Sorting of construction and demolition waste by hyperspectral-imaging

Frank Hollstein, Markus Wohllebe, and Martin Herling[1], Iñigo Cacho and Sixto Arnaiz[2]

[1] RTT Steinert GmbH, Hirschfelder Ring 9, 02763 Zittau; (+49) 3583 54084 25;
E-Mail: hollstein@unisort.com; Germany
[2] Fundación GAIKER, Parque Tecnológico, 202, 48170 Zamudio; (+34) 94 6002323;
E-Mail: cacho@gaiker.es; Spain

Abstract

A basic step to achieve a holistic recycling process for Construction and Demolition Waste (C&DW) is a relevant improvement in (automatic) sorting technologies. Hyperspectral-Imaging (HSI) is an outstanding candidate to support the process. Currently the biggest challenges with regard to C&DW detection cover the need of overlapping VIS, NIR and SWIR hyperspectral images in time and space, in particular for selectively recognition of contaminated particles. In the study on hand a new approach for HSI is described by exploiting VIS-NIR-SWIR spectral information in real time (350 Hz full frame rates). The contribution focuses on a development path for an industrial implementation in automatic sorting and separation lines for C&DW recycling. The main target is on the on-line detection and sorting of gypsum and stony items with organic contamination to close the recycling loops of gypsum (plaster to plaster), concrete (concrete to concrete) and ceramic materials (brick/ceramics to brick/ceramics) because of their exceptional potential for increasing sustainability by conserving construction resources.

Key words: C&DW, (Automatic) Sorting, Hyperspectral-Imaging.

Introduction

The recycling industry of building materials is currently dominated by conventional technologies. Sorting processes have been until now solely used for the separation of light components by gravimetric means or of steel by over-band magnetic separators, respectively. These technologies are not able to separate the incidentally mixed aggregates. Furthermore, residential and other buildings are becoming more and more complex. Especially from 1980 onward, new materials (e.g. polymers, composites) and new technical requirements (e.g. thermal and acoustic insulations) have been massively introduced into the market. The execution of demolition and refurbishment works from 2020 onward will correspond to those assets built from 1980. Therefore the prospective Construction and Demolition Waste (C&DW) will be more complex than the existing one and there is a need for shifting from traditional recycling approaches to novel recycling solutions.
Hyperspectral-Imaging (HSI) is an outstanding candidate to support the process. Currently the biggest challenges with regard to C&DW detection point to the need of overlapping VIS, NIR and SWIR hyperspectral images in time and space, in particular for selectively recognition of contaminated particles. The research described below expands on the findings

represented in [1]. There the possibilities and limitations of HSI-technologies for the NIR-SWIR spectral range were presented. That publication focused on the separation of non-contaminated stony C&DW debris into three fractions ("grey", "red" and "unwanted/unknown") by means of NIR-SWIR-HSI detection and classification methods. In the study on hand the investigations have been extended to the recognition of organic contaminated materials. In addition gypsum and gypsum like materials are considered deeper. This contribution is aimed at the development of solutions for an industrial implementation of HSI supported detectors in automatic sorting and separation lines for C&DW recycling.

Experimental method

Thirty reference samples of typical stony and gypsum items (each approx. 4 × 4 × 2 cm³) from different C&DW categories have been artificially polluted with organic contaminants. Six categories of demolition waste have been defined, namely concretes, natural stones, brick/roof-tiles, floor/wall-tiles, other ceramics and gypsum, respectively. Five organic pollutants, namely motor oil, enamel paint, resins (epoxy and phenolic types) and tar based emulsion have been applied. For each waste category and pollution type one item was polluted "half-page". The non-polluted areas served as reference surfaces and for verification of results from [1].

Fig. 1. RED-EYE-2.2 Imager

As Hyperspectral-Imager a RED-EYE-2.2 device from INNO-SPEC GmbH (Germany) has been used. The RED-EYE-2.2 imager (Fig. 1) consists of an InGaAs focal plane detector with 320 × 256 pixels, each for the wavelength range 1.2 – 2.2 µm, a grid as dispersion element and diverse other optical and electronically components. In full resolution mode the maximal frame rate is 350 Hz (fps). Power consumption is less than 9 W.

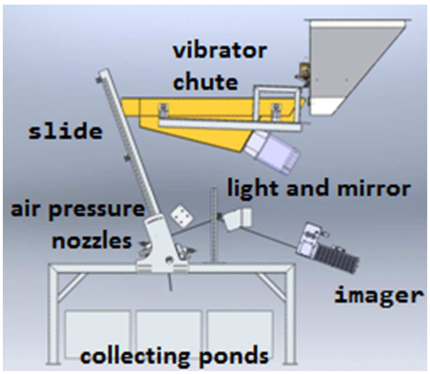

Fig. 2: Experimental Sorter

A demonstrator has been developed to carry out detection and sorting experiments (Fig. 2). The material to be sorted is delivered to a slide through a vibrator chute. After passing the optical detection area, RTT's embedded imager and classification software produces a so-called chemical image [2]. The image depicts for each surface pixel a color coded class affiliation related to the kind of waste material. The classification is based on NIR-SWIR spectral analysis and machine learning methods [3] in on-line mode. The geometrical shape of a stony item from the waste stream is then reconstructed from the pixels of the chemical image with the support of image processing software. According to the overall classification each piece is subsequently collected in separated bins by air pressure nozzles. Three collecting bins are available for a “gray fraction”, a “red fraction”, and an “unwanted fraction”, respectively.

