Development of intersection circle method for detecting and estimating the number of near-spherical clustered citrus fruits in robotic harvesting

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Abstract

Counting the number of clustered citrus fruits and extracting the features based on machine vision are key problems for a fruit-counting robot. In this study, the intersection circle (IC), and circular Hough transform (CHT) were used to detect the objects of interest, i.e. round-shape citrus fruits. The results indicated that these two methods could accurately detect the fruits. However, the objects extracted by the CHT method included false targets in addition to longer time and larger memory required. The IC method, on the other hand, could accurately extract the features in a real-time mode when the intersection area ratio is less than 40%. This method didn't have sensitivity to shape of fruits and it could detect an elongated shape accurately. But CHT method based on the circular features and it could not detect the elongated shape. Generally, the accuracy of the IC method for the fruits of our model (spherical) was found to be 79% and for the CHT it was 94%.

Key words: fruit, detection, image processing, evaluation,

1. Introduction

Nowadays the machine vision has many potential applications in agricultural tasks such as robotic harvesting, automated fruit detections, remote sensing and etc. This is because the machine vision methods are more effective than other methods such as manual or mechanical harvesting methods, which have two main negative points first, the cost of manual harvesting methods which is over 40% of total fruit production and second, the trees and fresh fruits damages which are caused by mechanical harvesting methods [1]. Therefore, robotic harvesting looks promising in this regard. Fruit recognition and location are two priority tasks and operations for a harvesting robot. Machine vision, thermal imaging and hyperspectral imaging techniques have been used in robot harvesters to perform these operations [2-3]. Machine vision is more preferred, because of its efficiency. Most of the machine vision methods are based on the images.

In general, the machine vision system of a harvesting robot is consisted of CCD or CMOS camera, which is used for capturing images, and a computer programmed to process and locate the desired objects through image processing steps. These steps can include, but not limited to, segmentation, feature extraction, classification, stereo match, and techniques of three-dimensional measurement. Since the appearance of products were recorded in images and the Machine vision methods are based on the images therefor the processes methods are made base on the appearance of the product. Applications such as grading or analyzing the fruits by their size, quality, or ripeness can be based on their appearance. These application are conventionally done by human visions [4]. Machine vision technology also mimics human vision methods to recognize the fruits. Some features like ripeness can be extracted from color images. Zhao et al (2004) detected mature tomatoes with the extraction of HSI color component from color images [5]. When the significant color or texture contrast exists, the color or texture features can be extracted form images easily, while extraction morphological features appear to be more challenging. . Some variables such as branches, leaves or fruit occlusion make it difficult to extract the morphological features. Therefore, the focus of machine vision is to find the method which can accurately extract features from incomplete target images. For near spherical fruits, the values of radius and the location of their centroids are the key features that can solve the detection problems. Ling, et al (2004) developed a method for detecting tomatoes based on arcs and circle geometry. In their approach they located the center of a circle as the interception of perpendicular bisectors of any two arbitrary chords. In this study since tomatoes are not perfectly circle-shaped all of their available edge points were used to fit the circles and determine the centers, which potentially could be any point in the image. Each potential center point receives a score every time they were voted as circle center. Based on these voting scores, an array with the same size of the image, called accumulator array, was created. The highest scores in this array was assumed to be associated to the centers of the tomatoes in the image [6].

Circular Hough transform and chord construction were implemented to identify and locate mature tomatoes based on the edge information (Chi and Ling, 2004). Chord construction was developed based on the simple geometry of circles: the interception of perpendicular bisectors of any two chords of a circle is the center of the circle. The schematic diagram of this algorithm is illustrated in Figure 1. Since tomatoes are not perfect circles, all available chords on the edge were used to locate the center. This voting process created an accumulator array which size is the same as the size of the image. The peaks in this array are the centers of the tomatoes in the image.

The other method can be used to detect circles in images is circular Hough transform (CHT). A modified CHT was applied to detect circular arcs that should correspond to tomato contours [7]. The obtained results were very sensitive to the user-specified threshold value and the best result was 68% correct detection and 42% false detection. The contour of the leaves was one of the major problems which were interpreted by the algorithm as possible fruits. Grasso and

Recce (1996) used CHT to estimate the locations of centers based on the citrus edges of images taken in natural scenes [8]. The authors reported problem when oranges were partially occluded by leaves. Cai et al. (2008) used modified CHT to extract the center coordinates and radii and recover the shapes of citrus without or with slight occlusion [9]. Although CHT is a simple approach to detect near-spherical fruit, it is computationally intensive with respect to time and memory usage. Therefore, we proposed a new method that could separate the intersection circle and detect the number of the clustered fruits and we compared the performance of our method with the CHT.

