Sorting for Plastic Bottles Recycling using Machine Vision Methods

SanaSadat Mirahsani[1,*], Sasan Ghasemipour[1], AmirAbbas Motamedi[2]

[1] *Faculty of computer, Hamedan University of Technology, Hamedan, Iran*
[2] Department of Science and Research branch, Islamic Azad University, Tehran, Iran

Abstract
Due to the increase in population and consequently the increase in the production of plastic waste, recovery of this part of the waste is an undeniable necessity. On the other hand, the recycling of plastic waste, if it is placed in a systematic process and controlled, can be effective in creating jobs and maintaining environmental health. Waste collection in many large cities has become a major problem due to lack of proper planning with increasing waste from population accumulation and changing consumption patterns. Today, waste management is no longer limited to waste collection, but waste collection is one of the important areas of its management, i.e. training, segregation, collection, recycling and processing. In this study, a systematic method based on machine vision for sorting plastic bottles in different colors for recycling purposes will be proposed. In this method, image classification and segmentation techniques were presented to improve the performance of plastic bottle classification. Evaluation of the proposed method and comparison with previous works showed the proper performance of this method.

Keywords:
Machine Vision, recycling, plastic bottles, Sorting, Image classification

1. Introduction

In most developed countries, the biggest environmental problem is after climate change, such as global warming, waste, and the resulting problems. Recycling plastic bottles and bags is very important because they remain in the soil for many years (even more than 500 years) and do not decompose. Nylon bags also cause the suffocation and death of thousands of sea turtles each year. New waste management, including plastic bottles, can add value and contribute to the environmental problem. If not managed, the bottles can be mixed with very low waste and taken out of the consumption cycle. Leading countries in the field of recycling have used the "waste separation at source" scheme to manage their recyclable waste [1-3].

Plastics can be divided into two aspects, thermal and functional. Thermal plastics can be divided into thermoplastic and hard heat by either incremental polymerization or compaction. Soft heat plastics are solid at room temperature and soften and melt when heated. Heat softeners are polymer products that have long chain linear molecules and therefore have the potential for molecules to slide relative to each other. Today, heat softeners are considered as one of the most important plastic materials commercially. Some materials also give a polymer product due to compression reactions that have a soft heat capability, but in certain conditions due to their structure, branched molecules are interconnected and form a three-dimensional network, which takes a fixed shape after molding. And after molding, they can not be re-melted and reused, and they are only destroyed by heating. This group of plastics is called hard heat [4].

Plastics are also divided into two groups in terms of application and economic value: engineering plastics and non-engineering plastics. Non-engineered plastics are characterized by low manufacturing costs and high production and sales volumes. These materials are like steel and aluminum in the metal industry and are mostly used in the manufacture of consumables such as containers and packaging films. This group basically includes four important categories of famous soft heat plastics: light and heavy polystyrene, polypropylene and styrene. Engineering plastics are more expensive in terms of production cost and less in terms of volume. But in terms of mechanical properties and durability, they are very stable and in terms of

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application, they are competitive with glass, ceramics and various metals [5-7].

Plastics are made from oil, which is a consumable resource, but because they are non-degradable, they are considered sustainable waste and polluting the environment. Plastic is energy efficient. For example, less energy is needed to make a plastic bottle of ketchup than a glass bottle. Although plastic recycling is easy, you must first know what type of plastic can be recycled. Plastics have different formulas and must be regulated to produce new products before recycling. Blended plastics can be recycled but are not as valuable as sorted plastics because the physical properties of recycled plastics may vary. In fact, the reason for the impossibility of recycling plastics is their diversity. Hundreds of plastics are used every day. Many plastics are chemically incompatible and do not have the ability to easily melt and turn into other materials. Plastic materials have a calorific value of about 600 Kcal / kg, are biodegradable, and are rarely attacked by bacteria, so they remain unchanged in nature for up to 350 years. Management of recyclable plastic bottles includes steps: bottle collection management, bottle transportation, processing, recycling or disposal and disposal of waste (bottle waste). This requires planning to create appropriate and necessary cultural and social contexts in urban society through education and information to raise the level of knowledge and awareness of people and stakeholders, using the capacity of mass media, environmental advertising, public participation of citizens and Specialized civic institutions, especially neighborhood councils in order to achieve the goals of the organization, planning to clean and collect bottles using the capacity of the private sector, planning and monitoring the reduction of production of disposable bottles by producers and producers of consumables and consumers and consumers of goods and Materials in the city, using the capacities of public participation and the cooperation of relevant civil and governmental institutions, are among the listed tasks for this organization. Also, cleaning, collecting and transferring bottles, disposal and post-disposal care, energy extraction from bottles, construction of new processing units for plastic materials obtained from bottle extraction and supervision and control are the responsibility of the waste management organization [8-10].

