DOI 10.5162/SMSI2023/D3.3

How can Raman spectroscopy support optical detection systems for plastic identification in complex recycling streams?

Andréa de Lima Ribeiro[1], Margret C. Fuchs[1], Sandra Lorenz[1], Christian Röder[2], Nadine Schüler[3], Johannes Heitmann[2], Richard Gloaguen[1]
[1] Helmholtz-Zentrum Dresden-Rossendorf, Helmholtz Institute Freiberg for Resource Technology, Freiberg, Germany,
[2] Technische Universität Bergakademie Freiberg, Institute of Applied Physics, Faculty of Chemistry and Physics, Freiberg, Germany
[3] Freiberg Instruments GmbH, Freiberg, Germany
a.ribeiro@hzdr.de

Summary:
Binary sorting between ABS and PS polymers is a challenge for the recycling industry, particularly when black pigments are present. We propose the sequential application of a hyperspectral sensor in the short-wave infrared (HSI-SWIR) and a Raman sensor unit (532 nm excitation). HSI-SWIR created maps which allowed for initial spectral and spatial assessment of the material stream and Raman point measurements enabled specific identification of ABS (white and black) and PS. The operationalisation of this sensor network requires advanced solutions for fast data acquisition, processing and classification.

Keywords: polymer, hyperspectral imaging, electronic waste, ABS, PS

Background and Experimental Context

In plastic recycling operations, the accurate identification of polymer types is essential to increase efficiency and particularly quality of recycling products. In complex waste streams, such as waste from electronic and electric equipment (WEEE), the distinction between Polystyrene (PS), Acrylonitrile butadiene styrene (ABS) and the presence of black pigments pose additional challenges to polymer identification by conventional optical methods [1].

Optical sensors aid sorting in recycling lines, and industrial operational requirements for such technologies include: i) fast acquisition of spatial and spectral information (< 2 seconds per acquisition); ii) compatibility with conveyor belt operations; and iii) robust identification of polymers in specific types, preventing downcycling. Polymer identification typically relies on diagnostic features in the short-wave infrared ranges that are recorded by fast hyperspectral reflectance sensors (HSI-SWIR, [970 – 2500] nm). The employment of HSI technology allows for instant mapping, displaying spatial variations in composition within the waste stream. Still, HSI-SWIR sensor applications are restricted to the identification of some transparent and light-coloured plastics, being unsuitable for the identification of black plastics [2] and for fast a differentiation between ABS and PS, which are the most common thermoplastics in WEEE [3].

In this contribution, we suggest the sequential employment of HSI-SWIR followed by acquisitions of Raman spectroscopic data. In order to operationalise this sequential sensing, fast data acquisition, process and fusion tools must be developed and integrated to the sensor network.

We selected the following polymer standards of known composition to highlight the capacities of each sensor in the proposed network for robust and improved recycling: transparent PS, white ABS and black ABS. We employed the HSI-SWIR sensor with acquisition speeds compatible with the recycling industry (SPECIM AisaFenix, @SWIR: [970 – 2500] nm, spectral resolution: 12 nm, spatial resolution: 1.6 mm, integration time: 4.5 ms). For Raman measurements, we designed a custom-based sensor and performed measurements using the following specifications: excitation laser @ 532 nm, 100 mW (maximum laser power); spectrometer WP 532, Wasatch Photonics: 11 cm^{-1} spectral resolution; range [200 – 2500] cm^{-1}; maximum integration times per acquisition: 500 ms).

HSI data corrections for geometric distortions, reflectance calculations and continuum removal (hull correction) were performed using in-house processing routines based on the Hylite toolbox [4]. We have calculated minimum wavelength (MWL) maps for each data cube indicating the strongest absorption feature for each pixel (range: [1650 – 1750] nm). Raman spectra were corrected for background and fluorescence signals (range: [700 – 2500] cm^{-1}).

