Fruit location and stem detection method for strawberry harvesting robot

Guo Feng[1], Cao Qixin[1], Cui Yongjie[2], Nagata Masateru[2]
(1. *Research Institute of Robotics*, *Shanghai Jiao Tong University*, *Shanghai* 200030, *China*;
2. *Faculty of Agriculture*, *Miyazaki University*, *Miyazaki* 8892192, *Japan*)

Abstract: A fruit localization and stem detection method for strawberry harvesting robot was introduced in this paper. OHTA color space based image segmentation algorithm was utilized to extract strawberry image from background; principal inertia axis of binary strawberry blob was calculated to define the pose of fruit. Strawberry was picked selectively according to its ripeness. Experimental results show that the average time of fruit localization is one second, the stem detection failure rate is 7% and fruit injury rate is 5%, which satisfy the speed and accuracy requirements of strawberry harvesting robot.

Key words: agricultural robot, machine vision，strawberry harvesting robot, stem detection
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Guo Feng, Cao Qixin, Cui Yongjie, et al. Fruit location and stem detection method for strawberry harvesting robot[J]. Transactions of the CSAE, 2008, 24(10)：89－94.**(in English with Chinese abstract)**

0 Introduction

As a variety of delicious and nutritious fruit, strawberry is very popular to Japanese consumers. Kyushu is one of the major strawberry planting areas, while the harvest and classification of strawberry is generally done manually in Japan. Because of extreme shortage of labor and aging population engaged in agriculture, there exists a large market requirement for strawberry harvesting robot.

In the development of harvesting robot, fruit localization and characterization method plays an important role. A successful location and quality judgment algorithm should avoid damage to fruit during harvest and execute selective picking task according to fruit appearance. A.R.Jimenez and R.Ceres[1] had presented three problems to be solved in developing fruit harvesting robot: (a) the guidance of the robot through the crop; (b) the localization and characterization of the fruit on the tree; (c) the grasping and detachment of each piece. Some successful sample machines have been reported recently: Seiichi Arima, Naoshi Kondo et al.[2,3] had developed a robot that could harvest strawberry grown on tabletop culture; Peter P. Ling, Reza Ehsani, et al.[4,5] had developed a Robotic Tomato Harvester for continuous, selective picking of mature tomatoes; Jun Qiao, Akira Sasao, et al.[6] had introduced a mobile fruit grading robot which could realize the harvest and on-line classification of sweet pepper and generate the yield map of fruit.

In the laboratory of Agricultural Engineering, Image Processing, Faculty of Agriculture, Miyazaki University Japan, some studies related to strawberry quality judgment and sorting system had been reported[7-11]. The robot introduced in this paper can harvest strawberries growing on the ground, and can be installed on a vehicle and execute mobile harvest task in the greenhouse.

In order to avoid impact on fruit during harvest process, specific stem-cutting mechanism was designed for fruit detachment, specific fruit localization and stem detection method was developed: OHTA color space based segmentation algorithm could detect fruit on black and white backgrounds; Principal inertia axis feature was utilized to detect the stem position, which could achieve high harvest accuracy; Strawberry was selectively picked according to its ripeness feature which was calculated under HSI color space. The performance of this method was tested on a simulated planting bed and experimental results were satisfying.

1 Materials and methods

1.1 Materials

1.1.1 Strawberry samples

The strawberry samples were selected in the greenhouse of Miyazaki-city's KIBANA area Japan, its variety is AKIHIME, which can be classified into five grades according to its ripeness (immaturity, 40%, 60%, 80%, 100%), and can be classified into two grades according to its shape (normal shape fruit and ill-shaped fruit).

1.1.2 Strawberry harvesting robot

The strawberry harvesting robot (shown in Fig.1) was developed by Laboratory of Agricultural Engineering, Image Processing, Faculty of Agriculture, University of Miyazaki. It consisted of XYZ three-axial moving stage (1); pneumatic end effector (2); global camera (3); local camera (4) and controller PC (5).