In this study, a systematic method for arranging plastic bottles in different colors for recycling purposes will be proposed. The present work tries to solve some basic problems, such as identifying the positional relationship between the surrounding bottles, improving adjacent bottles, and color classification of all bottles.

This method is innovative in several aspects, compared to previous works:

1- By presenting a new histogram-based segmentation method, it has an advantage over the methods that directly classify the image.
2- In the proposed method, a multi-objective function is used to improve the accuracy of image segmentation
3- In the proposed method, in the image classification stage, a fuzzy theory-based classification is used, which is superior to the traditional image classification methods.

In the reminder of this paper, in the Section 2, the literature of research and review of previous works will be discussed, in the Section 3, the proposed method will be described, in the Section 4, the performance of the proposed method will be evaluated, finally, Section 5 concludes the overall of the paper.

2. Literature review

The rapid growth of beverage bottle consumption has led to the emergence of various issues such as resource depletion and environmental pollution. It is worth noting that a significant amount of oil is used to produce plastic bottles. Currently, 4% of the world's oil is used to make plastics. As we all know, oil is a non-renewable resource and access to this important resource is becoming less and less. On the other hand, plastic waste can cause a lot of damage to the environment. An important strategy to deal with these problems is recycling. Recycled plastics can be used as raw materials for new products such as concrete, automotive products and textiles. Recently, plastic bottle recycling has become an important branch of the plastic bottle industry, which not only has the potential to save on fossil fuels, but also reduce greenhouse gas emissions. Beverage bottle recycling technology can be categorized as physical and chemical recovery. From an environmental point of view, physical methods have many advantages and are the most widely used, which usually include collecting, sorting, washing, crushing, floating, and drying bottles. There are two basic points to sort: material classification and color classification. Material classification for the identification and removal of non-polyethylene terephthalate (non-PET) plastic bottles and other impurities. Color classification for plastic bottles is based on their color because bottles in different colors have different amounts for recycling. Therefore, color classification is also very important for recycled bottles, but fewer studies have been reported on the color classification of recycled plastic bottles than the material classification. Color classification can usually be done in two ways: manual classification and automatic classification based on machine vision. Despite the advantages that car classification has shown in many areas, manual classification is still the main method. The efficiency and quality of the final product is largely determined by the color classification process, and automatic classification based on machine vision can yield higher efficiencies than manual classification. That is why some researchers have done related research in the field of color classification based on machine vision. However, most previous methods focused on the color classification of PET pieces by identifying the color after slicing. In fact, color classification can also be done before segmentation to classify the color of bottles. The color classification of bottles can be more efficient than the color classification of PET shells, so it has a wide range of perspectives and is worth researching.

Considering the application of machine vision methods in improving the methods of classifying plastic bottles, in the continuation of this section, an overview of machine vision methods will be done.

2.1 Image Classification

In image processing, image classification and retrieval are two very important operations. Image recovery methods are usually based on the color, texture, shape and meaning of the image. Today, the key parts of image classification and retrieval are based on three aspects.

1) Different methods of calculating the degree of similarity, which include extracting the color property and combining several properties;
2) Reciprocal retrieval figures using feedback network
3) Image classification using fuzzy clustering method. Recently, accuracy and recall rates have been used to evaluate the performance of image retrieval results.

