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A vision methodology for harvesting robot to detect cutting points on peduncles of double overlapping grape clusters in a vineyard

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ABSTRACT

Reliable and robust vision algorithms to detect the cutting points on peduncles of overlapping grape clusters in the unstructured vineyard are essential for efficient use of a harvesting robot. In this study, we designed an approach to detect these cutting points in three main steps. First, the areas of pixels representing grape clusters in vineyard images were obtained using a segmentation algorithm based on *k*-means clustering and an effective color component. Next, the edge images of grape clusters were extracted, and then a geometric model was used to obtain the contour intersection points of double overlapping grape clusters. Profile analysis was used to separate the regional pixels of double grape clusters by a line connecting double intersection points. Finally, the region of interest of the peduncle for each grape clusters was determined based on the geometric information of each pixel region, and a computational method was used to determine the appropriate cutting point on the peduncle of each grape cluster by use of a geometric constraint method. Thirty vineyard images that were captured from different perspectives were tested to validate the performance of the presented approach in a complex environment. The average recognition accuracy was 88.33%, and the success rate of visual detection of the cutting point on the peduncle of double overlapping grape clusters was 81.66%. The demonstrated performance of this developed method indicated that it could be used by harvesting robots.

1. Introduction

Grape harvesting is a time-consuming and labour-intensive procedure [1]. With the aging of the population and the decrease of the labour force due to fewer young and middle-aged people in China, the timely harvesting of fruits is becoming a significant challenge for fruit growers. To design strategies to improve picking efficiency, it is important to examine the use of intelligent robots for harvesting fruits. For the past 30 years, scholars from different parts of the world have studied fruit-harvesting robots, including harvesting robots for strawberry [2,3], cucumber [4], apple [5,6], sweet-pepper [7], citrus [8], and litchi [9,10]. However, up to now, commercial automatic harvesting robots are still rarely reported, and one of the main reasons is low location accuracy in unstructured orchards. To realize a practical robotics harvesting, the minimum accuracy required for real harvesting systems need be more than 80%.

For grape harvesting by a vision-based harvesting robot, grape characteristics such as softness, irregular shape, and contour preclude the direct grasping of the fruit, so grasping and cutting the peduncle of the grape is an effective alternative for harvesting [1]. Therefore, the accurate recognition and location of the appropriate cutting point on the peduncle of grape clusters in an unstructured vineyard is crucial for picking precision. However, due to the complexity and uncertainty of the orchard environment and the contour irregularity of fruit clusters, it is difficult to identify and locate the optimal plucking positions, particularly under overlapping conditions [11]. In order to achieve non-destructive harvesting, a vision system that can function in the complex orchard environment is urgently required. To address this need, various vision sensing systems and algorithms have been developed to detect overlapping fruits and determine the appropriate plucking positions.

For fruit detection from images, Luo et al. [12] presented a grape detection approach that fused the advantages of multiple color

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space features (e.g., RGB, HSV, La*b*) based on the Adaboost framework. To detect grape clusters for an automatic selective vineyard sprayer, Berenstein et al. [13] proposed an image segmentation process that utilizes the differences in edge distribution between grape clusters and the foliage. Reis et al. [14] presented a detection algorithm for grape clusters in vineyard images captured at night by defining a region of pixel intensities in the RGB color space based on trial and error. In [15], a grape detection method based on both visual texture and shape was developed to detect the green fruit against a green leaf background. To estimate vineyard yield, Font et al. [16] developed a color-based segmentation method for use with vineyard images captured at night by extracting the H component of the HSV color space. In [17], a grape bunch segmentation algorithm combining color and texture information and the use of a support vector machine (SVM) was proposed. Kondo et al. [18] proposed a grape identification method based on spectral properties. To overcome the challenges of the proper identification of overlapping apples, Xu et al. [19] presented a segmentation method based on a Snake model to obtain the contour of the overlapping apples, and then a corner detection algorithm based on distance measure was used to find the corner points of overlapped apples. A line that connected two of the detected corner points was then used to distinguish the overlapping apples. Xiang et al. [20] presented an algorithm based on binocular stereo-vision to recognize clustered tomatoes. In this approach, the clustered regions were first classified into two types (i.e., adhering and overlapping) based on the depth information obtained by a binocular stereo-vision system, and then the tomatoes were separated using an edge curvature analysis method.

