Classification of spectra through data compression and spectral mapping for selected consumer plastics in real time sorting process

V. Venkataraman,* R. Govindaraj, S. Md. Iqbal, T. Chinnu and K. Subrahmanyam

Central Electronics Engineering Research Institute, CSIR Madras Complex, Chennai - 600113, Tamil Nadu, India.
E-mail: venkynir_98@hotmail.com

Introduction

Waste disposal has become a major industrial problem. Consumer plastics are made of different types of resins and fillers. The most common consumer polymers are Polyethylene terephthalate (PET), low & high-density polyethylene (LDPE & HDPE), Polyvinyl chloride (PVC), Polypropylene (PP), and Polystyrene (PS). There are two methods for sorting recyclable plastics, either manual or automatic sorting. It has been noted that manual sorting had caused difficulties in achieving consistency in the plastic separation process. Automatic sorting gives a suitable option for recycling the plastics to achieve high throughput. An automated sorting system with intelligent, efficient, and timing optimized could be the solution for the above problem. The application of chemometrics, together with NIRS converts a complicated system into a simple one. Several attempts have been made for developing new technology, such as plastic identification, using a laser diode, with a view to bring a new solution to conventional plastic identification, and cost effectiveness.[1,2]

A laboratory scale prototype plastic waste sorting system, incorporated with an InGaAs diode array spectrometer was configured, and tested in real time to identify the above polymer types viz., PVC, PET, PP, PS and PE. Spectral data processing for classifying the type of polymer material from the waste cluster was developed and implemented using chemometrics techniques.[3] In this work, an attempt has been made to develop a time-optimized, efficient polymer classification method utilizing wavelet coefficient-based feature extraction. The spectral data of a variety of polymer samples were acquired in real time, and processed using the developed classification methods. The classification efficiency and processing time of different methods were evaluated, and the results are reported.

Materials and methods

Plastic waste sorting system

The laboratory-scale system (Figure 1) was configured for real time sorting of plastic waste materials.

This system consists of (a) a pair of 250-watt halogen light sources to illuminate the plastic sample, (b) front end light collection optics, (c) NIR diode array spectrometer (microParts steag, NIR 1.7) with a spectral range of 1100–1700 nm, (d) a conveyor arrangement to enable scanning the plastics for measurement and (d) a P4 industrial computer system, with standard hardware interfaced to the spectrometer and conveyor movement actuators. A Graphical User Interface (GUI) was developed in visual studio environment and implemented to enable spectral data collection through DAS in synchronization with conveyor movement. Software modules were also developed and executed in real time for spectral data acquisition, processing, analysis, and sorting the polymer material.

Plastic samples

The plastic waste samples for testing and validating the system were sourced and collected from a plastic recycling industrial plant. More than 300 samples of the PET type and 150 samples each of PP, PS, PVC, PE of different colors and shapes were used. For validation, and to test the robustness of the approach, a separate set of samples was procured from local vendors collected through street pickers.

