Item Recyclability Identification Based on Image Classification

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1. Introduction

Recyclable items are valuable material rather than trash. By reusing recyclable items, a great amount of energy cost to manufacture new materials and to deal with waste can be saved to help sustain a greener living environment for us all. Many kinds of glass, paper, metal, plastic, textiles, and electronics are recyclable materials, and should not be put into trash bins where non-recyclable materials should stay. [1]

Typical recyclable items include several material categories:
Aluminum: Aluminum Foil.
Cans: Pie tins, Tin Cans, Steel cans.
Glass: Glass bottles, glass jars.
Paper: Office paper, newspaper, paper rolls, paper cups, tissue box.
Plastic: #1 - #7 including soda bottles, detergent bottles, spray bottles, tupperware.

Typical Non-recyclable items include the following categories:
Trash bags, Hot Cup, Wood Chopsticks, Toothpaste, Candy Wrap, Bubble Wrap, Potato chip bags, Light bulbs, Soiled material, etc.

The goal of my project is to identify the recyclability of an item by taking a picture of it, which is a binary classification problem and a special case of Object Class Recognition. Training set contains hundreds of images, and is processed by computer vision methods. To simplify the task, a few restrictions are enforced on the quality of images: Images should be taken in a clear white blank background to ensure the item does not confuse with irrelevant objects; Item must be entirely contained within the image. The algorithm learns the major image feature extracted and classify the new images taken by users.

2. Approach

2.1 Image Segmentation

2.1.1 Contour Extraction

For this part I used python and OpenCV to calculate the edges and contours of the item for portability concerns. Each image in the training database and test database is first processed by python-OpenCV script I wrote to get the contours of the item. The preprocessing process is shown in figure 1.

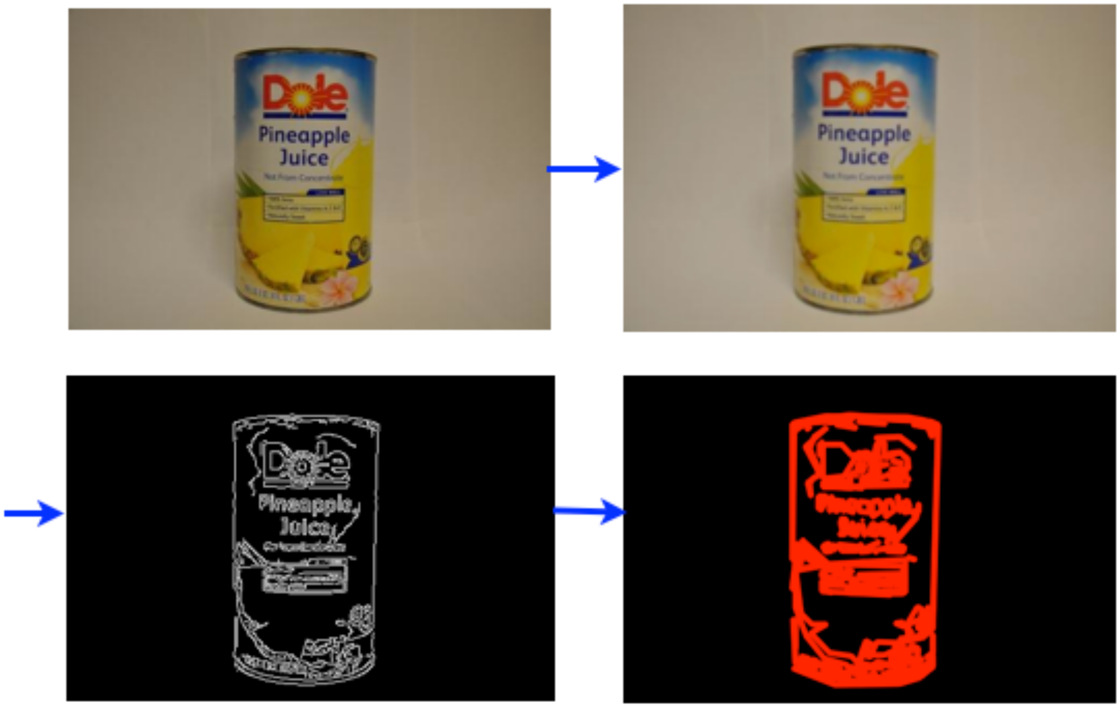

Figure 1: Preprocessing of the image

(1) Gaussian Smoothing: First Gaussian smoothing is performed on the input image to avoid the influence of noises on the result of edge detection. By blurring the pixel colors using gaussian function, noises in the image background are effectively reduced.

