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Detecting citrus fruits with highlight on tree based on fusion of multi-map

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ABSTRACT

Artificial vision systems are powerful tools for the automatic guiding of fruit harvesting robots, a novel method based on chromatic aberration map and luminance map is developed to identify citrus fruits with highlight within a tree canopy. Twenty images of citrus-grove scene under direct sunlight are taken, the color properties of target objects are analyzed. First, parts of citrus fruits from background are segmented from background by thresholding the CAM (chromatic aberration map), then the highlight region of citrus fruits could be detected correctly from the tree canopy by thresholding the LM (luminance map), at last the citrus fruits can be detected integrally by fusing the segmented results of CAM and LM. The results showed that the fruits under direct sunlight can be segmented wholly using this algorithm, the detection accuracy by fusion method is up to 86.81%, and the false alarm rate of fusion method is 2.25%.

1. Introduction

Automated harvesting requires accurate detection and recognition of fruits within a tree canopy in uncontrolled environments. However, occlusion, variable illumination, variable appearance and texture make this task a complex challenge. Fruit picking robots is an application that is strongly dependent on sensory information. The main way of controlling an efficient outdoor harvesting robot is using reliable sensory-based environment analysis, and from the various types of sensory information available, vision is the most important because of the high resolution that is achievable.

The color information were used to segment the citrus fruits from the background in most works. Slaughter and Harrell distinguished the citrus fruit by setting a threshold in the hue value, and the threshold in hue was found using spectral reflectance curves of citrus fruit [1]. Grasso and Recce described classification based on chromatic information mapped into a new two-dimensional space [2]. Slaughter recognized the citrus fruits using hue and luminance as the separation features. Ness presented an approach to solve the fruit recognition problem based on the hue difference of citrus fruit and leaves [3]. Moct presented a method to improve the illumination condition via stroboscopic light, and differentiate the citrus fruit from leaves based on R and G components [4,5].

H.Y. Xu and Y.J. Zhang put forward a rule for segmenting citrus fruit from background based on the difference of R subtracted by B component, the pixel belongs to citrus fruit if the difference is larger than the threshold value (T), which is decided by dynamic threshold segmentation method [6,7]. J.H. Wang used a fusion image which fuse H and S components as a mask to remove the non-citrus background of the ratio image which was gotten by the ratio transformation between R and G component [8]. J.R. Cai proposed a new method according to the self-adjusting threshold of 2R-G-B, the algorithm can recognize single or multi-fruits easily and accurately, especially a portion of the fruits overlapped or sheltered [9,10].

To sum up the above methods, most of them usually detect citrus fruits from the tree canopy based on color information, probably the greatest difficulty arisen from the extreme variation in the lighting [1]. Fruits like red apples and oranges apparently separate very well in color space from a green background under controlled light conditions, but in an outdoor environment the differences in illumination are much greater than the chromatic separation of the fruits from 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 a clear sky, some areas of the fruits may be saturated, with the result that the sensed image is not suitable for further processing [11]. In this situation some patches and holes are emerged in the segmentation results when using the color information and these patches cannot removed using traditional morphologic method. This paper focus on the detection and segmentation method of citrus fruits with highlight region, it is resolved by fusing the segmentation results of chromatic aberration map and luminance map.

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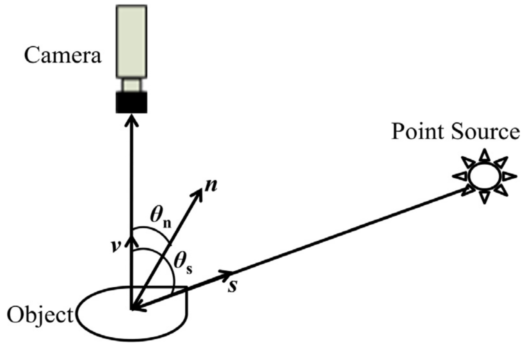

Fig. 1. Two-dimensional illumination and imaging geometry. (A surface element with orientation θ_n, reflects light from the point source direction θ_s, into the camera.)