Problems of clustering and intersection of the spherical fruits are the main concerns of this study. We required to have flexibility and options to arrange the fruits in different numbers and locations, leaves and their arrangements. Thus, we modeled a tree with artificial flexible-rib leaves and spherical fruits. This model tree allowed us to provide various leaves and fruits arrangements (Figure 1). The images were taken at Ferdowsi University campus with a Nikon Coolpix P510 digital camera (Nikon Inc., Japan). The images were of 3456×4608 resolution and taken in controlled lighting conditions provided by some white light sources. The use of sun as a light source could make unwanted errors on images due to casting shadows, creating reflections of light and generating local overexposed regions on objects in an image; consequently makes, detecting objects difficult and sometimes impossible [10].

Figure 1 the model tree used in this project with the manually arrangement of artificial fruits

The taken images were processed using MATLAB R2015a (Math works Inc., US). In first stage of this algorithm, the part of the image which was related to the tree was cropped from the image and some pre-processing operations were applied. The purpose of the pre-processing was to improve the image quality so that it reduces noise and highlights the contrast between objects of interest and background. This process is important for segmentation and feature extraction which are important next processing steps [11].

In pre-processing stage, a 3×3 averaging filter was used to reduce probable pulse noises and to smooth the image. In order to avoid elimination of image information, images were saved in lossless compression PNG format. Then each saved image was called to the MATLAB environment and color segmentation step was performed; first the blue image background was removed and the color difference between leaves and fruits to separate the fruit regions from other tree-related branches and regions. For this purpose, the images were decomposed into R, G and B (red, green and blue) component images first. Then we examined the intensity values of each color component to find a large difference between citrus and tree region (leaves, branches etc.). Table 1 shows the color indices used in this study to separate fruits from non-fruit regions in images (background and tree branches). A typical resulting binary image after segmentation step is shown in Figure **4**2

Table 1 - the color indices used in segmentation step

Channels	Purpose
B-R	Used to remove the blue background
$R > G$ & $(1.5 * R > 254)$	Used to separate the fruit from tree

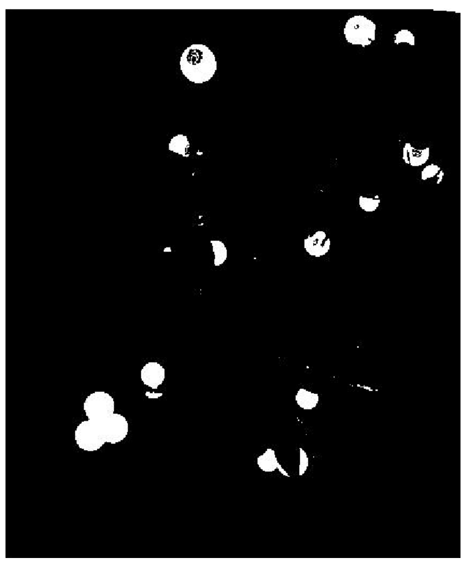

Figure 2 the resulting segmented image step is

After segmentation operation, we used shape feature extraction to detect the number of fruits. We proposed the intersection circle method in order to extract the features.

Intersection Circle Method (IC)

The number of fruits is the same as the number of isolated regions of interests (ROI) when the fruits appear isolated in the image. However, when fruits are overlapped, this is challenging problem. The IC method was used to correct the number of fruits when they are overlapped. In this method, an image of several isolated fruit regions was labeled first and the images of each labelled regions were processed separately. Therefore, for processing, each image had only one fruit region. The region was eroded until only two small (one pixel) regions, which we call them seeds, remained. Erosion is a morphological operation, which is typically applied to binary and grayscale images. The basic effect of this operator is to erode away the boundary pixels of regions of interest. Therefore, the region of interest shrinks in size every time this operation is applied. The flowchart of this method is shown in

