STUDY ON THE AUTOMATIC MONITORING TECHNOLOGY FOR FUJI FRUIT COLOR BASED ON MACHINE VISION

Meixiang Chen, Ming Li, Jianping Qian, Wenyong Li, Yong Zhang, Xinting Yang*

National Engineering Research Center for Information Technology in Agriculture
Beijing Academy of Agriculture and Forestry Sciences
Beijing, P.R. China

Yan'an Wang

College of Life Science
Shandong Agricultural University
Tai'an, P.R. China

ABSTRACT

Fruit color is one of the important indicators of quality and commodities. Three kinds of the traditional methods are used to evaluate fruit color, including artificial visual identification, fruit standard color cards and color measurement instrument. These methods are needed to be conducted in the field by persons, which are time-consuming and labored, and also difficult to obtain the dynamic color information of the target fruits in the growth process. This study developed a practical technology for automatically monitoring the fruit color in the whole progress based on machine vision, the apple fruits were photographed by infrared camera, and the dynamic color change information were obtained through applying MATLAB software to process the image. Color change rule of the whole apple and fixed local position apple was analyzed. The results showed that the trend of the fixed local position R/G ratio was similar to that of the whole fruits. Therefore, the fixed local position color information was representative for whole apple in the corresponding period. The R/G ratio of apple was close to 1 when the bag was just removed, with the bag-removed days increased, the apple's color became more red, and R/G ratio was increased gradually, the R/G ratio was about 1.4 on October 25th, and the fruit was bright red. We can get dynamic color information of apple fruit through automatic monitoring technology based on machine visions. This technology can lay the foundation for analyzing the influence factors of apple color and building color model, and also providing an important reference for picking and presorting apple in suitable period.

Keywords: machine vision; apple; fruit color; automatic monitoring technology

INTRODUCTION

Fruit color is important sensory quality of fruits, it is related to fruits' maturity and inner qualities. The more beautiful color the fruits are, the higher goods value the fruits have. Three traditional methods were used to evaluate fruit color: identification by human eye, fruit standard-color card (Li and Wang, 1991) and color-measurement instrument (Iglesias et al., 2008; Zhang, 2010; Xu et al., 2011; Sharma et al., 2013). The first method is lack of accuracy and objectivity, the second method is relatively less used for the fruit color evaluation, the third method has the advantages of accuracy, objectivity and so on, but the measurement have to be conducted by persons in the orchard, and this is a kind of contact measurement. The common feature of these methods is that the data is collected manually in the orchard and also time consuming, labored. For the above reason, it's crucial to develop a technology to realize noncontact and continuous monitoring the fruit color.

Recently, machine vision systems have been used increasingly in the fruits grading. The color feature is widely used for the fruits grading based on machine vision. Yan (2003) developed the grading system of apple's color based on computer vision. Kavdir and Guyer (2004) classified the Empire and Golden Delicious apples based on their surface quality conditions using backpropagation neural networks (BPNN) and statistical classifiers. Zhang (2005), Wang (2008) proposed computer vision grading technology based on apple coloration area. Hou (2006) proposed the method of apple automatic grading based on machine vision. Kavdir and Guyer (2008) studied the effects of using different feature sets and classifiers on classification performance of apple. Mizushima and Lu (2013) developed a low-cost color vision system for automatic estimation of apple fruit orientation and maximum equatorial diameter in order to separate undersized and defective fruit from fresh market-grade apples. Hayrettin and Kuscu (2014) All above studies made a great contribution to fruit grading, however, all required constant light source, light intensity and other conditions to obtain the fruit image, so it is not suitable for the apple color monitoring in orchard condition.

Machine vision systems have been used in the fruits harvesting, too. Si et al. (2009) proposed an apple recognition method based on K-means algorithm for the green apples that have similar color with leaves. Qin (2011) developed an apple detection system in natural scene. Liu et al. (2011) developed an algorithm for the automatic recognition of peach fruit in a natural scene. All above studies can provide technical support for the design and development of Harvesting Robot through analyzing ripe fruits color, but can't obtain the color change information of the fruits in the growth process.

