Identification and location of grapevine sucker based on information fusion of 2D laser scanner and machine vision

Wang Yaxiong[1], Xu Shasha[1], Li Wenbin[1], Kang Feng[1*], Zheng Yongjun[2]

(1. *School of Technology, Beijing Forestry University, Beijing 100083, China*;
2. *College of Engineering, China Agricultural University, Beijing 100083, China*)

Abstract: Chemical sucker control has been proven to be a more efficient method than manual and mechanical removals. The quick and effective identification and location of suckers are key technologies for targeted spray that can reduce chemical applications and alleviate potential problems. The goal of this research was to improve the accuracy of identification and location algorithm of grapevine suckers for real-time mobile targeted spray based on information fusion of two dimensional (2D) laser scanner and camera machine vision. A triangle white calibration board was used to determine the invisible laser scanning line. The positions of the terminated points of the scanning line on the calibration board in the laser scanner's coordinates were calculated. Suckers size and center location were obtained by ExGExR segmentation, then the relative position between the suckers and triangle calibration board was determined in the image coordinates. Eventually, the actual size and relative position between the identified suckers and the platform were calculated by integrating the laser line and image information. The results of the field trials showed that the consumed time of the developed algorithm was 0.787 s, the width recognition rate 91.8%, height recognition rate 88.2%, and the relative position accuracies 92.0%, 87.3%, which could meet the requirement of grapevine sucker precision targeted spray.

Keywords: grapevine suckers, information fusion, machine vision, ExGExR, triangle, identification, location
DOI: 10.3965/j.ijabe.20171002.2489

Citation: Wang Y X, Xu S S, Li W B, Kang F, Zheng Y J. Identification and location of grapevine sucker based on information fusion of 2D laser scanner and machine vision. Int J Agric & Biol Eng, 2017; 10(2): 84–93.

1 Introduction

Grapevine suckers are nonbearing shoots canes or limbs that grow up from the rootstock area of grapevine trunk[1] (Figure 1). The overdeveloped suckers snatch plant nutrition and will result in barren soil, which increase the possibility of being attacked from pathogen. Suckers are able to grow repeatedly during a season and must be removed to ensure that the grape can obtain enough nutrients, and avoid the interference of other types of orchard operations.

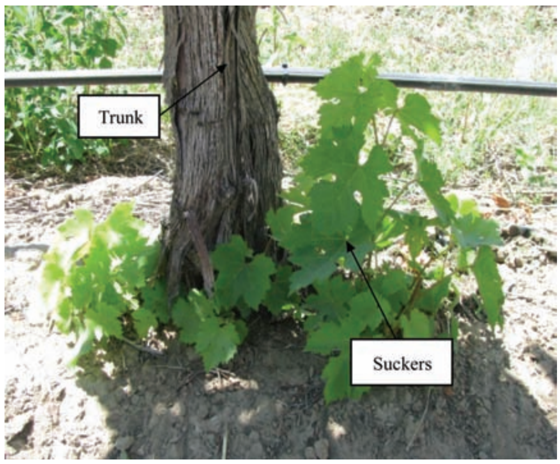


Figure 1 Grapevine suckers

Received date: 2016-03-22 **Accepted date:** 2017-02-05
Biographies: Wang Yaxiong, PhD candidate, research interests: precision agriculture, forestry engineering equipment, Email: yaxiongwang87@bjfu.edu.cn; **Xu Shasha**, Master, research interests: precision agriculture, machine vision, Email: bjfuxushasha@163.com; **Li Wenbin**, PhD, Professor, research interests: forestry machine automation, Email: leewb@bjfu.edu.cn; **Zheng Yongjun**, PhD, Associate Professor, research interests: automation, aerial spraying, Email: zyj@cau.edu.cn.
***Corresponding author: Kang Feng**, PhD, Associate Professor, research interests: agricultural & forestry automation, precision spraying. Mailing address: The School of Technology of Beijing Forestry University. No. 35, Qinghua East Road, P.O.Box 8, Haidian District, Beijing 100083, China. Tel: +86-10-62336137-709, Email: kangfeng98@bjfu.edu.cn.

Manual removal, mechanical removal and chemical control are the main sucker control treatments. Manual removal is to cut suckers off by using sharp knife-like tools. Although this method can completely remove suckers and cause fewer damages on grapes, it is time-consuming and costly. Mechanical removal is more efficient than manual removal, it remove suckers by using whip-like tools installed on a rotating head, which may cause damage to small grape and scrape the bark on the trunk. In addition, some suckers cannot be cleanly removed and the new suckers will grow later from the leaving stubs[2].

In order to find a more effective method for sucker removal, many chemical control methods have been researched in the past decades. 1-naphthaleneacetic acid (NAA)[3] and Paclobutrazol[4] have been proven to be effective methods to control the growth of suckers as a potential inhibitor. These attempts made chemical control an effective alternative and gradually replaced manual and mechanical removal. But, current spraying pattern of chemical is non-selective, which wastes chemicals in the inter-vine non-suckering area. Targeted spray according to the location and size of suckers can reduce chemical volume and alleviate the potential for this precision targeted spay.

