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STAGE 2

Combating the Challenge of Microplastics in Aquatic Environments using IoT

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Problem Description

Microplastics, insidious fragments of plastic less than 5 millimeters in size, have infiltrated aquatic ecosystems worldwide, posing a significant threat. These persistent pollutants originate from various sources, including synthetic clothing fibers, the breakdown of larger plastic items, and industrial microbeads used in cosmetics. Once in waterways, microplastics are mistaken for food by marine life, leading to ingestion and potential harm. These tiny particles can accumulate in the bodies of fish and shellfish, eventually finding their way onto our dinner plates, raising concerns about human health.

Sri Lanka, an island nation famed for its breathtaking coastlines and vibrant marine biodiversity, is not immune to this global challenge. Studies have revealed significant microplastic contamination in Sri Lankan waters. A 2019 survey, the first of its kind in four decades, identified microplastics in all coastal sampling stations, with the highest concentrations found in the northwestern seas [1]. This alarming trend coincides with a drastic decline in fish stocks, raising serious concerns about the health of Sri Lanka's marine environment.

The urgency to address microplastic pollution has intensified due to recent environmental disasters. In June 2021, Sri Lanka grappled with one of its worst environmental crises when tons of plastic pellets spilled from a burning ship, washing ashore near Colombo [2]. This incident not only threatened marine life but also devastated kilometers of previously pristine beaches, highlighting the vulnerability of Sri Lanka's delicate coastal ecosystems.

The impact of microplastic pollution in Sri Lanka is far-reaching and multifaceted:

- **Environmental Consequences:** Sri Lanka's fish stocks have plummeted by approximately 80%, partly attributed to high levels of microplastic contamination [3]. Microplastics not only physically harm marine life but also act as vectors for harmful chemicals, disrupting ecosystems and potentially impacting human health through contaminated seafood.

- **Fish Stock Decline:** The decline in fish stocks poses a significant threat to food security and livelihoods for Sri Lanka's fishing communities. With a large portion of the population relying on fish as a primary source of protein, a dwindling supply due to microplastic pollution could have severe social and economic consequences.

- **Polluted Beaches and Effect on Tourism Sector:** Microplastics not only harm marine life but also mar the beauty of Sri Lanka's beaches, a cornerstone of the nation's vibrant tourism industry. Plastic pollution deters tourists from visiting these once-pristine destinations, potentially impacting a vital sector of the Sri Lankan economy. [4]

- **Waste Management Issues:** Inefficient waste management practices are a major contributor to microplastic pollution. A lack of proper disposal methods leads to plastic waste ending up in waterways, further exacerbating the problem. Additionally, inadequate infrastructure for recycling plastic waste allows it to enter the environment, eventually breaking down into microplastics.

Considered alternatives

Microplastic detection methods employ various techniques such as visual identification, spectroscopy (Fourier Transform Infrared Spectroscopy and Raman Spectroscopy), chemical analysis (Pyrolysis Gas Chromatography/Mass Spectrometry), and density separation. Visual identification involves manual examination under a microscope based on physical characteristics. Spectroscopy techniques analyze chemical composition, while chemical analysis breaks down samples to identify plastic types. Density separation separates microplastics based on density differences. Methodology typically involves sample collection, preparation, and application of chosen techniques. Selection depends on sample type and microplastic size. Let's explore existing alternatives for microplastic detection to understand their applicability and effectiveness in countries like Sri Lanka.

Method 01: A confocal micro-Raman spectroscopy system combined with IOT

Micro-Raman spectroscopy is a technique that combines Raman spectroscopy with a traditional light microscope, enabling the chemical analysis of extremely small objects. It operates by illuminating the sample with a laser, which interacts with the sample and scatters off its surface. The scattered light is then detected to generate a Raman spectrum, serving as a unique "chemical fingerprint" for the compounds present. In confocal micro-Raman spectroscopy, a spatial filter is employed to regulate the analysis volume of the sample in both the XY (lateral) and Z (depth) axes. This precision allows for high-resolution analysis of individual particles or layers with dimensions as low as 1 μm.

