A Machine Vision System for Continuous Field Measurement of Grape Fruit Diameter

Qingbing Zeng[1], Chengliang Liu[1], Yubin Miao[1], Shengwei Fei[1], Shiping Wang[2]
[1]*School of Mechanical Engineering, Shanghai Jiao tong University, Shanghai, 200240, China*
[2]*College School of Agriculture and Biology, Shanghai Jiao tong University, Shanghai, 200240, China*
zengqingbing@sjtu.edu.cn

Abstract

It is necessary to measure dynamics of the fruit diameter to understand how plants respond to diurnal variation in water content and long-term growth conditions. Current techniques for measuring the fruit diameter are mostly touching measurements. The contact of the sensor places a stress on the grape fruit and may introduce erroneous results because of the touching of the grape fruit. We have presented a non-contact optical method for the accurate measurement of the fruit diameter in the grape field. The vision measuring system consists of a CMOS camera equipped with a telecentric lens, red back lighting board and PC. This system eliminates the fruit contact required by using the displacement transducers. Extensive experiments showed that the vision system is accurate and robust. This developed system achieves a repeatable accuracy of ± 7um for measuring the fruit diameter and provides an effective tool to better detect physiological disorders in plant.

1. Introduction

Plant growth measurement and analysis are useful in describing and interpreting the performance of whole-plant systems grown under various conditions. Among many useful indicators of plant growth, the fruit diameter is one of important variables for detecting physiological disorders in plants and for adjusting irrigation and climate control; thus, its measurement is of great importance. The measurement of fruit diameter can be done with a caliper. However, this technique is discontinuous and insensitive. Linear variable differential transformers (LVDTs) have been used to measure the fruit diameter continuously. LVDTs, which better than a caliper, have to be attached to fruit for months to years. This sensor can measure the fruit diameter growth for long periods of time. However, this sensor is attached to the measured fruit and touches the surface of the fruit [1]. The sensor crush berry and affect the fruit normal growth. This may happen because plants are very sensitive and respond in various ways to touch or movement. The sensor usually is expensive. Moreover, during the period of ripeness, the measurement error becomes larger because of a little of shrinkage of the target fruit. The advent of computer-based image processing systems has further boosted the applications of machine vision techniques for measurement of plant characteristics. Computer vision systems have been used increasingly in the agricultural industry for product quality inspection and grading. Recent research has highlighted the application of vision systems in the analysis of animal behavior, machine guidance, forestry, and plant feature measurement and growth analysis [2]. In this paper, we design a machine vision system to measure the fruit diameter of the target berry continuously and accurately.

2. Materials and methods

2.1. Plant material

The experiment was carried out during grape season (2008/7).The experimental site was located at the vineyard of the farm in MinHang School of Shanghai Jiao Tong University. A 3-year-old overhead trellised vineyard table grape (Vitis vinifera × V.labrusca, cv.kyoho) was used. Rows were spaced 1.5m apart with 1m between vines within a row. A single visually representative grapevine was selected for continuous measuring. Prior to the measurement, the berries in the bunch may be rearranged and the target berry measured was selected by the professional agronomist. For ease of handling in the image analysis, only the berry non-touching with other berries was selected as the target berry. The measured grape berry was monitored 5 days by recording images every half an hour. The images were relayed to the computer in the grape field by USB2.0.

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2.2. Image acquisition

The objective of the machine vision system is to measure the diameter of the target berry for detecting physiological disorders of grape. Many approaches exist for measuring dimensions using machine vision in many applications [3]. They vary considerably in performance and algorithms due to different application purposes. The diameter variation of the target berry every half an hour is very small. The position of the target berry will change due to the target berry growing. The image acquisition may be disturbed by sunlight. To design an effective measuring system based on machine vision technique, the most important issues one has to consider are: (ⅰ) selection of the Camera; (ⅱ) selection of lenses; (ⅲ) selection of illumination; (ⅳ) development of efficient image processing algorithms [4].