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

(2) Canny Edge Detection: Canny algorithm detects edges in horizontal, vertical and diagonal directions.

$$\mathbf{G} = \sqrt{\mathbf{G}_x{}^2 + \mathbf{G}_y{}^2}$$

$$\mathbf{\Theta} = \operatorname{arctan}\left(\frac{\mathbf{G}_y}{\mathbf{G}_x}\right)$$

(3) Contour Extraction: Contour is found by calculating all the connected components in the edge image.

2.1.2 Background subtraction and normalization

The rest of image segmentation and classification are implemented using Matlab.

(1)Bounding box: Once we have the contours, we can easily calculate the space that the item has occupied. Bounding box is the minimum rectangle area that entirely contains the item we are interested in, as shown in figure 2.

Figure 2: Preprocessing and Segmentation of the image

(2)Subtraction from background: Also based on contours, we fill the holes of the binary contour image and get a binary mask of the item, which also indicate the shape of the item.

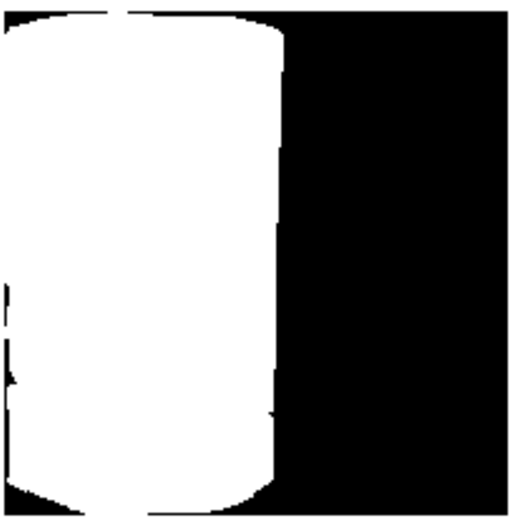

Figure 3: Binary mask (shape of the item)

(3)Normalization: The result image is resized to a square image with a user-specified dimensionality. The shorter side of width or height is filled with blank pixels. Classification benefits from normalization because it provides invariance to location and scaling of the item.

Figure 3: Normalized grayscale image

2.2 Feature Extraction

The visual patterns of materials vary a lot in different items and it is difficult to identify the global category of the item by local-scale features. For example, a recyclable item like white paper and non-recyclable item like trash bag can have similar local visual appearance, which is hard to tell apart even by human beings given the resolution of the camera. Therefore, it is unlikely to precisely identify the kind of material by simply applying local-feature filters. A feasible solution is to imitate the way humans recognize a item. By classifying the shape features, the algorithm can recognize an item without exactly matching two objects. Although it is not always true, it turns out that many of recyclability items have significant shape features. The algorithm doesn't have to recognize the exact specific object in the training database, since many kinds of recyclable materials contain a wide variety of items (like various brands of plastic package and wraps).

Initially I performed dimensionality reduction directly on contour images (as shown in figure 4) to eliminate redundant information. Contour image conveys shape information and part of appearance information.

Figure 4: Normalized contour image

I've used Principal Component Analysis (PCA) for dimensionality reduction, but result in relatively poor performance on test set images. I applied Linear Discriminant Analysis to classify the contour images. The objective of Linear Discriminant Analysis is to perform dimensionality reduction while preserving as much of the class discriminatory information as possible. Since there are two classes in total, the dimension is reduced to 1 by LDA.

I've also used edges in the color space as features for classification (as shown in figure 5) since it reduce the influence of illumination and shadows. However, I found dimensionality reduction on such appearance features experiences a drop of performance.

Figure 5: edges detected on image

As mentioned before, shape information is discriminative in terms of recyclability. As shown in figure 3, the binary image is used as features for classification algorithm like decision trees and support vector machines, with its dimensionality specified by users.

