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Recognition of overlapping and occluded apple in natural environment

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ABSTRACT

The work developed a recognition method for overlapping and occluded apple fruits in natural environment. We chose the OTSU dynamic threshold segmentation method with I_2 colour characteristic in the $I_1I_2I_3$ colour space after comparing apple segmentation images based on colour features in different colour spaces. Image perfection and noise removal were carried out for the segmentation image. Then apple fruits were recognized through edge detection and the improved random Hough transformation, during which the problems of non-perfect edge and edge fracture were solved by edge thinning and edge connection. Overlapping fruit and fruit occluded by branches and leaves were separated and restored before being recognized. Fruit recognition experiments were conducted for 60 images containing 113 apple fruits with three different visual characteristics, respectively, i.e., non-occluded, overlapping and severely occluded cases. Experimental results gave a recognition rate of apple fruits in non-occluded and overlapping occluded states of 100%, and that of apple fruits occluded by branches and leaves of 86%. The apple fruit average recognition times of the different visual characteristics were all less than 1 s. These results verified that the proposed method is feasible.

1. Introduction

It is a principal problem to develop algorithms that allow the apple harvesting robot to directly, quickly and accurately recognize fruits in a real-time [1]. In the natural environment, apple fruit recognition is usually more difficult due to the influence of lights, branches and leaf masking and so on. Consequently, it is significant to recognize apple fruits in the natural environment. Apple visual characteristics in the natural environment may be divided into two categories – non-occluded fruits and occluded fruits. Occluded fruits could also be classified into overlapping fruits and fruits occluded by branches and leaves. The recognition method will be different for the different visual characteristics of apple fruit [2].

Existing research literature on apple recognition methods [3–7,27] reported an ideal condition that apple fruits weren't occluded. Compared with the recognition methods of apple fruits under the non-occluded case, the recognition problems of the occluded apple fruits have been rarely considered. Ref. [8] detailed a procedure for detecting apples in tree images using shape analysis. The cor of the procedure consists of a so-termed convexity test that identifies edges that could correspond to three-dimensional convex objects of a given size range from a much larger set of edges. Analysis based on the edges led to correct detection of 94% of the apples visible in the images. Ref. [9] recognized apple fruits using a genetic algorithm, running the genetic algorithm multiple times for images with overlapping apple fruits. The overall fruit recognition rate was 97%. Ref. [10] segmented apple images by a three layer BP neural networks model, fitting circles to fruits and obtained their positions in the image according to their contour curvature variances. Fruit (include slightly occluded fruit by branches and leaves) recognition rate was 93%. However, these methods still had some disadvantages; for example, they didn't solve for the recognition of severely occluded apple fruits by branches and leaves, and the recognition rate was influenced by edge fractures on apple fruit outlines. Moreover, they didn't determine total recognition times, and whether their designed methods could meet the recognition requirement. In previous work, we adopted a composite method based on region growing and colour properties to segment the apple image after performing image enhancement, and using (Support Vector Machine) SVM based on colour and shape characteristics to classify and recognize the fruit [11]. The overall recognition rate was 89% with an average processing time of 352ms.

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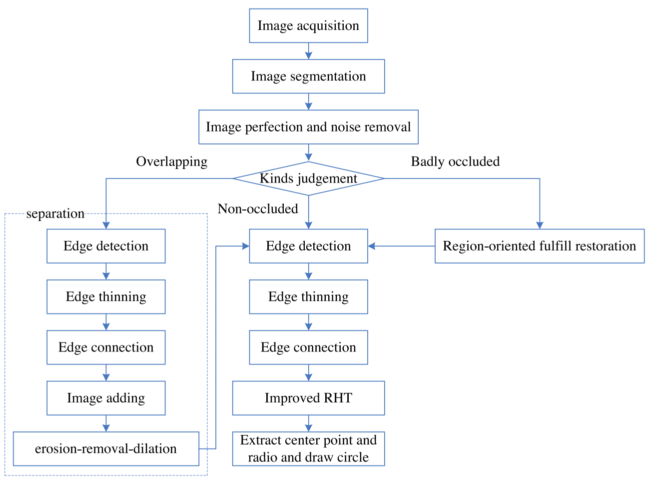

Fig. 1. The flow chart of apple fruits recognition.

However, these apple images only included non-occluded fruits. It is necessary to introduce a better, new occluded fruit recognition method with higher recognition rate and lower processing times. The objective is to realize at least 90% of recognition rate and a processing time of less than 1 s for occluded fruit images.