There are few studies related to apple color monitoring in orchard , Yuan, et al(2013) photographed the fruit photos by digital camera manually at regular time, then processed the images to obtain the color change information of fruits. However, the method can't get the continuous color change information of the target fruits. Based on all previous discussion, less work has been devoted to analyze the fruits' color change progress based on machine vision. Therefore, the aim of this study is to develop a practical method for automatically monitoring the fruit color in the whole progress based on machine vision, the apple were photographed by infrared camera automatically, and the dynamic color change information of apple were obtained through image processing. To achieve this goal, this paper describes a solution to image acquisition and procession for apples, effective monitoring and analyzing method of apples' color was proposed, which suitable to the complex orchard condition.

MATERIALS AND METHOD

Image Acquisition

Site of the experiment was in Feicheng City, Shandong Province. The monitoring object was the color change of bag-removed apples. The monitoring period was from October 9th to 25th, 2013, after the apples' bags were removed, fruit color was monitored by infrared camera LTL5210 automatically, the camera was vertical to the target fruits, and the distance between the fruits and the camera was about 90cm. The target apple fruits were photographed by infrared camera every two hours.

Image preprocessing

The size of original image is 4000×3000, it's too large to be processed by MATLAB Software directly, therefore it should be downsized to forty percent of the original image. In the late growth period of apples, with less changing size and relative steady position of the fruits, calibration area contained the target apples with the same position in each image was selected as the research object. In order to reduce the time of image processing, the size of the calibration area was selected as 510×255pixel, called the pre-segmentation image.

Image segmentation

In the study, the color of the target fruits changed from yellow-green to red gradually, target fruits were difficult to be segmented from background by single-color-segmentation method. In the study, the K-means algorithm was selected for target fruits segmentation. K-means algorithm is an adaptive search algorithm, the algorithm divided the individuals of the data set into K categories and made all the individuals keep nearest from its own scope center with the minimum Euclidean distance, through adjusting the clustering center continuously.

Processing steps: firstly, the RGB space of the pre-segmentation image was converted into L*a*b* space; secondly, the color was clustered into three categories according to a*and b* component for three times in order to avoid the local minimum; thirdly, the clustered image was selected that the target fruits color was obvious difference from background color, the color depth of selected image was distinguished further according to the L* brightness information in the L*a*b* space; finally, the deeper color image was selected to be binarized and reversed, in order to segment successfully, circular structure element was used to remove small section and segment adhesive fruits.

Apple size calculation

Each apple segmented from the binary image was around by the Minimum Enclosing Rectangle(MER), the length, width and midpoint of the MER was selected as length and diameter, midpoint of the apple.

Apple color change analysis

Two kinds of apple color analysis were proposed, including whole apple color analysis and fixed local position apple color analysis. Because RGB values will change under different lighting conditions, R/B ratio was selected as the indicator of fruit-color change to offset the effects of different light on the fruit color.

The color change analysis of whole apple

The whole apple color change analysis aimed to analyze the whole color change rule of target apples. Firstly, 180×180 pixel images only including one target apple was intercepted from pre-segmentation images, vertex coordinates of each intercepted image was equal to that of each target apple's Minimum Enclosing Rectangle(MER) to minus five, the RGB value of the intercepted areas was calculated. Secondly, a matrix with the same size as the intercepted square was established and 255 was assigned for each element, then the fruits district in the binary images was obtained and zero was assigned to the corresponding point of the fruit district matrix, then the matrix was reversed and 1 was assigned to fruits districts element. Thirdly, all RGB value of the fruit district was assigned to the binary image fruits district, only the fruit district had RGB value, and the others' RGB value was 0. The color value of all the fruits could be obtained from the RGB value of the images. R/G ratio was selected as the indicator to analyze the change of color.