Contemporary automation techniques have applied in different fields, such as agricultural navigation[5], crop disease detection[6] and precision agriculture[7]. Targeted application based on the size and position of the crops is one aspect of precision agriculture, the primary key technology of which is crop identification. Current crop identification methods include three-dimensional reconstruction based on binocular vision[8], and identification and positioning based on laser and camera[9,10]. Crop identification based on binocular vision is mainly used in fruit picking[11,12], the algorithm of which is complex and time consuming. Some attempts for fruit picking[13] and weed identification combined with laser and camera were implemented, which showed that laser-camera fusion was more practical than binocular vision[14].

Identification and location of grapevine suckers for precision targeted spray is rarely reported so far. This study conducted some related researches on this aspect. In the process of image treating, the ExG algorithm is commonly used, however, it shows a bad segmentation since it does not take in account of the red component of suckers and over-extracted greenness from the background[15]. And it is very difficult to ensure that all the scanning laser beams were on the wooden bar in the field when determining the invisible laser scanning line, which could reduce the accuracy of the identification and location. In order to improve the accuracy, a triangle white calibration board was used to determine the invisible laser scanning line and Extra-green & Extra-red (ExGExR) algorithm was used to segment suckers[15] in this research. The goal of this research was to improve the algorithm accuracy of identification and location grapevine suckers for feeding sucker information to precise targeted spray. The research focused on testing consumed time of algorithm, identification of size and accuracy of position to evaluate the algorithm.

2 System hardware configurations

The technology of information fusion based on laser and machine vision was adopted to identify and locate grapevine suckers. The hardware platform consisted of a notebook computer (Dell E5400, Intel(R) Core(TM) 2 Duo CPU P8700@2.53GHz, 3.45GB RAM), a 2D laser scanner (SICK LMS511 20100 PRO), a CCD color camera (DFK 23G618, The Imaging Source, Germany), and a holder, as shown in Figure 2. The laser scanner and CCD camera were installed on the holder, where the CCD camera was on the top of the laser scanner. The laser scanner communicated with the notebook via Ethernet while the CCD camera interfaced the notebook computer by USB. The laser scanner was used to obtain depth information of image; equilateral triangular calibration plate was used to calibrate the laser scanner, as the actual side length of the triangle was 300 mm; the image of grapevine sucker and equilateral triangular calibration plate was captured by the CCD camera; the installation angle β of CCD color camera was controlled by the holder; data information of the laser scanner and the CCD color camera was collected simultaneously, and then the positioning and identification for grapevine sucker were conducted with corresponding algorithm.

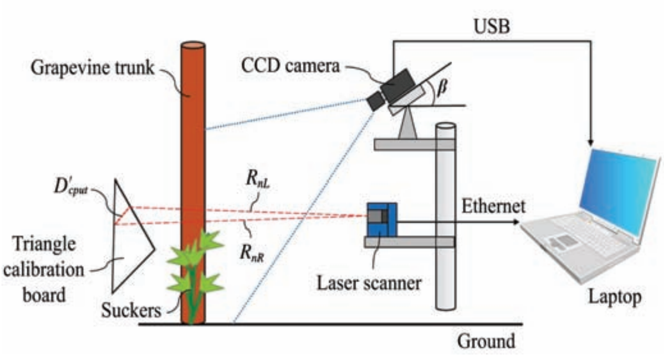


Figure 2 Overall design of the system hardware platform

3 Identification and location algorithm of grapevine sucker

3.1 Data processing of 2D laser

Currently, popular commercial available 2D laser scanners such as SICK LMS 511 PRO (http://www sickoptic.cm/) and Hokuyo UTM-30LX (Hokuyo Automatic Co., LTD) emit infrared eye-safe invisible laser beam. The wavelength of laser scanner used in the research is 905 nm. Laser spot is invisible, so that the laser information cannot correspond to camera information directly, which makes information fusion more difficult.

Existing information fusion method based on laser and camera can be divided into three aspects: 1) take infrared photos by an infrared camera[16] to make laser point visible to camera, but it would lose partial color and texture characteristics, which is not suitable for the identification of suckers; 2) find laser spot by using silicon cells[17], but the operation is complex and impacted by ambient light easily, which could not meet the actual needs in the field; 3) establish point to line communication by using special calibration board to fuse laser and camera information, such as the triangular calibration board[18,19]. Establish communication between laser and camera by matching the three sides of the triangle in image with distance jump point when laser scanning the edge of triangle. Environmental conditions have less influence on this method and it will not affect the data acquisition of other device. Outdoor experiments using special calibration board conducted by Park et al.[19] have proven that this method is more efficient than the other two mentioned above for identification and location of suckers in the field.

This research presented a method to find laser scanning line by using triangle as a calibration board that can reduce time consumption and improve accuracy of the algorithm. Laser data has different width when the laser scanning positions at different heights of triangle, then the laser scanning line could be found. The width of laser data is the D'_{cput} (Figure 2).

3.1.1 Laser scanning line determination algorithm

Laser scanning line determination algorithm is the primary key technology for identification and location of suckers. By determining laser scanning line, the information of laser scanner can reflect in the image; that is to say, find the corresponding pixels of laser scanning data in the image obtained by camera. Then, determine the relationship between the image coordination and world coordination, and finally calculate the relative position of the calibration board and sucker.