2.3 Image Classification

I took two approaches of classification methods depend on different selection of features. For the scalar result of dimensionality reduction, I used k-Nearest Neighbor algorithm for classification. For binary result of normalized shape image, I used decision tree algorithm and random forest algorithm for classification. Decision tree algorithm greedily choose the binary test of features that that minimize the impurity measure most at the chosen node. I used entropy as impurity measures.

$$i(\tau) = -\sum_{c \in \mathcal{C}} P_c^{(\tau)} \log P_c^{(\tau)}$$

$$\Delta i_s(\tau) = i(\tau) - P^{(\tau \wedge s)} i(\tau \wedge s) - P^{(\tau \wedge \neg s)} i(\tau \wedge \neg s)$$

where

$P^{(\tau \wedge s)}$ = fraction of points in $\mathcal{R}_\tau$ satisfying $s(x)$

[3] suggested random forest is a well-performing algorithm on shape features. Random forest algorithm randomly choose a subset of features and classify by most voted class or maximum class posterior [2]. In practice, I choose a dimensionality of 9 for the binary mask, resulting a 9 by 9 binary features for decision tree classification.

3. Experiment

I have collected a few hundred of images of recyclable and non-recyclable items including various categories of items.

	Positive	**Negative**
Training set	77	60
Test set	19	25

Figure 6: Sample recyclable items: aluminum can, milk bottle, coke bottle

Figure 7: Sample non-recyclable items: chopstick, shaver, highlighter

Training images and test images are preprocessed in the way discussed in 2.1. Features of the images are extracted as discussed in 2.2. I performed dimensionality reduction methods on contour and edge features, use decision tree classifier to classify shape features, and conduct classification experiments.

4. Result

Using 3-nearest neighbor classification, LDA achieves an error rate of 20.93% on contour features. Error rate is around 31% using PCA on contour features.

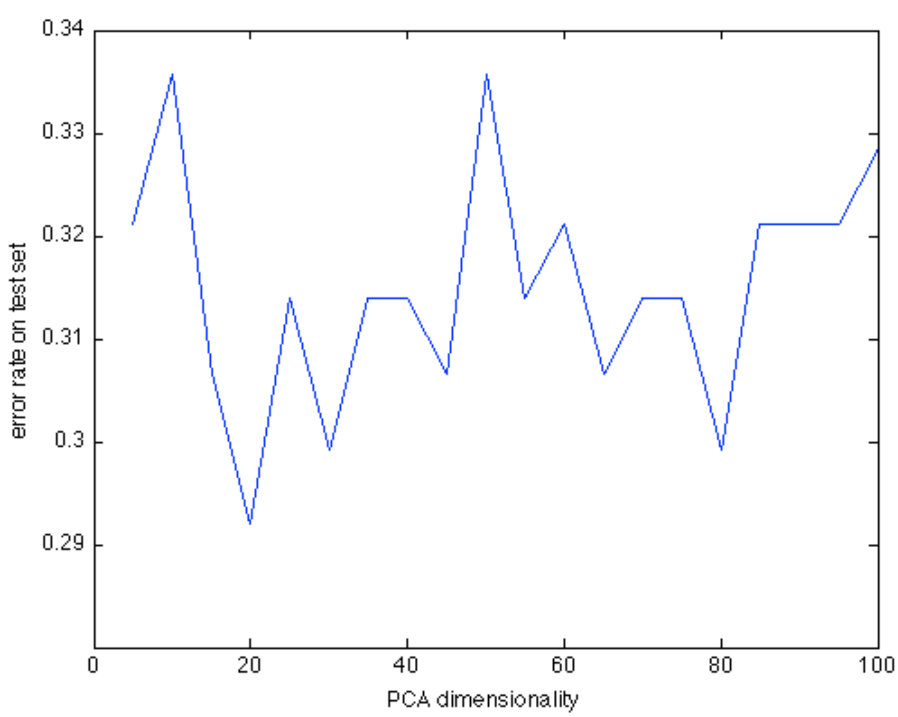

Figure 7: choice of dimensionality of PCA on contour features

Using 3-nearest neighbor classification, LDA achieves an error rate of 27.91% on edge features. Error rate is around 35% using PCA on edge features.

