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Segmentation of Natural Images Using an Improved Thresholding-based Technique

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Abstract

This paper investigates fundamental problems in image segmentation using traditional segmentation techniques and proposed an improved technique for segmenting images captured under natural environment. Image segmentation refers to a process of partitioning a digital image into multiple regions with the aim to extracts object of interest from the background. However, the segmentation process is very challenging especially for experiment which conducted in outdoor environment. It is difficult to produce a significant threshold value which required for segmenting images due to non uniform illumination and difference of reflection. Different illuminations may produce different colour intensity of the object surface and thus lead to inaccurate segmented images. The widely used traditional thresholding and clustering segmentation techniques are Otsu and Fuzzy c-means (FCM), respectively. Both traditional methods were unable to produce good quality segmented areas due to the complex background and non-uniform illumination of images captured under natural environment. Therefore, this paper proposed an improved thresholding-based segmentation integrated with an inverse technique (TsTN) that was able to partition natural images correctly. The three segmentation techniques were implemented on fruit images and their performance was evaluated based on the ground truth. The segmentation techniques performance was compared quantitatively using evaluation method, Rand Index (RI). The analysis results showed that TsTN has the ability to produce good quality segmented images. Furthermore, this segmentation technique was proven to be more accurate than the traditional thresholding and clustering techniques.

Keywords: segmentation; thresholding, clustering, Otsu; Fuzzy c-means

1. Introduction

Image segmentation is a process of dividing an image into distinct regions with the aim to extracts object of interest from the background. This process is a crucial stage in the image analysis where the result in this stage influences the performance of the entire process [1, 2]. Segmenting the selected region ensured that only the object of interest was processed during the colour analysis phase. A false segmentation will cause degradation of the object measurement and classification processes.

Technology advancement on the image segmentation technique has experienced tremendous growth both in theory and application. Image segmentation technique was widely used in pattern recognition and image classification in many areas such as agricultural [1, 3], medical [4, 5], and forensic [6, 7]. Many researchers reported that the segmentation is the one of most critical phase for image processing because the quality of segmented images influenced the results of the remaining processes. However, the segmentation process has become a challenging issue because of the complex background and changeable illumination on the images. Low quality of segmented images may lead to inaccurate and unsuccessful

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outcomes. Segmentation can be accomplished by different techniques such as thresholding-based [8, 9], edge-based [10, 11], region-based [12] and clustering technique. Among the segmentation techniques, thresholding and clustering approach are the most used method for segmenting images.

Thresholding-based segmentation technique has received extensive interest from researchers for many years. This technique is simple but effective for segmentation of images where it subdivides an image into meaningful non-overlapping regions or classes based on gray levels of images. The grayscale image was used because it allows further exploitation on the image in an efficient and easy approach where it can consistently partition the image into two classes. The thresholding technique classifies each of image pixels into two classes which correspond to object class and background class.

One of the thresholding-based techniques that was widely used is Otsu method [13]. This method works on gray scale image and selects an optimal threshold value automatically from a gray level histogram. The optimal threshold value was selected by maximing the between-class variance or minimizing the within-class variance. Otsu method was extensively adapted because of several reasons. First, it is simple and has the ability to process the gray level images directly. Second, it is able to work with a global threshold values due to its low sensitivity to dark areas [14]. Finally, the method covers a wide scope of unsupervised decision procedure where it does not require training images in order to get prior knowledge about the histogram shape [15].

However, this method has few disadvantages. One of the drawbacks is that the method was inefficient in determining the optimal threshold value due the fact that it involves a large number of repetitious computations of the zero and first order cumulative moments of the gray level histogram. This process requires high computational time especially for images that were classified into a large number of classes. Furthermore, the usage of Otsu technique alone in the application was not enough to produce accurate segmentation result especially for images under uneven lighting condition [16].