(1) Camera

The price and image resolution should be considered in the selection of the camera. The image resolution depends on the number of pixels available. The effective resolution can be reduced by using a higher resolution. Considering the requirement of detecting physiological disorders based on the fruit diameter, a monochrome industrial digital camera was used for image acquisition, providing images of resolution 1280×1024 pixels. The fruit diameter of the target berry is about 25mm. If the fruit fills the full CMOS sensor, the camera will yield $25/1208 \approx 0.02$mm effective resolution. The effective resolution can be improved by using a higher resolution CMOS Camera or the sub-pixel approach. The camera was controlled by home-made automatic software.

(2) Lenses

When the diameter of the target berry is measured, the position of the target berry will change due to the target berry growing. The size of the target berry in the image varies with its distance to the lens by using conventional lenses. Thus the conventional lens is not useable for measuring the fruit diameter. To measure the fruit diameter accurately, image size variations should be eliminated. An obvious way to solve this problem is to keep the distance between the target berry and the lens constant. However the target berry is not allowed to be disturbed. It is difficult to keep the berry-to-lens distance constant in the grape growing condition. The telecentric lens is perfect for the usage in the fruit diameter measuring system. The reason is that they ensure constant image size for substantial variations in berry-to-image distance.

(3) Illumination

An appropriate illumination of the object is crucial for measuring the diameter of the grape berry. Proper lighting techniques enhance the contrast between the object and the background. The berry diameter is derived from the berry edges. The berry edges must be determined accurately and their position in the image should not depend on light variations. The vision system developed in this study employs a red back lighting. The target berry is illuminated from the back. Such an illumination eliminates the non-uniform surface reflectance.

The image acquisition system consists of a computer, a red back lighting board, a telecentric lenses, and a 1/2″ CMOS camera (model ID-130M, Function-tech, China) with standard video output and 1280 pixels× 1024 pixels. The camera is equipped with Computar TEC-M55 telecentric lenses. The lens diameter is 55 mm. The USB2.0 is used for the communication between the camera and the PC. The images captured by the CMOS camera are transformed into an eight-bit monochrome format and stored on the hardware disk of the computer. The system set-up in the grape field is illustrated in Fig.1.

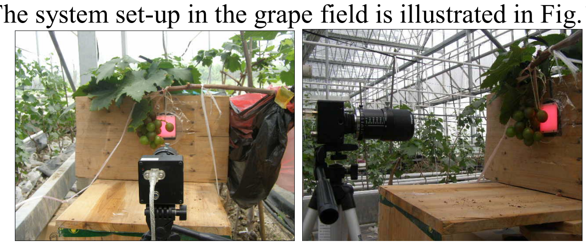


Fig.1 Set-up of a measuring system

2.3. Calibration

To measure the fruit diameter accurately, the vision system needs to be calibrated. The camera calibration is based on pinhole image model and provides a transformation relationship between 3D world coordinates and 2D computer image coordinates. The camera distortion, perspective error and spatial calibration are considered in the calibration process. A traditional camera lens produces radial distortion. Many techniques have been developed for rectifying the distortion in the image. However the telecentric lens offers an effective solution to this problem. The telecentric lens can overcome the problem of a traditional camera lens introducing radial distortion. Another reason image distortion occurs is that the camera is not perpendicular to the target berry. A height measuring instrument is used to calibrate camera axis ensuring that the camera axis is perpendicular to the target berry. Finally spatial calibration is performed and the pixel size coefficient k in mm/pixel is obtained. For that purpose, we use a caliper to measure the fruit diameter of the target berry. It is difficult to measure the fruit diameter by the caliper. The caliper tends to compress the berry slightly during measurement. The fruit diameter is calculated as the mean value of 10 times measurement. The fruit diameter is 22.46mm and the pixels of the fruit diameter in the image are 730. The physical length of the object corresponding to each pixel can be calculated by the following equation, where k denotes the pixel size coefficient.

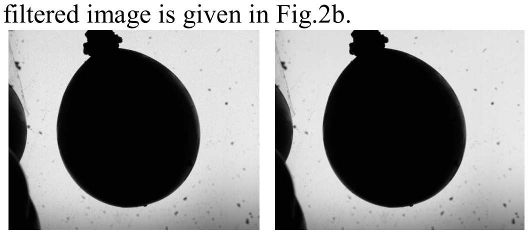
$$k = \frac{D_s}{D_d} = \frac{22.46}{730} = 0.03 = 30(\mu m / pixel)$$

2.4. Image analysis

The image analysis consists of: (i) image pre-processing; (ii) obtain the position of the berry diameter; (iii) calculates the diameter of the target berry.

