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A new classification scheme of plastic wastes based upon recycling labels

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ABSTRACT

Since recycling of materials is widely assumed to be environmentally and economically beneficial, reliable sorting and processing of waste packaging materials such as plastics is very important for recycling with high efficiency. An automated system that can quickly categorize these materials is certainly needed for obtaining maximum classification while maintaining high throughput.

In this paper, first of all, the photographs of the plastic bottles have been taken and several preprocessing steps were carried out. The first preprocessing step is to extract the plastic area of a bottle from the background. Then, the morphological image operations are implemented. These operations are edge detection, noise removal, hole removing, image enhancement, and image segmentation. These morphological operations can be generally defined in terms of the combinations of erosion and dilation. The effect of bottle color as well as label are eliminated using these operations. Secondly, the pixel-wise intensity values of the plastic bottle images have been used together with the most popular subspace and statistical feature extraction methods to construct the feature vectors in this study. Only three types of plastics are considered due to higher existence ratio of them than the other plastic types in the world. The decision mechanism consists of five different feature extraction methods including as Principal Component Analysis (PCA), Kernel PCA (KPCA), Fisher's Linear Discriminant Analysis (FLDA), Singular Value Decomposition (SVD) and Laplacian Eigenmaps (LEMAP) and uses a simple experimental setup with a camera and homogenous backlighting. Due to the giving global solution for a classification problem, Support Vector Machine (SVM) is selected to achieve the classification task and majority voting technique is used as the decision mechanism. This technique equally weights each classification result and assigns the given plastic object to the class that the most classification results agree on. The proposed classification scheme provides high accuracy rate, and also it is able to run in real-time applications. It can automatically classify the plastic bottle types with approximately 90% recognition accuracy. Besides this, the proposed methodology yields approximately 96% classification rate for the separation of PET or non-PET plastic types. It also gives 92% accuracy for the categorization of non-PET plastic types into HPDE or PP.

1. Introduction

Plastic products have become an inseparable part in our lives as many objects of daily use are made of some kind of plastic. They have special importance since they costs less, resists corrosion, have low density to volume ratio and being highly flexible and strong, (Bruno, 2000). However, biodegradation process of plastics is very slow because, plastics used today are synthesized using non-renewable fossil resources. Therefore, the plastic wastes should be recycled to decrease these effects.

Since there are about 50 various types of plastics with hundreds of different varieties, the American Society of Plastics Industry developed a standard marking code in order to help consumers identify and sort the main types of plastic; so the classification during classification can be easy. The plastic products are labeled and separated into seven groups as Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Vinyl/Polyvinyl Chloride (PVC), Polypropylene (PP), Polystyrene (PS), and OTHER (Other kinds of plastic products). The fractions of these plastic bottles used in the United States plastic bottle market are over 96% (96.4%) for PET and HDPE bottles. Moreover,

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the fractions for PP and LDPE are 1.9% and 0.84%, respectively. PET and HDPE bottles also continued to dominate the bottles collected for recycling, collectively being 98.3% and PP being 1.7% (American Chemistry Council, 2012). If a novel classification system is widely preferred, it can be a comprehensive solution to separate the PET, HPDE, and PP type plastic bottles since they dominate the bottles collected for recycling.

Sorting of plastic wastes at Materials Recovery Facilities (MRFs) can be done either manually or automatically. In manual systems, workers visually identify and physically sort plastic bottles moving on a conveyor belt system. Automatic systems analyze one or more properties of plastic wastes using some detection method, so they sort these bottles into several categories. Several important factors such as cost affect the implementation of an automatic sorting system for a particular facility. Serranti et al. examined hyperspectral imaging and Raman spectroscopy for separation of polypropylene and polyethylene from contaminants (Serranti et al., 2011). The authors state that applying PCA on HSI average spectral signatures gives 77.98% accuracy. The design of sorting system crucially depends on the incoming plastic quality. Besides, the mixtures of multiple plastic types require more detailed sorting methods (Al-Salem et al., 2009; Scott, 1995; Lotfi and Hull, 2003; Hendrix et al., 1996; Van Den Broek et al., 1998; Park et al., 2007; Tsuchida et al., 2009; Ramli et al., 2008). Serranti et al. classified plastic flakes according to their typologies using hyperspectral with sensitivity and specificity ranging from 0.90 to 0.99 (Serranti et al., 2012). PCA and partial least square discriminant analysis are used for dimension reduction and classification, respectively in the study. Furthermore, plastics with different sizes come to a classification area in the different orientations and shapes complicate the automatic sorting problem. In addition to different shape of plastics, the labels with different sizes and colors make the sorting process more challenging. Therefore, it is required to have a complex and intelligent algorithm that can overcome these difficulties and be able to classify the plastics regardless of their orientation, shape and label color (Shahbudin et al., 2010; Tachwali et al., 2007; Viola and Jones, 2001). Most common sorting methods for plastic wastes are triboelectric separation, density sorting methods, hydrocyclones, hyperspectral imaging, speed accelerator technique (Hu et al., 2013; Dalal and Triggs, 2005).