Laser data processing involved obtaining triangle profile information of laser scanning line, calculating width of laser scanning line and recording distance information. Data sequence including distance information and the corresponding scan angle was sent to computer after a scan. To avoid interference of other objects in background, only the data with the measured distance ranged from 20 mm to 2000 mm were stored in a two-dimensional array[14].

When extracting triangle profile information of laser scanning line, the algorithm compared the adjacent correlation between data points; that is to say, calculated the distance differences between the data points. There was large change in distance when laser scanning through the edge of triangle (Figure 3).

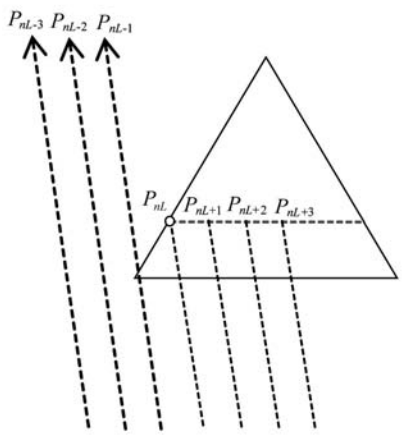


Figure 3 Triangle outline recognition

In this research, the distance differences of laser points in one plane were less than 50 mm according to many experiments. The data point P_{nL} which had a distance difference more than 100 mm than its previous three points ($P_{nL\text{-}1}$, $P_{nL\text{-}2}$, $P_{nL\text{-}3}$) and less than 50 mm than its following three points (P_{nL+1}, P_{nL+2}, P_{nL+3}) was considered as the start point of the n^{th} scan laser beam on the triangle calibration board. The laser point P_{nL} (x_{nL}, y_{nL}, z_{nL}) was the starting point with distance R_{nL} and the scanning angle θ_{nL}. Similarly, calculated the terminate point P_{nR} (x_{nR}, y_{nR}, z_{nR}) with distance R_{nR} and scan angle θ_{nR}. Laser scanning point space coordinates is shown as Equation (1):

$$\begin{aligned} x &= R\cdot\cos(\theta) \\ y &= R\cdot\sin(\theta) \\ z &= h_1 \end{aligned} \tag{1}$$

where, R is the laser measurement distance, cm; θ is the scanning angle, (°); h_1 is the height of laser scanner relative to the ground, cm.

Laser scanning width of the triangle was obtained by the law of cosines (Figure 2) shown as Equation (2).

$$D_{cput} = \sqrt{{R_{n\,L}}^2 + {R_{n\,R}}^2 - 2R_{n\,L}R_{n\,R}\cos(\theta_{n\,R} - \theta_{n\,\mathrm{L}})} \tag{2}$$

where, D_{cput} is the laser scanning width of the triangle, cm; R_{nL}, θ_{nL} are laser scanning distance (cm) and scanning angle of starting point (°), respectively; R_{nR}, θ_{nR} are laser scanning distance (cm) and scanning angle of terminate point (°), respectively.

Since the laser scanning boundary point will affect the calculation of the triangle width, the concept of the virtual point was introduced. The virtual point is between two successive scanning laser points that a laser point hits on the calibration board and another point hits on the background. As the black open circle shown in Figure 4, the virtual point P'_{nL} was between the point P_{n1} and P_{n0}. In the study, the triangle calibration board was placed vertically relative to the laser scanning plane and the laser scanning distances of adjacent points were approximatively equivalent. The calculation of the virtual point is mainly to calculate the laser scanning angle of the virtual point shown as Equation (3).

$$\begin{aligned} \theta'_{nL} &= \theta_{n1} - \frac{\Delta\theta}{2} \\ \theta'_{nR} &= \theta_{nm_n} + \frac{\Delta\theta}{2} \end{aligned} \tag{3}$$

where, θ'_{nL} was virtual scanning angle of the left edge point of the line n of laser scanning point, (°); θ_{n1} was laser scanning angle numbered 1 of the line n of laser scanning point, that is to say, laser scanning angle of the left edge scanning point, (°); θ'_{nR} was virtual scanning angle of the right edge point of the line n of laser scanning point, (°); m_n was the number of laser scanning point of one laser line on the triangle calibration board, cm; θ_{mn_n} was laser scanning angle numbered m_n of the line n of laser scanning point, that is to say, laser scanning angle of the right edge scanning point, (°); $\Delta\theta$ was laser scanning angle resolution, (°).

