Automated Recyclable Waste Classification using Multiple Shape-based Properties and Quadratic Discriminant

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Abstract: Nowadays, a crucial issue in major cities throughout the world is waste management where tons of waste being generated every single day. Fortunately, people can count on other methods to protect the environment through waste recycling. In most countries, waste that can be recycled are being categorised or handled manually by using human labour. The objective of this project is to develop an automated recyclable waste classification method which can replace the traditional ways of dealing with three types of waste, namely plastic bottles, papers, and soda cans. Firstly, we computed a global threshold value based on the Otsu method to obtain a binary image representation. Few morphological operators are then executed to obtain the regions of interest (waste's object). For feature representation, we calculated multiple shape properties of the waste's object such as perimeter, area, eccentricity, and major axis length. We experimented the extracted feature vectors with few classifiers. Our findings have shown that the waste classification prototype is able to effectively categorise waste up to 94.4% accuracy based on the proposed shape representation and Quadratic Discriminant classifier.

Index Terms: Quadratic Discriminant, Shape descriptor, Waste classification.

I. INTRODUCTION

Waste management is a crucial issue in major cities throughout the world, particularly in the developing countries [1-2]. This is due to lack of awareness and environmental education among the citizen itself. Thus, one of the initiatives is to adopt waste recycling as a long-term strategy to overcome this problem. With the aid of technology, it is hoped that the existing laborious method can be alleviated. Two important and prevalent fields in technological discipline are computer vision and machine learning.

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Computer vision is about making the computers to have the abilities of interpreting and understanding digital images at par as human visual system. Machine learning on the other hand is about teaching computers to have the abilities to learn and be intelligent at par as human learning skill. These two fields can play a big role in protecting the environment especially in waste management where instead of doing it manually, the waste can be separated according to its category automatically and almost accurately [3].

One typical task in computer vision is image recognition where it will identify objects in a digital image by analysing and extracting data from the image and matched them with the training data in the database. Various recognition systems have been developed for many purposes such as for medical [4], manufacturing [5], and others [6-8]. Waste recognition is a system that can recognise type of wastes by using the waste image's content for analysis, identification and classification in the waste management ecosystem. Recycling converts wastes such as paper, metal, and plastic into new materials and objects to be reuse. There are few existing waste recognition and classification systems with different approaches and ranges of accuracies but to our knowledge, none are reported from Malaysia.

In this study, we propose and formulate an automatic framework based on computer vision algorithms that can recognise three types of recyclable waste namely plastic bottle, soda can and crumpled paper. The output of this method is the category selected for each waste. It is hoped that this proposed technique can help to expedite the recycling initiative. The paper is organised as follows. A review of some related work is given in Section II. Section III explains the methodology of the proposed waste classification approach. The experimental results and analysis of the recognition process are presented in Section IV. Finally, in Section V, some conclusions and future work are given.

II. RELATED WORK

There are few studies that utilised deep learning techniques in waste recognition and classification [9-11]. A proposal of an automated solid waste recognition system is presented in [9]. They proposed a deep learning framework to recognise and further classify wastes as biodegradable or non-biodegradable type.

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In recognising the object, the captured waste image will be analysed using various image processing algorithms such as edge detection, feature extraction, and matching methods. As the study is only at the proposal level, no experimental results were presented. Recycling facilities in United States also make use of object-recognition techniques and robotic mechanisms to automatically identify and categorise wastes according to their type [10].

In [11], a mobile application has been developed for classifying waste on-the-go. They used a deep learning framework, namely CaffeNet model for training the classification network before being set up on a web server. Once the images taken by users are being uploaded on the server, the mobile application will analyse and classify them according to their type. However, the study used a pre-trained CaffeNet model on the ImageNet dataset, thus the classification categories relate to common objects in life instead of actual waste types. Through deep learning technology, a complete waste management system can be realised better in the future by using computer vision and machine learning fields. Since deep learning is a self-learning algorithm, the system can ultimately learn and train on its own. However, large number of inputs has to be collected and used to train the dataset in order to obtain accurate results.

Authors in [12] proposed an automated classification system using feature extraction and classification techniques which classifies polyethylene terephthalate (PET) and non-PET plastic bottles based on their labels. They experimented with five different feature extraction methods including Principal Component Analysis (PCA), Kernel PCA (KPCA), Fisher's Linear Discriminant Analysis (FLDA), Singular Value Decomposition (SVD) and Laplacian Eigenmaps (LEMAP). Support Vector Machine (SVM) and majority voting technique were used to classify and combine the recognition results of the five different extraction methods. The majority voting technique equally weighs each result and assigns the given plastic object to the class with the majority of votes. They achieved an accuracy rate of 96% for the classification of PET and non-PET bottles.