(1) Image pre-processing

Image pre-processing is to modify the pixel values to produce more suitable for subsequent operations. For reducing the noise, enhancing the boundaries of the target berry, a filter is usually used. A Gaussian low pass filter is often applied to reduce the noise existing in images. However, the traditional low-pass filter may cause the boundaries blurred and the loss of the boundary information. The blurred boundaries may lead to the false boundary results. The bilateral filtering [5] is a good answer to solve this problem. In this paper, the bilateral filtering is used to smooth original grayscale images. The bilateral filtering can smooth the grayscale image effectively, remove many small details, and preserve edges. The raw image is shown in Fig.2a. After the medium filtering and the bilateral filtering are performed respectively, noises are reduced and edges are preserved. The filtered image is given in Fig.2b.



(a) (b)

Fig. 2 Image pre-processing, (a) the raw image, (b) the filtered image

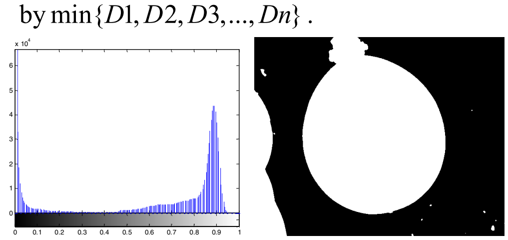
(2) Obtain the position of the berry diameter

The target berry is segmented from the background by thresholding. The histogram image of the filtered image is shown in Fig.3a. There are two obvious peaks in the histogram image. For segmenting the target berry, the OSTU algorithm is implemented [6]. The segmented result is given in Fig.3b. After thresholding, there are many small objects in the image. Small objects are big size noisy pixels which are not removed in the image pre-processing. A labelling procedure achieves the labelling of all objects in the image. A labelling procedure is to give a label to each object in the image to enable us differentiate them. The object C_i is masked by M_1, and the increasing label j (integer greater than zero) is attributed to objects in which there is at least one white pixel. Then the target berry is segmented by a pixels area thresholding. The target berry is shown in Fig.3c. After the target berry is segmented, the position of the fruit diameter is need to determined. During the grape growth, the position of the grape berry diameter is usually in the horizontal direction. However, the direction of the fruit diameter deviates from the horizontal direction because of the fruit growing. The direction deviation is over a range of a small angle. To locate the fruit diameter accurately, the target berry needs to rotate a proper angle so that the fruit diameter is in the horizontal direction. The rotation angle is difficult to be determined according to the image. So we define a range of rotation angle. The deviation angle of the fruit diameter does not exceed the defined range of rotation angle. Many rotation angles are defined over the defined range of rotation angle. At every rotation angle, the position of the candidate fruit diameter D_i is obtained. The position of the candidate fruit diameter is given in Fig.3d. The position of the candidate fruit diameter is the position of the lengthest line in the horizontal direction in the image.

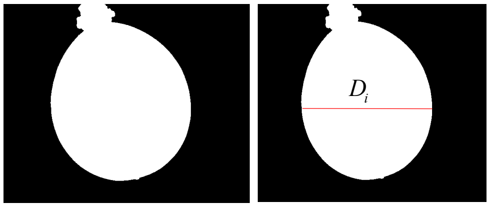
The lengthest line in the horizontal direction is detected by scanning the image from up to down. After scanning the image, the length of all the lines in the horizontal direction is calculated. The lenghtest line can be found among all the lines. Finally the positions of all the candidate fruit diameters over the range of small angle are determined. The position of the shortest fruit diameter $D_{\min}$ in all the candidate fruit diameters is the position of the fruit diameter.

