Deep Learning-Based Microplastic Detection in Water: An Innovative Approach for Environmental Monitoring

Abstract:

Microplastics are one of the major pollutant issues in the aquatic zone. Microplastics are required to be identified in the water and needed to take preventive measures in order to eliminate them, because they have become the major source of different problems like ecosystem disruption, water pollution, respiratory and endocrine system diseases. Major analytical techniques used to detect microplastics are Fourier-Transform Infrared Spectroscopy and Raman Spectroscopy. These analytical procedures of detecting microplastics approximately less than 5 millimeters can be replaced using different deep learning techniques. These techniques will be more accurate in detection of microplastics, with proper model training and building.

Introduction:

The issue of microplastics has become a pressing matter in environmental circles as these tiny plastic particles, usually measuring between 1 and 5 millimeters, pose a threat to aquatic ecosystems. These minute fragments are created through the gradual breakdown of larger plastics, as well as during manufacturing processes and the disintegration of products containing microplastics. The widespread presence of microplastics in bodies of water, from oceans and rivers to lakes and even groundwater, is cause for concern due to the potential harm it can cause to ecosystems, wildlife, and human health.

Microplastics take on a variety of forms, such as tiny beads found in personal care items, fibers shed from synthetic fabrics, and fragments created as larger plastic items break down. Their minute size makes them difficult to spot and eliminate, leading to their widespread presence in bodies of water. This persistence of microplastics, combined with their tendency to absorb and transport harmful chemicals, raises worries about the buildup of toxins in aquatic creatures and their potential inclusion in the food chain.

The origins of microplastics are varied, including primary sources like industrial practices and the deliberate use of microplastics in goods, as well as secondary sources like the breakdown of larger plastic objects through physical, chemical, and biological methods. When microplastics find their way into bodies of water, they can experience intricate interactions with environmental factors such as currents, sediments, and microbial populations, making their destiny and movement even more complex.

Literature Survey:

A comprehensive review of existing literature reveals various methodologies employed for microplastics detection, including visual inspection, spectroscopy, and microscopy. However, these conventional methods often suffer from limitations such as time-consuming sample preparation and subjective interpretation. In recent years, there has been a growing interest in leveraging deep learning models for automated microplastics detection, offering the potential for enhanced accuracy and efficiency.

- **Title: "Proceeding the categorization of microplastics through deep learning-based image segmentation"**

Summary: The study focuses on addressing the environmental threat posed by microplastics (MPs) in marine ecosystems. The researchers propose an automated technique using a deep convolutional neural network (DCNN), specifically a Mask Region Convolutional Neural Network (Mask R-CNN), for identifying and classifying MPs based on their shapes. The model is trained on diverse MP images, and erosion and dilation operations are incorporated to enhance segmentation results. The testing dataset shows promising results with a mean F1-score of 0.7601 for segmentation and 0.617 for shape classification. The study highlights the potential of the proposed method for the automatic identification and categorization of MPs. Additionally, the adoption of a specific nomenclature framework contributes to global standardization in the categorization of MPs. The work suggests future research directions to enhance accuracy and explore the broader applications of DCNN in identifying microplastics.

- **Title: "Effect of microplastics in water and aquatic systems"**

Summary: The excessive disposal of plastics in water generates microplastics, tiny particles harmful to aquatic life. These particles, prevalent in oceans, accumulate pollutants, disrupt ecosystems, and impact marine surfaces. Microplastics, formed through environmental processes, differ in color and density. Polyethylene and polypropylene dominate ocean microplastics, affecting water surfaces and seafloors based on their density. This paper reviews the consequences of plastic debris on aquatic ecosystems and explores the link between COVID-19 and microplastic pollution.

- **Title: "A new approach to classifying polymer type of microplastics based on Faster-RCNN-FPN and spectroscopic imagery under ultraviolet light"**

Summary: Tiny plastic bits harm marine life and humans. Studying them is expensive and complex. This paper proposes a new method using UV light and deep learning to automatically identify and count microplastics from images. This achieves high accuracy (85.5-87.8%) at lower cost and time compared to traditional methods. This opens doors for faster, cheaper monitoring of microplastic pollution. (Faster R-CNN model with a ResNet-50-FPN)

- **Title: "SMACC: A System for Microplastics Automatic Counting and Classification"**

Summary: Manually counting and classifying microplastics in beach samples takes too long. This study presents a computer vision system that automatically analyzes images of samples to achieve this task. By combining image processing techniques and deep learning, the system accurately counts and classifies microplastics into different categories at much faster speeds than humans. This technology could enable researchers to monitor wider areas and more frequently, improving understanding and management of plastic pollution.

Feature detection - SURF descriptor (Speeded Up Robust Feature)

Feature classification - K Nearest-Neighbor, Random Forest, Support Vector Machine

- **Title: "Automatic quantification and classification of microplastics in scanning electron micrographs via deep learning"**

Summary: This study uses deep learning to quantify and classify microplastics from daily supplies. A dataset of micrographs was used to train models for semantic segmentation and shape classification. The models achieved high accuracy and are much faster than manual methods.