In order to improve the speed of operation, two-camera imaging system was designed for strawberry harvesting

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Biography: Guo Feng (1976－), Male, Ph.D, Research Institute of Robotics, Shanghai Jiao Tong University, Shanghai China. Research interests include robot vision, agricultural robotics, and pattern recognition.
Email: guofeng07@hotmail.com

robot. One camera called global camera(SONY DXC-151A, 640×480) was installed on the top of robot frame, which could capture the image of 8 to 10 strawberries; the other camera (called local camera) was installed on the manipulator and could move with the XYZ moving stage. The image taken by local camera (ELMO EC-202 II, 640×480) often contained one or two strawberries. The global camera had a larger view field than local camera and was responsible for the general localization of fruits, while the local camera could capture the image of strawberries with high resolution and was responsible for fruit localization, stem detection and ripeness judgment. This imaging system could decrease fruit searching time and improve harvest speed effectively. Four fluorescent tubes (TOSHIBA FL20S.D-EDL-65) were installed around the robot frame as lighting source, which could reduce the exterior brightness disturbance to the harvest environment.

The procedure of strawberry harvest is listed below:

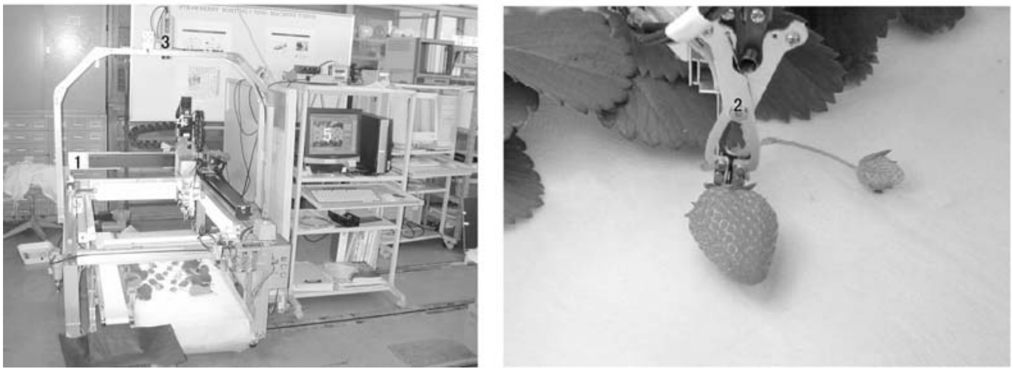
1) Global camera locates the general position of every strawberry in its taken image;

2) With the position coordinates provided by global camera, controller PC sends instruction to XYZ moving stage and makes it move to the destined position. Then local camera installed on the manipulator captures the image of strawberries;

3) Blob based algorithm is utilized to localize fruit in the central part of local image;

4) Inertia principal axis of singular strawberry blob is calculated to provide the orientation information of fruit. Then stem detection algorithm locates fruit's stem and quality judgment algorithm evaluates the ripeness of fruit;

5) If fruit meets the harvest standard, robot will execute strawberry harvest operation according to the extracted stem position coordinates.



1. XYZ three axial moving stage; 2. Pneumatic end effector; 3. Global camera; 4. Local camera; 5. Controller PC

Fig.1 Image of strawberry harvesting robot

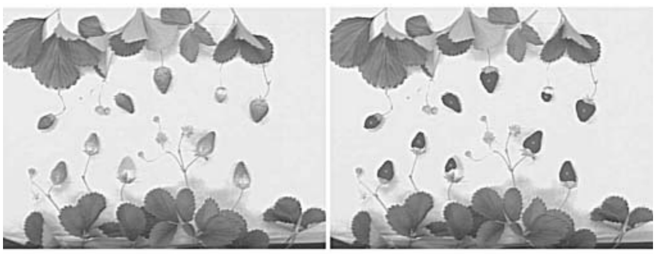
1.2 Fruit localization and stem detection algorithms for strawberry harvest