In most early image classification studies, only one feature was used among the various visual features of each image. As a result, it can be expected that the accuracy of these systems is not very good because in general, an image has several visual characteristics. Recently, effective research has been conducted on image retrieval using a combination of color and texture properties. In [11], two-dimensional or one-dimensional histograms of color coordinates are used as color features and differences extracted by analyzing discrete causal frameworks are used as texture features. Lane et al. [12] suggest three-image properties for use in image retrieval. The characteristic of the first image is based on the color distribution and is called the adaptive color histogram. The properties of the second and third images are called the simultaneous matrix and the gradient histogram, respectively, and are based on the properties of color and texture. Also in [13] the combination of genetic algorithm and feature selection is used to retrieve and categorize images. In the method presented by them, in the first step, the initial features of the image are extracted and then, based on a feature selection method based on genetic algorithm, the final features of the image are selected for the image classification operation. In [14], Haye et al. Proposed a new method in which texture image properties are extracted using inseparable filter wavelets to retrieve the tissue image. This new method provides more information about the edge and direction of texture images compared to previous tensor product wavelets. Tagarakis et al. [15] proposed a method for non-rotational tissue retrieval that uses the non-Gaussian behavior of subband coefficient distributions and shows tissue information with a guided pyramid. Hahn et al. [16] proposed immutable Gabor representations in which each representation requires only a few aggregations of Gabor filter impact responses; Texture properties are extracted from these new representations to retrieve the unchanged texture image. In the field of image retrieval, Nastagal [17] has introduced a method for calculating the fuzzy similarity criterion that uses the fuzzy part of the HSI color space. In this method, if there is no color in one image to calculate the degree of similarity of the ratio of that color between two images, by increasing the color ratio in the other image, the similarity criterion remains constant at zero; Although this method makes perfect sense, it does not make sense. In addition, the color spectrum feature includes 360 elements that are divided into 8 sections. Obviously, the number of these sections is not enough, and very large errors appear in the calculation of the complex image similarity criterion. In the field of image classification, Liu Pangio et al. [18] have proposed a modified fuzzy c-means algorithm to solve the problem of large-scale image retrieval and classification, in which the initial condition of time saving is considered. In this method, some images are always considered as just one large cluster, and therefore the classification result did not work well. To solve this problem, in this dissertation, a fuzzy criterion is used to determine the similarity of images, so cluster centers will be selected more accurately and purposefully.

2.2 Image Segmentation

Image segmentation and image analysis are among the most important steps in machine vision that have received more attention today. Image segmentation is one of the important steps that can be very helpful in extracting features and also in the field of classification of this information [19]. Image segmentation represents the action in which a raw input image is subdivided into meaningful areas. Identifying and separating an image into its components or image segmentation plays an important role in many image processing applications. In other words, segmentation is the division of an image into unequal areas. Areas are actually different objects in the image that are uniform in texture or color [20, 21]. Another method for slicing images is multifractal analysis. This method is able to describe the texture structure in the image. Among the multi-fractal features used in applications, we can mention the multi-fractal dimension. In this method, the multifractal dimension of the image is extracted using the differential box counting (DBC) method and then the images are segmented using the clustering (FCM) [22] and K-Means [23] methods. FCM is an unsupervised clustering method and is often used to segment multiple images based on space-only information. FCM often automatically divides the data space into quantitative vectors, with the aim of optimizing the cluster analysis process in which the necessary corrections are made using the fuzzy covariance matrix.

In [24], a color image segmentation algorithm based on genetic algorithm is used to classify raisins. In the proposed method, HSI color space instead of RGB space is used to improve the performance of the segmentation algorithm. The simulation results showed that the algorithm of this paper is able to segment images with good accuracy and thus classify different types of raisins. This article is based on article [25]. Reference [26] uses a combination of c-means fuzzy clustering algorithm and particle optimization algorithm for image segmentation. In the method proposed in this paper, instead of using the Euclidean distance criterion in fuzzy clustering, the Mahalabonis distance criterion is used. The particle optimization algorithm has also been used to optimize clustering centers. The simulation results showed better performance of the method proposed in this paper than the previous methods. Xiang et al. [27] used a combination of c-means fuzzy clustering algorithm with area segmentation algorithms for the problem of color image segmentation, which is one of the most important issues in machine vision and pattern recognition. In this method, the threshold of the histogram function is used to divide the image into the number of areas. Finally, these regions are used to initialize the c-means fuzzy clustering algorithm. The experimental results showed that the proposed method has good accuracy and speed in image segmentation. Paper of [28] presents an improved method for image segmentation using the c-means fuzzy clustering algorithm and the particle optimization algorithm. In the proposed method in this paper, three different techniques have been used to increase the performance of image segmentation: 1- Improving the initialization in the fuzzy clustering algorithm using the particle optimization algorithm. 2- Using Mahalanobis distance criterion to reduce the effect of geometric shape of colors. Correct the final clustering results for incorrectly clustered pixels. The simulation results showed the performance improvement of the proposed method compared to the previous works. One of the most recent studies on image segmentation is the paper presented by Ayala et al. [29]. In this paper, the Differential Evolution Algorithm (BDE) is used to segment images. In the method presented in this paper, the BDE algorithm is used to determine the n-1 threshold used in color image segmentation. The simulation results showed that the proposed algorithm has better performance than other evolutionary algorithms used for image segmentation. In another study, Markov's hidden model was used for a piece of color images [30]. In the segmentation method presented in this paper, expectation-maximization, parameter estimation and Bayesian multiscale have been used.

