From Spectral Characterisation to Learning-based Classification: MWIR Hyperspectral Imaging for Black Plastics in Automotive Recycling Applications

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Plastics account for up to 50% of the material volume in modern vehicles, with a substantial proportion consisting of black polymers and constituting a significant material stream in end-of-life vehicle (ELV) waste. New EU regulations address the entire life cycle and require that plastics used in new vehicles should contain a minimum of 15% of recycled materials by 2032 and 25% by 2036, with at least 20% of this recycled content coming from ELVs. Achieving these targets requires increased recovery of ELV plastics while ensuring sufficient quality for their reintegration in the automotive sector manufacturing as a recycled secondary resource stream.

The quality of recycled secondary materials depends directly on the efficient identification and separation of polymer classes into type-pure streams prior to further processing. Traditional industrial plastic identification workflows rely on hyperspectral imaging (HSI) sensors to detect material-specific spectral signals in the visible-to-near infrared (VNIR) and shortwave-infrared (SWIR) ranges (400–2500 nm). However, the strong light absorption by dark pigments substantially reduces the spectral information available in these ranges, limiting the identification of black plastics. Sensors operating in the mid-wave infrared (MWIR, 2700–5300 nm), including HSI-MWIR cameras, offer a promising alternative to this limitation, as chemically-specific molecular absorption features remain detectable even in plastics containing carbon black in their composition. Still, translating HSI-MWIR information into industrial sorting requires addressing challenges at both the spectroscopic and operational levels. Most existing polymer spectral libraries in the MWIR range are based on high-resolution point-based FTIR measurements, which significantly differ from the broader spectral channels, remote reflectance geometry, and spatially continuous acquisition of HSI-MWIR sensors. This limits the direct transfer of FTIR reference information to HSI-MWIR data. At operational level, hyperspectral imaging generates large, high-dimensional datasets that must be processed within the short time available between material detection and physical sorting on a moving conveyor belt.
In this scenario, machine learning (ML) and deep learning (DL) approaches are required to exploit the spectral and spatial patterns directly from the sensor data, while balancing classification performance, computational demand, and processing speed for real-time particle identification.

In this contribution, we investigate the spectral characteristics of highly engineered, specialised black polymers used in the automotive sector including PP, PA, PC, ABS-based blends, as well as associated additives such as talc and glass fiber. We analyse reference polymers of known composition to identify the spectral fingerprints detectable by HSI-MWIR sensors (e.g. ABS-linked fingerprints around 4474 nm), while evaluating their robustness and significance for material classification and addressing key challenges such as high-frequency noise and signal degradation. From this analysis, we establish a spectral framework defining the most reliable and informative wavelength ranges for training ML- and DL-based classifiers (e.g. spectrally-tuned transformers) on real-life shredded polymers recovered from ELV waste streams, assessing their suitability for the identification of automotive plastics under application-relevant conditions. The proposed workflow can be adapted to other polymer classes and material identification applications to support advanced recycling and sorting.