A variety of identification methods have been proposed and commercialized recently for the automatic plastic sorting systems (Lowe, 2004). Lotfi and Hull developed an algorithm to identify the plastic types using fuzzy-rule-based system as classifier, (Lotfi and Hull, 2003). They claimed that the high frequency components of an ultrasound wave applied to a material identify the type of material. Park et al. used charge polarity and charge-to-mass ratio to classify the plastic types (Park et al., 2007). Tsuchida et al. used Raman spectroscopy for the identification of shredded plastics (Tsuchida et al., 2009). In Raman spectroscopy, a molecular vibration is observed at each peak that gives information about the molecule structure, and plastic types are identified accordingly. Since the preprocessed dataset gives many peaks, this method is more efficient when used on preprocessed data. Ramli et al. classified plastic bottles as PET and non-PET using two different algorithms for feature extraction and Linear Discriminant Analysis (LDA) for classification (Ramli et al., 2008). In the first algorithm of feature extraction, bounding box image algorithm, where the average of white pixel values in the intensity histogram of the image is calculated was implemented. In the second algorithm, the segmented region of interest (ROI) algorithm, in which they segmented the images into five regions, was carried out. In both of the algorithms, they succeeded more than 80% accuracy while the segmented ROI had slightly higher identification rate than bounding box image algorithm. Like this study, Shahbudin et al. categorized the plastic bottles as PET and non-PET plastics using Support Vector Machine (SVM) with 97.3% accuracy (Shahbudin et al., 2010). Luciani et al. identified PVC, polyethylene, and rubber using near infrared – hyperspectral imaging (Luciani et al., 2013). Ulrici et al. classified PET and poly lactic acid with efficiency higher than 98% (Ulrici et al., 2013). Tachwali et al. proposed a two-stage classification scheme for sorting plastic bottles (Tachwali et al., 2007). In the first stage, Near Infrared Imaging (NIR) was used for feature extraction while Linear, Quadratic, and DiagQuadratic classifiers were utilized for classification; and plastic bottles were sorted with 94.1% accuracy with respect to their types. In the second stage, they classified the bottles according to their colors using a CCD camera, and the classification was resulted in 92% and 96% accuracies for the clear and opaque bottles, respectively. They succeeded 83.5% recognition rate for the overall system.

Despite of many methodologies developed, the majority of these technologies are relatively slow, and most of them involve expensive or complicated apparatus. When one may consider selecting waste plastic bottle separation systems, the issues of cost and speed should be certainly taken into account. The Near Infrared Imaging system (Tachwali et al., 2007) is expensive and slow. As another type of plastic waste separation systems, triboelectrostatic separation is not cost effective. Due to not only cost but also speed aspects, our decision mechanism uses a setup with a simple web camera and homogenous backlighting and performs five different feature extraction methods such as Principal Component Analysis (PCA), Kernel PCA (KPCA), Fisher's Linear Discriminant Analysis (FLDA), Singular Value Decomposition (SVD) and Laplacian Eigenmaps (LEMAP). While the conventional classification methods generally apply minimization of the empirical risk, SVM based classifier is built to minimize the structural misclassification risk. Therefore, SVM is selected to achieve the classification task. Ultimately, a majority voting scheme is performed for combining the recognition results of five different feature extraction methods. In this scheme, the outputs obtained from five feature extraction methods are combined and then the most voted plastic bottle type is accepted.

The rest of this paper is organized that the constructed experimental setup is introduced in the second section while all the feature extraction and classification methods are briefly explained in the third section. The fourth section presents the detailed results of this study whereas the last section includes all of the conclusions.

2. Experimental setup and preprocessing

An experimental platform with a camera and homogenous backlighting was constructed to take colored photos of plastic bottles. The photographic image for the constructed platform is given in Fig. 1. In this platform, the sorting capacity is 750 kg/h, the sorting belt speed is 0.25 m/s and the bottom limit size of plastic parts is not important since our study has a segmentation process prior to feature extraction step. Despite everywhere around conveyor belt has been shot brightly; in reality, the interior part of the conveyor belt is expected to be dark. It is also assumed that plastic bottle images will appear clearly. Once the images are captured, the sorting procedure has been automatically activated. The web camera, whose brand is A4Tech, was placed on the one side of the conveyor belt in order to take photos.

After the photographs of the plastic bottles have been taken, several preprocessing steps were carried out. All of the steps are illustrated by some photos and images in Fig. 2. The first step is to extract the plastic area of a bottle from the background (segmentation). There are various object detection algorithms proposed to extract objects in 2-D intensity images using boasted cascade (Viola and Jones, 2001), histogram of gradient (Dalal and