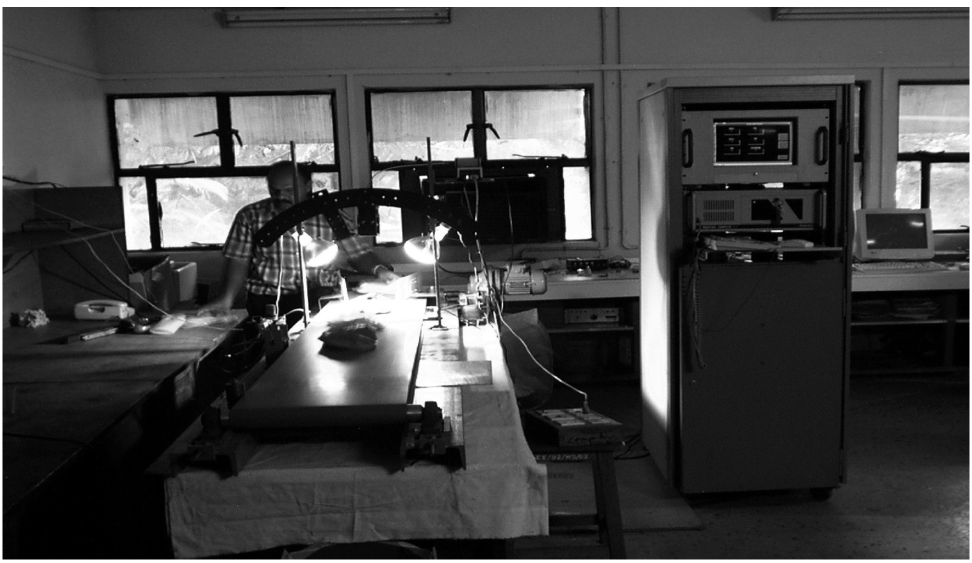

Figure 1. Laboratory-scale plastic waste sorting systems.

Classification methods

Classification was achieved by moving through the variables in the spectra, comparing the successive with previous data marking increasing value as a positive index, and decreasing value as a negative index, with equal value as zero for both standard and specimen spectra, followed by multiplying the occurrence of positive signs, which gives the value of *C,* designated as concurrent deviation. By applying the value of *C* and *n* that is number of such occurrence of pairs in the formula,

$$\mathbf{r_c = \pm \sqrt{((2C\text{-}n)/n)},}$$

the correlation coefficient, r_c is calculated. The value of $\mathbf{r_c}$ obtained using the above Concurrent Deviation method reflects the classification. Another type of classification is Fourier ranking. The fewest Fourier coefficients required to regenerate the spectra with less error can be obtained. The coefficient thus obtained is ranked, for both standard and specimen spectra. By calculating the sum of squares of the difference (*d*), the rank correlation (*r*) is obtained using the following equation.

$$\mathbf{r = 1\text{-}\ 6 \sum d^2 / (n^3 - n)}$$

The value of '*r*' reflects the efficiency of the classification.

Spectral Angle Mapping (SAM)

The projection of specimen spectra in the plane of library spectra is referred to as spectral angle mapping. This is obtained by using the following equation.

$$\mathbf{b(x) = \cos(\alpha(x)) = (x \bullet y / \| x \| \| y \|)}$$

where *b(x)* is the mapping index, α is the projection angle, *x* & *y* are the specimens and library spectra of the polymer respectively.

Self-Organizing Map (SOM)

SOM is a competitive network, which is an unsupervised learning method, a successful technique in various pattern recognition tasks involving noise signals.[4] The SOM neural is applied for polymer identification and classification using optimum Fourier coefficients of the spectra.

Wavelets transform (WT)

WT yields valuable results in building chemometrics models. It has been successfully applied to pre-processing of NIR spectra for identification purpose[5] and de-noising, or compression of signals through thresholding. The wave thrush properties, of Daubechies are used here for information extraction without loss. It was observed that the pattern remains the same and the variable index was considerably reduced, to half of the original spectral coefficient.

Results and discussions

The spectral data of the polymers were acquired and processed for identification and classification purposes using the above mentioned classification methods. It was found that the SAM method

Table 1. Results of SAM classification with various preprocessing techniques.

SAM classification applied with various preprocessing techniques	Processing time in seconds/sample	Classification percentage
Baseline, smoothing & derivative	0.110	100
Baseline, smoothing & SNV	0.120	80
Fourier coefficients with SOM	0.200	100
Baseline, SNV & Wavelets	0.030	100

took the least time for efficient classification, compared to other methods. The results obtained using SAM classification with various preprocessing techniques are shown in Table 1.

It was observed that wavelet transform optimized the preprocessing and reduced the computational time further. The classification result through wavelet transform along with SAM was found be close to hundred percent and its processing time was about 30 milliseconds. The classification efficiency and the processing time thus achieved through SAM are very effective and could be implemented for real- time sorting of plastics.

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