1.2.1 OHTA color space based image segmentation algorithm

Segmentation of fruit image is the foundation of fruit localization and stem detection. In order to extract red strawberries from image, OHTA color space was selected. This color space was introduced by Ohta[12], who analyzed more than 100 color features which were thus obtained during segmenting eight kinds of color pictures and found a set of orthogonal color features. Compared with other traditional color spaces, the conversion from RGB to OHTA color space is linear and computation inexpensive. OHTA color space has two different kinds of expression as shown in equation (1), strawberry segmentation was realized by a threshold based algorithm with the I_2' feature (R-B).

$$\begin{cases} I_1=(R+G+B)/3 \\ I_2=(R-B)/2 \\ I_3=(2G-R-B)/4 \end{cases}, \quad \begin{cases} I_2'=R-B \\ I_3'=(2G-R-B)/2 \end{cases} \tag{1}$$

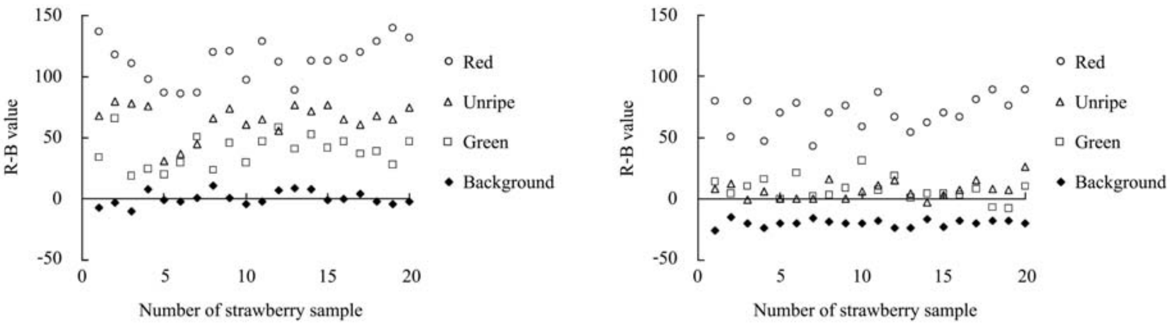
The image taken by global camera was transformed from RGB color space to OHTA color space firstly, then threshold based method was selected for image segmentation. The threshold value can be set with software interface, which will make the segmentation algorithm work well in various illumination intensities. The approximate center coordinates of every strawberry can be achieved by calculating the average coordinate of the pixels in row and column. Segmentation result is shown in Fig.2.



a. Original image b. Segmentation result

Fig.2 OHTA color space based image segmentation algorithm (taken by global camera)

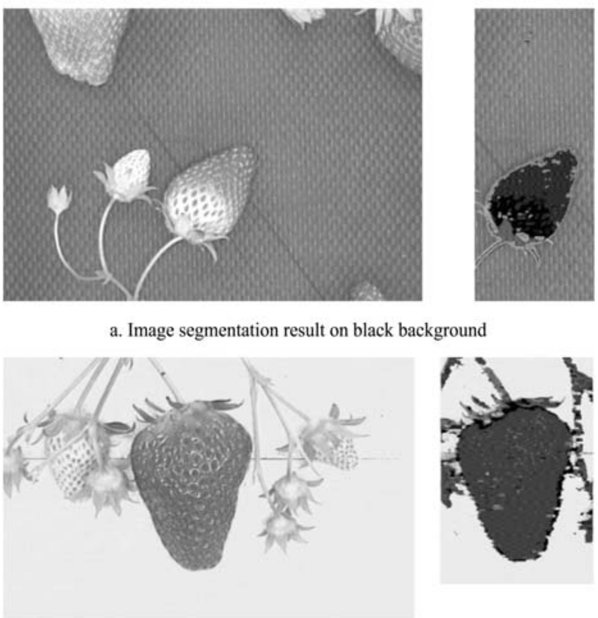
Because farmers usually utilized white or black thin sheets to cover planting bed, so fruit extraction experiment was done on different backgrounds. Simulated planting bed was covered with white and black plastic sheets, images of 20 samples were taken on different backgrounds with local camera. The image pixels were classified into four groups: red, unripe, green and background. The average R-B value of each part was calculated, calculation results of 20 samples on different backgrounds were shown in Fig.3.



