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Detecting citrus fruits and occlusion recovery under natural illumination conditions

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ABSTRACT

A method based on color information and contour fragments was developed to identify citrus fruits in variable illumination conditions within tree canopy, in order to guide the robots for harvesting citrus fruits. The color properties of fruit targets within citrus-grove scene were analyzed, a preliminary segmentation method was put forward by fusing the chromatic aberration information and normalized RGB model. The set of contour fragments was constructed by detecting the significant edges of chromatic aberration map and the corners within these edges. The valid subset was chosen out by three indicators of every fragment: length, bending degree, and concavity or convexity. The combination analysis was done for these valid contour fragments, and the ellipse fitting was used for every subset of valid fragments to recover the occluded fruits. The partial order relationship was derived based on the distribution of the edge within the overlapped area. The results showed that occluded fruits were effectively recovered under natural outdoor light conditions using the proposed method, and the relative error was 5.27%. The partial order relation of fruit targets provide key cues for path planning of harvesting robot.
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1. Introduction

Automated harvesting requires accurate detection and recognition of fruits within tree canopy in uncontrolled environments. Machine vision is the most important method for this task. However, occlusion, variable illumination, variable appearance and texture make this task a complex challenge.

Most works used chromatic information to differentiate fruits from background. Slaughter and Harrell (1989) and Harrell et al. (1989) distinguished citrus fruits by setting a threshold in the hue value. Ness (1989) presented an approach to solve the fruit recognition problem based on the hue difference of citrus fruit and leaves. Moct et al. (1992) presented a method to differentiate the citrus fruit from leaves based on R and G components. Xu et al. (2005) and Zhang et al. (2009) put forward a rule for segmenting citrus fruits from background based on the difference of R and B components. Wang et al. (2009) used a fusion method to get a mask to remove non-citrus background of the ratio image which was gotten by ratio transformation between R and G components. Cai et al. (2007, 2008) proposed a new method according to the self-adjusting threshold of (2R–G–B), this algorithm can recognize single or multi-fruits easily and accurately.

To sum up, most of the above methods detected citrus fruits from the tree canopy based on chromatic information. Probably the greatest difficulty arise from two aspects: one is the extreme variation of the lighting (Jimmez et al., 1999), the other is occlusion ubiquitously in natural scene.

The first difficulty lies in the extreme variation of the natural illumination. Fruits like red apples and oranges can be separated very well by color information from green backgrounds under controlled light conditions, but in an outdoor environment the changes in illumination are much greater than the chromatic difference of the fruits and the leaves. There is a technological upper limit determined by the dynamic range of the CCD of the camera. When irradiated by the sun in clear sky, part area of fruits may be saturated, with the result that the sensed image is not suitable for further processing. In this situation some patches and holes emerge in the segmentation results when using the color information and these patches cannot be removed by traditional morphologic method. When the natural illumination is very weak, such as during morning, evening, or cloud days, the integral or part surface of fruits were shaded for occlusion. These areas are so dark that their appearances have significant difference with the diffuse region in bright illumination. The shade on fruit surface cannot be detected by the traditional chromatic aberration information.

Another challenge is occlusion ubiquitously in natural scene. For self occlusion and mutual occlusion, some shades will appear

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on fruit surface, which will decrease the detection validity by chromatic information. On the other hand, one fruit will be divided into multiple parts for occlusion, the outer contour of fruits will not be a ideal conic.

In view of above challenges, this paper proposed a new detection method of citrus fruits within tree canopy by analyzing the salient edges of the chromatic aberration map of R and B channels in RGB color model. One reason of using chromatic aberration map of R and B channels is that it is very effectively to segment the diffuse region of fruits from orchard backgrounds (Moct et al., 1992; Xu et al., 2005; Zhang et al., 2009; Wang et al., 2009), and another important consideration is its quick calculating speed, which can meet the needs of real-time requirements.

The novel segmentation method detects the visible parts of fruits by fusing the segmentation results of chromatic aberration map and normalized RGB model. The set of contour fragments was constructed via significant edge detection and corner detection. The valid subsets were chosen out based on three indicators of every contour fragment: length, bending degree, and concavity or convexity. The combination analysis was done for these valid contour fragments, and the ellipse fitting was used to recover the fruit targets. The partial order relation was derived for all recovered fruit targets based on the distribution of edges within the overlap area.

There are three key steps in this method including preliminary segmentation, valid contour selection and occlusion recovery. The flowchart of the proposed method was shown in Fig. 1, and the details of each step were described in Section 2.