Results

The main results can be summarized by examples according to Fig. 3. First a database of classifiers is created by using the spectra of non-contaminated item areas. Then a self-recognition test is performed. Fig. 3a depicts the chemical images from the self-recognition view. Each color codes one of the C&DW categories studied. Best results are obtained for GC and gypsum (YESO). The simple perceptibility of gypsum is already known from [4]. Some GS items are misclassified as GC, but they fall into the right gray fraction. Most of the floor/wall-tiles (RT) are decided as RB, but both are red fractions. The classification of ROC (red category) is difficult. Most of the items are segregated as gray fraction. The reason for this misclassification is that some items have high gloss surfaces, a killing property for classification by NIR-SWIR means. In the case of sorting, such items would be separated into the unwanted fraction and would be lost for the ceramics. By overlapping a VIS detection (here not performed) such NIR-SWIR misclassification can be corrected.

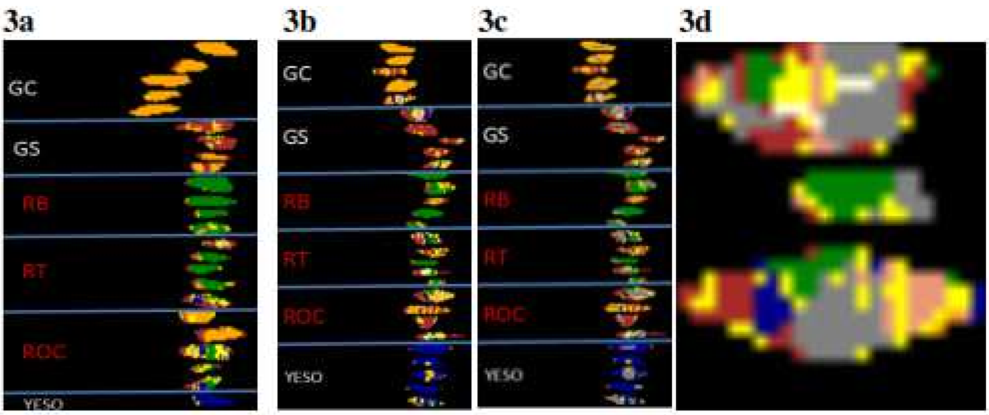

Fig. 3: Chemical images of items

3a: without contamination **3b: with** contamination (no plastics classifiers)
3c: with contamination (with plastics classifiers) **3d**: partial zoomed **Fig. 3c**

abbreviation:	**GC** (grey)	**concrete**	**GS** (grey)	**natural stone**
	RB (red)	**brick/roof-tile**	**RT** (red)	**floor/wall-tile**
	ROC (red)	**other ceramics**	**YESO**	**gypsum**

Fig. 3b depicts the chemical image of contaminated surface areas. At first glance, no significant influence of the pollution is recognized; the spectral information of the bulk materials is dominant. But nevertheless, the organic contaminants influence spectral fingerprints slightly due to their carbon based substance components. To determine whether organic contaminants are present on the stony surface, detection of hydrogen oxygen compounds must be carried out. This can be easily done by expanding the database of stony classifiers with a standard plastics classifier database. Fig. 3c depicts the result obtained by applying the idea in such a way. Here all pixels detected as plastics in the chemical image are colored gray, partial zoomed in Fig. 3d. By statistical analysis the presence of organic pollution can be concluded.

Conclusion

Non-contaminated stony C&DW is classifiable as already explained in [1]. RB and RT should not be distinguished as different waste categories. ROC has some risk for misclassification by NIR-SWIR means because some items with high gloss surfaces fall into the ROC category. Gypsum is clearly recognizable as autonomous material class. Organic contaminants (oil, resin, paint, tar) influence spectral fingerprints slightly due to their carbon based substance components. In the here investigated case of very low and inhomogeneous distributed concentrations of pollutants the spectral information of the stony bulk materials is dominant. The presence of organic contaminants can be detected by HSI; however, to distinguish each kind is hardly straightforward (too many options). If it should be necessary to determine the type of present organic pollution, which is not impossible by HSI, a substantial extension of the spectral database would be necessary.

Acknowledgment

The authors wish to acknowledge the support of the European Union’s Horizon 2020 Research and Innovation Framework Program (Grant Agreement No 642085) as frame within this research has been conducted. Some of the results were verified thankworthy by free permission of using WEKA [3] software from University of Waikato (Hamilton, New Zealand).

References

[1] Frank Hollstein, Íñigo Cacho, Sixto Arnaiz, and Markus Wohllebe, "Challenges in automatic sorting of construction and demolition waste by hyperspectral imaging", Proc. of SPIE Vol. 9862, pp J01 – J10, 2016

[2] Chein-I Chang, "Hyperspectral Imaging: Techniques for Spectral Detection and Classification", Springer, 2003

[3] Ian H. Witten, Frank Eibe, Mark A. Hall, and Christopher J. Pal, "Data Mining: Practical Machine Learning Tools and Techniques – 4th edition“, Morgan Kaufmann Series in Data Management Systems, 2016

[4] Roberta Palmieri, Giuseppe Bonifazi, and Silvia Serranti, "Automatic detection and classification of EOL-concrete and resulting recovered products by hyperspectral imaging", Proc. of SPIE Vol. 9106, pp D01 – D14, 2014