To determine the plucking position, a precision harvesting strategy for sweet pepper was proposed by Bac et al. [7]. In this approach, the support wire that twisted around the stem was used as a visual cue to locate the pepper stem. This was also the first study of stem localization under varying lighting conditions. Yang et al. [21] presented an approach to locate targets for a grape-bagging robot by extracting the external rectangle of the grape contours, but this study did not address the problem of the localization of the overlapping grape clusters. Zhang et al. [22] proposed an image processing procedure to determine the plucking position of strawberry. In this method, the strawberry images were first segmented by color difference, and then the barycenter and the tip position of the strawberry image were extracted by computing the geometric feature of the segmented strawberry image. This information is then used to determine the plucking position. Li et al. [23] a presented a barycenter calculation approach for pineapple based on a monocular vision that employed image processing and morphological technologies to get fruit-eye central points, allowing application of a hierarchical clustering algorithm to calculate the approximate barycenter of the pineapple. Guo et al. [24] proposed an approach based on the Harris algorithm to determine the plucking position of litchi, in which the cutting points of the litchi were calculated by detecting the corner points on the stem of the litchi.

The above studies of vision detection methodology applied in unstructured orchard environments have focused on image segmentation as a strategy to estimate the vineyard yield. Although many fruit detection methods for harvesting robots have been proposed by researchers, an ideal method to accurately determine the plucking position of two overlapped grape clusters has not yet been described.

To ensure picking precision in an unstructured vineyard, an approach to detect the cutting points on the peduncles of double overlapping grape clusters was developed. First, the regions of pixels containing grape clusters in vineyard images were identified using a segmentation algorithm based on *k*-means clustering and the H component of the HSV color space. Next, the edge images of grape clusters were extracted based on the segmented image, and then a geometric model was established to obtain the contour intersection points of double overlapping grape clusters by using profile analysis, such that the regional pixels of double grape clusters were separated by a line connecting double intersection points. Finally, the regions containing the peduncle for each grape cluster were identified based on the geometric information of each pixel region, and a computing method was used to detect the cutting point on the peduncle of each grape cluster by a geometric constraint method. The innovation of this study is the development of a sequential machine vision procedure to determine the plucking position of double overlapped grape clusters based on profile analysis and geometric constraint.

2. Vision equipment and image acquisition

The vision sensor and test platform are as follows: a digital camera (D5200, Nikon, Wuxi, China) and a laptop (Lenovo T430) with 4G RAM and Intel(R)Core(TM)i5–3230 M CPU@2.60 GHz. The software systems include a Windows 7 operating system, OpenCV2.4.13, and a Visual C++ 2013 programming environment. The summer black grape was selected as the test variety. To verify the practicability of the method proposed in this study, we captured test images on July 27th, 2016 (sunny day) and August 6th, 2016 (cloudy day) during the ripe season of the summer black grape. Images were captured by the digital camera in the Tianjin ChaDian Grape Science Park using auto-exposure control mode for shutter speed, and the exposure time was fixed to 1/100s. Thirty images containing double overlapping grape clusters were recorded using the camera at a resolution of 2592×1944 pixels, and most parts of the grape clusters were not covered by other objects. The shooting distance was 600–1000 mm. In order to reduce the calculation time of the algorithm, all of the tested images were resized to 640×480 pixels using a bicubic interpolation algorithm.

3. Detection of a cutting point on the peduncle of a grape cluster

The approach to detect the cutting points on the peduncles of double overlapping grape clusters consists mainly of the following three steps, and the overall procedure of this approach is summarized in Fig. 1.

Step1: the pixel area of grape clusters was obtained using a segmentation algorithm based on the k-means clustering method and the effective color component. The details are presented in Section 3.1.

Step 2: the edge images of grape clusters were extracted, and then a geometric model was established to obtain the contour intersection points of double overlapping grape clusters by profile analysis. Next, double grape clusters were separated and the regional pixels of each grape clusters were obtained by a line connecting double intersection points. The detailed procedures are described in Section 3.2.

Step 3: the barycenter and external rectangular size of each pixel area of the grape cluster were calculated, allowing determination of the region containing the peduncle for each grape cluster. A computational method is then used to detect the cutting point on the peduncle of each grape cluster using a geometric constraint method. The details are presented in Section 3.3.

3.1. Grape image segmentation

The first key step in the procedure for the detection of overlapping grape clusters is image segmentation. Recently described methods to detect fruits in images are mostly color-based or shape-based