One of the researches which adopted methods using computer vision can be found in [13]. The authors classified a PET and a non-PET plastic bottle based on its image histogram analysis. They make use of the fact that PET is made up of transparent material where the bottle image and its background can easily be distinguished, compared to other types of waste. The technique was selected for its simplicity and agility as both elements are important in sorting plant or centre. Researchers in [14] created a prototype to identify between aluminium cans, plastic bottles, and plastic cutlery. Instead of using commonly used feature extraction, the researchers opted for extracting characteristic of invariant moments to analyse the waste images. The moments attributes extracted from the images are considered as global properties where they can be used to classify images although they are in different geometric distortions.

The closest existing system to our study is [15] where they proposed an automatic system to classify recyclable items in high schools. The system consists of three modules that is the image acquisition module, the image processing module and the robotic classification module. The system managed to classify PET bottles, aluminium cans and carton boxes at over 75% of accuracy rate. In the image acquisition module, the object to be identified is being placed inside a box attached with a webcam. Then the image of the object will be taken by the webcam to be processed in the second module. The image processing module will analyse the acquired image using gray image correlation between the image and 50 different images stored in the database, then choosing the best one as the right category. The actuation of the classification module is done by using robotic mechanism and trash cans. The performance of the classification in their study is focused on the image processing module. Although the performance is quite low, the system could be used in scholar contexts to teach and motivate people especially the youngsters about the waste classification and recycling efforts, as they have mentioned in their paper.

III. METHODOLOGY

Fig. 1 shows our proposed waste classification framework. There are two phases involved, which are the training phase and the testing phase. Training phase is to train the classifier using the extracted features associated to the respective type of waste. Once the classifier has undergone enough training process, testing is executed to validate the capability of the proposed algorithm for waste classification when an unknown image is given as the input. MATLAB R2018a software is used to develop the proposed framework and the prototype. This proposed waste classification framework consists of three modules which will be elaborated further.

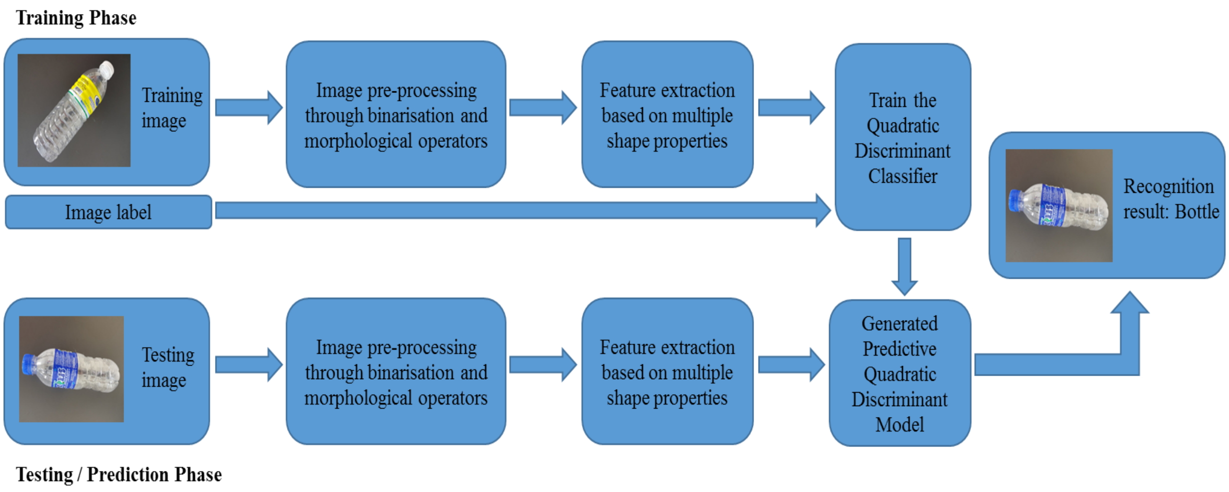

Fig. 1 Waste classification framework

A. Pre-processing

A common procedure for any image processing work is to process the raw image in obtaining the desired image quality or regions of interest. This also includes separating the background and the foreground of the image. In order to obtain quality regions of interest, firstly we convert the RGB colour space into grayscale to reduce the colour information as we would want to highlight the structure of the object within the image. We then computed a global threshold value of the image based on Otsu method to perform a binarisation on the grayscale image. This process will convert the image to contain only black and white pixels to differentiate between the background and the foreground details. During this stage, the regions of interest may have some holes or gaps which hinder from a quality representation for the waste's object. To overcome this problem, we further improve the quality of the regions of interest by executing few morphological operators to the regions which include filling, closing, and the utilisation of rectangular structuring element of size 200 × 100. Once these steps are completed, the shape of the waste object is obtained.

B. Feature Extraction

Once the shape of the waste object is obtained, the details of the object will be represented and stored in the database by extracting the features. Based on the waste dataset, we have constructed four shape features for each image which include perimeter, area, major axis length, and eccentricity. These shape properties are used in order to give both region-based and contour-based representations for the waste's object.