(Mask-RCNN, SVM (Support Vector Machine), decision tree, KNN (K Nearest

Neighbor), and bagging (random forest) or boosting (AdaBoost))

- **Title: "Raman Spectroscopy and Machine Learning for Microplastics Identification and Classification in Water Environments"**

Summary: This study uses Raman spectroscopy, which generates "fingerprint" data of microplastics based on their unique molecular vibrations. This data is then fed into a machine learning algorithm (sparse autoencoder and SoftMax classifier) to automatically identify and classify different types of microplastics.

- **Title: "Microplastic Identification via Holographic Imaging and Machine Learning"**

Summary: Detecting microplastics (MPs) in water is crucial, but traditional methods are slow and require expert analysis. This study presents a new approach using 3D holographic imaging and machine learning (ML). Combining these techniques allows for automatic and accurate MP detection with over 99% accuracy, regardless of MP shape, size, or material. This could significantly improve the speed and efficiency of MP analysis in environmental studies and monitoring.

- **Title: "A Handy Open-Source Application Based on Computer Vision and Machine Learning Algorithms to Count and Classify Microplastics"**

Summary: Analyzing microplastics is difficult and time-consuming. This study presents a new system using computer vision and machine learning to automatically count and classify them into categories based on shape and size. While the system needs some improvement in classifying

shapes visually, it achieves high accuracy in counting and size classification. Additionally, it can identify potential biases in traditional analysis methods, making it a valuable tool for standardizing and streamlining microplastic research. (Computer vision, OpenCV, K – Nearest Neighbors)

Types of Microplastics:

Microplastics are generally classified into two main categories based on their origin, size, and production processes: primary microplastics and secondary microplastics.

1**. Primary Microplastics**:

- **Nurdles or Pellets**: These are small, pre-production plastic pellets, typically less than 5mm in diameter. They are the raw material for manufacturing plastic products and can be accidentally released into the environment during production, transportation, or handling.
- **Microbeads**: These are tiny, manufactured plastic beads commonly used in personal care products such as exfoliating scrubs, toothpaste, and cleansing products. Microbeads easily pass through wastewater treatment plants and end up in aquatic environments.

2. **Secondary Microplastics**:

  - **Fragmented Microplastics**: Secondary microplastics are created through the breakdown of larger plastic items. Over time, plastic debris in the environment is subjected to physical, chemical, and biological processes, leading to fragmentation into smaller particles.

  - **Fibers**: Microscopic plastic fibers shed from synthetic textiles during washing or from the breakdown of larger plastic items like fishing nets. These fibers are often released into wastewater and can end up in aquatic ecosystems.

  - **Film Particles**: Thin plastic films, used in packaging and other products, can degrade into smaller particles due to environmental factors like sunlight and mechanical stress.

These categories encompass a variety of microplastic types, each with its unique characteristics and sources. The distinction between primary and secondary microplastics helps in understanding their different pathways into the environment and potential impacts on ecosystems and human health. It's important to note that the size range for microplastics is typically defined as particles smaller than 5mm, with further subcategories such as "mesoplastics" (1-5mm) and "microplastics" (less than 1mm).

Parameters of water effected by microplastics:

The presence of microplastics in water can affect various parameters, both physical and chemical. Here are some key parameters that may be influenced by the presence of microplastics:

- **Chemical Contaminant Transport**: Microplastics can adsorb and accumulate chemical pollutants from the surrounding water. The presence of microplastics may influence the transport and release of these contaminants, affecting their concentrations in the water.
- **Water Quality:** Microplastics can contribute to water turbidity, reducing water clarity. This can impact light penetration, photosynthesis, and overall water quality.
- **Toxicological Effects:** Microplastics may contain additives and chemicals from their manufacturing process. These substances can leach into the water, potentially leading to changes in water chemistry and introducing toxic elements.
- **Microbial Activity:** Microplastics can provide a substrate for microbial colonization. This can lead to the formation of biofilms on the surface of microplastics, potentially influencing microbial communities and nutrient cycling in water bodies.
- **Sorption of Nutrients:** Microplastics may sorb nutrients from the water, affecting nutrient cycling and availability. This can have implications for the growth of aquatic plants and algae.

It's important to note that the specific effects on these parameters can vary depending on the type, size, and concentration of microplastics, as well as the characteristics of the water body. Ongoing research is being conducted to better understand the complex interactions between microplastics and water quality parameters and to assess the overall environmental impact of microplastics in aquatic ecosystems.

Problems due to microplastics:

Microplastics, which are tiny plastic particles measuring less than 5 millimeters, pose several environmental and health problems. Here are some key issues associated with microplastics:

Environmental Problems:

- Ecosystem Disruption: Microplastics can accumulate in various ecosystems, disrupting food chains and affecting aquatic and terrestrial organisms. This can lead to imbalances in ecosystems and biodiversity loss.
- Water Pollution: Microplastics are found in oceans, rivers, and lakes, contributing to water pollution. They can absorb and transport harmful pollutants, potentially spreading contaminants throughout the water.

