **Flow Chamber Design:**
 - The **flow chamber** design allows for smooth, controlled movement of water through the sensor, ensuring even distribution of particles for consistent and accurate readings.
- 4. **IoT Connectivity and Cloud Integration:**
 - The sensor is equipped with **IoT connectivity** via the **MQTT protocol**, enabling the real-time transmission of data to a cloud dashboard. This facilitates remote monitoring, pollution mapping, and tracking of microplastic concentrations across multiple locations.
- 5. **User Interface and Data Visualization:**
 - A **mobile app** and web-based dashboard display the detected microplastic levels in **real-time** through interactive graphs and geo-tagged pollution maps. The interface is designed to be intuitive, allowing easy access to data by environmental organizations and local communities.
- 6. **Modular and Scalable Design:**
 - The hardware is designed to be **modular**, offering flexibility in component upgrades or replacements. This makes the system both cost-efficient and scalable for broader deployments, enabling large-scale environmental monitoring initiatives.

System Workflow:

1. **Water Sample Flow:** Water is introduced into the sensor's flow chamber for testing.
2. **Light Interaction:** The laser/LED light interacts with waterborne particles, triggering optical scattering and fluorescence responses from microplastics.
3. **Data Analysis:** Data captured by the photodiode or CMOS sensor is processed locally by the TinyML classifier for real-time results.
4. **Transmission:** The processed data is transmitted to the cloud using the MQTT protocol, providing instant updates on the IoT dashboard and mobile app.
5. **Pollution Mapping:** The dashboard visualizes the data with geo-tagging and provides pollution concentration maps for monitoring purposes.

System Requirements:

Software Requirements:

- LED / Laser source
- Photodiode / CMOS detector
- Flow chamber

Hardware Requirements:

- Node.js + Express.js
- Firebase / AWS IoT Core
- MQTT Protocol

- Python
- React.js\

Impact and Benefits:

1. **Early Detection and Pollution Management:** By offering **immediate results**, the sensor enables early detection of microplastic contamination, allowing for quick intervention to prevent further environmental damage.
2. **Cost-Effective Solution for Field Monitoring:** Unlike laboratory-based methods, which are **expensive** and **slow**, this sensor provides a **low-cost** alternative suitable for routine field monitoring, making it accessible to a wider range of users.
3. **Supports Marine Conservation and SDG-14:** The device aligns with **Sustainable Development Goal 14 (SDG-14)**, which calls for the conservation of oceans and marine resources. By enabling effective monitoring of microplastics, the sensor contributes to protecting marine ecosystems from contamination.
4. **Community Empowerment:** The sensor's **portability** and **affordability** allow local communities, non-profit organizations, and small-scale researchers to actively monitor water quality, contributing to grassroots environmental protection efforts.
5. **Data-Driven Decision Making:** The **cloud-based platform** allows for large-scale data collection and analysis, empowering policymakers, environmentalists, and scientists to make informed decisions about water quality management and pollution control.
6. **Widespread Adoption Potential:** The sensor's **low cost** and **user-friendly design** make it suitable for global deployment, including in regions with limited access to advanced laboratory equipment, thus expanding the reach of microplastic monitoring efforts worldwide.

Future Scope and Enhancements:

1. **Expansion of Machine Learning Datasets:** Collaboration with **research institutions** to expand the spectral datasets used for machine learning training will improve the sensor's accuracy and enable detection of more plastic types.
2. **Miniaturization and Consumer-Grade Devices:** Future developments will focus on **miniaturizing** the sensor for handheld or even consumer-grade devices, making microplastic detection more accessible to individuals and non-expert users.
3. **Predictive Analytics and Forecasting:** Future iterations of the dashboard could include **predictive analytics** that forecast pollution trends based on historical data, helping communities prepare for future contamination events.

Conclusion:

This innovative **microplastic detection sensor** offers a practical, cost-effective, and scalable solution for combating microplastic pollution in aquatic environments. By combining cutting-edge technologies like **optical scattering**, **fluorescence detection**, and **AI/ML classification**, the system allows for accurate, real-time monitoring of water quality. Its integration with **IoT connectivity** ensures that pollution data is accessible and actionable, supporting global efforts in **marine conservation** and **sustainability**. The device has the potential to revolutionize environmental monitoring, offering a powerful tool for the protection of water resources and ecosystems worldwide.

