EAEF Engineering in Agriculture, Environment and Food published by AABEA
Research Paper
EAEF 4(1) : 7-11, 2011

Development of a Mobile Grading Machine for Citrus Fruit*

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Abstract

A mobile grading machine for citrus fruits has been developed to collect crop information such as fruit yield, diameter, and sugar content of fruits of each tree part. It consists of a mobile mechanism, a differential global positioning system, a fruit conveyer system, a color camera for machine vision, a NIR spectrometer, and a personal computer for control and database. Preliminary field tests were conducted to investigate basic performance of this machine in a mandarin orange orchard. Using the collecting data of fruit yield and diameter and sugar content of fruit, crop information maps of each tree part was made. These maps indicated that each tree part has large variability of yield, size, and sugar content of fruit.

[Keywords] citrus fruit, traceability, machine vision, yield map, sugar content map

I Introduction

Recently, fruit grading machines with machine vision systems and NIR inspection systems have been distributed widely (Ishii *et al*. 2003a; 2003b; Kondo et al. 2006; Kondo, 2010) and data on fruit qualities are now managed in databases. Especially, citrus fruit grading systems were earlier developed and used so that citrus orchard management could be conducted. However, it is known that there is variability in each orchard, and fruit tree management is desirable for more precise farming.

To manage each fruit tree, researche on mobile grading robots for sweet pepper and eggplant (Chong et al., 2006; Okayama et al., 2006; Qiao et al., 2004; 2005; Shibusawa and Kondo, 2006) was studied. Since these robots can record information such as harvest date, each fruit quality and location of the plants in the fields, similar robots shall be able to collect data for the fruit tree management. The targets (sweet pepper and eggplant) of the mobile grading robots were annual plants so that whole fruit fields could be drastically changed by removing all plants and appropriate fertilization after the harvesting seasons, if much variability was found in fruit quality or yield. It is, however, not easy to change condition around the tree every year like the annual plants, because average life of citrus tree is 30 years. It is considered that the mobile fruit grading robot plays an important role for farming guidance and precise agriculture, due to the necessity to manage each tree for a long time.

In this study, a mobile grading machine was developed to practice precision agriculture for citrus fruit. This machine can travel in citrus orchards and it can measure outer and inner quality of a fruit harvested by human on site as well as harvest date and location. This paper describes the outline and performance of this grading machine.

II Material and Methods

1. Overview of mobile fruits grading machine

Figure 1 shows a prototype mobile grading machine for citrus fruit. It consists of a mobile mechanism, a differential global positioning system (DGPS), a fruit conveyer system, a color camera for machine vision, a NIR spectrometer, and a personal computer (PC) for control and database. This machine can move by a electric motor. A human operator can manually drive the machine by controlling switches. The DGPS (GIR1600, Sokkia Co. Ltd.) measures the location, date, and time of the grading machine in a field. It outputs longitude, latitude, altitude, date, and time at a rate of 1 Hz in GGA data format in a NMEA message.

The fruits conveyer system is a roller pin type conveyor (RPC), whose speed is controlled by an inverter (FR-E510W-0.1K, Mitsubishi Electric Co. Ltd.). The human operator harvests a fruit from tree, and then he puts it into an inlet of the grading machine. The fruit is conveyed to a

* Partly presented at the Joint Conference on Environmental Engineering in Agriculture 2009

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sequence of the fruit grading system by RPC. The grading system includes a machine vision system and a NIR spectrometer. These systems can measure outer and inner qualities of fruit.

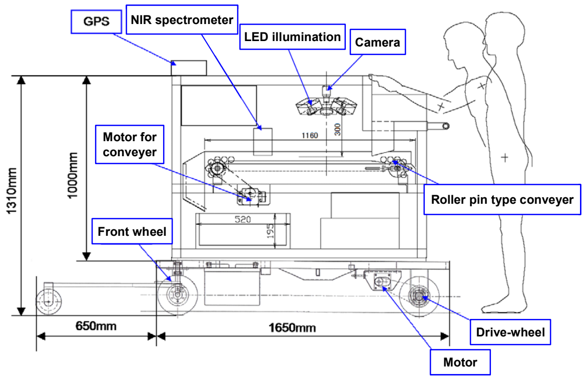


Fig. 1 A prototype mobile fruit grading machine for citrus fruit

These measured data are sent to the PC to create a database for site-specific crop management. The PC records the outer and inner qualities of each fruit with location, date, and time from the GPS. After the sugar content measurement, the conveyer moves again and carries the fruit to a container.

Since the developed grading machine is used to collect the information of outer and inner qualities of fruit, it has no separator system according to fruit quality. Therefore, it is necessary that all the fruits are separated and packed into a box by a separate fruit sorting machine after collecting by this grading machine.