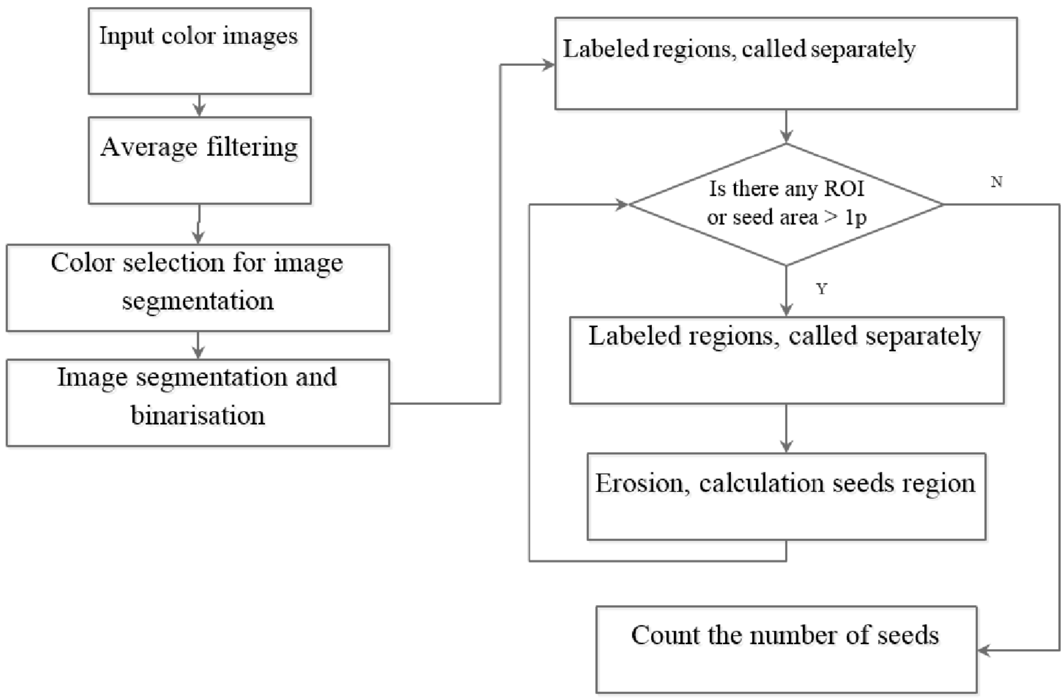

Figure 3 Flow diagram of the proposed algorithm

The erosion operation can be expressed mathematically as follows:

$$(f \ominus b)(x, y) = \min\{f(x + x', y + y') \mid (x', y') \in D_b$$

Where f is an image, b is a structuring element, x and y are locations of pixels, x' and y' are the location of the D_b structure pixels.

This erosion cycle was stopped when there was no ROI pixel remained in the resulting image. The number of seeds showed the number of fruits in one cluster. Figure 4 shows the step of this method.

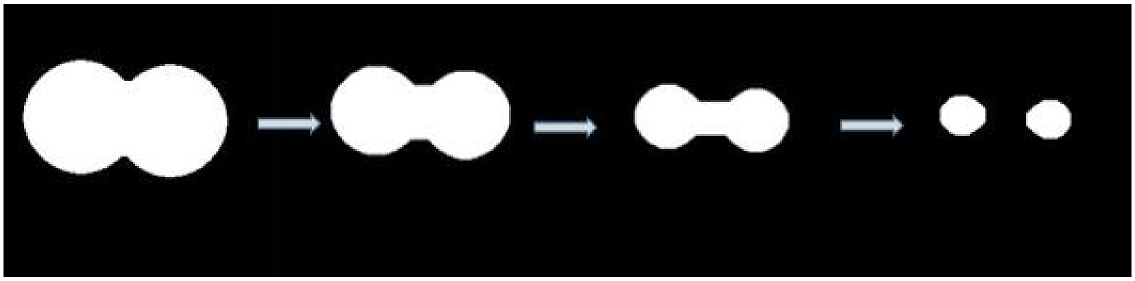

Figure 4 Separating operation of intersection circles

Discussion

This method can separate the overlapping circles successfully but it is subjected to the special condition as the circles overlap to less than 40% of their area. If the intersecting amount among two or more fruit regions is more than 40% the algorithm would detect the fruit as one object.