The color change analysis of fixed local position of apple

Because the reflection of the light, branches with leaves overlapped and adjacent fruits touched the target fruits, the color information of the whole fruits was difficult to get. The color change information of fixed local position was proposed on behalf of the whole apple's in the study. The length, diameter and center coordinates of target fruits in pre-segmentation image was equal to that of the Minimum Enclosing Rectangle(MER) in binary images. The center of rectangle was used as circle center, 1/4 diameter circle in every target apple center position of the pre-segmentation image was called fixed local position, average RGB value was calculated within the circle in the apple center position, R/G ratio was used as the color change indicator.

RESULTS AND ANALYSIS

Fruit image preprocessing

All the images from October 9th to October 25th, 2013 were preprocessed by MATLAB. The original image was shown as fig.1a, fig.1c. Fig.1a was the image of October 12th, 2013, the apple bags were removed for 4 days and the apple's color just started to become red. With the bag-removed days increased, the apple's color became redder, the apple was bright red on the date of October 25th, 2013(fig.1c). The target apples area (fig.1b, fig.1d) was obtained by intercepting the original image for the size of 510×255pixel, called the pre-segmentation of image. The fruits on the left side and the middle of every image were the target apples, called apple-1 and apple-2 respectively. Apple-1 was in relatively isolated position, apple-2 was overlapped by leaves and touched by adjacent apple.

(a) **(b)**

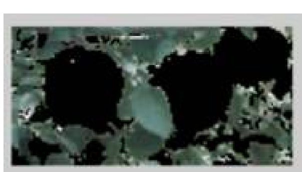
(c)

(d)

Fig.1 The original image and the pre-segmentation image, (a) the original image on October 12th, 2013, (b) the pre-segmentation image on October 12th, 2013, (c) the original image on October 25th, 2013, (d) the pre-segmentation image on October 25th, 2013.

Target fruits image segmentation based on K-means algorithm

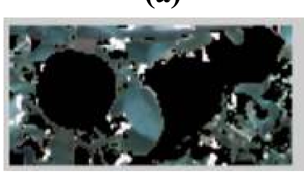
The pre-segmentation image was converted from RGB space to the L*a*b* space. The converted image was clustered into three categories according to the a* and b* component. As shown in fig.2, the fig.2a, fig.2b and fig. 2c were the clustering results of the pre-segmentation image on October 12th,2013, fig.2d, the fig.2e and fig.2f are the clustering results of the pre-segmentation image on October 25th, 2013, and different color apple had similar clustering results. As shown in fig.1b and fig.1d, the color of target apples was light red, bright red respectively, the color of fruits and leaves was obvious different after clustering(fig.2a, fig.2d). Therefore, fig.2a, fig.2d were selected for further color depth distinguishing according to the L* brightness information to obtain fig.2g, fig.2j. Because the area of target apples was black after clustering, the binary image was reversed to make the fruit area white (fig.2h, fig.2k). Finally, the target apples were segmented by choosing circular structure elements with opening operation to get rid of the small target and adjacent fruit(fig.2i, fig.2l). Image segmentation method based on K-means indicated that whether it was a green or red apple, all target fruit can be segmented from the background.



(a)

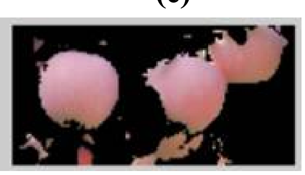
(b)

(c)



(d)

(e)



(f)

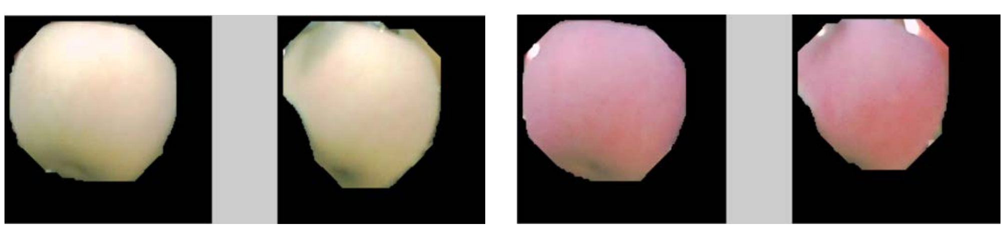
(g) (h) (i)

