Hyperspectral imaging based cascade detection applied to paper, cardboard, plastics and multilayer packaging sorting

Bonifazi G.[1*], Gasbarrone R.[1], Serranti S.[1]

[1] Department of Chemical Engineering, Materials & Environment, Sapienza University of Rome, Via Eudossiana 18 - 00184, Rome, Italy.

*corresponding author: e-mail: giuseppe.bonifazi@uniroma1.it

Abstract
Recycling of post-consumer packaging wastes involves a complex chain of activities, usually based on three main stages, that is: i) collection from households or recovery from municipal solid waste (MSW), ii) sorting and, finally, iii) mechanical recycling. This paper investigates sorting logics, hyperspectral imaging based, to design, implement and set up with the specific aim to perform an automatic separation of paper, cardboard, plastics and multilayer packaging.
Keywords: hyperspectral imaging, near infrared spectroscopy, plastic packaging, sorting

1. Introduction

Post-consumer plastic packaging waste is one of the primary sources for polymers recovering (Bonifazi et Al., 2015). Such waste stream, resulting from separate collection, is usually very heterogeneous and characterized by the presence of contaminants and multi-layer materials. These materials are difficult to separate using classical methods (i.e. gravimetric separation and optical based sorting) being characterized by similar physical characteristics. The need to assess the composition and both fed and sorted product thus arises. In this paper, a Near InfraRed (NIR) based hyperspectral imaging (HSI) detection logic to perform a real-time identification of the polymeric, the cellulose-based and the multi-layers material fractions (i.e. laminated cards and laminated plastics), as resulting from a recycling process, is presented.

2. Material and Methods

2.1. Analyzed materials and sampling

The material under study comes from a waste flow stream of post-consumer household plastic packaging. Sampling was performed on a waste bale composed of post-consumer packaging fragments, resulting from manual and semi-automatic sorting (i.e. oversize of a drum sieve separator: +10 cm). Ideally, the output of this specific sorting line should not contain paper-based material. However, this does not happen. Quality analysis performed on this product highlighted the presence of paper-based packaging fragments and similar material, i.e. laminated card (about 3.5 % in weight of the output). Coning and quartering methods were used to subdivide the sample to collect (about 5 kg). 70 particles were selected and analyzed.

2.2. HSI system and data handling

The HSI acquisition system used in this study works in the NIR range (1000-1700 nm), consisting of an ImSpector N17E imaging spectrograph, developed by SpecIm™ Oy, a temperature stabilized InGaAs camera and an illuminant system. This equipment is mounted on a conveyor belt and is controlled by a personal computer unit (Serranti et Al., 2010). After calibrating the spectrograph, eigth hyperspectral images of the sample under study were acquired.
The hyperspectral images were analyzed using Eigenvector Research, Inc PLS_toolbox (ver. 8.7) and MIA toolbox (ver. 3.0) in MatLab® (MATLAB R2018a ver. 9.4) environment.
A combination of pre-processing algorithms was applied on the data (i.e. spectra) in order to reduce/eliminate noise and scattering artifacts, and to enhance material spectral response differences. Principal Component Analysis (PCA) was also applied to perform an exploratory analysis of the acquired spectra.

2.3. Cascading classification model

Partial Least Square Discriminant Analysis (PLSDA) was applied, in each step of the cascading classification, in order to recognize materials. PLSDA is a supervised recognition technique able to predict the class of each sample under study (Wise et Al., 2008).
Forty plastic polymer-based and paper-based particles were used as a training set. Six hyperspectral images, containing: 24 plastic/polymer-based particles (including laminated plastics) and 16 paper-based particles (including laminated cards and papers) were acquired. Two hyperspectral images were then acquired in order to produce a validation set constituted by 30 particles.