3. Proposed method

This section details the proposed method for classifying plastic bottles for recycling using machine vision techniques. This proposed method includes two main steps: image segmentation and image categorization for recycling plastic bottles. In the reminder of this section these two stages are detailed.

3.1 Image segmentation

In the first stage of the image segmentation, Gaussian filler is used to reduce image noise. Gaussian filter is one of the conventional filters in reducing digital image noise that by adjusting the dimensions and variance of this filter, the effect of noise reduction and smoothing can be controlled. Since the noise added by the scanners is generally Gaussian, the use of this filter as a preprocessing step in image processing is quite common, which has also been used in the proposed algorithm. In the proposed method, using a Gaussian filter with a size of 9. 9, the noise caused by imaging and digitizing it is reduced and its image information is extracted for the next parts.

In the method proposed in this paper, the image histogram is used to optimize the segmentation. To calculate the competency function, we used a combination of two goals, the sum of the differences between the clustering centers and the pixels belonging to that class, as well as the distance between the centers. In fact, the smaller the difference between the clustering centers and the pixels belonging to that class and the greater the distance between the clustering centers, the higher the fit function. In fact, the objective function of the particle optimization algorithm is the sum of two different functions, one of which must be minimized and the other maximized.

The sum function of the difference between the clustering centers, and the pixels belonging to the same class is shown below.

$$fitness = \sum_{i=1}^{c} \sum_{k=0}^{255} \mathrm{D}(\mathrm{V_i}, \mathrm{X_k}) * \mathrm{h(k)} \quad (1)$$

Where $\mathrm{D}(\mathrm{V_i}, \mathrm{X_k})$ represents the distance of k th pixel from the center of the i-th cluster. Also, h (k) represents the normalized histogram of km light intensity. As can be seen in Equation (1), the smaller the sum of the distances of the different pixels from the center of their respective clusters, the smaller the objective function will be. In this regard, the histogram value of each pixel also affects the value of the objective function. In fact, the larger the histogram of a pixel, the greater the effect on the value of the objective function. In the proposed method in this research, it is preferred that the centers of each piece be selected close to the peaks of the histogram to reduce the segmentation error. Combining this goal, which is the error of clustering different parts, with the aim of spacing the centers of the clusters from each other, can provide a suitable objective function in segmenting images.

3.2 Image Classification

This step of the proposed method is the main step of the machine vision-based classification method. In this stage of the proposed method, a color image classification and retrieval method using clustering and fuzzy similarity criteria is introduced. In this method, the criterion of similarity of two images, even when there is no color in one of the two images, seems reasonable. On the other hand, choosing a clustering center would be much more logical than the method mentioned in the previous methods, and thus, the classification result would be more efficient.

The similarity criterion plays an important role in the result of image categorization. To classify the image, the modified feature vector is used to identify the image and use it to calculate the amount of similarity in the next steps. This retrieves the image. In this paper, a method is proposed in which the similarity between two images is measured by considering the color characteristics of an image such as the color spectrum. The F-Stat criterion has also been used in this study; The criterion that finds the best threshold for finding fuzzy segmentation. Finally, the c-means fuzzy algorithm is used to classify the image and calculate the degree to which an image belongs to a class. A computational model of this method is also created. Also, in this article, a framework is introduced in which the images can be compared with each other in relation to the fuzzy similarity criterion, which is calculated based on the color spectrum feature vector, and thus, the image can be retrieved. Image classification is also done using fuzzy clustering. Result Comparison of image recovery between the RGB feature vector and the color spectrum feature vector are compared in terms of image specifications.