2. Materials and methods

2.1. Image acquisition

Dozens of images of citrus trees laden with fruits were obtained by Canon EOS 7D, with EF-S 18-135/3.5-5.6 IS Len during consecutive months from October to December of 2012. The brightness, contrast, shutter speed, and aperture of the camera were kept constant most of the time during imaging. These photos were obtained in an experimental citrus grove in Huazhong Agricultural University in some sunny days and some cloudy days. In sunny days, some fruits in the image were saturated for the direct sunlight. In cloudy days, many fruits were shaded by others or themselves. All the images were obtained in a stationary mode, and the resolution of them was 3456 columns by 5184 rows. They were resized to 648 × 432 pixels during the processing procedure. The CPU of the computer which was used to process and analyze the images was Intel(R) Core i7 930 2.80 GHz, the memory of which was 4 G. The operation system was Microsoft Windows XP, and the software for image processing was Matlab 7.1.

Fig. 2 is an example under natural illumination. It was found that occlusion existed ubiquitously within tree canopy, so some fruits were divided into multiple parts. The contour of fruits is not an unbroken circular or oval, but the fragments belonging to the outer contour of fruits were all smooth arc. Based on these smooth arcs, guided by the shape knowledge of fruits, the integral contour of these targets can be recovered by fitting method.

2.2. Salient edge detection

According to (Xu et al., 2005; Zhang et al., 2009), the diffuse reflection area can be detected effectively with chromatic aberration map of R and B channels. In original image with RGB color model, the value of every point is denoted as *I*. *I* is a vector, it consists of three components: R, G and B. $I = (I_{R(x,y)}, I_{G(x,y)}, I_{B(x,y)})$. The value of every point of chromatic aberration map is denoted as $I_{CAM(x,y)}$, it is calculated as follow:

$$I_{CAM(x,y)} = \begin{cases} |I_{R(x,y)} - I_{B(x,y)}| & ((I_{R(x,y)} - I_{B(x,y)}) >= 0) \\ 0 & ((I_{R(x,y)} - I_{B(x,y)}) < 0) \end{cases} \quad (1)$$

Fig. 3a is the chromatic aberration map of Fig. 2. There are significant differences between fruits and backgrounds in it, so the salient edge which surrounded the fruits was drawn from this map. Here the canny operator was chosen to detect the notable edge of fruits (Canny,1986). Three parameters should be set when using canny operator: two thresholds-upper (T_h) and lower (T_l), and the size of Gaussian filter (δ). The upper threshold set too high can miss important information. On the other hand, the lower threshold set too low will falsely identify irrelevant information (such as noise) as important. In this step, we processed more than twenty images by varying these two thresholds, and the results were judged by three group members. The more significant edges detected, the less texture details detected, the results were thought better. Based on this rule, the final thresholds were set as follow: $T_h = 0.4$, $T_l = 0.1$. δ is set to 2, it is the default value in Matlab. The salient edge could be detected preferably with these three parameters for all examples in this paper. Fig. 3b is the results of Fig. 3a with these parameters.

2.3. Constructing the set of contour fragments

In general, the contours of fruits are smooth arcs. However, the actual contours are not so ideal for occlusion by the leaves, trunks, other fruits, or the existence of highlight and shade. Some of the edges in Fig. 3b detected by canny operator belong to the outer contour of fruits, while others belong to the results of occlusion.

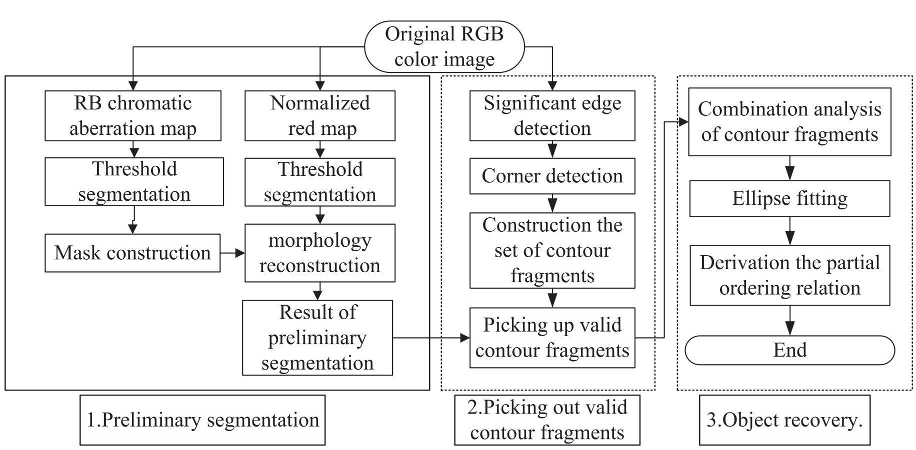

Fig. 1. Flowchart of occlusion targets recovered.

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