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PET and PVC separation with hyperspectral imaging

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Abstract: The proper design of a product life cycle may contribute both to the optimization of primary raw material usage and to the reduction of waste environmental impacts. Recycling may enter the life cycle of products in the contexts of production of secondary raw materials and reduction of waste extensive disposal in landfills. Tradition plants for plastic separation in homogeneous products employ material physical properties (for instance density). Due to the variability of the properties of various polymers in reduced intervals, the output quality may not be adequate enough. Sensing technologies based on hyperspectral imaging enter this framework being suitable to separate materials and increase the quality of recycled products, which have to comply with specific standards determined by industrial applications. This paper presents the results of the characterization of PET and PVC in some phases of their life cycle (raw materials, waste and regenerate conditions). This is accomplished via near-infrared (900-1700 nm) reflectance spectra acquired with a linear spectrometer. Characteristic spectral profiles of PET and PVC samples have been obtained allowing a robust statistical analysis to be developed. Wavelengths 1200 nm and 1650 nm result to be the most suitable for sample classification.

Keywords: Hyperspectral imaging; PET; PVC; classification; statistical analysis; recycling

1. Introduction

In 2012, the annual production of plastic wastes in Europe was 57 millions of tons with a decrease of 3 % compared to 2011; 62.2 % of the total derives from household waste (mainly container and packaging). In the same year, mechanical recycling involved about 26 % of total post-consumer plastics, 35.6% was recovered for energy in municipal waste incineration plants or as refuse derived fuel material. The residual 38.1 % of plastic waste was landfilled. Though an important decrease in the delivery of plastic materials in landfill is occurring in the last years, improvements in plastic recovery are still needed to reduce the disposal rate down to the goal of zero plastic wastes in landfills by 2020 in Europe (PlasticEurope, 2013).

The separation of different polymers by gravimetric techniques is quite difficult in case of slight differences in density. This is the case of PVC (density: $1.32 - 1.37$ g/cm^3) and PET (density ranging from 1.33 to 1.37 g/cm^3) present in the same mixture. Moreover, cross-contamination problems may arise among the different polymers. In fact, PET melting temperature is 250-260 °C, higher than the PVC one, 140-160 °C. This implies that during PET processing, PVC degrades producing a residue material. On the other hand, PET does not plasticize at PVC processing temperatures and must be removed by filtration (Burat et al., 2009). Finally, during melting processes for material recycling and thermal energy recovery, the presence of PVC in plastic waste may generate environmentally hazardous chlorinated compounds such as gaseous hydrogen chloride and dioxins (Andricic and Kovacoc, 1999; Anthony et al., 2001).

Thus, it is necessary to develop effective technologies to separate chlorinated plastic from other heavy plastics. The hyperspectral method represents a methodology alternative to more traditional tools to separate both different types of plastic polymers and contaminants from plastic wastes. This technology combines spectral reflectance measurements and image processing technologies. It is an effective, low cost, reliable and efficient method that allows overcoming the typical problems of the most used separation methods, such as the influence of moisture, surface status and low feeding speed of particles in electrostatic separation; the need of additive addition in separation by flotation and density; the wide range of density values for the same typology of plastic materials making the choice of the density for sink and float separation challenging; the need for more separation steps to classify a heterogeneous mixture of plastic wastes containing different (more than two) useful fractions.

2. Experimental Section

2.1. Plastic materials tested

Plastic samples of PET and PVC have been collected at different stages of their life cycle (Figure 1). Table 1 presents the characteristics of the samples in terms of origin, color, density, mean particle size. Three samples of virgin plastic (PET 1-V, PVC 1-V, PVC 2-V), consisting of nearly spherical granules of different color, density and composition, represent the raw materials used for the manufacture of products (Figure 1a and b). Plastic wastes have been collected from many sources, in particular urban and industrial waste plants. To analyze operating conditions similar to those occurring in a plant, samples of plastic materials in flakes (PET 3-F, PET 4-F, PVC 3-F, PVC 4-F; Figure 1a and b) and in large pieces (PET 3-P, PET 4-P, PVC 3-P, PVC 4-P; Figure 1c) have been selected. This

allows the investigation of the influence of the sample geometry on the measured spectral signatures. Each waste sample was washed, purified from any impurities and then triturated manually or with a knife mill. As can be seen from Figure 1c, plastic wastes in pieces used in the experimental investigation, unlike previous samples, have irregular shapes. This allows reproducing the shape of fragments originated from coarse crushing operations.

