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# Title: Novel analysis of microplastics using infrared hyperspectral imaging and machine learning

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**Abstract:** This study develops an advanced high-resolution microplastic analysis technology that leverages infrared hyperspectral imaging integrated with a microscope and various machine learning models. Infrared hyperspectral data were collected from plastic particles of five types (polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polyamide (PA), and polystyrene (PS)) and the spectrum signals were used to train different algorithms of machine learning. Among 6 different models, the stacked ensemble and gradient boosting machine (GBM) models demonstrated exceptional performance, achieving classification accuracies of 89% and 91%, when applied to mixed microplastic samples. Notably, for microplastics larger than 30 μm, the models achieved a remarkable 100% classification accuracy, effectively surpassing the previous detection limit of 100 μm with an accuracy of 68%. This innovative methodology represents a significant advancement in rapid and efficient microplastic analysis, offering potential applications across diverse environmental and industrial domains.

**Keywords**: Microplastics; Infrared hyperspectral imaging; Machine learning

## 1. Introduction

Microplastics (MPs), defined as plastic particles smaller than 5 mm, are categorized into primary (e.g., microbeads in cosmetics) and secondary (from degradation of larger plastics). These particles are widespread in ecosystems, raising concerns about ingestion by organisms, bioaccumulation, and human health impacts [1]. Analytical technique such as Fourier-transform infrared (FT-IR) and Raman spectroscopy are widely regarded for their precision. However, their reliance on particle-by-particle analysis renders them labour-intensive, time-consuming, and expensive cost, limiting their scalability for large sample volumes [2]. To address these challenges, hyperspectral imaging (HSI) has emerged as a promising alternative which offers simultaneous detection of multiple particles reducing analytical time and expense. However, its application to smaller particles remains challenging due to weaker spectral signals and insufficient training datasets [3]. This study seeks to overcome the limitation by integrating high-resolution infrared HSI and machine learning to enhance the detection and classification of MPs. This framework provides insights into MPs pollution distribution and impact, overcoming previous technical limitations.

## 2. Materials and Methods

Five types of standard polymer PE, PP, PET, PA, and PS were selected and ground into micrometer-scale particles using a grinder. The particles were then sorted by size through a series of standardized sieves.

An integrated system combining a hyperspectral camera and a microscope was used to optimize conditions such as materials of filter papers, exposure time, and halogen lamp brightness to minimize noise in the spectrum signals. Under these optimized conditions, high-resolution infrared HSI was performed, generating raw data for MPs particles ranging from 25 to 850 μm in size.

## 3. Results

### 3.1 Particle analysis model

To facilitate the automated classification of MPs particles from hyperspectral imagery, Roboflow software was employed for model training based on image data. Two distinct datasets were generated for this purpose: one comprised of hyperspectral images, and the other consisted of images with pixels explicitly marked to represent MPs. A comprehensive set of 1,400 hyperspectral image datasets was used for training, validation, and testing, achieving a classification accuracy of 90% (Figure 1.1). To assess the detection threshold, untrained particles

ranging from 0.45 to 25 µm were tested and resulted successfully identifying particles down to 10 µm with 100% accuracy.

3.2 Polymer classification model

Approximately 1,000,000 hyperspectral spectrum signals from the identified particles were collected and utilized to train six machine learning models on the H2O.ai platform. The models included Decision Random Forest (DRF), Gradient Boosting Machine (GBM), XGBoost, Generalized Linear Model (GLM), Deep Learning, and Stacked Ensemble. Among these, the stacked ensemble and GBM models demonstrated robust classification performance, achieving an accuracy of 84% (Figure 1.1). Further evaluations on the detection limits confirmed that the developed method could classify particles as small as 30 µm with 100% accuracy, thus surpassing the previous detection threshold of 100 µm with an accuracy of 68%.

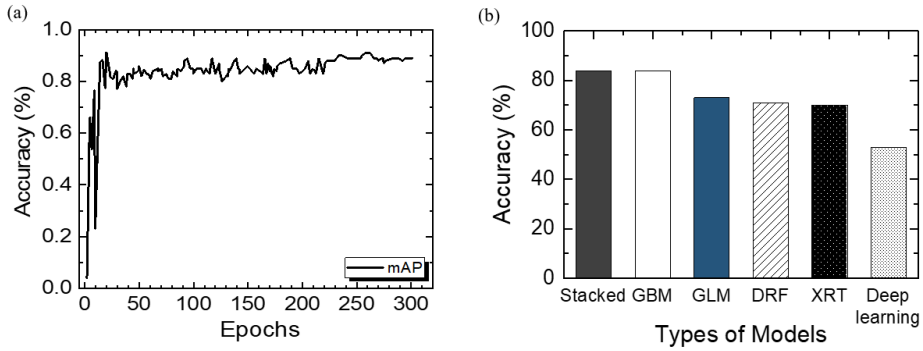


**Figure 1.1** (a) Accuracy result of particle analysis model. (b) Accuracy result of polymer classification model.

3.3 Model evaluation using composite samples

To evaluate the classification performance of the trained models, composite samples were prepared by mixing 5 distinct types of MPS and analyzed with HSI. The predictive results were validated by comparing with Raman spectroscopy for the same samples. This comparison was repeated across 300 particles to ensure reproducibility and reliability. The stacked ensemble and GBM models exhibited high predictive accuracy of 89% and 91%, respectively, thereby confirming their robustness and reliability.

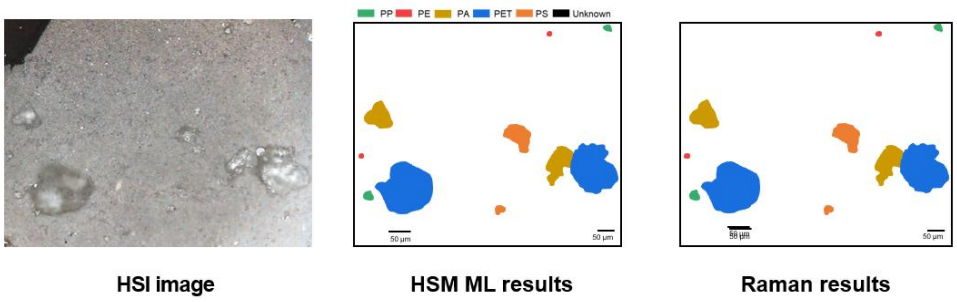


**Figure 1.2** Model evaluation result based on high resolution infrared HSI with machine learning (HSM ML) and Raman spectroscopy

**4. Conclusion**

This study marks a significant advancement in microplastic detection and classification through the integration of hyperspectral imaging, high-resolution microscopy, and machine learning. The technology achieves 100% accuracy in analyzing microplastics as small as 30 µm, while

drastically enhancing analysis efficiency and scalability. Compared to conventional methods like Raman spectroscopy and FT-IR, it reduces analysis time by 99% and costs by 90%, offering a transformative leap forward. With its exceptional precision and efficiency, this innovative approach has immense potential for applications in monitoring the type and size distribution of microplastics across various domains, including aquatic ecosystems, soil, groundwater, and food safety. By addressing the urgent global challenge of microplastic pollution, this methodology provides a powerful and scalable solution to deepen our understanding and guide mitigation strategies for its environmental and health impacts.

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