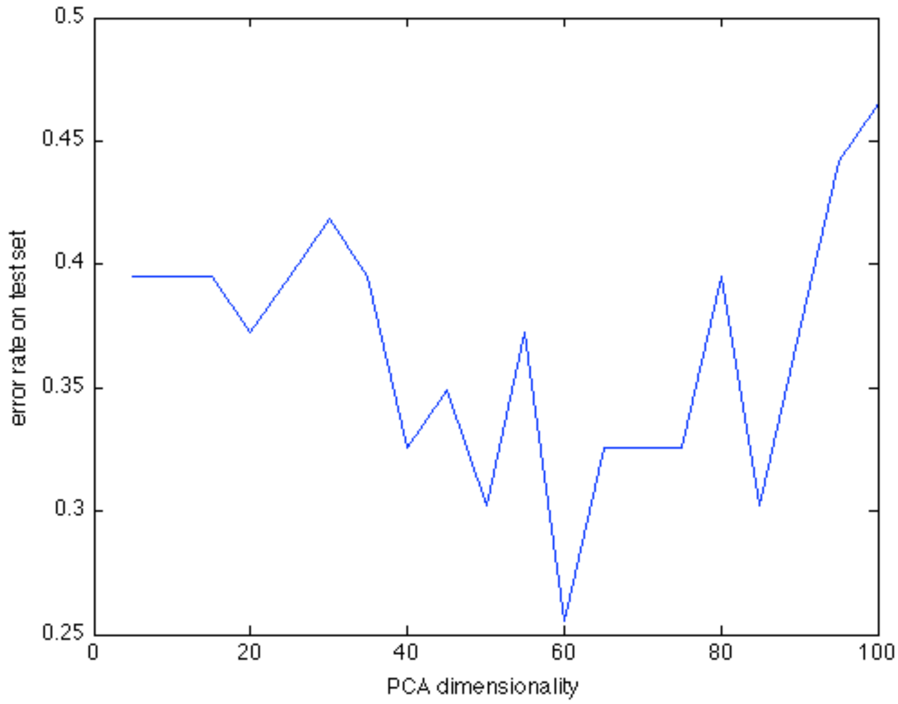

Figure 8: choice of dimensionality of PCA on edge features

Using decision tree classification on shape features, the error rate is around 20%. Figure 9 illustrates the relationship between error rate and the choice of stopping criterion (the maximum number of examples on a leaf).

