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Short Communication

DEVELOPMENT OF AN IMAGE-BASED ANALYSIS METHOD TO DETERMINE THE PHYSICAL COMPOSITION OF A MIXED WASTE MATERIAL

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Abstract

An experimental study was undertaken to assess the suitability of an image-based approach for determining the physical composition of mixed organic wastes. Samples arriving at 6 different waste sorting facilities, each visited twice during the study, were physically sorted to examine the composition these materials. During these surveys the waste was processed in order to obtain digital images covering 30 m^2, representing approximately 250-500 kg of mixed waste. The images were processed using ERDAS Imagine software in order to assess the area covered by each component within the waste material. The composition determined from the image analysis was compared with the results from the physical hand sorting. The image analysis results indicated a strong correlation between the physical results (mean r = 0.91) however it was evident that components such as film plastics and paper were over-estimated by the image analysis approach. This short communication provides initial results, demonstrating the potential of an image-based method, and discusses further research requirements and future applications of this technique.

Keywords- Waste composition, residual wastes, commercial and industrial wastes, image analysis

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1. Introduction

Waste management practices are rapidly changing and adapting in a number of countries as legislative and economical drivers incentivise more sustainable options such as reduction of landfill disposal and recovery of valuable resources. In Europe the management, treatment and disposal of waste materials are governed and influenced by a number of European Union legislations including the Waste Framework Directive (Council of the European Union, 2008), the Landfill Directive (Council of the European Union, 1999) and the Waste Incineration Directive (Council of the European Union, 2000).   These directives are adopted at national levels within each of the EU member states; and to establish realistic and achievable waste strategy targets, including recycling rates, an accurate understanding of waste composition and arisings are required (Burnley, 2007a).

In Europe, national and international targets have been set up for waste recycling, recovery and diversion from landfill (Burnley et al., 2007), which combined contribute to an integrated waste management system (Grosso et al., 2010). Understanding the quantity and composition of a waste stream produced is important in establishing quantities of potential recyclable materials and implementation of improved collection regimes; also to forecast future waste generation in given regions (Parfitt and Flowerdew, 1997). The composition and variation of wastes is also important in the design of suitable sorting and residual treatment technologies (Burnley, 2007b), of which includes energy recovery processes (Wagland et al., 2011).

Currently in the UK, local authorities and treatment operators carry out time-consuming and expensive studies to gain information on the percentages of material not recycled in the residual waste (Resource Future, 2008). There is an increasingly high cost and time premium to undertake the waste analysis, yet the need for constant monitoring of the waste stream to support and monitor the implementation of the strategy is obligatory (Burnley et al., 2007). The common approach of direct waste sampling involves hand sorting waste into individual components (Burnley, 2007a; Burnley et al., 2007; Entec UK Ltd and Eunomia Research and Consulting Ltd, 2004; Friends of the Earth, 2008); this is time consuming and carries a number of issues regarding labour costs and health and safety concerns.

Research towards new, non-invasive, remote imaging and image recognition methods to provide faster and more sensitive technologies for waste characterization could lead to significant savings in time and cost, and a reduction in the risk of worker exposure. The main principle of image analysis is that all objects have a series of visual characteristics that allow differentiation, these can be: shape, size, pattern, tone, association, shadow and texture (Paine and Kiser, 2003). An example of a non-complex, simple approach that could be used to quantify the area coverage of items in a waste picture is the dot grid method, which can be considered a rapid, repeatable, and precise method (Nowak et al., 1996). A dot-grid consists of a set of dots superimposed on digital imagery. The sum of dots intersecting the object of interest divided by the total amount of dots computes an estimation of the area occupied by the object. The use of a dot-grid in calculating the area occupied by object in an image has already been widely used in a number of different applications including tree area coverage (Nowak et al., 1996), marine organism populations (Foster et al., 1991), seed production (Gray et al., 2009) and to calculate area of deformation on a surface (Blomberg and Persson, 2004).