2. Machine vision

The machine vision system has a VGA color camera (VCC-8350CLT, CIS Co. Ltd.) and three LED illuminators (Fig. 2). This system measures the fruit diameter and the color value as an outer quality of fruit. The conveyer can position the fruit at a correct place for the machine vision system. A photoelectric sensor (EX-11B-PN, SUNX Co. Ltd.) was installed in front of the camera to detect and position the fruit. As soon as this sensor detects the coming fruit, the conveyer pauses to take an image of fruit. Images from the camera are input to the PC by a frame grabber board (MTPCI-TL, Micro-technica Co. Ltd.). White light emitting diodes (LEDs) were used for illumination of the machine vision. These LED illuminators were also equipped with polarization filters to prevent halation (Kondo 2006). LED radiation time was set in 2 ms and shutter speed of camera was 1/500 s.

In machine vision data processing, the following equations (1)-(3) for color transformation were applied to discriminate a fruit from background.

$$R' = \frac{R}{R+G+B} \times 255 \quad (1)$$

$$G' = \frac{G}{R+G+B} \times 255 \quad (2)$$

$$B' = \frac{B}{R+G+B} \times 255 \quad (3)$$

Where R, G, and B are the intensities of the red, green, and blue color pixels, while R', G', and B' are color values transformed by Eq.(1) to (3).

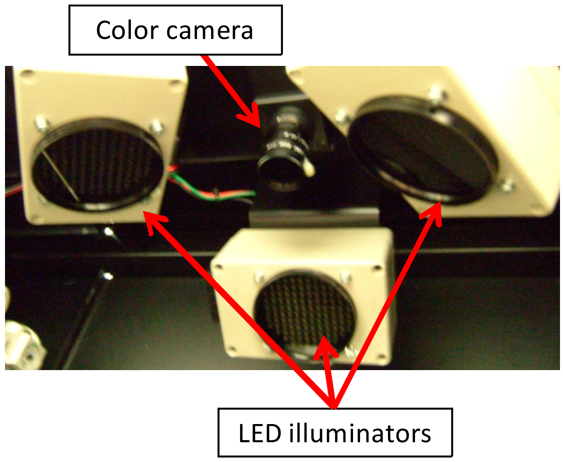


Fig. 2 Machine vision system

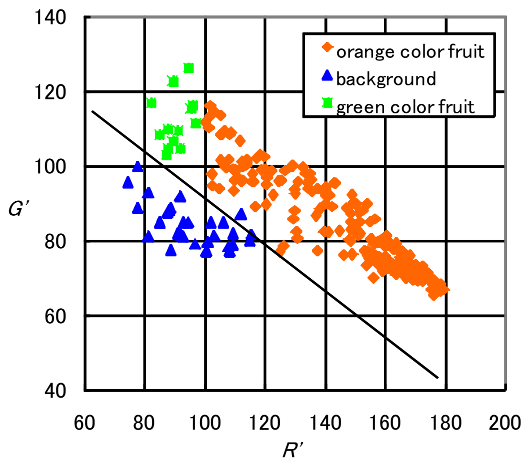


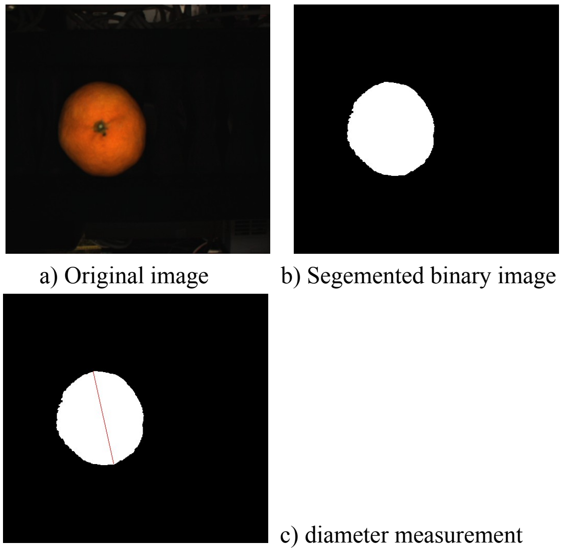
Fig. 3 Chromaticity distribution of fruit and background

Figure 3 shows a chromaticity distribution between R' and G' concerning fruit and background. Distribution of fruit was different from that of background as shown in the figure. It was possible to separate most of the fruit pixels from the background pixels manually drawing a line as shown by the black line. Although some of background pixels were classified into fruit pixel group, they were easily eliminated by noise reduction process on images in addition that they were discriminated by intensity of R, G, and B grey levels. Color value of each fruit was calculated as an average value of all pixels on the fruit for obtaining fruit color information.