This work proposes an apple fruit recognition method for overlapping apples and apples occluded by branches and leaves in the natural environment. The outline is organized as follows: in Sections 2.1–2.3, apple image acquisition, segmentation and perfection are presented; apple image recognition is presented in Section 2.4, mainly including fruits edge detection, fruits edge thinning and fruits edge connection; the test results are discussed to show the validation of the proposed method in Section 3; finally, the conclusions and suggestions for future research are drawn in Section 4.

2. Materials and methods

The total implementation process of apple fruits recognition is shown in Fig. 1. Apple fruit images were acquired, then we chose the segmentation method after comparing apple segmentation images based on colour features in different colour spaces. Image perfection and noise removal were carried out for the segmentation image. Then apple fruits were recognized through edge detection and the improved random Hough transformation, during which the problems of non-perfect edge and edge fracture were solved by edge thinning and edge connection. Overlapping fruit and fruit badly occluded by branches and leaves were separated and restored before being recognized. Fruit recognition experiments were conducted for 60 images containing 113 apple fruits with three different visual characteristics, respectively, i.e., non-occluded, overlapping and severely occluded cases. The program software of fruit recognition experiments was Matlab R2010b based on the following computer configuration: Intel (R), Core (TM) 2, Duo CPU E7300@2.66 GHz, 2 G (Memory), 320 G (HDD).

2.1. Apple image acquisition

The variety of apple tested in this study was Fuji, which is the most popular variety in China. Colour images of Fuji apple fruits in the orchard were acquired using a digital camera (Sony Cyber-shot) in the different times during the third week of October, the harvesting season. The colour signals from the camera were transferred as a 24-b red, green, blue (RGB) colour image data (320 pixel by 240 pixel in each colour band). The acquired images included the separate and non-occluded fruits, the overlapping fruits and the occluded fruits under different lighting conditions ((a) full sun, front lighting; (b)full sun, back lighting; (c) full sun, fruits in the shade). The fruit trees were randomly selected from the apple demonstration orchard of Feng Country Government, Xuzhou City, Jiangsu Province (longitude 116.57°E, latitude 34.79°N).

2.2. Apple image segmentation

2.2.1. Selection for colour space and feature

It was necessary to choose a suitable colour space and colour feature for image segmentation. Images of fruits (including branches, leaves and sky) in RGB colour space were transformed to *XYZ*, Lab and $I_1I_2I_3$ colour space.

RGB colour space was converted to *XYZ* colour space by the following set of equations [12]:

$$\begin{cases} X = 0.607R + 0.174G + 0.201B \\ Y = 0.299R + 0.587G + 0.114B \\ Z = 0.066G + 1.117B \end{cases} \quad (1)$$

RGB colour space was converted to Lab colour space by the following set of equations ([13]; Wang, 2011):

$$\begin{cases} L = 0.2126R + 0.7152G + 0.0722B \\ a = 1.4749\,(0.2213R - 0.339G + 0.1177B) + 128 \\ b = 0.6245\,(0.1949R + 0.6057G - 0.8006B) + 128 \end{cases} \quad (2)$$

RGB colour space was converted to $I_1I_2I_3$ colour space by the following set of equations [14]:

$$\begin{cases} I_1 = \dfrac{R+G+B}{3} \\ I_2 = R - G \\ I_3 = 2R - G - B \end{cases} \quad (3)$$

2.2.2. Segmentation Method

The adaptability of the fixed threshold segmentation method was not strong, especially for the apple images with complex background. Therefore, we adopted a dynamic threshold segmentation method – OTSU [15,16]. For a certain image, it is assumed *T* was the segmentation threshold between the foreground and background in image; w_0 was the ratio of its foreground points and its total points; u_0 was the average grey of its foreground; w_1 was the ratio of its background points and its total points; u_1 was the average grey of its background. The total average grey value was obtained from Formula (4). *T*, traversed from the minimum grey value to the maximum grey value, was the best segmentation threshold when making the variance value σ^2 of the Formula (5) maximum. Usually the calculation cost of applying OTSU method was larger, so the variance value σ^2 of this work used the modified equivalent Formula (6).

$$u_T = w_0 \times u_0 + w_1 \times u_1 \quad (4)$$

$$\sigma^2 = w_0 \times (u_0 - u_T)^2 + w_1 \times (u_1 - u_T)^2 \quad (5)$$

$$\sigma^2 = w_0 \times w_1 \times (u_0 - u_1)^2 \quad (6)$$

2.3. Apple image perfection and noise removal

There were many holes and even the large area loss in the tail of fruits due to the evident colour differences between the end calyx and other parts of apple fruits after image segmentation. In addition, there were still other small holes and split pieces in image, so image perfection and noise removal operations were made. The floodfill algorithm [17] was used to fill holes. For the large missing area of apple tail image, the eight-neighbours labelling method [18] was applied to label the connected image region in the image

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