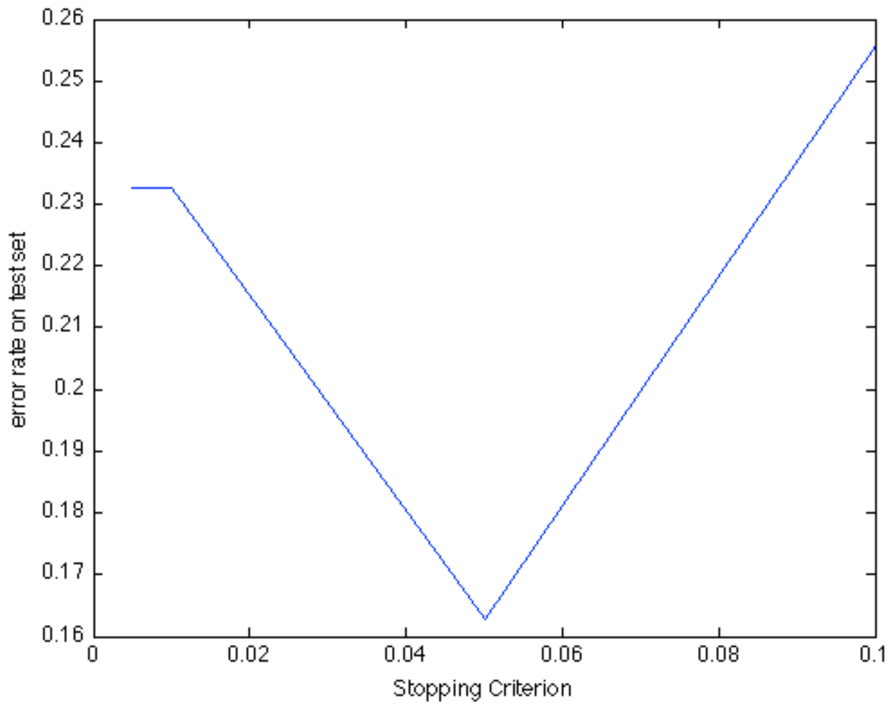

Figure 9: choice of stopping criterion of decision tree

Using random forest classification on shape features, the error rate is around 15%. Figure 10 and figure 11 illustrate the relationship between error rate and the choice of stopping criterion respectively using average class posterior and most voted class as classification method. Figure 12 illustrate the relationship between error rate and number of features randomly selected at each node (stopping criterion C=0.05, use average class posterior and most voted class as classification method).

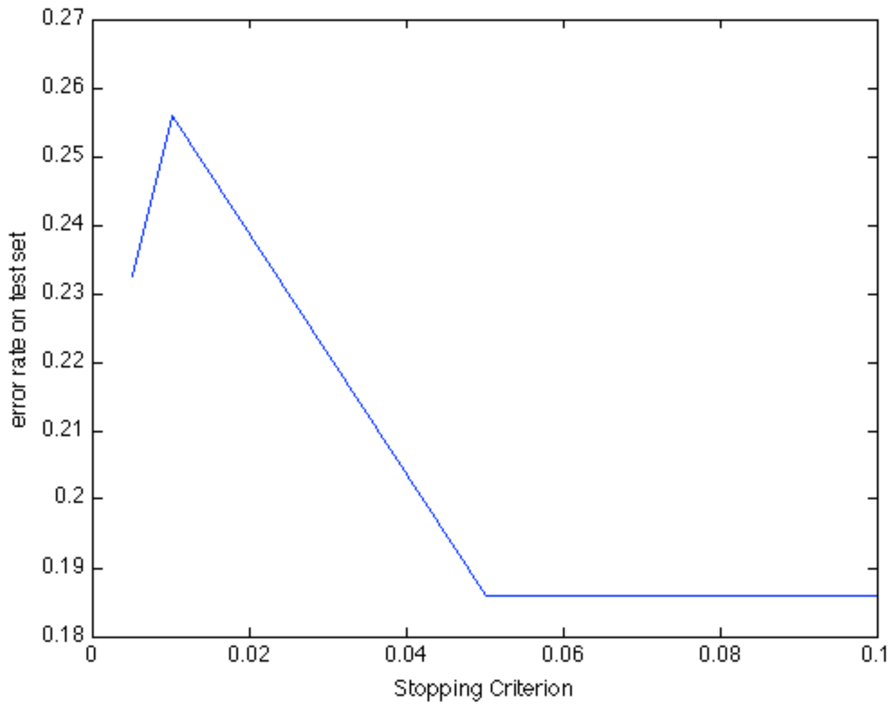

Figure 10: choice of stopping criterion of random forest (average class posterior)

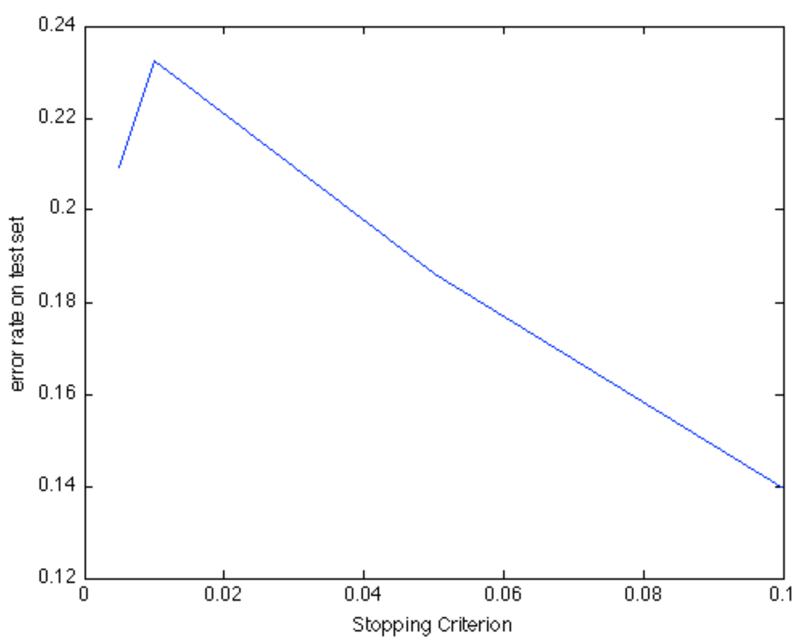

Figure 11: choice of stopping criterion of random forest (most voted class)