In this study we suggested developing a method by matching the region with template circle. Hence we made a template of circle with the scale of 60*60 pixels. Then the regions that were separated, matched to this scale. In next steps we matched these shapes and calculated the percentage of unmatched areas. Results showed that this is a suitable method to detect the seeds as circles (Figure 5)

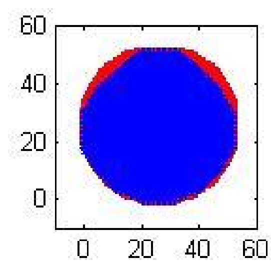

Figure 5 matching the region (blue) and the template circle (red)

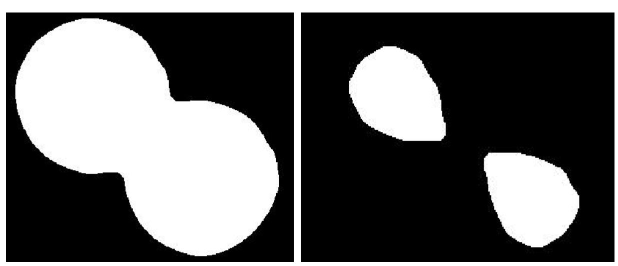

Figure 6 the angled circles that were transformed to the spindle shape after erosion

This method works well for those circles placed horizontally next to each other. However, this method faces challenges or the circles located diagonally, which means the line connecting circle centers holds at an angle with respect to the horizontal line In this case, erosion makes seeds to spindle shapes, rather than smaller circles, that finally dilation does not make it return to a full circle shape (Figure 6). Therefore, the dilated shape would not match with the original circle. For such cases, the angle of longest chord (major axis) was found first and the image was rotated by that angle in order to have horizontally laid circles (Figure 7). But as previously was expressed that the purpose of this research was detection the number of clustered fruits hence the shapes of fruits were not considered. In such research that the shapes of spherical fruits were important this methods can be attached to IC.

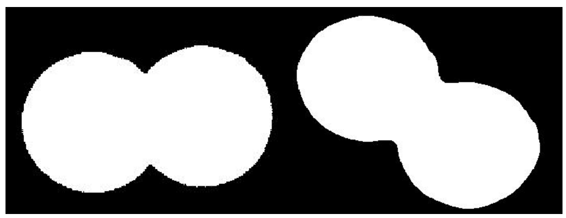

Figure 7 rotated picture by the maximum chord

The performance of our method was compared with those from CHT. CHT has been proven to be powerful method that could accurately detect more fruits on the image with low false detections. However, the accuracy of the CHT was limited when the accumulation cells discretized. Decreasing the size of the accumulation cells drastically increased its computational time, making the CHT practically less effective for many applications, especially those that required real-time processing. Table 2 compares the performance of our algorithm with CHT in terms of the accuracy of circle detection in sample images. For images used in this project, the accuracy of CHT in circle detection was found to be 94% and for our proposed IC method was 79%.

Table 1 number of fruits

Methods	Number of fruit	Number of true detection
CHT	73	69
IC	73	58

The fruits with the higher intersection area than 40% or the Fruits that have elongated shape with low compactness value could not be detected easily by CHT while they were easily detectable by IC method because as the shows CHT detected elongated fruits as clustered fruits. But the IC method detected this fruit as one object, because such cases didn’t have any indent points. Hence on the erosion steps it detected as one object.

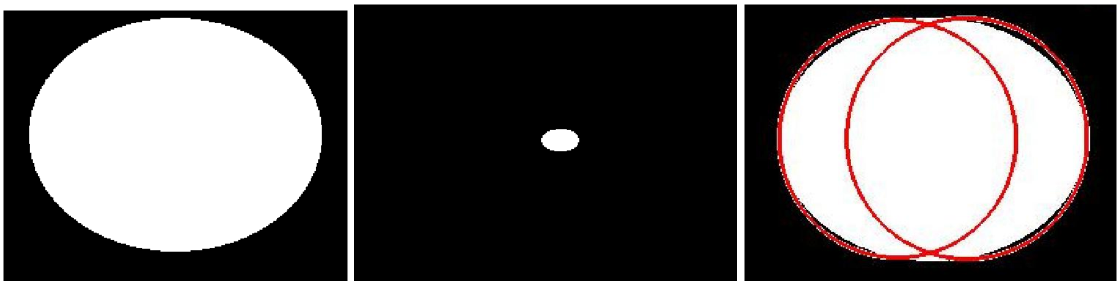

Figure 8 Left:an elongated shaped fruit; middle: a resulting morphological seed that was the result of IC method and; right: the result of CHT method showing false positive error (two fruits instead of correct one)

CONCLUSIONS

The IC and CHT methods were presented and used to extract the features of near spherical fruits. It was shown with simulation and real examples that the IC method could detect and estimate the number of fruits accurately, reliably and in a real-time mode. If the intersection area was less than 40%, the object could be located accurately, suggesting that this algorithm can be used for designing the fruit-counting robot working in natural conditions.

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