4. Experimental Result

In this section, the proposed method for classifying recycled plastic bottles using machine vision is evaluated. The experimental platform requires to be made first. The shining situation have been implemented and evaluated, in which the bright flux is 24 lm and the value of CCT (related color temperature) is 3200 K (working current @IF = 60 mA). For the color identification, the proposed method trained in proposed method is utilized. Then, color identification of 1446 plastic bottles is performed in this experiment.

Figure 1 shows the results of segmenting and classifying a plastic bottle for a sample image. As seen in this Figure, the proposed method has an appropriate performance. The steps of this proposed method include receiving the original image, graying, histogram-based segmentation, segmentation optimization and contour acquisition.

Figure 1: the steps of proposed method for segmenting and classifying a plastic bottle

Another experiment also compares different methods in terms of MSE criteria and F (I) function. These two criteria are obtained using the following equations:

$$MSE = \frac{1}{N}\sum_{j=1}^{M}\sum_{i\in S_j}\left|x_i - c_j\right|^2 \quad (2)$$

$$F(I) = \frac{\sqrt{M}\sum_{j=1}^{M} e_j^2}{\sqrt{N_j}} \quad (3)$$

In the above relations, N is the number of pixels, M is the number of components obtained in the output image, S_j is the number of pixels in the j-th component, c_j is the brightness of the j-th cluster, and x_i represents the brightness of the i-th pixel in the j-th cluster. Table 1 compares the different methods from the MSE benchmark perspective. As the data in these tables show, the proposed method performs better in all cases.

Table 1: Comparison of different methods in terms of MSE criteria

Image Sample	**Proposed method**	**image recognition [31]**	**hyperspectral imaging [32]**	**hyperspectral imaging [33]**
1	**2.68**	3.17	2.89	3.13
2	**0.59**	0.61	0.71	0.68
3	**2.73**	3.19	2.96	2.89
4	**1.61**	1.86	1.73	1.67
5	**3.91**	4.12	4.38	4.17
6	**0.94**	1.87	1.19	1.73

Table 2: Comparison of different methods in terms of F(I) criteria

Image Sample	**Proposed method**	**image recognition [31]**	**hyperspectral imaging [32]**	**hyperspectral imaging [33]**

1	**1.17**	1.76	1.24	1.38
2	**0.18**	0.73	0.25	0.69
3	**0.48**	0.59	0.61	0.71
4	**0.28**	0.49	0.31	0.56
5	**0.24**	0.28	0.18	0.67
6	**1.29**	1.84	1.79	1.38

The confusion matrix acquired by train data and test data is displayed in Table 3, where light blue, lilac, brown, blue, light green, dark green, and colorless bottles are labeled 1 to 7, correspondingly. The recognition accuracy of plastic bottles in all colors is appropriate for this application.

Table 2: Confusion matrix of the test data

	Predicted category							
Actual		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Category	**1**	178	16	0	2	0	0	0
	2	16	176	0	7	0	0	0
	3	0	0	200	0	0	0	0
	4	2	4	0	194	0	0	0
	5	0	0	0	0	193	7	0
	6	0	0	0	0	5	195	0
	7	8	0	0	0	0	0	192

5. Conclusion

Mass production of waste in cities has created health, environmental, socio-economic, transportation and traffic problems. Improper waste management leads to environmental pollution, unpleasant odors, growth and reproduction of insects, rodents and worms and disease transmission. Such as typhoid, cholera, hepatitis and AIDS. Increasing production of plastics, including polyethylene terephthalate bottles and its improper disposal in the environment, in addition to wasting national capital, also destroys natural resources. Recycling is a solution that imposes lower costs on municipalities than landfilling or incineration, resulting in energy savings and environmental protection.

In this paper, isolated plastic bottles can be identified directly by the ratio of the contour area to the convex body area based on their image. For adjacent plastic bottles, the proposed method called distance conversion and segmentation was useful to distinguish them from other plastic bottles. The technique presented in this paper combines histogram-based segmentation and image processing techniques to improve the identification and classification of plastic bottles.

Implementing the proposed method and comparing its performance with previous work showed the proper performance of this method**.**

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