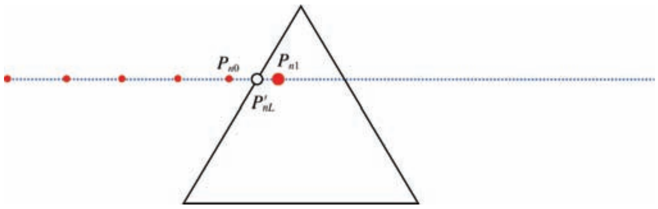


Figure 4 Laser scanning virtual point

After the introduction of the virtual point, the laser scanning width of the triangle D'_{cput} was calculated as Equation (4):

$$D'_{cput} = \sqrt{{R_{n\,L}}^2 + {R_{n\,R}}^2 - 2R_{n\,L}R_{n\,R}\cos(\theta'_{n\,R} - \theta'_{n\,L})} \tag{4}$$

Distance of laser to calibration board was defined as Equation (5):

$$Dis = \frac{R_{nL} + R_{nR}}{2} \tag{5}$$

3.2 Camera image processing

3.2.1 Identification algorithm of suckers

Segmentation algorithms based on color feature are widely used in crop recognition due to the fact that crops are often rich in color information. By observing in field, suckers show “green” in early stage and “reddish green” in later growth. The consumed time of identification algorithm of suckers had an impact on spraying errors in the real-time targeted spraying[9]. If the algorithm takes too much time, the best spray timing even the suckers may be missed. Therefore, it is necessary to choose an effective, simple identification algorithm.

ExGExR algorithm[15] can extract the information of green crops by considering the green and red features. In addition, ExGExR is a linear transformation from R, G, and B, which can shorten image processing time. The algorithm was proven to be a suitable algorithm to segment suckers[15]. Thereby, ExGExR (Equation (6)) was chosen as follows:

$$I_{ExGExR}=\begin{cases}0 & 3G-2.4R-B\le 0\\ 255 & 3G-2.4R-B\ge 255\\ 3G-2.4R-B & others\end{cases} \tag{6}$$

where, I_{ExGExR} is gray values of each pixel in sucker image; *G*, *R*, and *B* are the *G*, *R*, and *B* values of the pixels in the sucker image, respectively.

3.2.2 Identification algorithm of calibration board

White triangle was used as calibration board due to less white background in the field, which made the acquired image easy to be segmented. Color image was converted to grayscale image, and then grayscale image was converted to binary image. Finally, the white calibration plate was segmented from the image.

3.3 Information fusion

Information fusion was the data association between two-dimensional image information and laser information. Grapevine suckers grow up from the rootstock area of grapevine trunk and triangle calibration board was put in the same plane with the trunk in the experiment. Therefore, the algorithm assumed triangle calibration board, trunk and suckers were on the same plane. Field background was too complex, which made segmentation become more complicated and time-consuming. In order to achieve rapid segmentation and establish relative simple background, camera was installed on the top of laser scanner and tilted down with fixed angle (β) to horizontal direction of ground (Figure 2), and there was a horizontal interval Δd between the laser range finder and the CCD camera, the value of Δd in this study was 60 mm. Information fusion algorithm is shown in Figure 5.

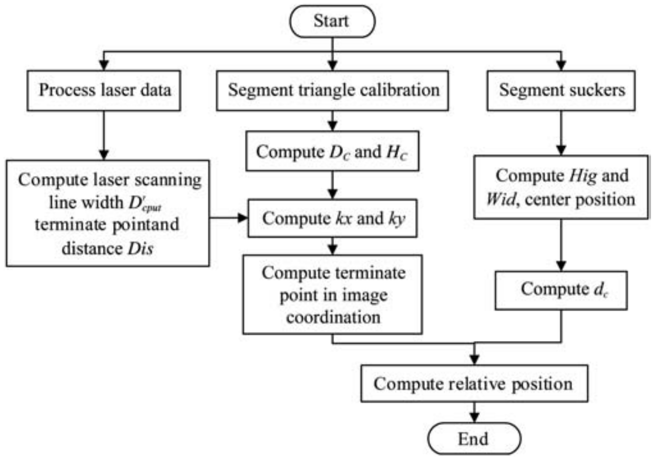


Figure 5 Flowchart of algorithm

Firstly, calculate triangle laser scanning line width D'_{cput} (mm), scanning line terminate point coordinates P_{nR} (x_{nR}, y_{nR}, z_{nR}) and distance *Dis* between laser scanner and triangle calibration board by using the algorithm in section 3.1.1. Then convert the original sucker image to binary image with threshold 0.9 that performed best according to many experiments (Figures 6a and 6b), compute triangle side length *Dc* and height *Hc*, compute the scale factor *kx* (Equation (7)) between the image coordination and the word coordination in the direction of the abscissa as the actual side length of the triangle D was 300 mm. Since the triangle was deltoid, the scale factor *ky* in the direction of ordinate was computed as Equation (8). Triangle laser scan line width d_c (pixel) in the image coordination was computed as Equation (9):

$$kx = D/D_c \tag{7}$$

$$ky = \sqrt{3}D/2H_c \tag{8}$$

$$d_c = (f\cdot D'_{cput})/(kx\cdot f+\sin(\beta)/f) \tag{9}$$

where, *f* is the camera focal length, 3.5 mm; β is the angle of the camera with the ground, 40°.