Methodology:

- **Sensors and Devices:** These are attached to the confocal micro-Raman spectroscopy system to collect data. They can vary widely, from simple temperature sensors to sophisticated multi-functional devices that measure a range of variables.
- **Connectivity:** This involves various communication protocols like Wi-Fi, Bluetooth, and cellular networks. The IoT device communicates with the cloud server via Wi-Fi, allowing for remote monitoring and control of the system.
- **Data Processing and Analysis:** Advanced algorithms, like machine learning models, process and analyze the collected data. This step turns raw data into actionable insights.
- **Cloud Server:** The data collected by the confocal micro-Raman spectroscopy system is sent to the cloud server, where it can be accessed and analyzed through a web-based application.

There could be several challenges in implementing this technology in Sri Lanka:

- There might be challenges related to setting up the necessary infrastructure, especially in remote areas where internet connectivity might be poor.
- The cost of setting up the confocal micro-Raman spectroscopy system and the IoT devices might be high.
- There might be a lack of technical expertise in operating the confocal micro-Raman spectroscopy system and the IoT devices.
- Regular maintenance of the system and the IoT devices might be challenging, especially in remote areas.

Advantages	Disadvantages
• Mapping areas of a sample, useful for patterned or diverse regions. • Depth profiling without sample preparation. • Non-destructive, applicable to solids, liquids, and gases. • No sample preparation required.	• Susceptible to fluorescence interference from certain materials. • Some materials may not yield strong Raman signals. • Risk of sample damage. • Relatively slow process.

Method 02: Method of detecting 3–500 µm sized microplastics in the urban marine

This method focuses on the validation and application of cost and time-effective methods for detecting microplastics in the urban marine particularly those ranging from 3 to 500 micrometers in size. This approach involves sample collection, digestion, and microplastic counting using both traditional and advanced techniques. Additionally, we explore the potential integration of Internet of Things (IoT) communication to enable real-time monitoring and data collection, aiming to enhance the efficiency and scalability of microplastic detection efforts.

Methodology:

- **Sample Collection:** Water samples are collected from various sources in urban marine and estuarine environments.
- **Digestion:** Collected samples undergo digestion using hydrogen peroxide to break down organic matter, facilitating microplastic detection.
- **Microplastic Counting:** Samples are examined for microplastics using unstained visual examination and Nile Red staining identification techniques.
- **Integration with IoT Communication:** Exploration of IoT integration for real-time monitoring and data collection to enhance detection efficiency.

There could be several challenges in implementing this technology in Sri Lanka:

- Implementing IoT solutions in countries like Sri Lanka faces challenges such as the need for significant investment in IoT infrastructure, particularly in establishing a robust network.
- Compliance with diverse regulatory standards for imported IoT solutions presents a significant hurdle, complicating the adoption process.
- Lack of network cooperation impedes the transfer of innovation from research institutions to practical applications, emphasizing the necessity of collaboration among stakeholders.

Advantages	Disadvantages
• Immediate detection and quantification of microplastics. • Facilitates data collection from multiple locations. • Reduces manual effort in sample collection and analysis.	• Expensive development and deployment of IoT devices. • Requires robust data transmission infrastructure for IoT implementation. • Challenges in accurate microplastic detection with IoT devices.

Method 01 and Method 02 represent groundbreaking approaches to microplastic detection. Method 01 harnesses the power of a confocal micro-Raman spectroscopy system, augmented by IoT innovations for streamlined remote monitoring and control. Conversely, Method 02 is tailored to identify microplastics within urban marine and estuarine environments, presenting unique challenges in integrating IoT technology for enhanced detection capabilities. Despite their distinct focuses, both methods share common attributes, including scalability and the potential for miniaturization. However, they also encounter similar obstacles, such as the initial financial investment required for implementation and the reliance on ongoing developments in IoT device technology to ensure widespread availability and effectiveness.

Combining existing methods, we aim to enhance our approach to microplastic detection and monitoring in urban marine and estuarine environments using the IOT tocology more efficiently.

Our solution - IOT based HyMuDs System for Detection and Monitoring of Microplastics in Aquatic Environments

Microplastic pollution is a growing threat to aquatic ecosystems. Existing monitoring methods are often limited in scope and effectiveness. This project proposes an innovative solution: deploying an Internet of Things (IoT) based HyMuDS (Hybrid Multimodal Data Acquisition System) on smart buoys for real-time detection and monitoring of microplastics in aquatic environments.