Results

Hyperspectral image analysis using the MWL method generated similar results for white ABS and transparent PS (see Fig 1, right). Both polymers exhibit minimum absorption features within the same range ([1677 – 1689] nm) and close inspection reveals strong spectral similarities between these thermoplastics (Fig 1, left). The overlap of diagnostic features indicates the impossibility of discerning PS from ABS using this SWIR sensor relying solely on MWL analysis. Previous investigations have identified spectral differences between ABS/PS in the midwave-infrared (MWIR) range, however, the commercial availability of HSI-MWIR sensors is somewhat limited. Still, HSI-SWIR spectral information can be used for initial assessment and separation of ABS/PS from other polymers in recycling streams. Furthermore, our HSI-SWIR sensor was able to record the spatial homogeneity with minimum variations of fingerprint positions and hence, consistent with spectral behaviours of the given reference material (Fig 1, right).

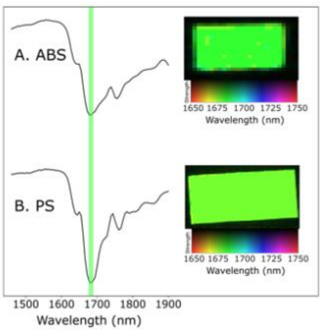

Fig 1. Left: Median spectra calculated for hyperspectral data. The spectral range of diagnostic features for selected polymers is indicated in green. Right: Minimum Wavelength Maps for hyperspectral data cubes (range: [1650 – 1750] nm). A) ABS; B) PS.

Characteristic Raman signals were obtained from all samples, including black ABS. Raman spectra for ABS and PS were marked by benzene ring vibrational modes at ~1001 cm^{-1}. An additional Raman peak is present only on ABS, linked to the butadiene stretching vibrational mode, and allows for clear distinction between ABS and PS polymers, including black ABS. Nevertheless, Raman data acquisitions are restricted to point measurements and do not allow for mapping and 2D digitalization of the recycling stream.

Sensor integration

We propose a sensor network benefitting from both HSI-reflectance and Raman spectroscopic sensors for the identification of PS and ABS polymer types. HSI-SWIR provides information for an initial classification. Depending on these results, regions of the material stream will be selected, where additional validation is required by Raman measurements. Subsequently, the final material classification can be updated and then up-scaled to the entire material stream by fast, AI-based algorithms relying on spectral libraries.

Conclusion

The integration of hyperspectral imaging sensors in the short-wave infrared and Raman scattering measurements has potential for solving binary sorting of ABS (including black ABS) and PS using optical methods. An integrated sensor network aiming towards this separation should apply both sensor types and rely on advanced data processing strategies for ABS/PS classification based on spectral features.

Acknowledgments

This research was supported by EIT RawMaterials within the KAVA up-scaling project “RAMSES-4-CE” (KIC 19262). We thank Helmholtz Institute Freiberg for Resource Technology for funding the AisaFENIX sensor.

References

[1] A. Vázquez-Guardado, M. Money, N. McKinney, D. Chanda, Multi-spectral infrared spectroscopy for robust plastic identification, *Applied Optics* 54(24), 7396 (2015); doi: 10.1364/ao.54.007396

[2] O. Rozenstein, E. Puckrin, J. Adamowski, Development of a new approach based on midwave infrared spectroscopy for post-consumer black plastic waste sorting in the recycling industry, *Waste Management* 68, 38–44 (2017); doi: 10.1016/j.wasman.2017.07.023

[3] G. Martinho, A. Pires, L. Saraiva, R. Ribeiro, Composition of plastics from waste electrical and electronic equipment (WEEE) by direct sampling, *Waste Management* 32(6), 1213–1217 (2012); doi: 10.1016/j.wasman.2012.02.010

[4] S. Thiele, S. Lorenz, M. Kirsch, I. C. Contreras Acosta, L. Tusa, E. Herrmann, R. Möckel, and R. Gloaguen, Multi-scale, multi-sensor data integration for automated 3-D geological mapping, *Ore Geology Reviews* 136 (2021); doi: 10.1016/j.oregeorev.2021.104252