- Bioaccumulation: Microplastics have the potential to bioaccumulate in organisms as they move up the food chain. This can lead to higher concentrations in predators, posing risks to species at the top of the food web, including humans.
- Habitat Alteration: Microplastics can alter habitats by accumulating in sensitive areas such as wetlands and coastal regions, affecting the behavior and survival of resident species.

Human Health Problems:

- Contaminated Food and Water: Microplastics can enter the food chain through contaminated water and food sources, leading to potential human exposure.
- Ingestion: Humans can unintentionally ingest microplastics through the consumption of seafood, drinking water, and other food items. The extent of health risks associated with this ingestion is still being studied.
- Respiratory Exposure: Airborne microplastics, generated through processes like the breakdown of larger plastic items, may be inhaled, potentially leading to respiratory issues.
- Endocrine Disruption: Some studies suggest that certain chemicals associated with microplastics may have endocrine-disrupting effects, impacting hormonal systems in the body.

Research in microplastic detection:

In recent years, the intersection of machine learning and microplastics research has gained attention, with researchers using computational techniques to analyze, classify, and model various aspects of microplastic pollution. The two major fields in this area are:

- **Automated Detection and Classification:**
  Machine learning algorithms, particularly computer vision models, are employed for the automated detection and classification of microplastics in images. These models can analyze microscopy or camera images to identify and quantify different types and sizes of microplastics. In this type of models, automatic segmentation and classification of microplastics is done based on the standard RGB images and the further classification is done using different algorithms like KNN, Random Forest and Support Vector Machines.
- **Spectral Analysis:**
  Machine learning is used in the analysis of spectral data, such as those obtained through spectroscopic techniques (e.g., FTIR and Raman spectroscopy). These methods can assist in identifying the chemical composition and types of microplastics.
- **Detection using CNN:**
  Microplastic detection can be done efficiently using CNN in deep learning. Phases like image labelling, object detection and classification are undertaken for microplastic detection. The object detection can be done in two ways:

- o **Two-stage object detection** which include algorithms like RCNN, Fast-RCNN, Faster-RCNN and Mask RCNN.
- o **One-stage object detection** which include algorithms like YOLO, SSD, Retina-Net.

Limitations of methods used to detect microplastics in water:

While various methods are used to detect microplastics in water, each method comes with its own set of limitations. Here are some general limitations associated with the mentioned detection methods:

Microscopy:

- **Size Limitation**: Microscopy may not detect very small particles, and its effectiveness diminishes as particle sizes approach the lower limit of visibility.
- **Labor-Intensive**: Manual counting and identification can be labor-intensive and time-consuming, especially for large sample sizes.

Spectroscopy:

- **Surface Analysis**: Techniques like FT-IR and Raman spectroscopy may be limited to surface analysis, and they might not penetrate deeply into particles, potentially missing internal components.
- **Mixed Polymer Identification**: It can be challenging to identify mixed polymers or polymer blends accurately.

Filtration:

- **Particle Loss**: Small particles may pass through filters, leading to underestimation of microplastic concentrations.
- **Filter Contamination**: Filters can introduce contamination, affecting the accuracy of results.

Automated Imaging Systems:

- **Algorithm Challenges**: Automated systems may face challenges in accurately classifying and distinguishing between different types of microplastics.
- **Costly Equipment**: Advanced imaging systems can be expensive to acquire and maintain.

Multi-Sensor Systems:

- **Integration Challenges**: Integrating multiple sensors into a single system can be complex and may require careful calibration.
- **Interference**: Cross-interference between sensors can impact accuracy.

Proposed Model:

Objective: Develop an efficient CNN model for automated microplastic detection in water.

Key Steps:

- Diverse dataset collection.
- CNN architecture with transfer learning.
- Training, fine-tuning, and evaluation.
- Optimization for real-time processing.
- Validation with real-world samples.

Major Outcome:

- Accurate detection with key metrics.

Advantages of Proposed Model:

- **Image Recognition Capability**: CNNs automatically extract crucial features like shape, color, texture, and patterns, enabling robust microplastic identification.
- **Convolutional Layers:** CNNs recognize patterns at different scales, crucial for varied microplastic particle sizes, shapes, and arrangements.
- **Adaptability to Different Environments:** CNNs adapt well to diverse environments by leveraging pre-trained models, facilitating efficient training on smaller datasets.
- **Handling Nonlinear Relationships:** CNNs capture complex relationships, vital for detecting microplastics with diverse shapes and characteristics.
- **Real-time or Near-real-time Analysis:** Trained CNN models provide quick, real-time analysis, suitable for time-sensitive applications like continuous environmental monitoring.

These advantages collectively contribute to the efficacy of CNNs in automating microplastic detection in water samples.