The position determination of the fruit diameter involves the following steps:

1. define the range of an angle as $(-\theta, \theta)$. Many rotation angles are defined over the defined range of an angle. The angle is 0.5° between the two neighboring rotation angles. The rotation center is the center of the target berry. In this study the angle θ is 5°.
2. define the rotation angle $\theta_0 = -\theta + i \times 0.5^{\circ}, (i = 0, ..., n)$.
3. rotate the target berry at an angle of θ_0, detect the position of the candidate fruit diameter D_i, then add 1 to the counter i.
4. repeat steps 2-3 for all the rotation angles until $\theta_0 = \theta$. The position of the fruit diameter is the same as $D_{\min}$. $D_{\min}$ is obtained by $\min\{D1, D2, D3, ..., Dn\}$.



(a) (b)



(c) (d)

Fig.3 Obtain the position of the berry diameter, (a) the image histogram, (b) OSTU algorithm, (c) the target berry, (d) the position of the candidate fruit diameter

(3) Calculates the diameter of the target berry

After the position of the fruit diameter is determined, the fruit diameter can be calculated. However non-uniform illumination and noise in the image acquisition will introduce error for the diameter measurement. To make the measurement robust and accurate, the lines which are within 100 pixels in vertical direction from the fruit diameter are detected. The mean length of the lines is considered as the fruit diameter. It is reasonable because the measured fruit diameter is used for detecting physiological disorders of grape and not used for the description of grape berry characteristics.

3. Results

The results presented include the validation of repeatability and accuracy, and time-course data on the fruit diameter of the target berry.

To define the repeatability of the vision system under the conditions of the test, the target berry was kept in place and measured 10 times. The repeatability accuracy of the vision system is ±7um.

The objective of this study is to monitor the fruit diameter variation in the grape field. The measurement of the fruit diameter began after calibration. The measurement began in July 9, 2008. It is assumed that the pixel size coefficient k was invariable over this period. The growth in the fruit diameter was monitored over the 5 days. The growth of the fruit diameter in July 10, 2008 is given in Fig.4. From Fig.4, it can be seen that the target berry shrinks during the day and thickens at night. This is a common response attributed to changes in hydration status of the tissues. The growth of the fruit diameter over the 5 days is shown in Fig.5. The fruit expanded 1.46 mm over the period suggesting that carbon is being allocated to the fruit during this time. The diurnal pattern in diameter indicates that the fruit lost water during the day. The daily diameter increment (DI) of the berry increase slowly on the day July 14, 2008. The berry growth begins to change from the active growth stage to the retardation phase.

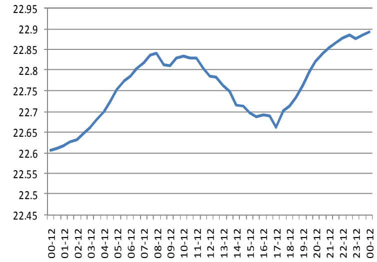


Fig.4 One day records of the fruit diameter

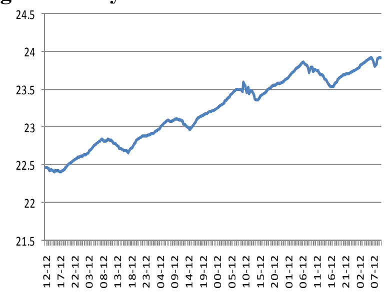


Fig.5 Five days Records of the fruit diameter

4. Conclusions

We described a machine vision approach to measure the fruit diameter of the target berry non-contact.

According to the results mentioned above, the following conclusions can be drawn.

1. A telecentric lens used in the vision system eliminates the influence of the berry-to-lens distance variation.
2. Back lighting enables a clear image to be acquired. This enables the vision system achieve a repeatable accuracy of ±7um.
3. The acquired images can be used for the visualization research of the fruit growth.
4. The proposed vision system can be applied to measure other fruits with various sizes and varieties.

The proposed method has been proved to be useful and efficient for measuring the variation of the fruit diameter and detecting physiological disorders of grape accurately. A good repeatable accuracy is also shown in this study.

Future research on this topic will be focused on two main directions. First, in this paper a front lighting is applied in the fruit measurement test. However, the front lighting is more perfect for the fruit diameter measurement in agriculture applications. Therefore, the front lighting, telecentric lens and RGB color camera will be integrated in a new vision system for the measurement of the target berry. Second, the effective resolution can be improved by the sub-pixel approach. The sub-pixel approach will be studied in the image analysis.

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