(j) (k) (l)

Fig.2 Target apples segmentation based on K-means algorithm. (a) objects in cluster 1; (b) objects in cluster 2; (c) objects in cluster 3; (a) to (c) were the clustering results of October 12th,2013 according to the a* and b* component**; (d) objects in cluster 1; (e) objects in cluster 2; (f) objects in cluster 3;** (d) to (f) were the clustering results of October 25th,2013 according to the a* and b* component**; (g) the further clustering results of fig.2a according to the L* brightness information; (h)binary image of fig.2g; (i)segmentation result of fig.2h;(j) the further clustering results of fig.2d according to the L* brightness information;(k) binary image of fig.2j;(l) segmentation result of fig.2k.**

The color change results of the whole target apples

The whole fruit color changes was to analyze the color change rule after bags removed. On October 9th, R/G ratio was close to 1 when bags just removed, the target fruits became red when R/G ratio was about 1.1 on October 12th. As the time going on, the color of fruits gradually become red, R/G ratio increases gradually. On October 25th, fruits were bright red, R/G ratio of apple-1 was 1.36, R/G ratio of the apple-2 was 1.44, daily variation of R/G ratio for apple-1 and apple-2 was 2.25%, 2.74% respectively.



(a) (b)

Fig.3 Color target apples. (a) apples on October 12th, 2013, (b) apples on October 25th, 2013.

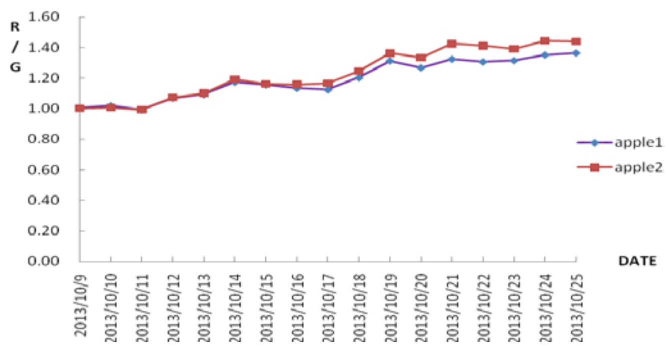
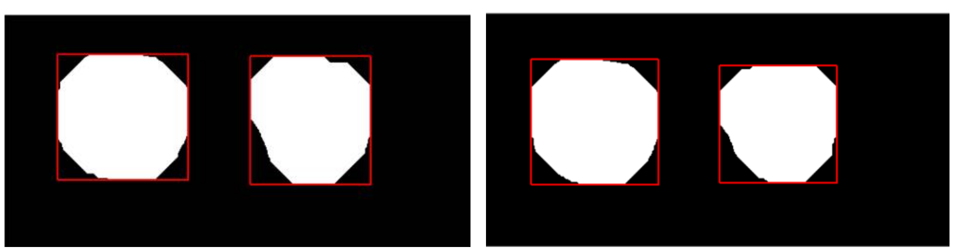


Fig.4 The dynamic R/G ratio of whole bag-removed target apples

Fig.3 also showed that the whole fruit was affected by the light reflecting, branches with leaves overlapping and adjacent fruits touching, the whole target fruits were difficult to be segmented, the color information was also affected by these factors, so the more effective color analysis method should be proposed.

The color change results of fixed local position of target apples

The whole fruit color information was affected by the reflection of the light, branches with leaves overlapping and adjacent fruits touching easily, such as the apple-2 in the study, local color change information was proposed to represent that of the whole fruit. In the method, the information of the fruit such as the length and diameter and the center position can be extracted from the Minimum Closing Rectangle (MCR) of the target fruits segmented from the binary image. The center of rectangle was used as circle center, 1/4 diameter circle in every target apple center of pre-segmentation image was the fixed local position, the RGB value was calculated within the fixed local position. R/G ratio in the area was used as the color change indicator.