This study investigates the novel application of a dot-grid approach to assess the physical composition of a mixed residual waste material. The aim of this method is to demonstrate a basic technique for determining the composition of large quantities of waste materials, without the disadvantages of lengthy site operation disruption and the health and safety implications of hand sorting the equivalent waste sample.

This investigation is part of a large project which aims to understand the arisings and composition of commercial and industrial (C&I) wastes, due to a lack of understanding of this waste stream in the UK. Consequently in this study the dot-grid and the conventional hand sorting methods have been used to determine the composition of a number of samples from C&I waste collection rounds.

2. Methods

2.1. Sample location and preparation

Three waste transfer stations were studied in this investigation, all of which received mixed residual wastes collected by Shanks Waste Solutions from commercial and industrial premises in the respective local areas. Each of the transfer stations were visited twice during this study, providing a total of 6 sets of data. Each of the sites receive between 30,000-60,000 tonnes of residual C&I waste per annum; the waste is either sorted by manual sorting lines to extract recyclable components, or is sent onwards for landfill disposal.

From the input waste material 3 mechanical bucket loads (ca. 250 kg) were isolated from the main waste pile and unloaded onto the sample area floor. The refuse bags were then manually split and the contents spread evenly across the designated sample area to a depth of 20-30 cm.

2.2. Imaging of waste sample

A total of 30 unique sections of the evenly spread waste sample were segregated using a 1 m^2 quadrat as shown in Fig. 1, with each section captured from directly above using a standard 12 megapixel digital camera. The images, representing 900 m^2 or approximately 270 m^3, were then transferred onto a PC off-site for analysis with specialist software (Erdas Imagine v9.3).

>>>>>>>>>>>>>>>>>**Please insert Figure 1.**<<<<<<<<<<<<<<

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The images were processed by sub-setting/cropping the quadrat area, geometrically correcting to produce a square of equal, and defined, dimensions. A dot-grid (11 x 11) was then placed over the images (Fig. 2), and the number of dots covering each waste component was counted digitally.

2.3. Hand sorting

From the evenly spread sample material 15 sub-samples were taken, after imaging, to ensure a representative sample (European Committee for Standardisation, 2005) for hand sorting. The waste was sorted into categories including paper, card, dense plastics, film plastics, metals, wood etc. Each of the categories were then weighed and recorded, and the results reported as a percentage of the total mass.

The individual components of a fixed volume (30 litres) were weighed to determine the density (g/cm^3) of each component, where suitable literature values were not available, which was used to assist in the image analysis process.

3. Results and discussion

The compositional results of the physical and image sorting are shown in Table 1.

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As shown in Table 1 the composition shown by physical sorting and from image analysis are different. Conversely there is strong evidence that two sets of data are not equal ($p < 0.01$, two tailed *t*-test). However, despite this, there is a strong correlation between the two datasets with correlation (r), with the lowest correlation being 0.55. The significance of these correlations are $p<0.005$; and $p<0.05$ for the weakest correlation ($r = 0.55$).

The physical composition of the wastes analysed indicate, on average, a higher quantity of plastics than in previous studies (Burnley et al., 2007; SLR Consulting, 2007). In the UK the proportion of plastics, paper and card in mixed residual C&I wastes are generally higher than in municipal solid waste (MSW). This is largely due to recycling targets applied to MSW, but not to C&I (Defra, 2007). The samples included within this study appear to be typical of a mixed residual C&I waste from the UK. There is very limited information regarding C&I waste in the UK, despite being significantly higher in volumes generated than MSW (Burnley, 2007a; Burnley et al., 2007; Jacobs Engineering Ltd, 2010).