Methodology and Implementation

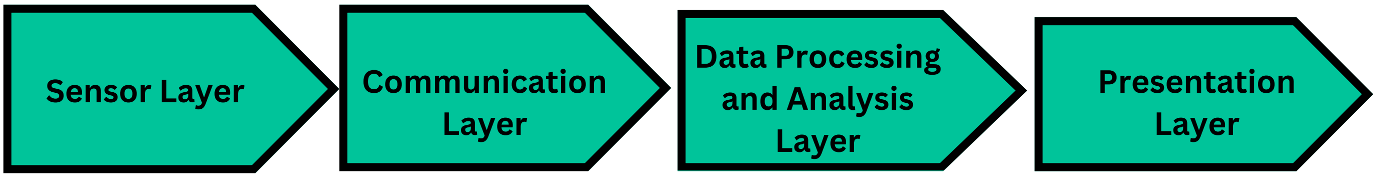
The implementation of the IoT-based HyMuDS system for detection and monitoring of microplastics in aquatic environments will follow a systematic approach.

1. **Requirement Analysis:** Identify the specific requirements for the system, including the types of sensors needed, the parameters to be measured, the desired accuracy and resolution, and the specific aquatic environments where the system will be deployed.
2. **System Design:** Design the hardware and software components of the system. This includes selecting the appropriate sensors, designing the data acquisition and processing algorithms, and designing the communication protocols for data transmission.
3. **System Development:** Develop the hardware and software components. This includes building the smart buoys, programming the data acquisition and processing algorithms, and setting up the communication infrastructure.
4. **System Testing:** Test the system under controlled conditions to ensure it meets the specified requirements. This includes testing the accuracy and reliability of the sensors, the effectiveness of the data processing algorithms, and the robustness of the communication protocols.
5. **System Deployment:** Deploy the system in the selected aquatic environments and start collecting and transmitting data.
6. **Data Analysis and Reporting:** Analyze the collected data to detect and monitor microplastics, and generate reports to inform relevant stakeholders.

System Architecture

The system can be visualized as a three-tier architecture:

- **Tier 1: Sensor Layer**
  To capture microplastic images in varied lighting conditions, we integrate visible, infrared, and ultraviolet cameras. These cameras ensure precise detection. Environmental sensors measure water temperature, salinity, and turbidity, providing essential context. An onboard computer collects and processes data from these sensors and cameras in real-time, aiding informed decision-making.
- **Tier 2: Communication Layer**
  Integrating a cellular or satellite modem enables seamless transmission of data from the smart buoy to a central server.
- **Tier 3: Data Processing and Analysis Layer**
  Employing a cloud-based server facilitates efficient storage and processing of sensor data, ensuring scalability and accessibility. Tailored software analyzes camera images and sensor data to identify potential microplastics, enhancing detection accuracy. A user-friendly interface provides intuitive data visualization and reporting tools, enabling stakeholders to interpret and communicate findings effectively.



Communication Architecture of the proposed solution

- **On-field Deployment:** The bottom layer consists of HyMuDS units equipped with sensors for data collection (cameras, environmental sensors) and 5G mobile gateways for communication
- **Communication Layer:** The 5G mobile network transmits data from the HyMuDS units to the cloud-based application server.
- **Cloud-based Processing:** The application server receives data from all deployed units. Here, the data is:
  - Processed and converted into a suitable format for analysis (feature extraction).
  - Analyzed using intelligent computing methods (potentially machine learning algorithms) to detect potential microplastics in the collected data.
- **Presentation and Analytics:** The processed data and detection results are visualized on a user-friendly interface. This allows researchers, policymakers, and the public to monitor microplastic presence and gain insights from the data.
- **Security and Reliability:** The system incorporates robust security measures to protect sensitive data. Additionally, mechanisms are implemented to handle large data loads efficiently and ensure system recovery from potential failures.

HyMuDS Data Acquisition System

The Hybrid Multimodal Data Acquisition System (HyMuDS) is an advanced monitoring solution initially introduced in a paper from the 2015 Asia-Pacific Conference on Computer Aided System Engineering. Key features of HyMuDS include its hybrid nature, multimodal data acquisition capabilities, and a combination of hardware and software components.