Figure 1. Images of (a) virgin, waste and regenerated PET samples; (b) virgin, waste and regenerated PVC samples; (c) PET and PVC samples in pieces (for the nomenclature refer to Table 1).
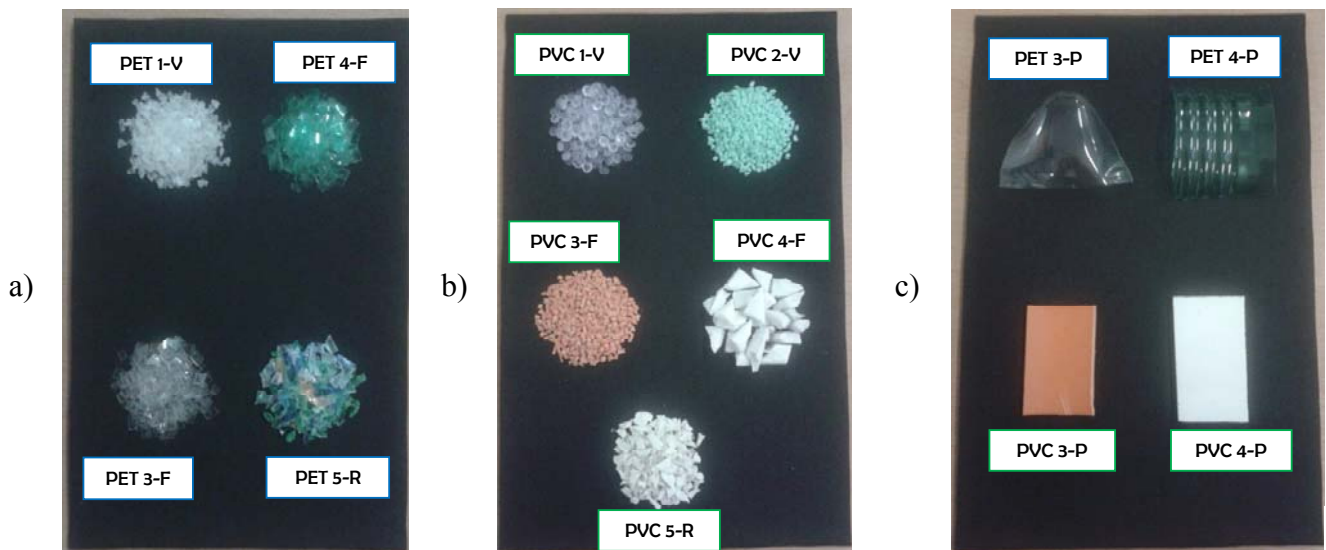
Finally, two samples (PET 5-R, PVC 5-R) have been selected from an Italian plant for recovery and recycling of plastic materials (Regenerate S.r.l., Terni). The materials entering the plant consist of well-selected industrial wastes. Plastic wastes are first subjected to operations of manual separation, subsequently washed and sent to shredding. Finally, the material is mixed to produce a final product with the characteristics required by the market. These materials represent the regenerated second raw materials used for the production of new goods and products. Samples present a rather irregular shape consequence of the recycling process they have been gone through.

Each sample was characterized by determination of average size (geometric characterization); density by pycnometer (physical characterization) and infrared analysis (chemical characterization). Table 1 shows the large range of density values characterizing the same polymer, mainly PVC, due to the auxiliary substances used for its transformation.

2.2. Platform for data acquisition

The hyperspectral platform is based on the use of two linear spectrometers. Each spectrometer captures a line image of a target and disperses the light from each line image pixel into a spectrum. Each spectral image contains then line pixels in a spatial axis and spectral pixels in a spectral axis. Therefore, a 2D spectral image sequence can be formed by sequentially acquiring images of a moving target or by moving the spectral device (Moroni et al., 2012).

Table 1. List of PET and PVC samples investigated.