Find the nearest pixel width with d_c from the segmented triangle calibration board in the image coordination (Figure 6c), and regard it as the laser scanning line (Figure 6d). Then find the left edge point position of triangle in the laser scanning line in the image coordination (x_{c2}, y_{c2}). Segment suckers by using ExGExR algorithm and then compute the height *Hig* (pixel), width *Wid* (pixel) and center position (x_{cc}, y_{cc}) (Figure 7d) of suckers. The actual height and width of suckers in the camera coordination was computed as Equation (8). The relative position (Δx, Δy) between suckers and laser scanning terminate point P_{nR} was computed as Equation (11):

$$\begin{aligned}H_{recg} &= ky\cdot Hig\\ W_{recg} &= kx\cdot Wid\end{aligned} \tag{10}$$

$$\begin{aligned}\Delta x &= kx\cdot(x_{cc}-x_{c2})\\ \Delta y &= ky\cdot(y_{cc}-y_{c2})\end{aligned} \tag{11}$$

4 Experimental method

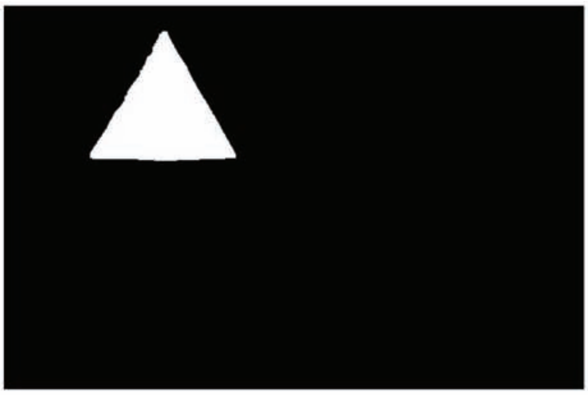
In this research, all sucker images were acquired in

Beijing Forestry University using color charge-coupled device (CCD) industrial camera (DFK 23G618, The Imaging Source, Germany) with a lens (LM3NCM, Kowa, Japan) in May 2015, on a sunny, cloudless day with breeze. The camera was set to capture images at 640×480 pixel spatial resolution with the maximum frame rate of 120 fps. Laser data was acquired by two-dimensional laser scanner (LMS 511, SICK, Germany) in 25 Hz scanning frequency and angular resolution of 0.1667°. The starting angle of laser scanner was 45° and the terminate angle was 135° in order to reduce the effect of other objects in background. The triangle calibration board, camera and laser scanner was fixed. Laser scanner was perpendicular to the ground, and the camera had a 40° angle with the ground. Since calibration board was placed on the same plane with the trunk and grapevine suckers grown up from the rootstock of the trunk, the experiment assumed that the triangle calibration board, trunk and grapevine suckers were on the same plane.

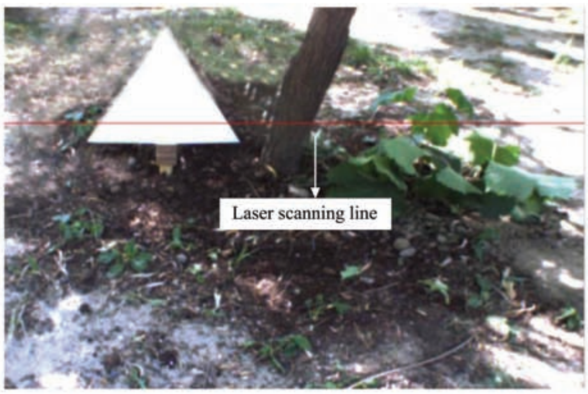
The segmentation result of suckers by ExGExR algorithm is shown in Figure 7. Due to space limit, only the results of one picture was listed (Figure 7). It needed further process including dilation and erosion to filter weeds due to its poor effectiveness (Figures 7b and 7c). Unfortunately, small size suckers will be omitted during erosion. Therefore, the ExGExR algorithm was followed by a further process that searching the maximum connected region for weeds exclusion and edge correction in order to achieve better binary segmentation. The maximum connected region was treated as the suckers. Finally, the color segmentation of suckers was completed by displaying the segmented suckers using the color in the corresponding region of the original sucker image. The color segmentation results of ExGExR, and followed by the above further process is shown in Figure 7.

a. Original picture

b. Binary result of threshold which needs further process including dilation and erosion to filter small object



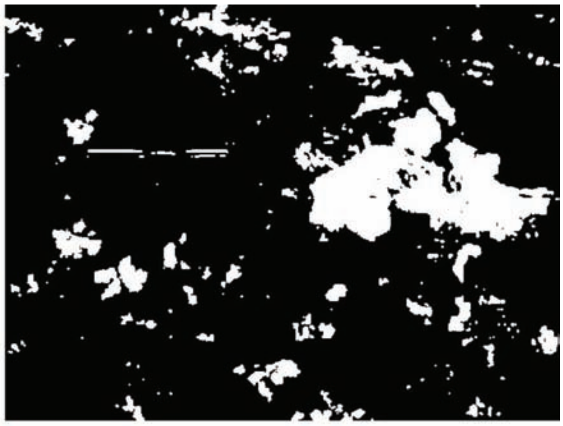
c. Segmentation results after filtering out noise, the largest connected region extracted is the triangle



