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Recognition of green apples based on fuzzy set theory and manifold ranking algorithm

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ABSTRACT

Accurate recognition of green apple targets is one of the most practical technologies applied to agricultural sciences. The primary goal of this study was to solve the difficulties of distinguishing green apples in similar background areas, such as leaves, by fusing fuzzy set theory and the manifold ranking algorithm (FSMR). First, the original images were roughly enhanced to make apple targets more prominent by using fuzzy set theory in the HSI color space. Second, the specific query nodes were selected for ranking pixels in the whole image to obtain the final recognition results. Then, a series of operations including hole filling, edge smoothing and the mathematical morphology method were carried out to extract the contours of apple targets. Finally, the proposed method was compared with the additional methods based on manifold ranking (MR), saliency detection by self-resemblance (SDSR) and the K-means clustering algorithm. 100 images of green apple targets with different statuses in natural scenes were tested in the experiment. The results showed that the proposed method could effectively extract the real contours and achieve a high degree of coincidence with the edge lines of the targets, indicating that the recognition results were more accurate. Additionally, the average overlapping coefficient was 90.87%, which was 17.34% higher than the SDSR algorithm and 15.98% higher than the K-means clustering algorithm. In conclusion, the proposed method could provide a reference for the developments of growth monitoring, yield estimating and automatic fruit picking.

1. Introduction

With the gradual diversification of fruit types, green fruits such as green apples, green jujubes, muskmelons, citrus, and kiwifruits have occupied a large proportion of the Chinese market, which has adjusted the agricultural structure and production layout to a certain extent [1]. Meanwhile, in the periods of early growth and enlargement, the fruit targets contain more chlorophyll and accumulate a variety of organic acids, which result in the green epidermis of immature fruit and a sourer taste [2]. At present, the recognition of green fruit targets is one of the key technologies to monitor fruit growth [3],

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estimate crop yields [4] and automatically determine the picking point for agricultural robots [5]. Therefore, the research has important implications for the development of automation and intelligence in the fruit industry.

In the management of apple production and operations, traditional manual monitoring and picking methods are characterized as more time-consuming, less efficient and less accurate. Therefore, it is imperative to develop intelligent monitoring and the automatic picking technologies for apples. In response to these issues mentioned above, Si et al. [6] used the K-means clustering algorithm to recognize green apples in complex environments. The recognition accuracy was approximately 80.00%. However, the recognition results were susceptible to some external factors such as the environment, weather and so on. Bansal et al. [7] determined the appropriate segmentation threshold by calculating the fast Fourier transformation of immature fruit and leaves in citrus groves. The overall correct recognition rate was 82.2%. To complete the recognition and counting of green apples in close-up images, Zhang et al.'s work [8] was effectively merged with a support vector machine classifier (SVM) and a threshold classifier characterized by the super-green operator, and the counting accuracy could reach 89.30%. Li et al. [9] proposed a novel method based on the fast normalized cross correlation algorithm (FNCC) for recognizing immature citrus targets. The result showed that 84.40% of the area of the fruit target could be identified. Ma et al. [3] segmented the immature tomato targets according to the saliency detection method of intensive and sparse reconstruction, and the accuracy of the identification of immature tomatoes was 77.60%. Zhao et al. [10] detected the immature green citrus growing in citrus grove based on color features and the sums of absolute transformed differences (SATD), which obtained more than an 83.00% recognition accuracy. In the natural environment, the color of green fruit targets is similar to its background. Traditional image processing methods will lead to false recognition of fruit targets. Furthermore, the recognition difficulties will increase and the success rate will be low.

Although these methods have achieved good results, limited research has been conducted for green apple detection. To meet the green apple detection needs for agricultural monitoring systems, it was necessary to identify appropriate image detection software and techniques. The objective of this study was to propose a new recognition method for green apple targets in complex scenes that can overcome the difficulties of distinguishing foreground targets from similar backgrounds. In the study, fuzzy set theory was used to enhance the target images, which could reduce the impact of light intensity and light angles in fruit recognition. Then, the target apples were segmented using the saliency detection method based on the manifold ranking algorithm. Finally, through hole filling, open operation and other mathematical morphology methods, the edge and background noise of fruit targets can be effectively removed.

2. Materials and methods

2.1. Materials

A digital camera (SONY W730) was selected to shoot the green apple targets. The image frames were 4608 × 3546 pixels in the JPG format and RGB color model. All of the images used in the experiment were collected from natural conditions in April 2016 at the test site affiliated with the College of Horticulture in Northwest A&F University in Yangling, Shaanxi, China. In this study, 100 green apple targets (including 67 cis-light images and 33 backlit images) were selected to test the performance of the proposed algorithm. To ensure the reliability of the test results, images consisted of both single fruit targets occluded by leaves or branches and overlapping or separate double fruit targets. These were used to verify the performance of green fruit target recognition with different background areas. Since thunderstorms, haze and other bad weather have great impacts on image quality, all the images were acquired under natural sunshine conditions.

A personal computer with a 2.30 GHz processor and 3.89 GB of RAM was used as the hardware part of the computer vision system. All algorithms were programmed in the Matlab version R2010a software.

2.2. Proposed method

Since light situations could cause uneven colors on fruit surface, in this paper, the segmentation method of apple targets combining fuzzy set theory and the manifold ranking method was proposed to realize the recognition of green apples in complex environments.

2.2.1. Apple image enhancement based on fuzzy set theory

Fuzzy set theory was proposed by Dr. L. A. Zadeh in 1965 to describe the blur of things [11]. To the existing uncertain elements, the objects to be processed were treated as fuzzy sets, and the appropriate membership function would be established. Then, the fuzzy objects were analyzed by relevant computations and transformations using fuzzy set theory. With the continuous improvement and development of fuzzy theory, it has been widely used in image processing [12], control engineering [13], intelligent identification [14] and many other fields.

An assumed pending image of size $M \times N$ pixels that contains L grayscales can be mapped to the same size fuzzy matrix. The fuzzy matrix $\boldsymbol{F}$ can be expressed by Eq. (1).

$$\boldsymbol{F} = \bigcup_{m=1}^{M} \bigcup_{n=1}^{N} \mu_{mn}/g_{mn} \tag{1}$$