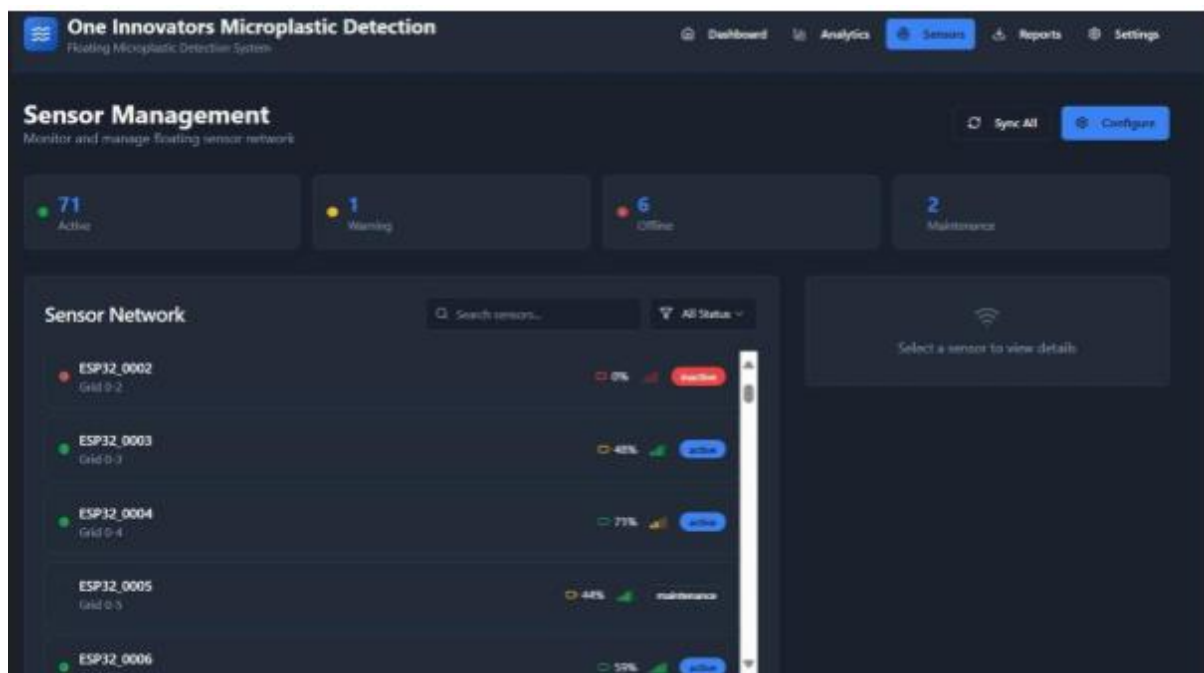
Claims:

1. **Low-Cost, Portable Microplastic Detection:** A portable, low-cost device for detecting micro plastic particles in water in real time using optical scattering and fluorescence techniques.
2. **Combined Optical Techniques:** The system combines optical scattering and fluorescence methods to differentiate between micro plastics and natural material, providing accurate detection in field settings.
3. **AI/ML Classifier Integration:** The sensor integrates an AI/ML classifier for the automatic identification and classification of micro plastic particles in water samples, reducing human intervention.
4. **TinyML-Based Edge Processing:** Utilization of TinyML for edge processing to run machine learning models directly on the device, enabling real-time data analysis without relying on cloud processing.
5. **IoT Connectivity for Data Transmission:** Integration of IoT connectivity through the MQTT protocol, enabling real-time transmission of detected data to an IoT dashboard for monitoring and geo-tagged pollution mapping.
6. **Modular and Scalable Architecture:** A modular hardware design that allows for cost optimization, component replacement, and easy scalability for large-scale deployments or mass production.
7. **Real-Time Pollution Mapping:** Capability to display live microplastic detection results and geo-tagged pollution data on a cloud-based dashboard and mobile application, aiding in environmental monitoring.
8. **Flow Chamber Design:** A specialized flow chamber optimized for smooth water sample movement, ensuring consistent interaction between the laser/LED light and microplastic particles for reliable measurements.
9. **Compact and Field-Ready Design:** A miniaturized, rugged design that is optimized for field use, ensuring durability, portability, and ease of use in various environmental conditions.
10. **Open-Source Datasets and Collaboration:** The use of open-source datasets for machine learning model training and the potential for collaboration with environmental research labs to expand spectral datasets and improve detection accuracy.
11. **Cloud Integration for Remote Access:** Integration with cloud services (e.g., Firebase, AWS IoT Core) for remote monitoring, storage, and secure access to collected data for analysis by environmental agencies and researchers.
12. **Enhanced User Interface (UI):** A user-friendly interface developed with React.js, featuring real-time graphs, microplastic detection alerts, and pollution mapping for easy interpretation of the data by end-users.

Drawings



IOT dashboard for the data management and information



Model - Sensor information and management



Concentration distribution and other analytics