NAME	DESCRIPTION	SAMPLE ORIGIN	COLOR	MEASURED DENSITY (g/cm^3)	MEAN PARTICLE SIZE (cm)
PET 1-V	Virgin particles in granules	Virgin material	White/transparent	1.30	0.20
PET 3-F	Coca-Cola bottle flakes	Wastes in flakes	Transparent	1.35	0.43×0.52
PET 4-F	Water bottle flakes	Wastes in flakes	Green/transparent	1.35	0.36×0.72
PET 3-P	Coca-Cola bottle piece	Wastes in pieces	Transparent	1.35	4.07×3.31
PET 4-P	Water bottle piece	Wastes in pieces	Green/transparent	1.35	4.81×3.71
PET 5-R	Bottle flakes	Secondary raw plastics (regenerated) in flakes	Multicolor/ transparent	1.33	0.64×1.02
PVC 1-V	Virgin particles in granules	Virgin material	Transparent	1.30	0.40
PVC 2-V	Virgin particles in granules	Virgin material	Green	1.37	0.18
PVC 3-F	Tube flakes	Wastes in flakes	Orange	1.61	0.17×0.28
PVC 4-F	Processing waste flakes	Wastes in flakes	White	0.61	0.40×0.61
PVC 3-P	Tube piece	Wastes in pieces	Orange	1.61	2.47×4.97
PVC 4-P	Processing waste piece	Wastes in pieces	White	0.61	3.16×4.88
PVC 5-R	Recovered from waste flakes	Secondary raw plastics (regenerated) in flakes	White	1.44	0.36×0.622

Figura 2 shows a diagram of the system configuration, comprising one NIR Specim Imspector spectrometer (S2), centered in the near infrared region (from 900 nm to 1700 nm), mounted in front of an InGaAs Sensor Unlimited camera, 320×240 pixel resolution, 25 μm×25 μm pixel pitch, 50 fps maximum frequency of acquisition; the images presented in this work were acquired at 50 fps and the spectral resolution is 3 nm; one high-speed DVR CORE with two Camera Link inputs used to acquire and manage the data, containing 1-terabyte solid state disk array; one power supply for all system devices; one processing computer for controlling the entire system and acquiring images; one lighting system consists of two 500 Watt halogen lamps; one conveyor belt to allow the target displacement at a constant rate. The system includes a VIS Specim Imspector spectrometer (S1), centered in the visible range of the electromagnetic spectrum (400 nm to 1000 nm) mounted in front of a Dalsa Falcon 1.4M100 CMOS camera. The spectral profiles detected in the visible range of the spectrum have not been included in this paper.

3. Results and Discussion

Figure 3 shows the spectral responses of PET and PVC samples of different form and life cycle

stage, respectively. PET samples present well-recognizable characteristic peaks at wavelengths of 1120-1130, 1160-1180, 1410-1420 and 1660-1670; PVC samples at wavelengths 1190-1200 nm and 1410-1430 nm.