Key Features:

- **Hybrid Nature:** HyMuDS is designed to integrate data from various sensor types, offering a comprehensive understanding of the monitored environment.
- **Multimodal Data Acquisition:** The system can detect environmental parameters like temperature, salinity, moisture, and illumination, providing a holistic view of environmental conditions and potential contamination sources.
- **Hardware and Software Components:** HyMuDS comprises analog sensing nodes connected to a wireless gateway for data acquisition and a C# .Net-based software architecture for data processing.
- **Real-Time Monitoring:** HyMuDS offers real-time monitoring capabilities, enabling timely detection and response to contamination events in urban waterways.
- **Scalability and Concurrency:** The system is scalable to handle large-scale monitoring projects and can manage increased concurrency due to the parallel processing of massive data volumes.

Hardware Considerations

- **Smart Buoy Selection**:
  The choice of a smart buoy platform revolves around key considerations. Sensor compatibility with HyMuDS sensors is essential for seamless integration. Power generation, whether through solar panels, wind turbines, or a blend of both, must meet system requirements. Data transmission capabilities, such as cellular or satellite communication, ensure remote data transfer. Deployment suitability, particularly in freshwater or saltwater environments, is critical for optimal performance.
- **HyMuDS System Integration:**
  Integrating the HyMuDS system with the selected smart buoy platform entails several steps. Firstly, physical integration involves securely mounting cameras and sensors onto the buoy to ensure stability and functionality. Secondly, electrical integration is crucial, requiring the connection of sensors and cameras to the onboard computer for seamless data collection. Lastly, software configuration is essential, involving setting up the onboard computer to collect data from all sensors and transmit it for processing, ensuring efficient data management and analysis.

Software Development

- **Data Acquisition Software:**
  The software running on the on-board computer is pivotal in facilitating key functions. It collects data from all sensors at specified intervals, ensuring comprehensive data capture. Additionally, it pre-processes sensor data, such as image compression, to optimize transmission efficiency. Furthermore, the software is responsible for transmitting data packets to the central server at regular intervals, ensuring timely and consistent data delivery.
- **Data Analysis Software:**
  Cloud-based software for receiving and storing data from the buoys ensures seamless integration and accessibility. Implementing image processing algorithms within the software enables precise analysis of camera images to identify potential microplastics based on size, shape, and color. Correlating image data with environmental sensor data offers insights into influencing factors affecting microplastic distribution. Additionally, the software generates reports and visualizations to effectively communicate the presence of microplastics, aiding in informed decision-making.
- **Communication Protocols**: Standard communication protocols (e.g., MQTT) will be used for reliable data exchange between the buoys and the central server.

Machine Learning Algorithms, Frameworks

Machine Learning (ML) plays a crucial role in automating the detection and analysis of microplastics in aquatic environments. ML algorithms can be trained to identify microplastics based on their size, shape, color, and texture, using the image data captured by the cameras onboard the smart buoys. Additionally, ML can help in correlating image data with environmental sensor data to understand potential influencing factors.

Machine Learning Algorithms

Algorithm	Application	Use Case
Random Forest	Python library providing simple and efficient tools for data analysis and ML.	Classifying detected microplastics into different categories (e.g., size, type) based on image and sensor data.

Convolutional Neural Networks (CNNs)	Image classification and object detection.	Detecting microplastics in camera images based on their visual features.
Support Vector Machines (SVM)	Classification and regression tasks.	identifying and classifying microplastics from image and sensor data.
Unsupervised Learning Algorithms (e.g. K-means clustering)	Clustering and segmentation.	Segmenting images to identify regions of interest where microplastics are likely to be present

Frameworks and Tools

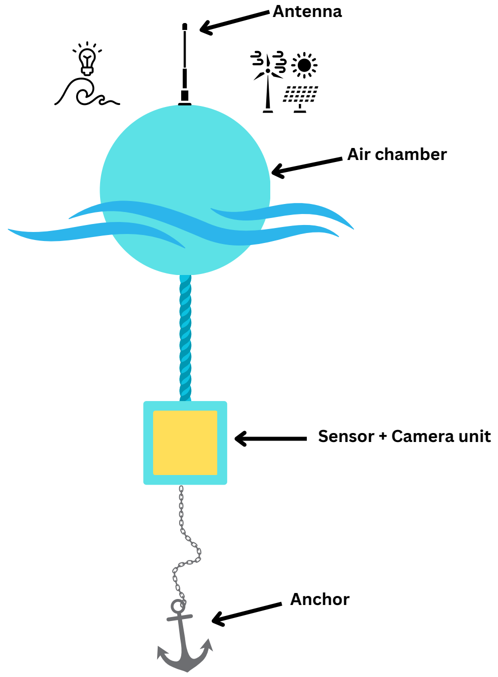
Tools	Description	Use
TensorFlow and Keras	Open-source ML frameworks with extensive support for CNNs and other neural network architectures.	Training and deploying ML models for microplastic detection.
Scikit-learn	Python library providing simple and efficient tools for data analysis and ML.	Implementing Random Forest, SVM, and clustering algorithms for classification and analysis.
OpenCV	Open-source computer vision library.	Image preprocessing, feature extraction, and image segmentation for microplastic detection.
PyTorch	ML framework with dynamic computation graphs.	Alternative to TensorFlow for implementing neural networks and other ML algorithms.