Recent years, variety of extended segmentation techniques has been explored in the literature including clustering techniques. A clustering technique is an unsupervised classification of objects into meaningful groups or clusters based on their similarity [17]. This process is done by identifying the structure of a given data sets without prior knowledge about the distribution of the data. There are two types of clustering techniques: crisp (hard) and fuzzy techniques. For crisp clustering, the data item is added to only one cluster and membership value is only one or zero. The crisp is better for separating data into mutually exclusive clusters where each objects belong to only one cluster. However, in many real cases, data tend to belong to more than one cluster. Therefore, fuzzy clustering technique provides a better solution because it allows data object to be assigned partially to all clusters with different membership values ranging from zero to one. The fuzzy technique offers flexibility in clustering effort and also able to handle outliers.

One of the well-known fuzzy clustering techniques is fuzzy c-means (FCM) [18]. This technique was also proved to be a better technique than hard clustering [19]. Generally, FCM calculates fuzzy partition matrix to classify data into c clusters (c represents number of clusters). The method of assigning cluster is suitable for the study of images under natural light which must consider the element of vagueness and uncertainness. FCM permits data to be assigned to one or more clusters with different membership values and it is still stable even though with the existence of overlapping clusters. In addition, this technique is efficient, straightforward and easy to implement [20]. However, this technique was not extensively applied in classifying images captured under natural environment. This is because FCM is sensitive to the variation of colours on the objects surface due to the existence of sunlight illumination. In addition, this technique required more computational time to process larger image.

Therefore, a modification to the existing segmentation method was required to extract quality segmented images from the background. The above weaknesses were solved by an improved thresholding-based technique which included an inverse technique (TsTN). This research was conducted to evaluate the performance of Otsu, FCM and TsTN. In the experiment, it was observed that segmentation of natural images is challenging when using Otsu and FCM methods. Both Otsu and FCM methods do not have the ability to process images under direct illumination and images that are too dark. In order to address these limitations and improve the segmentation process, a better segmentation technique was required to segment the in the area of interest perfectly and correctly. The improved segmentation technique was designed based on the thresholding-based method and it was able to segment images which captured under natural environment accurately.

The rest of this paper is organized as follows: Section 2 discusses on the traditional and proposed segmentation methods and Section 3 explains the methodology used in this study. Section 4 focuses on the comparison of three different segmentation techniques and result obtained. Finally, concluding remarks and future directions are discussed in Section 5.

2. Segmentation Algorithms

2.1. Thresholding-based segmentation technique

In this study, Otsu method was added to calculate threshold value automatically, and thus enable researchers to extract objects of interest from its background. This histogram-based method divided the gray level of an image into two classes. The gray level is composed of different shades of gray varying from black at the weakest intensity to white at the strongest intensity which range from 0 to 255. The two classes are area of interest and background. In this case, the area with different gray levels (first peak) was considered as an area of interest, whereas area with the same gray-level (residual peaks) was assigned as background. The optimal threshold value on the image was selected when the variance between the two classes was maximum, which gives the best separation of classes in gray level.

The threshold values were then used to isolate the interest area from its background by converting the grayscale images into binary images. The binary images consist of black and white pixels where pixels with gray level bigger than the threshold values were set to white and all the remaining pixels were set to black. The produced binary images were segmented images where ‘1’ (white) and ‘0’ (black) representing object of interest and background, respectively. However, it was observed that some images do not have the exact shapes to represent the investigated region because of the unsuitability of the automated calculated threshold values. This showed that the existing Otsu method was unable to segment images in natural environment correctly. Therefore, modification to the threshold values was required to extract the area of interest only.

2.2. Fuzzy c-means technique

Fuzzy c-means (FCM) is a clustering-based segmentation technique that divides an image into a number of distinct clusters where each data element belongs to one or more clusters with different membership values. FCM allows each data to be appointed to all clusters but in the different degree of fuzzy membership values between 0 and 1. The larger the membership values, the higher the confidence in assigning data to the particular cluster.