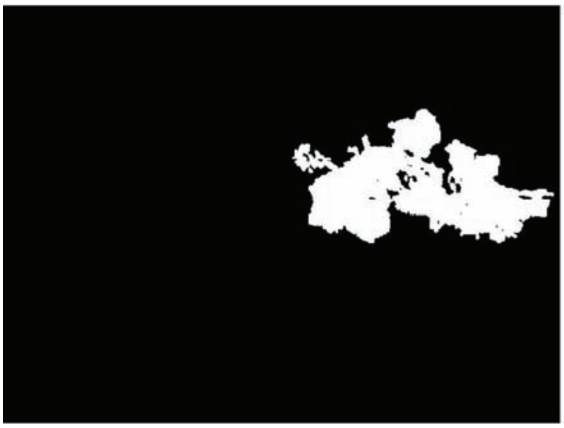
d. Position determination of laser scanning lines, where the red line is the laser scan line computed by the Equation (9)

Figure 6 Triangle calibration board segmentation results

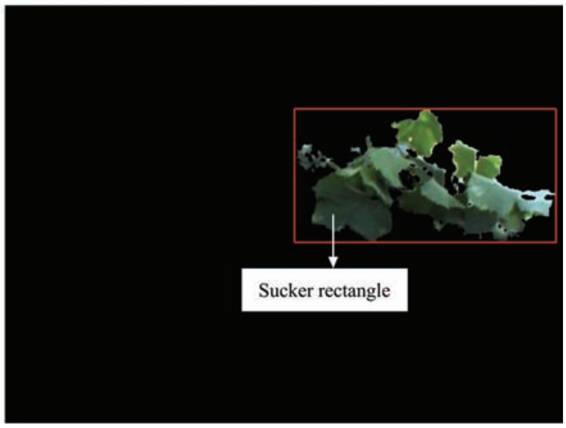
a. Original picture



b. Graying results of ExGExR



c. ExGExR segmentation results after removing the weeds



d. Segmentation results of color sucker image by ExGExR, where the red boxes are sucker square

Figure 7 Sucker segmentation results of ExGExR

4.1 Evaluation of time consuming

All algorithms ran in Matlab R2010a on the same laptop (Lenovo, Think Centre 1 Mini Tower with 2.20 GHz 2 processors, 3.0 GB RAM, and 32-bit operating system). Other software was disabled during running. The time consumed for processing the same original sucker image using the same algorithm varied slightly so that five repetitions were conducted for each image under each algorithm. The time consumed of five repetitions was averaged and treated as the final consumed time for the image. The time consumed of the algorithm on eight suckers is listed in Table 1.

Table 1 Time consumptions of algorithm

No.	1	2	3	4	5	6	7	8	Average	Standard deviation
Time consumed/s	0.784	0.774	0.784	0.761	0.816	0.795	0.785	0.796	0.787	0.016

Kang et al.[14] segmented sucker by using ExG algorithm. However, it was proven that ExG took more time to segment sucker than ExGExR and ExG had large time consuming variation which was influenced by sucker size[15]. Table 1 showed that the time consumptions of the entire algorithm varied from 0.761 s to 0.816 s with an average time of 0.787 s, which involved sucker image processing, laser data processing and the information fusion. The consumed time of the algorithm on different suckers differed but on one level with the standard deviation of 0.020. Therefore, the average time can reflect the time consuming of algorithm. Therefore, the entire algorithm is suitable for precise targeted spray on the aspect of time consuming.

4.2 Accuracy of sucker size

Actually, the chemical spray volume and width are determined by the circumscribed rectangle of suckers in mobile targeted spray in vineyards. Here, it was called sucker rectangle. So a width-based and height-based criterion was established for evaluating the accuracy of the algorithm.

$$H_{TrueR}=\left|1-\frac{|H_{recg}-H_{real}|}{H_{recg}}\right|\times100\%$$
$$W_{TrueR}=\left|1-\frac{|W_{real}-W_{real}|}{W_{real}}\right|\times100\% \quad (12)$$

where, H_{TrueR} and W_{TrueR} are the height and width accuracy, respectively; H_{real} and W_{real} are the actual height and width of grapevine suckers (manual measured in actual experiment), respectively, cm; H_{recg} and W_{recg} are the height and width that identified by algorithm (cm), respectively.

The eight pictures are in descending order according to sucker size. The width recognized by the algorithm varied from 12.5 cm to 58.4 cm and the height recognized by the algorithm varied from 22.5 cm to 55.4 cm. The algorithm was conducted on different suckers so that there is no need to consider the average and standard deviation of the height and width of suckers. The width recognition rate varied from 88.2% to 98.0% with an overall average recognition rate of 91.8% and standard deviation of 6.4% while the height recognition rate varied from 75.0% to 96.7% with an overall average recognition rate of 88.2% and a 10.8% standard deviation. The smaller the size, the correct identification rate declined. Even if the height of suckers S_8 is less than the height of suckers S_3, the recognition rate of the height of suckers S_8 is higher than the height of suckers S_3, because the growth attitude of suckers also affects the recognition rate.

Suckers size recognition rate in height (88.2%) was less than the width recognition rate (91.8%) because the several twigs or leaves at the branch top of suckers were missed. Although some wrong recognition rate existed, the main body of suckers closed to its rootstock was clearly identified. It is acceptable because suckers can be killed as long as its main body is identified and treated with chemical in precision targeted spray.