The differences between the determined mass of waste components can be attributed to the use of density values for each of the materials. It is evident from the table that paper and light plastics (i.e. film packaging) are over-estimated by the image analysis method. These are the lightweight fractions of waste, relative to other components and so the use of a density of each material is limited by the effect of sample overlap and spreading. For example 2-3 sheets of paper could cover a large, whereas 2-3 compacted sheets of paper will cover a relatively small area; as a result the image analysis technique evidently over-estimates the paper content due to this limitation. As a result of these observations it is necessary to investigate alternative methods of relating a 2 dimensional image to a mass unit for a specific component. Previous studies have investigated methods of calculating mass from a 2D image such as Banta *et al* (2003). However this study focused (Banta et al., 2003) on the characterisation of limestone particles; mixed waste materials are much more heterogeneous.

The results have highlighted that this technique could potentially be used in large-scale waste composition studies, such as those frequently undertaken by Local Authorities in the UK (Burnley, 2007a; Parfitt, 2002; Resource Futures, 2009). Such technique would mean that the time involved in processing the waste would be significantly reduced; the images could be processed offsite, thus providing a digital record of the samples collected. Work is currently ongoing to enhance the accuracy of the technique, specifically with regards to the density conversion for each of the materials; determining the maximum waste layer depth and improving the timescale involved with processing the images. Further work aims to automate the technique as far as practically possible, resulting in a powerful tool for assessing waste composition and aiding decisions regarding adaptation of waste treatment processes to allow for changes in waste composition.

4. Conclusions

This paper has presented early findings of ongoing research. The image analysis technique has shown early potential that it could be a suitable methodology for assessing the composition of mixed waste materials, however further work is required to reduce limitations of the method. Research is currently ongoing at Cranfield University to improve the accuracy of the process and to investigate other potential applications within the waste industry.

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Table 1. Composition data of waste materials from physical and image sorting.

Physical Analysis							
	Site A1	**Site A2**	**Site B1**	**Site B2**	**Site C1**	**Site C2**	***Mean***
Paper	50.3	24.7	40.3	24.5	13.8	23.0	*25.3*
Cardboard	20.0	10.4	27.7	15.9	15.4	19.8	*17.8*
Light Plastics	1.4	28.5	14.2	9.2	8.3	9.4	*13.9*
Dense Plastics	12.3	9.2	12.7	7.9	3.9	9.4	*8.6*
Glass	3.5	0.3	0.0	4.3	12.7	0.4	*3.5*
Organics	4.9	12.5	3.9	20.7	32.0	11.9	*16.2*
Metals	3.4	13.5	1.3	6.1	0.1	11.9	*6.6*
Wood	0.0	0.0	0.0	0.0	13.2	6.8	*4.0*
Textile	4.3	0.0	0.0	8.8	0.1	5.4	*2.9*
WEEE	0.0	0.3	0.0	0.0	0.1	1.8	*0.4*
Inert	0.0	0.6	0.0	2.6	0.6	0.4	*0.8*
Image Analysis							
Paper	75.9	39.4	58.8	30.6	31.5	40.9	*40.2*
Cardboard	11.5	19.4	22.6	12.2	18.9	17.9	*18.2*
Light Plastics	8.0	31.2	18.2	23.9	29.1	20.1	*24.5*
Dense Plastics	9.2	5.8	3.9	7.1	2.8	11.3	*6.2*
Glass	0.1	0.3	0.1	1.4	1.6	0.0	*0.7*
Organics	0.2	5.8	1.1	12.1	19.7	12.8	*10.3*
Metals	2.3	2.0	1.1	2.6	2.2	1.7	*1.9*
Wood	0.7	1.6	0.0	0.6	1.4	4.1	*1.5*
Textile	0.9	2.7	0.6	9.3	0.8	1.2	*2.9*
WEEE	0.0	0.0	0.3	0.0	0.1	1.0	*0.3*
Inert	0.0	1.2	2.3	8.4	0.0	0.4	*2.5*
Correlation [*r*]	**0.96**	**0.87**	**0.94**	**0.77**	**0.55**	**0.84**	***0.91***

Figure 1. Placement of quadrat on mixed waste sample.

Figure 2. Processed image with completed dot-grid analysis.