Computers and Electronics in Agriculture 122 (2016) 118–123

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

A method of segmenting apples at night based on color and position information

Xiaoyang Liu *, Dean Zhao, Weikuan Jia, Chengzhi Ruan, Shuping Tang, Tian Shen

School of Electrical & Information Engineering, Jiangsu University, Zhenjiang 212013, China

ARTICLE INFO

Article history:
Received 5 November 2015
Received in revised form 23 January 2016
Accepted 23 January 2016
Available online 5 February 2016

Keywords:
Machine vision
Apple-harvesting robot
Color space
Color and position information
Night images

ABSTRACT

This paper proposes a method to segment apples on trees at night for apple-harvesting robots based on color and position of pixels. Images of apples acquired under artificial light with low illumination at night include less color information than daytime images, so it is necessary to take position of pixels into consideration. The new method has two main steps. Firstly, color components of sampled pixels in RGB and HSI color space are used to train a neural network model to segment the apples. However, the segmentation results are incomplete and not able to guide apple-harvesting robots accurately, because partial edge regions of apples are dark in shadows and difficult to be recognized due to uneven illumination. Secondly, the color and position of pixels around segmented regions and pixels on the boundary of segmented regions are taken into consideration to segment the edge regions of apples. The union of two segmentation results is the final result. The complete recognition can increase the accuracy of location by about 6.5%, which verified the validity and feasibility of the method.

1. Introduction

Fruit-harvesting robots have attracted a wide attention in recent years (Plebe and Grasso, 2001; Tanigaki et al., 2008; Hayashi et al., 2010; Bachche and Oka, 2013). They are used to replace humans to harvest fruits on trees. It's obvious that the application of fruit-harvesting robots can reduce the labor cost and improve work efficiency. The emphasis of the research is the machine vision system, which is the core of the robots (Bulanon et al., 2004).

The features of images are treated as the basis of recognizing and segmenting fruits in complex natural background. Ji et al. adopted region growing based on color features to segment images, then extracted color and shape features of segmented images (Ji et al., 2012). The classification algorithm of support vector machine was applied to classify the extracted features and recognize apples. Lu and Sang adopted RB chromatic aberration map and normalized red map of original RGB images to segment images preliminarily (Lu and Sang, 2015). Then the contour fragments of segmented images are used to separate occluded citrus fruits. Teixidó et al. proposed a method to detect red peaches (Teixidó et al., 2012). Sampled pixels of leaves, branches and peaches are used to construct linear color models in RGB color space. Color distance from each pixel to different constructed models is the standard to classify pixels.

Experiments in references listed above were conducted under natural illumination in the daytime. If fruit-harvesting robots can work at night, the average work efficiency during a day will be improved prominently. Although researches on fruit harvesting at night are rare, some scholars have conducted researches on estimating fruit yield based on images that acquired at night. Font et al. acquired red grape images in vineyards under artificial lighting at night (Font et al., 2014). The specular reflection peaks from the spherical surface of the grapes are detected and the morphological method is applied to define the intensity peaks. Nuske et al. proposed a method to estimate yield by detecting green grapes in vineyards at night (Nuske et al., 2014). Cameras and illumination were installed on a vehicle to acquire images. The keypoints of images were detected firstly and classified on the basis of six-dimensional color vector from three RGB channels and three Lab channels and three texture features from three broad classes of features. Payne et al. used night time mango images at 'stone hardening' stage to estimate crop yield (Payne et al., 2014). Variance filter, gray scale, border limited mean, hessian filter and color components Cb and Cr are applied to recognize the mangos step by step.

The apple is selected as research object of the paper because it is one of popular fruits. This paper is aimed at solving the problem of image recognition at night and guiding robot to harvest apples

* Corresponding author.
E-mail address: liuxiaoyang@ujs.edu.cn (X. Liu).

http://dx.doi.org/10.1016/j.compag.2016.01.023
0168-1699/

rather than estimate yield. So, how to detect and locate apples on the tree at night is the key of the paper. Image recognition is divided into two steps. The first step is to recognize apples preliminarily on the basis of color information of images. The second step is to recognize the edge regions of apples based on the mixture of color information and position information from edge regions and not-edge regions. The experiment in this paper shows that the method is effective and feasible, which can increase the accuracy of location by about 6.5%.