The diameter of fruit was calculated using a segmented binary image. First a profile line of the fruit was obtained on the binary image. Secondly, the distances between one pixel and another on the profile line were calculated. Finally, the maximal value of all the distances was defined as a diameter of the fruit. All the diameters of fruits were stored in the database. Figure 4 shows results of image processing for one fruit. In addition, the color value C of the fruit was obtained by the following equation.

$$C = \frac{1}{M}\sum_{i \in M} R_i \tag{4}$$

M is a number of total pixels of a fruit in a segmented binary image. R_i is red color value of the pixel i of the fruit part on the image. If C is large, it is judged that the fruit has a color indicating high ripeness.



a) Original image b) Segemented binary image

c) diameter measurement

Fig. 4 Image processing for outer quality

3. NIR spectrometer

The NIR spectrometer, which is a fruit selector "K-BA100R-1" made by Kubota Co. Ltd., measured sugar content and acidity of each fruit as inner quality. Figure 5 shows the measuring components, including the NIR spectrometer. Sugar content was expressed in Brix.

In order to measure sugar content and acidity of fruit, the probe of the spectrometer had to closely touch the fruit. For the purpose, the conveyer pauses for sugar content measurement and pneumatic arms fix the fruit position. The probe pushed on the fruit surface firmly and it measured the sugar content and acidity of fruit. The same photoelectric sensor as that of the color camera was used for fruit detection.

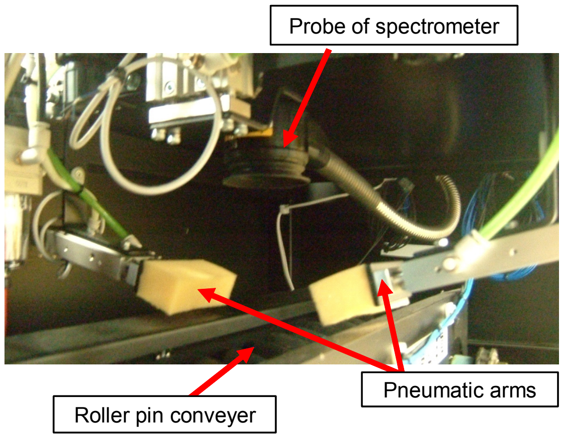


Fig. 5 Measuring components for fruit inner qualities using NIR spectrometer

4. Materials

Twenty-four trees of Mandarin orange variety of "*Himenoka*" were harvested at the Citrus Research Center of Ehime Research Institute of Agriculture, Forestry and Fisheries (latitude:33°52'49"N, longitude:132°48'30"E).

Figure 6 shows tree location in the orchard of this research center. Each tree was divided into four parts. north-east, north-west, south-west, and south-east. Fruits from each tree part were harvested separately.

5. Experimental method

The fruit grading machine entered from north-east of the field and it traveled east to west. The fruits harvested were thrown into the grading machine, and then the information such as harvested date, time, position, diameter, color value, and sugar content of each fruit were collected and recorded in the database. In addition, the tree location was measured by

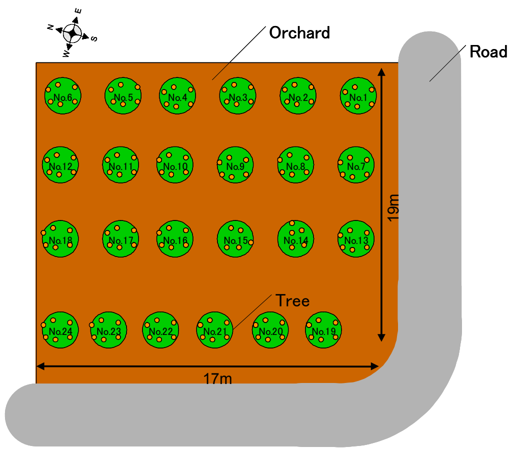


Fig. 6 Tree location in the orchard of the research center

a tape measure in order to compare with the position measured by the DGPS. This experiment was conducted in the field on December 24, 2008, 10:00-16:00.

III Results and Discussions

1. Harvested fruits

The grading machine travelled in the orchard while measuring the diameter, sugar content, color value of fruits. No fruit were harvested in tree, 5, 6, and 19-24. The number of fruits measured by the grading machine was 998. Table 1 shows the diameter, sugar content, acidity, and color value data which the grading machine measured in the field. The fruit processing time for a single fruit was 12-20 seconds because of the NIR spectrometer installed in this machine, which should be improved in the future.

