A fast and cost-efficient method for rapid monitoring of foreign substances in biogenic waste and organic recycled fertilizer based on hyperspectral imaging and artificial intelligence.

P. N. Mandaliev[1], R. M. Schreiber[1] and Julien Dupont[2]

[1]University of Applied Sciences and Arts Northwestern Switzerland, 5201 Windisch, Switzerland
[2]Cortexia SA, Route de Vevey 105, 1618 Châtel-St-Denis, Switzerland
Keywords: artificial intelligence, compost, microplastics, biogenic waste
Presenting author email: petar.mandaliev@fhnw.ch

Machine learning, multi-class classification of reflectance spectra in the 900nm - 1700nm range from four common plastic materials in organic recycled fertilizer was achieved in near real time. A dense artificial neural network applied pixel-wise to each spectrum from hyper spectral images in the 900 nm – 1700 nm range renders a high resolution 2D mapping of the distribution and type of microplastics within a plane sample in the field of view. Spatial resolution of 0.224 mm/pixel was achieved using a Specim FX17 hyperspectral camera (Specim, Spectral Imaging Ltd., Oulu, Finland) featuring a InGaS near infrared sensor with an effective pixel size of 18.7 µm. In the case of a compost sample containing reference microplastics mixed in the organic recycled fertilizer a correct classification rate of 96% for individual spectra was achieved.

Recycled fertilizer is an important lever for a circular economy. It is a renewable source of nitrogen, phosphorus, and potassium for agriculture in the face of rising fertilizer prices and raw material costs, as well as global soil erosion due to lack of humus build-up. In western Europe, North America, and Australia over 100 million metric tons of compost are produced yearly, whereas a potential of more than 150 million metric tons could be achieved if systematic biowaste separation from the source was applied. Obtaining worldwide a higher recycling rate and an increase of the quantity produced is limited by the lack of quality insurance. Today, there is no comprehensive, cost-effective, and automatic analysis method for measuring the fraction of inert foreign matter in organic fertilizer and in biogenic waste. In Switzerland, the current technology for the determination of plastics in organic recycled fertilizer is based on the RAL quality assurances of the German Federal Quality Assurance Association for Compost (Bundesgütegemeinschaft Kompost e.V.). In practice, even if optical instruments such as reflected-light microscope or flatbed scanner support human cognition, quantification remains mainly a manual task, which is laborious, time-intensive and associated with high efforts and costs.

High-resolution, hyperspectral imaging (HI) is a promising tool for automating rapid monitoring of plastics and contaminants in recycled organic fertilizers. The overtones and combination bands from molecular energy transitions present in the near infrared region allow for the identification of the chemical composition of plastics. The technology was first used in satellites and later in (un)manned aircraft (drones) and has been successfully used to identify plastics in soils and marine debris (Balsi, Esposito et al. 2018). In some industrial and research areas, drones have been combined with HI to successfully monitor vegetation status (Uto, Seki et al. 2013) or detect plant diseases at an early stage (Näsi, Honkavaara et al. 2015). Unfortunately, the further application of HI for the analysis of recycled organic manure is non-existent, as the data collected must be evaluated manually. This gap can be closed by using artificial neural networks (ANN) to automatically analyze the collected HI data.

Laboratory-based measurements were performed with a 20 cm x 40 cm scanning stage for a moving speed of approximately 90 mm/s. The HI camera device scans the compost sample line by lines providing an image height of 640 pixels with 224 spectral bands in the color space. The optical axis is normal to the plane with a vertical FOV of 38° corresponding to a projected image height of 180 mm. The sample is illuminated by two halogen light sources featuring a black body like illumination spectrum. The intensity images used to produce hyper spectral lines were acquired at a frame rate of 300 fps and an exposure time of 5 ms. The parameters were synchronized to obtain HI images with correct aspect ratio. The background material of the sample base was a soot-blackened styrene-butadiene rubber. The ambient air temperature during imaging was 20±1 °C.