Table 2 Size recognition rate of suckers

No.	1	2	3	4	5	6	7	8	Average	Standard deviation
W_{recg}/cm	58.4	25	41.3	50.9	31.2	32.2	49.1	12.5	—	—
W_{real}/cm	59.6	25.5	44.4	52.5	35.5	36.5	52.0	15.2	—	—
W_{TrueR}/%	98.0	98.0	93.0	97.0	87.9	83.5	94.4	82.2	91.8	6.4
H_{recg}/cm	25.8	30.5	33.4	53.2	33	32.5	40.6	15.6	—	—
H_{real}/cm	27.2	31.8	39.7	55.4	44	34.6	42.0	22.5	—	—
H_{TrueR}/%	94.9	95.9	84.1	96.0	75.0	93.9	96.7	69.3	88.2	10.8

4.3 Accuracy of sucker position

Actually the chemical spray position is determined by the suckers' position in mobile targeted spray in vineyards. Since the position of the triangle calibration board was acquired by the laser, a relative position-based criterion was established for evaluating the accuracy of the sucker position.

$$\Delta x_{TrueR}=\left|1\text{-}\frac{|\Delta x_{recg}-\Delta x_{real}|}{\Delta x_{recg}}\right|\times100\%$$
$$\Delta y_{TrueR}=\left|1\text{-}\frac{|\Delta y_{recg}-\Delta y_{real}|}{\Delta y_{recg}}\right|\times100\% \quad (13)$$

where, Δx_{TrueR} and Δy_{TrueR} are the relative position of the height and width accuracy rate, respectively; Δx_{real} and Δy_{real} are the actual relative position of height and width of grapevine suckers (manual measured in actual experiment), respectively, cm; Δx_{recg} and Δy_{recg} are the relative position of height and width that identification by algorithm, respectively, cm.

As shown in Table 3, the smaller the size, the location accuracy decreased. The y direction was the direction of sucker's height and x direction was the direction of sucker's width. Different suckers had different relative position to the calibration board, varying from 47.8 cm to 76.3 cm in the direction of x and 8.3 cm to 20.4 cm in the direction of y. The algorithm was conducted on different suckers so that there is no need to consider the average and standard deviation in the height and width of suckers. The accuracy rate of the relative position in the direction of x varied from 84.1% to 98.5% with an overall average accuracy rate of 92.0% and standard deviation 6.2% while the accuracy rate of the relative position in the direction of y varied from 76.8% to 97.2% with an overall average accuracy rate of 87.3% and standard deviation 7.3%. The accuracy rate of the relative position in the direction of y (87.3%) was less than the direction of x (92.0%), because the sucker's size in height recognition rate (88.2%) was less than the width of the recognition rate (91.8%). Therefore, according to the relative position between the center point of suckers and terminate point P_2 (x_2, y_2, z_2) measured by 2D laser scanner and described in section 3.1.1, we can control spraying position of spraying facility for precise targeted spraying in position.

Table 3 Suckers' center position relative to the calibration board position

No.	1	2	3	4	5	6	7	8	Average	Standard deviation
Δx_{recg}/cm	62.0	76.3	62.8	55.8	71.8	47.8	48.5	63.4	—	—
Δy_{recg}/cm	13.8	17.9	16.6	8.3	20.1	20.4	10.8	17.8	—	—
Δx_{TrueR}/%	98.5	91.3	97.0	97.6	85.8	85.0	96.8	84.1	92.0	6.2
Δy_{TrueR}/%	82.3	89.4	96.2	76.8	87.2	89.2	97.2	80.2	87.3	7.3

Although the height recognition rate was 88.2%, the width recognition rate was 91.8% and the relative position accuracies were (92.0%, 87.3%) of the algorithm, the spraying scope can be expanded in the center of suckers, even in the direction of y, which is acceptable because suckers can be killed as long as its main body is identified, located and treated with chemical in precise targeted spray. The presence of weeds and the posture of suckers were the factors that lowering the segmentation accuracy. In addition, the posture of suckers would change because of the changeable wind speed and orientation at different times during the experiment, which also affect the manual measurement of actual data. Since calibration board was placed on the same plane with the trunk and grapevine suckers grown up from the rootstock of the trunk, we assumed that triangle calibration board, trunk and grapevine suckers were on the same plane. The industrial camera we used in the experiment is the two dimensional camera, calibration board and grapevine suckers were acquired on one plane in the image regardless of slightly different depth of field, which will affect the size recognition rate of suckers slightly. Based on the plane of the trunk, the sucker size recognized by the system would be smaller slightly than its real size if the sucker located behind the plane. Otherwise, it would be larger. This is just static experiment, regardless of influence of the movement of the camera and laser because the image was acquired in the rate of 120 fps and the laser data was obtained in 25 Hz scanning frequency.

Future work is being conducted on three aspects. The first is to develop algorithms combined with other features such as texture and shape for improving segmentation accuracy. The second is to take sucker images from multi-angles. The last is to do the mobile experiment to consider the movement of the camera and laser.