a. White background　　b. Black background

Fig.3　R-B values of four parts of 20 sample images on different backgrounds

Fig.3a shows average R-B value of four parts of 20 sample images taken on white background, Fig.3b shows average R-B value of four parts of 20 sample images taken on black background. As shown in Fig.3a and 3b, the red part has the maximum R-B value; the background has the minimum R-B value; the variation of background value is relatively constant compared with other three parts; the difference between background and other three parts is obvious; so OHTA color space based image segmentation algorithm can work well on black and white background. The segmentation result of image taken by local camera is shown in Fig.4.



a. Image segmentation result on black background

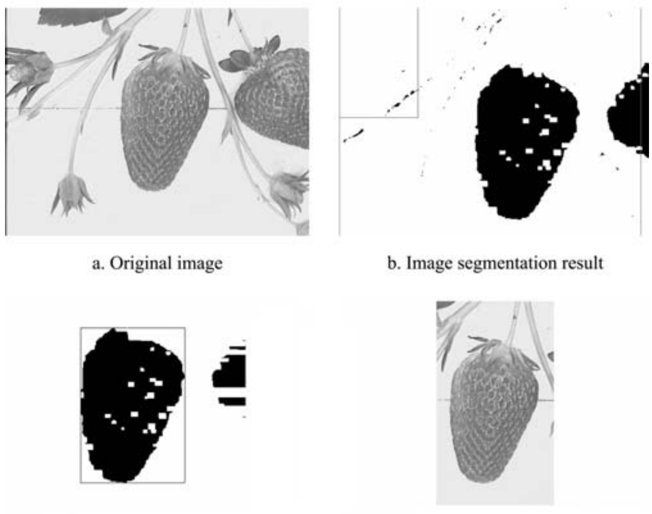
b. Image segmentation result on white background

Fig.4　Image segmentation result with OHTA color space (taken by local camera)

1.2.2　Blob based singular strawberry localization algorithm

Because of the randomness of strawberries distribution, there often exists more than one strawberry in the image taken by local camera, so a localization algorithm to extract complete singular strawberry from image is necessary.

A blob based singular strawberry localization algorithm was designed. The image taken by local camera was transformed from RGB color space into OHTA color space, and fruit parts were extracted from the image; morphology algorithm was introduced to erase image noises, then blob based algorithm was utilized to extract fruit part in the image; the central blob was defined as the strawberry that could be harvested, consequent image processing was executed only within the range of central blob. The procedure and result of fruit localization algorithm are shown in Fig.5.



a. Original image　　b. Image segmentation result

c. Detected central blob　　d. Strawberry localization result

Fig.5　Strawberry localization result with blob algorithm

1.2.3　Inertia principal axis based stem detection algorithm

The inertia principal axis and center are inherent properties of object, the direction of given object principal axis defines its orientation, so the pose of strawberry matches the longer inertia principal axis of binary strawberry blob approximately. The principal axis of an object is a line that passes through the mass center of object, around which the first order moment of object is minimum. The segmented binary image was recognized as a two dimensional inertia object, and two order central moments of binary image were calculated to get the inertia principal axis of fruit. The stem part can be found along the principal axis. To inertia principal axis, the arctangent value of orientation angle can be calculated with equation (2), which was introduced in[13]:

$$\theta = \frac{1}{2}\,\mathrm{tg}^{-1}\left(\frac{2m_{11}}{m_{20}-m_{02}}\right) \tag{2}$$

Where θ is the orientation angle of inertia principal axis; m_{20}, m_{02} and m_{11} are the two order central moments of binary image, they can be calculated with equation (3).

$$m_{ij} = \sum\sum (x-\bar{x})^i (y-\bar{y})^j f(x,y) \tag{3}$$

Where $f(x,y)$ is the function of binary image.

$$f(x,y) = \begin{cases} 1, if\left(pixel(x,y) = object\right) \\ 0, if\left(pixel(x,y) = background\right) \end{cases} \tag{4}$$