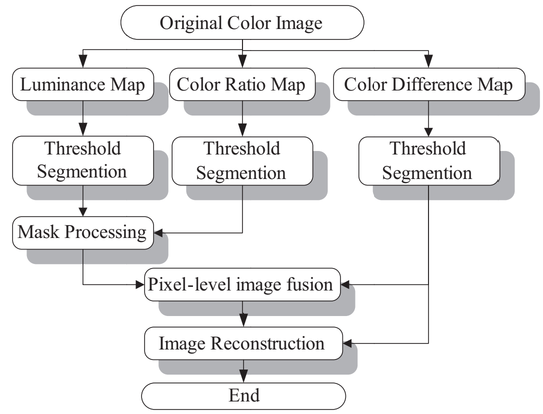

Fig. 2. Flowchart of detection of citrus fruits with highlight.

2. Materials and methods

2.1. Data acquisition

Ten images of the citrus trees, laden with fruits, were obtained using Canon EOS 7D, with EF-S 18-135/3.5-5.6 IS Len, the brightness, contrast, shutter speed, and aperture of the camera were kept constant most of the time during imaging. The images were obtained on different days in an experimental citrus grove in the University of Huazhong Agricultural University in sunny and cloudless days during the months of November to December 2011, and most of the fruits were exposed in the sunshine. All the images were obtained in a stationary mode with each image having 5184 × 3456 pixels, they were resized to 648 × 432 pixels. The CPU of the computer which was used to process and analyze the images is Intel(R) Core i7 930 2.80GHz, the memory of it is 4G, the operation system is Microsoft Windows XP, and the software for image processing is Matlab7.1.

2.2. The theoretical principle

Consider the illumination of an object by a point source of light, as shown in Fig. 1. The point source emits light in all directions. Light energy reflected by the surface in the direction of the camera causes an image of the surface to be formed in the camera. For a given orientation of the surface and direction of the point source, the amount of light energy reflected by the surface in a particular direction is determined by its reflectance properties. The reflectance model of a large number of surfaces comprises two components, namely, the diffuse component and the specular component. In general, the energy of light reflected by a surface in any direction is a combination of the diffuse and specular components. Therefore, the intensity at an image point may be expressed as:

$$I = I_L + I_S \tag{1}$$

where I_L is the image intensity due to diffuse reflection and I_S is the image intensity due to specular reflection.

When irradiated by the sun in a clear sky, some areas of the mature fruits which orientation θ_n is equal to the angular angle between itself and the point source direction may be arisen of specular reflection (Fig. 1). These parts reflect whole spectrum of the input sun light, it looks like more whitely and brightly than other parts of the same fruit, so these areas cannot be detected based on the color difference between fruits and other parts in the image, but it can be detected based on the luminance for it is more brightly than surrounding area with diffuse reflection. The fruits under the sunshine can be detected wholly for the diffuse reflection parts can be detected by color information and the specular reflection parts can do by luminance information. This paper focused on the detection and segmentation method of citrus fruits with highlight region, it was resolved by fusing the segmentation results of chromatic aberration map and luminance map.

2.3. Initial segmentation of the citrus fruits and background

The whole processing procedure is shown in Fig. 2, and the detailed analysis is given in next sections. Fig. 3 is an example of on-tree citrus fruits with highlight, the processing procedure is described with this image.

An important practical aim of image processing is the demarcation of objects appearing in digital images, this process is called segmentation, and a good approximation to it can be achieved by thresholding algorithm, in this task there is one outstanding problem – how to devise an automatic procedure for determining the optimum thresholding level. The technique that is most frequently employed for determining thresholds involves analyzing the histogram of intensity levels in the digital image. If a significant minimum is found, it is interpreted as the required threshold value.

In this section, on account of their different characters, they were adopted diverse selecting algorithm of threshold for luminance map and chromatic aberration map.

2.3.1. Segmentation by thresholding for chromatic aberration map

The chromatic aberration map (CAM) of R and B components was used to detect the diffuse reflection area of citrus fruits. A estimated global threshold [12] was used, at first the global average T of CAM value was selected as the initial threshold, the image binaryzation was done and the chromatic aberration map is divided into foreground G_1 and background G_2, the individual average of G_1 and G_2 are a_1 and a_1, then the average of a_1 and a_2 is used as the new threshold T', the iterated step will stop when $(T' - T)$ is lesser than

Fig. 3. An example of on-tree citrus fruits with highlight.