Enhanced Polymer Classification via CNN Analysis of Wavelet-Transformed MIR Spectra: From 1D Signals to 2D Scalogram Representations

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Abstract — Mid-infrared (MIR) spectroscopy enables accurate plastic classification, including challenging black plastics that evade traditional optical methods. However, our previous work using 1D spectral data revealed fundamental limitations in real-world conditions, with certain polymers consistently misidentified due to overlapping spectral signatures and environmental noise. This study advances polymer classification by transforming 1D MIR spectra into 2D scalogram representations using Continuous Wavelet Transform (CWT), extracting richer time-frequency features that capture both spectral peaks and their scale-dependent characteristics. We developed a CNN architecture incorporating Inception modules, residual connections, and CBAM attention mechanisms specifically tailored for scalogram analysis. Systematic evaluation across multiple acquisition conditions from 10ms to 30ms per spectra, and achieved 99% accuracy across eight material categories (ABS, HDPE, PC, PET, PP, PS, PVC, plus conveyor background) while maintaining >500 fps processing on RTX 6000 Ada GPU. Validation on 100 unseen samples per class confirmed genuine polymer discrimination capabilities, with the model maintaining 99% accuracy on this independent test set. This 1D-to-2D transformation approach significantly enhances MIR spectroscopy's capability for rapid, accurate plastic characterization, establishing the foundation for advanced material analysis and quality control applications.