$(\bar{x}, \bar{y})$ can be calculated with equation (5).

$$\bar{x} = \frac{\sum\sum x f(x,y)}{\sum\sum f(x,y)} \qquad \bar{y} = \frac{\sum\sum y f(x,y)}{\sum\sum f(x,y)} \tag{5}$$

The head and rear of fruit are defined according to the length and color feature along the longer principal axis. The ends of principal axis with green pixels are potential head parts. According to the fruit shape investigation, the distance from head to fruit mass center is smaller than that from rear to fruit mass center. So the head part of fruit is defined with the shorter semi-axis of principal axis with green pixels on it. The opposite end of principal axis is defined as the rear of fruit.

When the judgment of head and rear completed, a trapezoid range was defined on the head of strawberry to execute stem detection task. Because the direction of stem does not coincide with the direction of principal axis, trapezoid range can search more space than rectangle space. The trapezoid range is classified into two parts along the direction of principal axis and the mass center of green pixels in each part is calculated separately, the connected line of two centers represents the information of stem. The procedure and result of stem detection algorithm is shown in Fig.6.

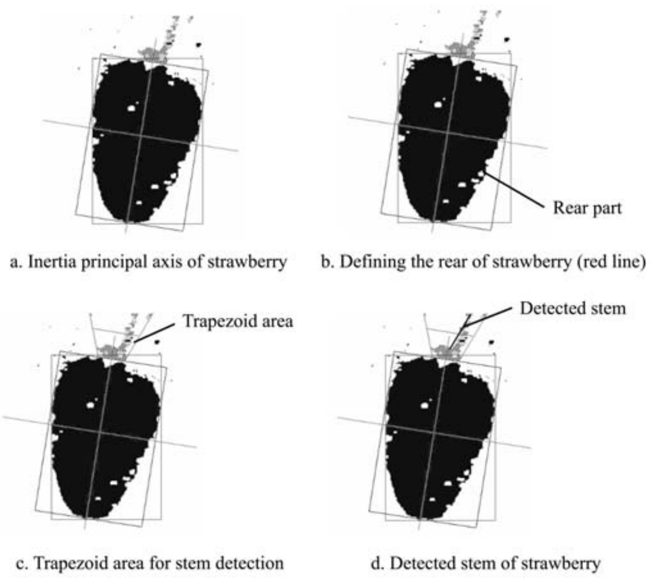


Fig. 6 Process and results of stem detection algorithm

For a fruit harvesting robot, the measurement of distance from detected fruit to the initial position of robot end effector is difficult. While the robot is developed for harvesting strawberries growing on the ground, the distance from fruit to the robot is relatively constant (0.4m approximately), and this parameter can be defined beforehand in system calibration process, so with the extracted image X-Y coordinates, robot can control the manipulator to execute harvest operation.

1.3 HSI color space based strawberry ripeness judgment method

Ripeness judgment method is developed for selective harvest of fruit, robot only picks strawberry whose ripeness is over 80%. Strawberry ripeness is defined as the color ratio between the red distribution area and the whole fruit surface area, which can be calculated with equation (6):

$$C = R / A \tag{6}$$

Where C represents color ratio; R represents the area of red pixels in fruit image and A represents the area of strawberry in the image, which can be calculated with the sum of segmented unripe part and red part.

In order to extract red strawberries from image, HSI color space was selected. This color space is claimed to be the closest approximation to human interpretation of colors, hue is independent of illumination variation[14]. In HSI space, color is represented by hue angle from 0 to 360, threshold method can be used to detect red pixels of fruit in the image. Red pixel detection result is shown in Fig.7.

Fig.7 Red area of strawberry detection result

This method can only detect the red area on one side of fruit, while because the red area of strawberry is distributed evenly, so the ripeness judgment result is reliable.

