Plastic sorting by X-ray radioscopy with photon counting detector

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Abstract
Plastic sorting technique is of great impotance to avoid major environmental and health problems. Acrylonitrile-butadiene-styrene (ABS) is a commonly used thermoplastic polymer that often contains flame retardant (FR). The present work investigates the decomposition feasibility of different ABS-FRs using X-ray radioscopy with photon counting detector. We build a phantom that contains 3 ABS-FR materials and a PCD array with 6 energy bins. A material decomposition method based on patchwise regularization and least log-squares is poposed and evaluated. Results show that the proposed method can not only sepatate 3 ABS-FR materials but also obtain high quantification accuracy of the basis materials.

Keywords: plastic sorting, photon counting detector, X-ray, material decomposition

1 Introduction

Waste electrical and electronic equipment (WEEE) has been increasing rapidly due to the development of electronic industry. In European Union, the amount of WEEE generated in 2005 is 9 million tonnes and this number is supposed to grow to 12 million by 2020 [1]. The sorting technique is important for subsequent treatment and recycling of WEEE to avoid major environmental and health problems. Acrylonitrile-butadiene-styrene (ABS) is a commonly used thermoplastic polymer that often contains flame retardant (FR) [2]. The present work investigates the decomposition feasibility of different ABS-FRs using X-ray radioscopy with photon counting detector (PCD). PCD is able to characterize photons having different energies and makes it possible to separate various materials with a single acquisition. To set up this study, we build a phantom that contains three ABS-FR materials for simulated radioscopy imaging. We propose a material decomposition method based on regularized least log-squares criterion for the objective function and evaluate its performance for ABS-FR materials identification.

2 Method

Let $\mu(E,\vec{x})$ deote the the linear attenuation coefficient of a point at location $\vec{x}$ within the object under energy E. For a mixture object, if we choose a basis of M materials, then $\mu(E,\vec{x})$ can be considered the linear combination of these materials' mass attenuation coefficients $\mu_{m\alpha}(E)$ [3] weighted by their densities $\rho_\alpha(\vec{x})$, where α denotes the type of material. According to Beer-Lambert law, the expected number of photons $\lambda_i(P_\alpha(px,py))$ at pixel $(px,\ py)$ in energy bin $B_i(i=1,2,\ldots,N$ with N indicating the total number of energy bins) with the start energy of $E_s(i)$ and final energy of $E_f(i)$ can be expressed as:

$$\lambda_i(P_\alpha(px,py)) = \sum_{E_S(i)}^{E_f(i)} N_0(E)\exp\left[-\sum_{\alpha=1}^{M} P_\alpha(px,py)\mu_{m\alpha}(E)\right], \text{ with } P_\alpha(px,py) = \int \rho_\alpha(\vec{x})ds \tag{1}$$

where $N_0(E)$ is the initial number of photons of X-ray spectrum at enrgy E. A log-squares criterion has been introduced in [4] for the objective function to obtain $P_\alpha(px,py)$. Based on this formula, we propose to add a patchwise regularization term in the objective function:

$$P_\alpha(px,py) = \arg\min_{P_\alpha(px,py)}\left\{\sum_{(px,py)\in C}\sum_{i=1}^{N}[\ln(\lambda_i(P_\alpha(px,py))) - \ln(m_i)]^2 + rR(P_\alpha(px,py))\right\} \tag{2}$$

where C represents a small patch of the acquired image, r is a relax parameter and $R(P_\alpha(px,py))$ is the regularization term that considers the total variation of $P_\alpha(px,py)$ within patch C.

In the present study, the object is supposed to be isotropic and X-rays are nearly parallel. Therefore, after obtaining $P_\alpha(px,py)$ for each pixel, we devide it by the depth of object to calculate $\rho_\alpha(\vec{x})$.

We use INSA software Virtual X-ray imaging (VXI) [5] to simulate the radioscopy process of different ABS-FR marerials. Figure 1 shows the system scheme. The phantom is composed of 3 cubes with height of 10 mm, width of 10 mm and depth of 2 mm, representing different ABS-FR materials. The detailed components of each cube are listed in Table 1. The simulated

system uses 100 kVp X-ray spectrum with tube current of 15 mA and a 24×68 cadmium telluride (CdTe) detector array with pixel size of 0.5mm×0.5mm. Six energy bins are set to be evenly distrsibuted from 30 keV to 90 keV. Scanning time is 1 s, and the distances from source to rotation center and detector to rotation center are 2000 mm and 2 mm, respectively.