Figure 2. Diagram of the hyperspectral device with two spectrometers (Platform A - linear spectrometer configuration). CL: stands for Camera Link, eST for eSATA connection, SYNC for synchronization signal.
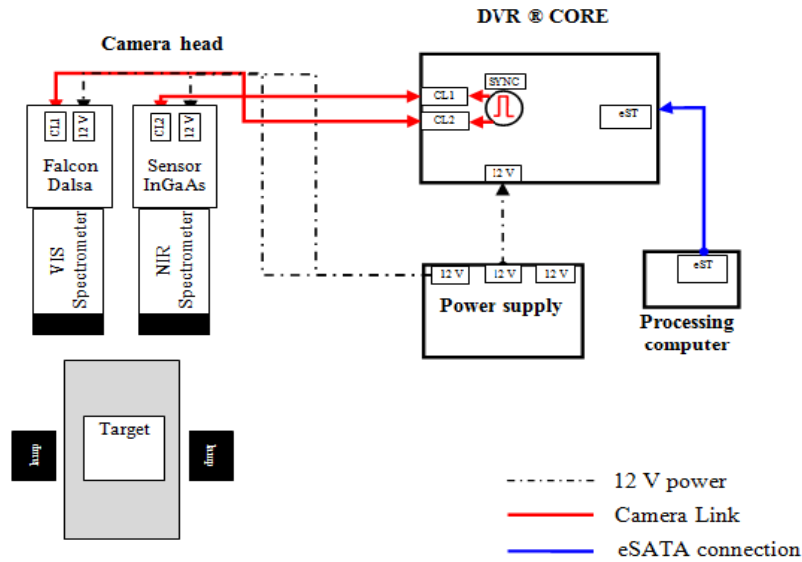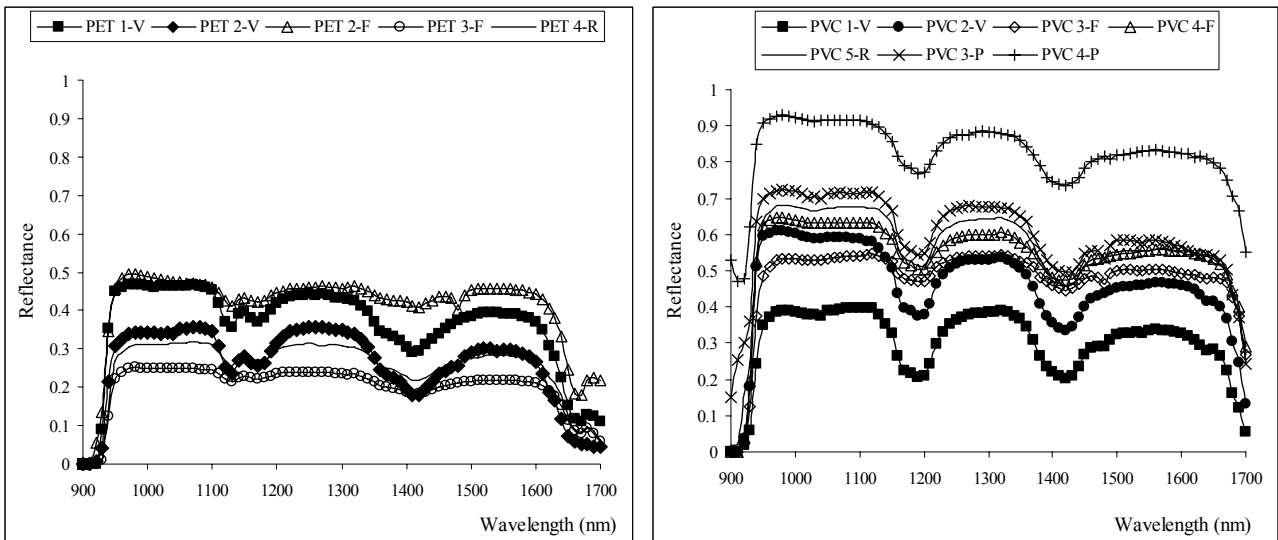

Figure 3. NIR signatures of PET and PVC samples.

Near-infrared reflectance spectra extracted from hyperspectral images of PET-PVC samples were used to determine wavelength pairs that can be used to distinguish the two plastic materials. The optimal wavelengths were selected based on a correlation analysis between the wavelengths. The lowest correlation occurred at 1200 nm and 1650 nm, suggesting an index formed by the couple of wavelengths may be effective in plastic sample classification.

4. Conclusions

The wide range of density assumed by the same typology of plastics demonstrates how hyperspectral systems represent a viable alternative to traditional systems of separation by type of polymer based on density. The results obtained show that the hyperspectral analysis is suitable to be used to identify, and then separate, PET and PVC. Though reflectance values depend on many factors such as the characteristics and the thickness of the materials, the lighting conditions, the characteristics of the instrumentation used, and the background, the two different materials are characterized by distinguishable profiles. The hyperspectral analysis conducted in the near infrared region (900-1700 nm) has highlighted as materials belonging to the same type of polymer present spectral curves similar, differing only in the reflectance values. This behaviour characterizes samples belonging to a given plastic typologies no matter the dimension, the phases in the product life cycle (virgin, recovered or post-consumer), or, finally, the form (flakes or pieces). This confirms the validity of hyperspectral imaging for plastic separation, which can be used in any stage of the life cycle of a product.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

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