C. Waste Classification

The features extracted will be the input to the classification model. Before the wastes can be classified accurately, the classification model will first need to be selected and trained. We have experimented with few classifiers for this work such as Tree, Quadratic Discriminant, Support Vector Machine, K-

Nearest Neighbour, and others. We are adopting the default setting for all of the classifiers used for training. From the conducted empirical study (result can be found in Section IV), it has been found that the Quadratic Discriminant gave us the best training result. Quadratic Discriminant is originated from Linear Discriminant where it is based on the assumption that covariance matrices between groups are not equal. In forecasting the class association of an observation, the respective covariance matric R_i of the i^{th} class is employed. The classification function in Quadratic Discriminant is shown in Eq. 1 below:

$$D_i^2(y) = (y - \bar{y}_i)' R_i^{-1}(y - \bar{y}_i), \quad i = 1, 2, \ldots, k \qquad (1)$$

Where the observation y will be allocated to the class with least $D_i^2(y)$. Quadratic Discriminant is also known to have low computation complexity, more flexible, work well for many situations, and without the needs to tune any hyper parameters. Due to these reasons and result obtained from the empirical study, we have selected the Quadratic Discriminant classifier for further validation of the framework.

IV. RESUTS AND DISCUSSIONS

In this study, 60 waste images were manually collected for the training and testing purposes. Three types of recyclable waste products were being experimented which include crumpled paper, plastic bottle, and soda can. Each type of waste consists of 20 images. Samples of the dataset are shown in Fig. 2.

In order to evaluate the proposed algorithm, the dataset is divided randomly into 70% for training and 30% for testing. The training dataset generated from the above process is used to perform a *k*-fold cross-validation, where k = 10, for estimating the performance of the proposed classification work. *k*-fold cross-validation provides a statistically sound platform for performance testing with a fair balance between statistical significance and computational complexity [16]. The training dataset will be separated into 10 parts for 10 fold cross-validation and for each round, one of the subset folders is used for training while the other subset folders are used for testing.

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The training will loop continuously until every subset in the folder has been used once as testing. We will describe below our output and findings which include the developed prototype, training result of various classifiers in determining the suitable predictive model for the waste classification, and overall testing result.

A. Waste Classification Prototype

For training and testing purposes, we have developed a prototype which implemented the mentioned multiple shape-based properties for representation. Figs. 3 - 4 show the waste classification prototype that is ready to be used.

Fig. 2 Sample of waste image dataset

Fig. 3 Main interface

Fig. 4 Testing interface

B. Training Result

Table I shows the classifiers that have been experimented. They are Tree variations, Support Vector Machine (SVM) variations, *K*-Nearest Neighbour variations, Linear Discriminant, and Quadratic Discriminant. It is crucial to perform this experiment since each classifier performs differently for different data. From the experiment that has been conducted, it is shown that the Quadratic Discriminant classifier is able to achieve the highest accuracy (95.2%) compared to other type of classifiers. Thus, we have used the trained Quadratic Discriminant as the predictive model for validation purpose.

C. Testing Result

From the previous experiment, we have constructed the predictive model for waste classification based on Quadratic Discriminant. We then tested the proposed framework on the 30% testing data. Table II below shows the accuracy rate for the testing experiment according to the respective waste categories. From the result, it can be seen that the proposed framework can successfully classify all soda cans and papers up to 100% accuracy rate.

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As for bottle, the accuracy rate is slightly lower, which is 83.3%. This is happening probably due to the nature of the bottle which the proposed descriptor may have difficulties in obtaining a solid region for bottle representation. A bottle has many curves where the method may end up generating few dominant regions to represent the object. We found that the shape-based properties can represent the regions of interest well and distinguish object of different categories but refinement may be required for the pre-processing part by utilising better combination of the morphological operators.

Table. 1 Accuracy Rate for various classifiers

Classifier	Accuracy (%)
Fine Tree	85.7%
Bagged Trees	88.1%
Linear Discriminant	73.8%
Quadratic Discriminant	95.2%
Fine *K*-Nearest Neighbour	78.6%
Weighted *K*-Nearest Neighbour	81.0%
Linear Support Vector Machine	92.9%
Quadratic Support Vector Machine	90.5%
Fine Gaussian Support Vector Machine	83.3%

Table. 2 Accuracy rate for waste classification according to category

Waste Category	Accuracy (%)
Bottle	83.3
Soda can	100
Paper	100
Average	**94.4**

Nevertheless, it can be concluded that the proposed framework has successfully classified the waste accurately according to the type of each waste, where the average accuracy rate obtained is 94.4%. The combination of multiple shape-based properties with Quadratic Discriminant is very effective to be used in classifying the waste automatically.

V. CONCLUSION

The proposed waste classification framework is able to classify the waste accurately based on the feature extraction steps. Each of the waste image is represented by few shape-based properties which are perimeter, area, major axis length, and eccentricity. The Quadrative Discriminant is then used to classify the waste accordingly. The proposed framework has successfully achieved the accuracy rate of 94.4%. The classification of waste can now be done easily with the help of the feature extraction algorithm method and the generated predictive model.

For future work, we plan to refine the morphological operators, expand the dataset by including more types of waste, as well as helping the recycling initiative. Hence, hopefully our citizen will be more open-minded to manage the waste with the help of this framework.

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