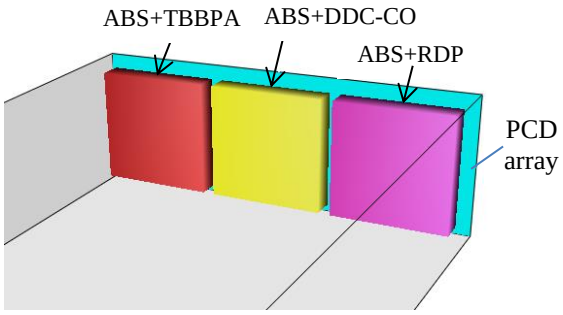

Figure 1: Simulated radioscopy system scheme (X-ray source is too far to be visble).

Table 1 Components of materials in the 3 cubes

	Cube1	Cube 2	Cube 3
Material (ABS+FR)	ABS +		
	TBBPA	DDC-CO	RDP
Denity of material $\rho_{mixture}$	1.06 g/cm^3	1.06 g/cm^3	1.06 g/cm^3
FR chemical formula	$C_{15}H_{12}Br_4O_2$	$C_{18}H_{12}Cl_{12}$	$C_{30}H_{24}O_8P_2$
Massive % of FR	15%	15%	15%
Mass % of Br, Cl and P, resp	8.82%	9.76%	1.62%
ρ_{eff} of Br, Cl and P, resp	0.0935g/cm^3	0.103 g/cm^3	0.0172 g/cm^3

TBBPA: tetrabromobisphenol A DDC-CO: dechlorane plus

RDP: resorcinol bis (diphenyl phosphate) ρ_{eff} : efficient density ($\rho_{mixture}$*mass %)

3 Results

In view of the material composition of the object, we choose ABS, bromine (Br) and chloride (Cl) as a basis of materials. The reason for having not selected phosphorus as the basis is that P and Cl have too close atomic numbers and experiments showed that they can be barely separated. Patch size for regularization is set to be 2×2. Figure 2 demonstrates the decomposition results of the scanned phantom. All three cubes are visible in Figure 2 (left), due to the containment of ABS. The ABS+TBBPA cube is well separated and highlited in the Br basis image (middle). The other two tubes all appear in the Cl basis image (right), but there exists significant density difference between them, therefore they can be easily distinguished by the observer even if the concentration of FRs changes more or less. Figure 3 gives the 1-D profile along dash lines in Figure 2, the comparison between theoretical densities (see Table 1) of 3 basis materials and our measurements is illustrated. Their high consistence indicates that the proposed method can not only sepatate 3 ABS-FR materials but also obtain high quantification accuracy of the basis materials.

Figure 2: Decomposition results of the proposed method: ABS basis image (left), Br basis image (middle) and Cl basis image (right)

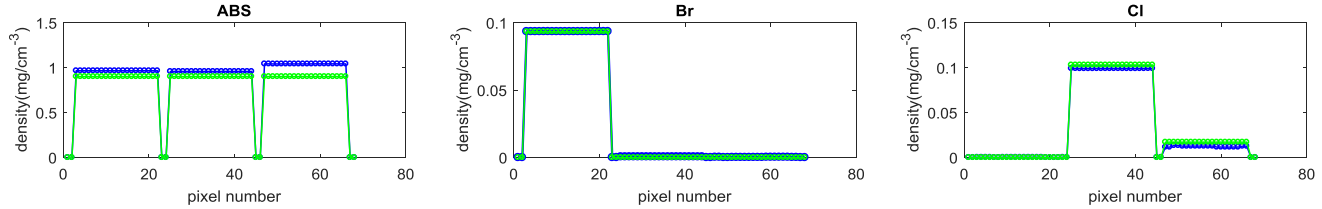

Figure 3: 1-D profiles along dash lines in Figure 2. Green curve represents the theoretical density of basis materials if the decomposition is perfect, blue curve represents our measurement: ABS basis (left), Br basis (middle) and Cl basis (right).

Acknowledgements

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