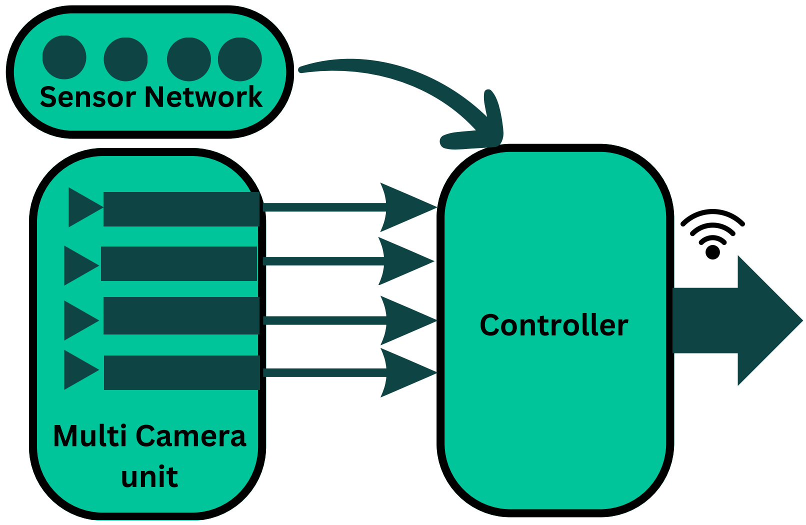
Feasibility and Challenges

- The technical feasibility is promising. Smart buoys with various sensor capabilities and communication options are commercially available. The HyMuDS system offers a foundation for data collection, and image processing algorithms can be developed or adapted for microplastic detection.

- **Challenges**:

  - **Data processing:** Large volumes of image and sensor data require efficient processing algorithms and potentially high-performance computing resources.
  - **Biofouling:** Marine organisms accumulating on the buoy and sensors can affect sensor performance and require regular cleaning.
  - **Cost:** The initial investment in smart buoys, sensors, and data analysis infrastructure can be significant.





Novelty and Impact

- **Novelty:** This project combines the HyMuDS system with smart buoys, offering a potentially more comprehensive and automated solution for microplastic monitoring compared to traditional methods.

- **Impact:**
  This IOT based HyMuDs System offers enhanced monitoring capabilities, delivering real-time, continuous data on microplastic presence in aquatic environments. This contributes significantly to scientific understanding by providing valuable data on the distribution and ecological impact of microplastics. Moreover, it plays a crucial role in policy development by furnishing policymakers with data necessary for crafting effective strategies to combat microplastic pollution. Additionally, the system serves as a tool for raising public awareness about the issue of microplastic pollution and its detrimental environmental consequences.

Conclusion

Sri Lanka faces a significant challenge in combating microplastic pollution within its vital waterways. This report has explored the limitations of solely relying on communication technologies for awareness and behavioral change. To address this gap, we propose an innovative solution: an Internet of Things (IoT)-based monitoring system.

In conclusion, the proposed IoT-based HyMuDS system on smart buoys solution will provide real-time data on microplastic presence in the country's waters. The system uses interconnected devices to collect and transmit vital environmental data, which can be communicated to stakeholders like scientists and citizens through dashboards or mobile applications. This transparency empowers informed action, allowing scientists to gain insights into the dynamics of microplastic contamination, guiding future research and mitigation efforts. Additionally, citizens can be informed about the state of their waterways, fostering a sense of environmental responsibility and potentially driving positive behavioral changes. The system's ability to collect and transmit data in real-time empowers scientists to guide future research and mitigate microplastic contamination, while also fostering a sense of environmental responsibility among citizens.

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