Traditionally, FCM is fully unsupervised clustering technique which does not require any labeled data in order to identify the structure of the data set. However, this technique has several weaknesses. The first weakness was where this technique failed to produce meaningful results in the case of high dimensional data set [21]. The second, FCM techinque was sensitive to the initial cluster centers where inaccurate initial centers may produce poor classification result [22]. Hence, the FCM technique was executed with the initial cluster centers obtained from earlier stage.

2.3. An improved thresholding-based segmentation technique for natural images (TsTN)

In this section, an improved segmentation technique for images captured under natural environments was described. The improvement to the segmentation technique was achieved by integrating modified threshold value algorithm with an inversion technique (TsTN). The flowchart of the improved technique is shown in Fig. 1.

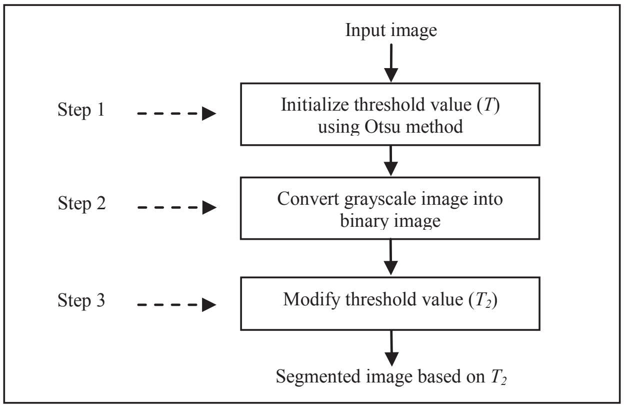


Figure 1: Flowchart of the Improved Segmentation Technique (TsTN)

Step 1 refers to the initializing an optimal global threshold value (T) using Otsu method. The Otsu was applied on the image to obtain the initial value automatically and rapidly. The initial value was calculated to acquire a set of disjoint regions that corresponds to interest object and background. This process was done to ensure that at least part of the object being investigated can be extracted. Step 2 refers to the converting of the grayscale image into binary image based on the existing T. The binary image represented the separable area between investigated object and background. The transformation process from grayscale image into the binary image is defined in Eq. 1.

$$g(x,y)=\begin{cases}1(white) & if \quad f(x,y)>T \\ 0(black) & if \quad f(x,y)\le T\end{cases} \quad ; \tag{1}$$

where *g(x,y)* and *f(x,y)* are pixel values of binary image and grayscale image, respectively.

However, the global threshold value (T) produced by Otsu is insufficient to produce acceptable segmented images for some objects. Therefore, in the improved algorithm, a modified global threshold value (T_2) was introduced. In order to generate the best value of T_2, several improvements were made to the segmentation algorithm in Step 3. First, the middle element of binary images produced must be examined to identify the pixel value. If the pixel value point was not '1', an inverse process was required to inverse each pixel in the image from value '1' to '0' and vice verse by executing Eq. 2.

$$g(x,y)=\begin{cases}1(white) & if \quad g(x,y)=0 \\ 0(black) & if \quad g(x,y)=0\end{cases} \quad ; \tag{2}$$

where *g(x,y)* is pixel values of binary image.

The inversion process was often needed for cases where investigated objects were darker than the background. Due to the dark images that conceal the shape of the objects, the inversion operation was required so that the background appears black and the investigated image appears white.

The second improvement was the expansion of the segmented area by modifying T in order to obtain the best T_2. The modification to the threshold value was done based on Eq. 3.

$$T_2=\begin{cases}\left.\begin{matrix}T_2-0.01(area\uparrow) \\ T_2+0.01(area\downarrow)\end{matrix}\right. & if \quad inverse=0 \\ \\ \left.\begin{matrix}T_2+0.01(area\uparrow) \\ T_2-0.01(area\downarrow)\end{matrix}\right. & if \quad inverse=1\end{cases} \quad ; \tag{3}$$

where T_2 is modified threshold value. The current T_2 is updated and the segmentation process is iterated until the best segmented image was achieved.

3. Materials and Methods

In order to evaluate the performance of Otsu, FCM and TsTN segmentation techniques, three main steps were carried out in this study. The two steps are (a) image acquisition and (b) image pre-processing, and (c) image segmentation.