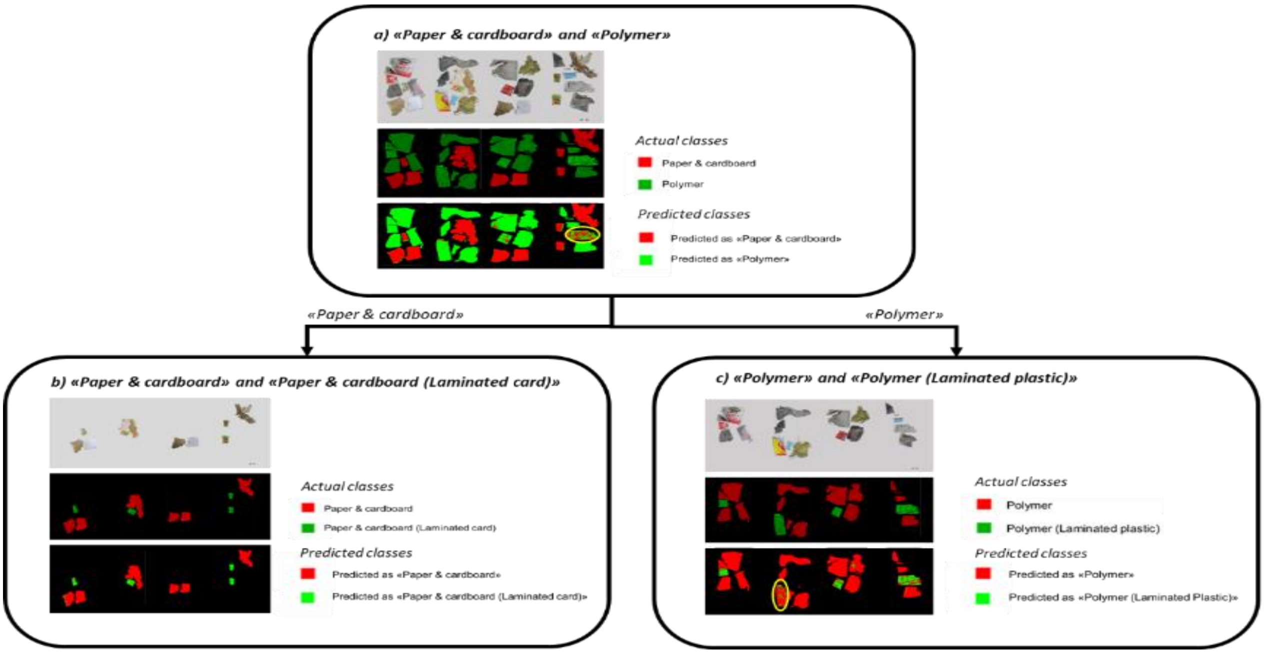

Figure 1. PLS-DA based cascading classification models architecture and results. Figures depict the digital image, the actual classes and the prediction map of the validation set for each step of the classification. The misclassified particles/fragments are evidenced, in the prediction maps, by a yellow ellipse.

The 1st step of the cascading classification model was performed in order to identify the class: PAPERS & CARDBOARDS (i.e. cellulose-based and laminated card fragments) from POLYMERS class (i.e. plastics/laminated plastics). The 2nd classification step was carried out to discriminate inside the PAPERS & CARDBOARDS class the presence of laminated cards from the other cellulose-based particles and to identify inside the POLYMERS class the laminated plastics. Each model was calibrated with the spectra extracted from regions of interest (ROIs) selected on the calibration set and cross-validated with Venetian-blinds method. Models were finally validated on the 30 particles constituting the validation set.

3. Results

Each modelled class, in the calibration phase, showed *Sensitivity* and *Specificity* values very close to 1. In prediction, PAPERS & CARDBOARDS/POLYMERS model is able to identify all fragments/particles, apart from one laminated plastic fragment that is classified in the PAPERS & CARDBOARDS class (Figure 1a). In the 2nd classification step, all laminated cards fragments were correctly identified from other cellulose-based particles (Figure 1b). While 3 out of 4 laminated plastic fragments were correctly identified (Figure 1c). The not correct identification of one particle is probably due the scattering effects generated by the winkled surface of the fragment.

4. Conclusion and future perspectives

A PLSDA-based cascading classification model able to recognize polymeric fragments from cellulosic ones and to identify multi-layer materials (i.e. laminated plastics and laminated cardboards) was build and validated. NIR-based HSI can represent an optimal, reliable and low-cost answer to systematically identify impurities and composite materials inside plastic waste streams. The proposed approach, if fully implemented, could profitably utilized to set up *on-line*, and low cost, innovative detection/monitoring strategies.

References

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