(a) (b)

Fig.5 Minimum Closing Rectangle(MCR) of the target fruits segmented from the binary image. (a) apples on October 12th, 2013 ; (b) apples on October 25th, 2013.

On October 9th, 2013, when the bag was just removed, the R/G ratio was close to 1; with the bag-removed days increased, the fruit color became more red, and R/G ratio was increased gradually. On October 25th,2013, the fruit was bright red and the fixed local position R/G ratio of the apple-1 and apple-2 was 1.42 and 1.48 respectively, which increased 0.06 and 0.04 than the whole apple fruits respectively due to the center area of the apples is more red; daily average change rate of the fixed local position R/G ratio of the apple-1 and apple-2 were 2.69% and 3.04% respectively, which increased 0.44% and 0.3% than the whole apple fruits respectively, it indicates that the R value of center position are more red than other position. Fig.4 and fig.6 indicated that the color change trend of fixed local position(1/4 diameter circle in every target apple center) was similar to that of the whole apple, the results showed that the fixed local position fruit color information can represent that of the whole fruit in the orchard monitoring.

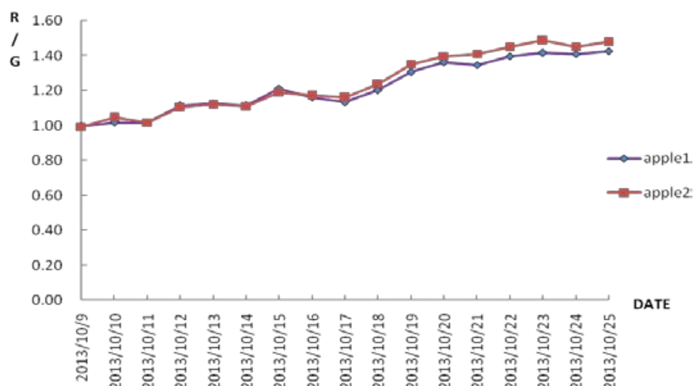


Fig.6 The dynamic R/G ratio of fixed local position of bag-removed target apples.

CONCLUSION

The study developed a practical method for automatically monitoring the fruit color in the whole progress. The apple image information was photographed by the infrared camera. The target fruits with color changed from the yellow-green to red were segmented from background by K-means algorithm. Color change rule of the whole apple and fixed local position apple was analyzed. Because target fruits were often in complex background, such as affected by the light reflecting, branches with leaves overlapping and adjacent fruits touching, the whole target fruits were difficult to be segmented, the whole fruit color information was affected by the above factors, the color change information of fixed local position was proposed on behalf of the whole fruit. The results of color change rule showed that the trend of the fixed local position R/G ratio was similar to that of the whole fruit.

We can obtain dynamic color information of apple fruit through automatic monitoring technology based on machine vision. The influence factors of apple color can be analyzed through combining the results with environmental factors, which can provide foundation for building color model. Furthermore, the study can provide suitable picking period through combining the resuts with quality analysis. With the ability of saving manpower and material resources, the technology has widely application prospects for fruit quality monitoring in the future.

Future research on this topic will be focused on two main directions. First, the background of the image is complex, the target fruits overlapped by branches with leaves and touched by adjacent fruits are difficult to be segmented accurately, additional methods will be tried for better segmentation of target fruits. Second, the fruit color information obtained by applying this method is a relative value, the color reference object will be used in the nature scene in the future in order to get actual color value of fruits, and this method will provide more useful information for fruits production and improve fruits quality.

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*Corresponding author: Dr.Yang Xinting. China National Engineering Research Center for Information Technology in Agriculture(NERCITA).
Address: Room 310a, Building A, Beijing Nongke Masion, 11#Shuguang Huayuan Middle Road, Haidian District, Beijing, China, 100097.
Tel:++8610-51503476, Fax:++8610-51503750.
Email: Yangxt @nercita.org.cn http://www.nercita.org.cn

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