The measurements formed the basis for building the database for training and evaluating machine learning models. HI of four plastic reference materials (PE (polyethylene); PP (polypropylene); PET (polyethylene terephthalate); PS (polystyrene); average diameter of approx. 3.5 mm) isolated on the reference background or mixed with organic recycled fertilizer was carried out (Fig. 1). Approximately 1`200 images were acquired per sample. Data preprocessing techniques such as pixel binning, spectral decomposition and normalization, noise removal and combinations thereof as well as modeling were performed using MATLAB scripts (MathWorks Inc., USA). The number of spectral bands was reduced at the edge of the acquired spectral range due to a low signal-to-noise ratio. The train and test data sets contained different randomly selected pixel-wise spectra per material category. The trained ANN-based model results in semantic segmentation of unseen images acquired with different mixtures. The results are shown in figure.

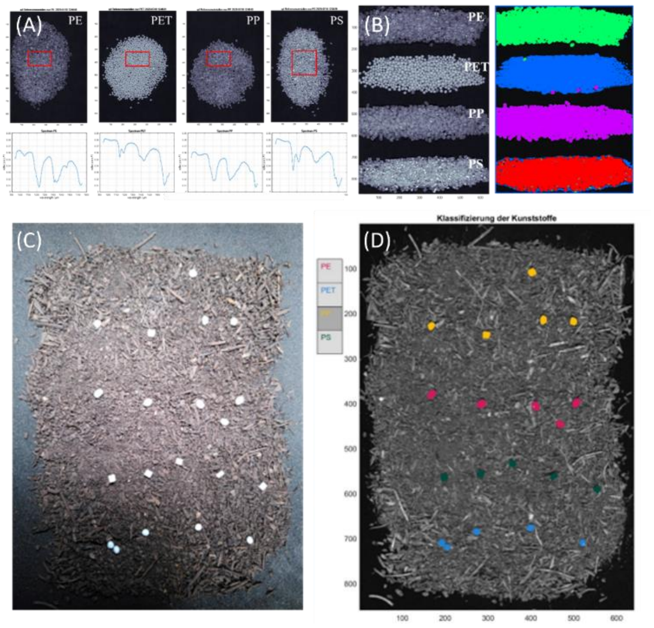

Figure 1. (A) Individual HI spectra of four plastic reference materials (PE, PET, PP, and PS); (B) HI segmentation of the mixed plastics using ANN; (C) plastic reference materials mixed with organic recycled fertilizer; (D) analysis of organic recycled fertilizer mixed with plastic reference materials using ANN and Specim FX17 HI camera (the different plastic classes are shown in different colors).

The present results clearly show that HI coupled with ANNs builds a powerful tool for the analysis of foreign substances in organic recycled fertilizer. Not only can the technology be adapted for laboratory sample inspection and scale up to an extensive monitoring in composting and digestion facilities, but it also provides a powerful annotation tool. The segmentation provided, when combined with RGB image acquisition, results in the production of large data sets for the training of deep learning models to work with cost-effective standard optical systems for an improved economic margin. Convolutional Neural Networks (CNN), when applied to visible light images, would identify foreign matter impurities from shape, colors, and textures rather than the chemical composition extracted from NIR spectra. Applications of the present technology are not limited to recycled fertilizer only.

Different waste fluxes and their entire treatment chain can be considered. A particular example would be its application to monitoring biogenic waste during collection, or large-scale areal observations with drones of compost piles or agricultural fields.

In addition, the instrument is the precursor for active triage and removal of contaminants at the end of the recovery chain at composting and digestion facilities.

References

Balsi, M., S. Esposito and M. Moroni (2018). "Hyperspectral characterization of marine plastic litters." 2018 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea): 28-32.

Näsi, R., E. Honkavaara, P. Lyytikäinen-Saarenmaa, M. Blomqvist, P. Litkey, T. Hakala, N. Viljanen, T. Kantola, T. Tanhuanpää and M. Holopainen (2015) "Using UAV-Based Photogrammetry and Hyperspectral Imaging for Mapping Bark Beetle Damage at Tree-Level." Remote Sensing **7**, 15467-15493 DOI: 10.3390/rs71115467.

Uto, K., H. Seki, G. Saito and Y. Kosugi (2013). "Characterization of Rice Paddies by a UAV-Mounted Miniature Hyperspectral Sensor System." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing **6**(2): 851-860.