2 Results and discussion

2.1 Strawberry harvest performance test

In order to test the harvest performance, growing environment of strawberry was simulated in laboratory. With 100 strawberries collected from farmers, performance of strawberry harvest was tested in the simulated growing environment. Strawberries (10～12 samples at a time) were placed on the planting bed (1.3 m×0.5 m) to simulate the real growing environment (inter-plant distance is 0.1 m, inter-strip distance is 0.2 m), The strawberry samples were placed along the longer edge of planting bed, 5～6 samples on each side. Fruits were arranged in the way to simulate their distribution in real environment. Experimental results are shown in Table 1.

With GetTickCount () function of Windows API, the execution time of fruit localization algorithm (from fruit segmentation to stem detection) could be calculated with accuracy of 10 ms. A complete harvest process started when the end-effector moved from its initial position and finished when the end-effected released the harvested fruit and returned to initial position. The harvest process is timed manually and its accuracy is 1s. The event of stem detection failure was counted when the robot missed the stem or the fruit was injured even if the robot harvested fruit successfully. The number of injured fruits was recorded and the ratio of injured fruits and correctly harvested fruits was calculated as fruit injury rate.

Table 1　Performance of strawberry harvesting robot

Tested items	Test results
Fruit localization time	0.95s
Average harvesting time	30s
Average stem length	8mm
Fruit injury rate	5%
Stem detection failure rate	7%

Table 1 showed that it only took about one second for the controller PC to give the stem position information, while the developed experimental mechanism slowed the harvest process. With optimal harvesting mechanism, improvement of the speed of moving stage and harvesting end-effector, the harvest speed could achieve 10 samples per minute which was as fast as manual operation. The average stem length was 8 mm, and only 5% of tested samples were injured during harvest process. The injury was mainly caused by ill-shaped fruit that made principal axis algorithm failed to judge the head of fruit. The stem detection algorithm failed to locate 7% of strawberries because of the occlusion of leaves or the strawberries were so close that the blob algorithm could not separate them. So in the future, some artificial intelligence algorithms should be developed to improve the harvest performance.

2.2　Experiment on on-line judgment of strawberry quality

In order to test selective picking performance during harvest process, 50 strawberries (40 above 80% maturity and 10 below 80% maturity) were selected manually. These samples were placed specifically so that the stem detection method could work correctly. The experiment proceeded on both black and white background, experimental results were shown in Table 2.

Table 2　Harvesting rates on black and white backgrounds

Background	Number of picked samples (ripeness above 80%)	Number of picked samples (ripeness below 80%)	Missing harvest rate
White	38	0	5%
Black	40	0	0%

The result showed that the robot could harvest all mature strawberries on black background, while missed two samples on white background. The white background reflected more light than black background, and caused some bright spots appearing on the fruit surface, which had influenced color ratio calculation result. While robot did not pick samples whose ripeness below 80%, which would not bring losses to farmers.

3　Conclusions

A fruit localization and stem detection method for strawberry harvesting robot was introduced in this paper. Robot can realize accurate localization of fruit with principal inertia axis based stem detection method and selective harvest with on-line ripeness quality judgment. Experimental result shows that this robot can achieve high accuracy of fruit localization, stem detection and ripeness quality judgment.

The study of harvesting robot is still in its initial stage, future work should be focused on improving the robustness of image processing algorithm and designing specific mechanism, which can sweep small obstacles on planting bed and redistribute strawberries to simplify image background.

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用于草莓收获机器人的果实定位和果柄检测方法

郭 峰[1]，曹其新[1]，崔永杰[2]，永田雅辉[2]

（1．上海交通大学机器人研究所，上海 200030； 2．宫崎大学农学部，宫崎 8892192，日本）

摘 要：介绍了一种用于草莓收获机器人的果实定位和果柄检测方法。利用基于 OHTA 颜色空间的图像分割方法从背景中分割草莓；通过计算二值化草莓 blob 的惯性主轴来判断草莓的姿态，根据草莓的成熟度实现了果实的选择性采摘。试验证明这种方法的平均判别速度为 1 s，果柄误判率为 7%，在采摘过程中仅对 5%的果实造成损伤，满足草莓机器人的收获速度和精度要求。

关键词：农业机器人，机器视觉，草莓收获机器人，果柄检测