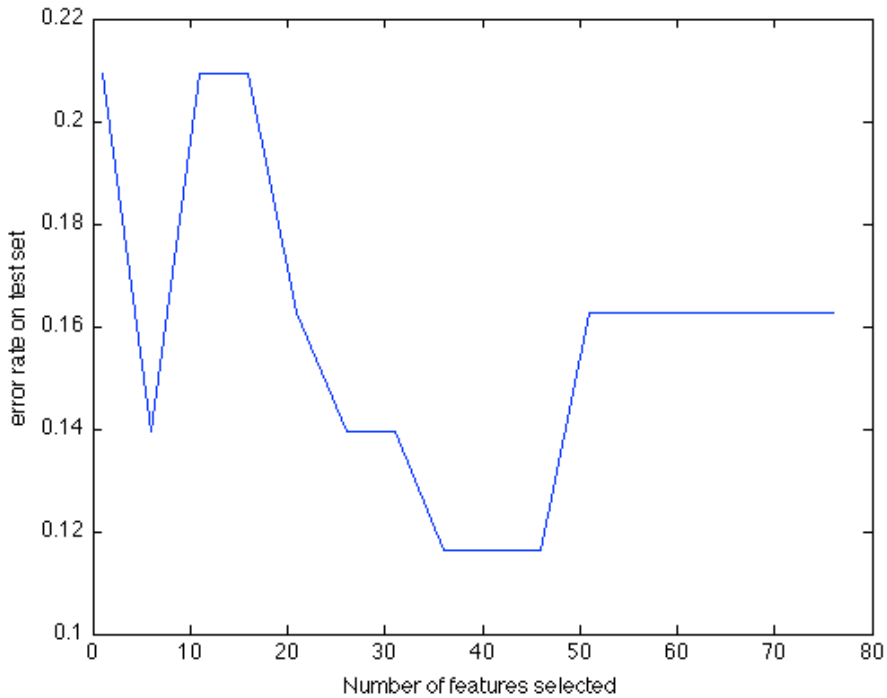

Figure 11: choice of stopping criterion of random forest (most voted class)

5. Conclusion

In conclusion, this project present several algorithms for item recyclability classification. Classification rate rely heavily on features selected particularly on shape features, and on classification algorithm. By using random forest algorithm, the correctness rate of classification reaches around 85%. Classification on contour images is also a feasible method with a correctness rate of 80%.

Since I have tested on a pretty limited category of item images, the result I have gotten so far might not be a exceptional classifier for all possible item images. But after analyzing the result, I found a few limitations to the method. Identifying item recyclability by human being is an inherently difficult task already. Items such as toothpastes and bottles have a much distinguishable appearance from other objects, but hardly if any differences exist between items like recyclable paper cup and non-recyclable styrofoam cup. Even items that belong to the same category can have entirely different appearances. For example the appearance of beverage bottles of different brands can vary a great deal. Besides, recyclable regulations are not the same across the country, much less the world. To be more informative to the users, the system should decide the accurate category of the item, and whether it should be put in a recyclable bin, a compostable bin or a non-recyclable bin (trash bin). SIFT (Scale Invariant Feature Transform) is a good method to exactly match and invariant to planar transformations, however it might not be suitable for this case because rarely two items exactly the same present in training set and test set.

The possibility of item appearance in the real world is countless, although the algorithm can still identify items with significant shapes such as cans, bottles and cups. More precise categorization of the item images and excessive item kinds might be necessary for practical use, but this might be implying a huge database of images.

6. References

[1] http://en.wikipedia.org/wiki/Recycling
[2] A. Liaw and M. Wiener. Classification and regression by randomForest. R News, 2/3:18–22, December 2002
[3] J. Winn and A. Criminisi. Object Class Recognition at a glance. In Video Proc. CVPR, 2006