5 Conclusions

A sucker detection method based on information fusion using 2D laser scanner and machine vision was developed to identify and locate grapevine sucker. The ExGExR algorithm was adopted to segment the image and a triangle calibration board was used to determine laser scanning line and fuse the 2D laser scanner information and machine vision information. By evaluating the algorithm from three aspects of consumed time of algorithm, identification of size and accuracy of position, it can be concluded that:

1) The algorithm with the consumed time of 0.787 s, the width recognition rate of 91.8%, height recognition rate of 88.2%, and the relative position accuracies of 92.0%, 87.3% were suitable for real-time mobile targeted spray.

2) The camera used in the study was a two-dimensional camera, and the depth of field for it was not considered, which would affect size and position detection of the grapevine sucker. A depth camera will be considered to use for further study.

3) The minimum capture distance of 1 m for the camera was chosen to capture the information of suckers in this study due to the field of view. Different distances could be considered to use in collecting sucker information, and compare their detection accuracy. Then the most appropriate detection distance will be found according to the line spacing of the grape trees.

Acknowledgments

This research was partially funded by National Natural Science Foundation of China (No. 31600588) and the Fundamental Research Funds for the Central Universities (No. 2015ZCQ-GX-01).

[References]

[1] Takeda F, Drane V, Saunders M S. Inhibiting sprouting in muscadine grapes. Proc. Fla. State Hort. Soc, 1982; 95: 127–128.

[2] Smith R J, Klonsky K M, DeMoura R L. Sample costs to establish a vineyard and produce wine grapes, PhD Dissertation, University of California, Davis, California, USA, 2010.

[3] Ahmedullah M, Wolfe W H. Control of sucker growth on Vitis vinifera L. Am. J. Enol. Viti, 1982; 33(3): 198–200.

[4] Reynolds A G. Control of vegetative growth in Vitis by paclobutrazol-implications for winegrape quality. Acta Horticul, 1989; 239: 235–242.

[5] Hu J T, Li T C. Cascaded navigation control for agricultural vehicles tracking straight paths. Int J Agric & Biol Eng, 2014; 7(1): 36–44.

[6] Shi Y, Wang X F, Zhang S W, Zhang C L. PNN based crop disease recognition with leaf image features and meteorological data. Int J Agric & Biol Eng, 2015; 8(4): 60–68.

[7] Kang F, Pierce F J, Walsh D B, Zhang Q, Wang S. An automated trailer sprayer system for targeted control of cutworm in vineyards. Transactions of the ASABE, 2011; 54(4): 1511–1519.

[8] Cai J R, Sun H B, Li Y P, Sun L, Lu H Z. Fruit trees 3-D information perception and reconstruction based on binocular stereo vision. Transactions of the CSAM, 2012; 43(3): 152–156. (in Chinese)

[9] Jiménez A R, Ceres R, Pons J L. A vision system based on a laser range-finder applied to robotic fruit harvesting. Mach.Vision. Appl, 2000; 11: 321–329.

[10] Monta M, Namba K, Kondo N. Three dimensional sensing system using laser scanners. Transactions of the ASAE, 2004; 2: 1216–1221.

[11] Wang H, Mao W H, Liu G, Liu X A, Li S J. Identification and location system of multi-operation apple robot based on vision combination. Transactions of the CSAM, 2012; 43(12): 166–170. (in Chinese)

[12] Liu B, Wang H F, Huang W Q, Zhang C. Construction and in-field experiment of low-cost binocular vision platform for pineapple harvesting robot. Transactions of the CSAE, 2012; 28: 188–192. (in Chinese)

[13] Zhang K L, Yang L, Zhang T Z. Object locating method of laser assisted machine vision for strawberry-harvesting. Transactions of the CSAM, 2010; 41(4): 151–156. (in Chinese)

[14] Kang F, Wang H, Pierce F J, Zhang Q and Wang S. Sucker detection of grapevines for targeted spray using optical sensors. Transactions of the ASABE, 2012; 55(5): 2007–2014.

[15] Xu S S, Li W B, Kang F, Zheng Y J, Lan Y B. Evaluation of grapevine sucker segmentation algorithms for precision targered spray. Int J Agric & Biol Eng, 2015; 8(4): 77–85.

[16] Yang H, Liu X L, Patras I. A simple and effective extrinsic calibration method of a camera and a single line scanning lidar. International Conference on Pattern Recognition, 2012; pp.1439–1442.

[17] Nagai M, Shibasaki R, Manandha D. Calibration methodology for laser scanner external parameters. Available at: http.www.gisdevelopment.net/aars/acrs/2004/gensensors/acrs2004_a4008pf.htm.

[18] Li G H, Liu Y H, Li D, Cai X P, Zhou D X. An algorithm for extrinsic parameters calibration of a camera and a laser range finder using line features. Proc. IEEE/RSJ Int'l Conf. Intelligent Robots and Systems, 2007; pp.3854–3859.

[19] Park Y, Yun S, Won C S, Cho K, Um K, Sim S. Calibration between color camera and 3D LIDAR instruments with a polygonal planar board. Sensors, 2014; 14(3): 5333–5353.