3.1. Image acquisition

In image acquisition step, a digital camera was used to capture images of jatropha fruit. The fruit image was captured under natural environment in order to get realistic data. The jatropha fruit was chosen because it has different surface colours indicating its maturity stages at different level. For this study, four categories of jatropha fruit were chosen; green, yellow, yellowish brown and black. All mages of the fruit on a tree were captured in a jatropha orchard at Universiti Teknologi Mara (UiTM), Perlis, Malaysia

3.2. Image pre-processing

The RGB images were resized into 250 x 250 pixels in order to reduce the computational processing time and to have standard pixel intensity values for all images.

3.3. Image segmentation

Image segmentation refers to a process of partitioning a digital image into multiple segments or regions to simplify the representation of an image. Segmenting the selected region ensured that only the object of interest was processed during the colour analysis phase. In this study, a separation between jatropha fruit image and its background was performed by using three segmentation techniques; Otsu, FCM and TsTN.

4. Results and Discussions

In this section, the performance evaluation for all the three segmentation techniques was demonstrated. In order to verify the potential and limitation of each segmentation techniques comprehensively, a ground truth dataset was created and used as a benchmark for the evaluation. In order to ensure the highest possible accuracy, the ground truth was created entirely by hand. The ground truth image is a series of binary masks where pixels with value ‘1' denoted the object of interest and pixels with value ‘0’ denoted the background. Samples of original images and their ground truths are presented in Fig. 2. There are four categories were chosen to represent the natural object conducted in this study. The categories are green, yellow, yellowish-brown and black.

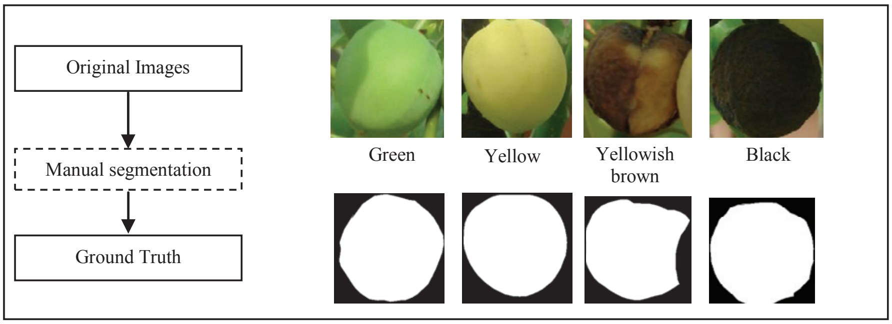


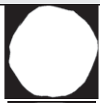
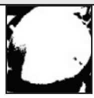
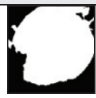
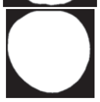
Figure 2: Original Images and Correspond Ground Truth

Initially, performance evaluation of the segmentation techniques was done manually based on human observations and perceptions to the ground truth. Later, the ground truth dataset was used to evaluate the performances of the segmentation techniques quantitatively.

4.1. Visual Evaluation

The result in Table 1 shows the visual performance of the three segmentation techniques. The table illustrates the manual segmentation (second column), segmented images by using Otsu (third column), segmented images by using FCM (fourth column) and segmented images by using TsTN (fifth column).

Table 1. Comparison of Segmented Images

Images	Manual Segmentation	Segmented Images by Otsu	Segmented Images by FCM	Segmented Images by TsTN
1				
2				
3				
4				

It was observed that some of the binary images produced by Otsu do not have the exact shapes of the investigated area. In this experiment, three weaknesses of segmented binary images by Otsu were observed. The first weakness was the investigated area merged with the background area. The existence of the background area in often leads to the inaccuracy and misclassification of the image. Sample of the images are shown by image 1 and 3. For the second weakness, the selected interest area was smaller than the expected output as illustrated in image 2. The small area was not sufficient for the subsequent image analysis because it often leads to wrong classification of the image. The third weakness was where the dark images were segmented wrongly by Otsu method. It was observed that the investigated area was reversely classified as the background area and vice versa. This type of image was experienced by image 4. Therefore, it can be claimed that the traditional thresholding-based segmentation technique was unable to segment the dark objects under natural environment correctly.