2. Image recognition preliminary

Artificial light is applied to acquire images at night. Compared with natural illumination in the daytime, artificial illumination at night is uneven and in a limited range with low intensity because sunshine is approximately parallel and has higher intensity. Even if fruits are shaded by leaves, the illumination intensity on surface of the fruits is about 200 lx or more in a sunny day. However, the uneven illumination at night may cause regions in shadow under 10 lx. The camera can take photos clearly at 200 lx, but it is difficult to capture original color and details information of objects under 10 lx. Although the disadvantages of artificial light will damage partial color information of images, the color is still important feature of images because it still has enough information. Therefore, color information is used to recognize images preliminarily, which is divided into three small steps: image acquisition, color features extraction and neural network training.

2.1. Image acquisition

Image acquisition is the first and important step. The quality of images will exert effect on subsequent image processing. The orchard in which the images were captured is located in Feng Country, Xuzhou City, Jiangsu Province, China. The variety of apples in this orchard is Fuji apples. Canon IXUS 275HS is used to take images, of which the sensor is color complementary metal oxide semiconductor (CMOS). In order to reduce the volume of data, image resolution is set as $640 * 480$ pixels with jpg format. Every pixel includes 24 bits RGB (Red, Green and Blue) color information.

Incandescent lamps are used as artificial light for its good color rendering property. Incandescent light and sunshine are similar and the spectrums of them are both continuous. The color rendering index of incandescent lamps closes to $100R_a$ that is the maximal, which can make objects present their original color with little deviation. The color temperature is about 2900 K. The type of incandescent lamps is 12 V and 40 W because 12 V portable power source is adopted in field orchard. Two lamps were fixed on both ends of 1 m wide support, which can provide higher illumination intensity than only one lamp and weaken the shadow to a certain extent.

2.2. Color features extraction

The color information is significant and distinct feature of images that includes abundant valuable information. In order to analyze and apply the information adequately, some pixels in images are extracted as samples. These samples are representative for the main objects in images. These objects include apples, leaves, branches and other objects.

The color of different parts of one object is not identical. The pixels of apples are extracted from different regions of the surface of apples. The pixels of leaves are extracted from the obverse and the reverse sides of leaves. Fig. 1 shows an example about color feature extraction. These pixels are displayed in RGB color space as Fig. 2 shows. Fig. 2 also shows that the color of apples is different from the color of other objects obviously, which demonstrates the feasibility of image recognition.

Fig. 1. Color feature extraction example.

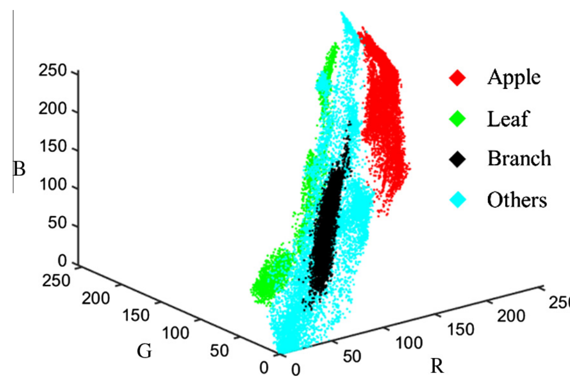

Fig. 2. Extracted pixels in RGB color space.

Besides RGB color space, HSI (Hue, Saturation and Intensity) color space is a common choice to describe color. Intensity is separable from the color space and HSI color space is closer to human visual system than RGB color space. So, HSI color space is also chosen to describe colors in the experiment. The conversion formula (Weeks and Hague, 1997) from RGB to HSI is displayed as follows:

$$\left.\begin{array}{l} H=\begin{cases}\theta,(B\leqslant G)\\ 360-\theta,(B>G)\end{cases}\\ S=1-\frac{3}{(R+G+B)}[\min(R,G,B)]\\ I=\frac{1}{3}(R+G+B)\end{array}\right\} \quad (1)$$

In formula (1), $\theta=\arccos\left\{\frac{[(R-G)+(R-B)]}{2[(R-G)^2-(R-G)(G-B)]^{1/2}}\right\}$.

In formula (1), R, G, B color components is normalized and angle θ is measured with respect to the red axis of the HSI color space. S and I are in the range [0, 1] and H can be normalized to [0, 1] by dividing by 360° (Gonzalez, 2009). HSI color space is described by a circular cone model. In order to display samples in HSI color space expediently, the circular cone is converted to rectangular coordinate system, as shown in Fig. 3. Fig. 3 also shows that the color of samples from apples is different from other samples in HSI color space.

2.3. Neural network training and data classification

In order to apply the color information of samples, a feed-forward back propagation neural network (BPNN) is established. BPNN is one of classical artificial neural networks, which has been applied to data classification widely (Hecht-Nielsen, 1989). The