Table 1 Descriptive statistics of harvested fruit

$N = 998$	Diameter [mm]	Sugar content [Brix]	Acidity [%]	Color value
Average	68.1	14.8	0.4	152.9
Standard deviation	6.1	1.7	0.2	10.6
Max.	88.9	24.7	1.6	179.0
Min.	46.7	9.8	0.1	74.0

2. Diameter of fruits

Figure 7 shows relationship between fruit diameters that measured by machine vision and a vernier caliper. The number of fruits measured manually by the vernier caliper was 593. The coefficient of determination was 0.8665. The root mean square error of prediction (RMSEP) by machine vision was 10.0 mm. As the result, the accuracy of diameter prediction was sufficient in consideration that the fruit diameter was subjectively measured by the inspector.

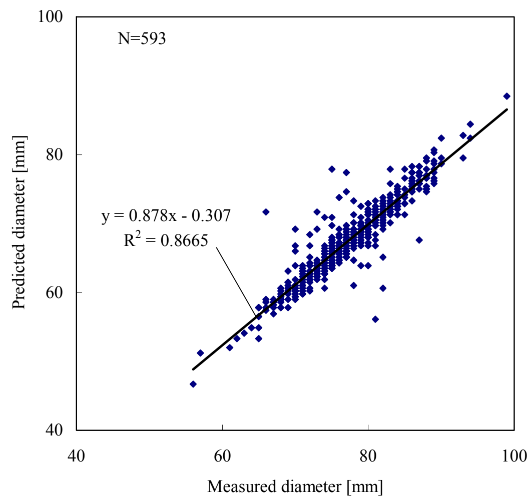


Fig. 7 Relationship between manual measured and predicted diameters

3. Yield map

Figure 8 shows a fruit yield map of each tree part divided into north-east, north-west, south-west, and south-east. Each arc in the map indicates the number of fruits harvested that tree part. It was shown that the fruit yield of tree part had large variability in the same tree. It was, therefore, considered that it is important to control the crop management according to the growth condition of tree part. The fruit yield map will be useful to investigate the information of the growth condition of each tree part.

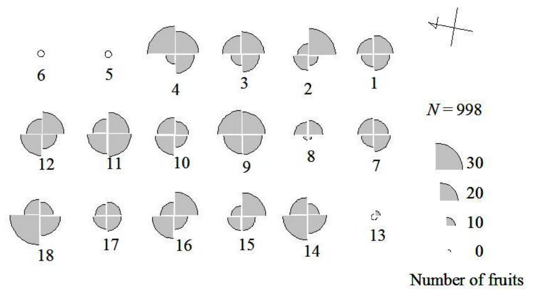


Fig. 8 Fruit yield map

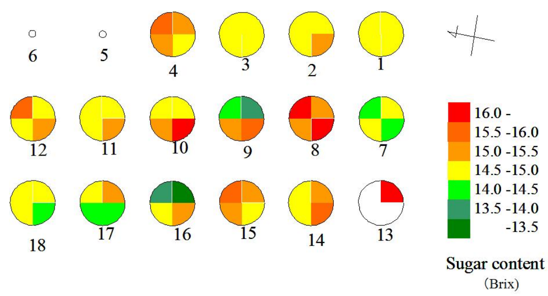


Fig. 9 Sugar content map

4. Sugar content map

Figure 9 shows average sugar contents of the fruit harvested on each tree part. It was observed that the sugar contents of fruit in each tree had a large variability in the map. From these results, it was considered that it is necessary to collect those information of each tree part, such as fruit yield and sugar content, for a long time in order to perform precision farming of orchard.

5. Location measurement

The results of robot location measurement error of the DGPS were shown by difference between the DGPS data and a tape measure as follows: average 38cm, maximum 144cm, and minimum 1cm. Although the maximum 144 cm error was shown, it was not so big problem, if a map of orchard with tree locations were used when this robot practically operates. If operators determined to harvest in order of the tree number, the GPS may not be always necessary. It was considered that the sensor might assist operator's tight operations and could reduce human mistakes.

IV Conclusions

A prototype mobile grading machine for citrus fruit was developed. This machine could collect yield and quality information, harvesting time and tree location while harvesting fruit. A database was created using the collected information to present the spatial variability of yield and quality, while the database may be used for a traceability. Using the database, both fruit yield and quality maps of each tree were also created. These maps indicate that a lot of information of yield and quality each citrus tree is visualized simply. Although the effectiveness and feasibility this grading machine utilization were shown, it was considered that improvement is necessary to enhance the speed of data collection and to reduce the processing time for the whole system.

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(Received: 8. January. 2010, Accepted: 15. November.2010)