The segmented images produced by FCM showed that this technique also has limitations in producing good images under natural environment. However, in some cases, the images produced by FCM were better than the segmented images by Otsu where it removed the background image correctly as illustrated by image 1 and 3. Other limitations of FCM were that this technique was too dependable on the initial value of cluster centers and was very sensitive to noise. These constraints were not suitable for classifying images of natural objects where it lead to poor result in further analysis stage. This is because the inaccuracy of initial cluster centers and the presence of direct illumination on the object surface produced ineffective segmentation results.

Both Otsu and FCM techniques were unable to segment objects captured under natural environment well because of the illumination and the background factors. In order to address these limitations and improve the segmentation process, a better segmentation technique was required to segment the area of interest correctly.

The proposed technique extended the theory of thresholding with the integration of inverse technique and known as TsTN. The improved segmented images produced by TsTN are shown in fifth column. The results showed that TsTN has the ability to produce good quality of segmented images. This technique was able to solve all the weaknesses occurred in segmented images produced by Otsu and FCM methods. First achievement of TsTN was this technique has successfully reduced the presence of the background area in the images. This achievement is shown by segmented results for images 1 and 2. The second achievement, TsTN was able to increase the investigated area. The broadness of the area produced by this technique was sufficient for the next process as shown in image 3. Finally, TsTN has the ability to solve the misclassified area between investigated object and background as presented by segmented image of image 4. TsTN has successfully produced more accurate and better segmented images and therefore it can be concluded that TsTN is superior to the traditional treshosholding-based segmentation technique especially for dark images.

4.2. Quantitative Evaluation using Rand Index (RI)

The performance evaluation of different segmentation techniques in the previous section was measured visually based on human perception. However, the evaluation based on visual observation is very subjective and argumentative. Therefore, this section compared the performance of the different segmentation techniques quantitatively by using an evaluation method, Rand Index (RI). This method calculates the performance by counting the fraction of pixels pairs whose labelling are consistent between test (*S*) and ground truth (*S'*) segmentations. RI is given by the sum of the number of pixel pairs that have the same label in *S* and *S'*, divided by the total number pixel pairs. The output value is ranging between 0 and 1 where the higher the RI value, the greater is the performance of the segmentation technique. The result of RI values for segmented images in Table 1 produced by Otsu, FCM and TsTN techniques is shown in Table 2.

Table 2: Rand Index (RI) of Otsu, FCM and TsTN Techniques

Images	Otsu	FCM	TsTN
1	0.7776	0.7350	0.8500
2	0.8343	0.6746	0.8782
3	0.3468	0.1827	0.8846
4	0.0449	0.1574	0.8527

The result shows that the RI values produced by TsTN for all images are the highest among other segmentation techniques. This infers that the performance of TsTN is the best for segmenting images which captured under natural environment. The good result in segmentation process increases the accuracy of objects classification.

5. Conclusion

Segmentation process on the natural images becomes challenging due to the non-uniform illumination and the complex background. Using Otsu or FCM only was not sufficient to properly separate the interest area and background. Although thresholding-based segmentation is suitable for segmenting images from the background, a complementary technique is required to segment images captured under natural environment. Objects with bright surface area such as yellow and green tend to appear clearer under natural light illumination. However, object with dark surface colour tends to blend with its shadow in the background. Therefore additional techniques such as modified thresholding-based and inverse techniques must be applied.

In this study, an improved segmentation technique which modified the threshold value and added the inverse technique (TsTN) was developed. TsTN was able to increase the investigated area and therefore allowed better classification for poor captured images. Several successful preliminary tests were performed on other fruit images under several illumination conditions such as in the dark and direct sunlight. The ability of this new technique therefore has the potential to classify poor images with inconsistent illumination conditions.

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