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Development of automatic grading machine prototype for citrus using image processing

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Abstract

Citrus is one of fruits with high economic value in Indonesia. The production increases from year to year due to national fruits development program. However, postharvest equipment for citrus is very limited, leading to low technology utilization in the citrus postharvest handling. The objective of this research was to develop a real-time grading machine for citrus using an image sensor and processing unit for the quality evaluation of the citrus. The grading machine consist of a rotating fruit feeder, a belt conveyor, a color CCD camera placed in an image acquisition chamber, four openings each for a different grade of citrus, four collecting boxes to accommodate the graded citrus, a logic control panel, a computer with an image frame grabber, and a developed software to run all the installed hardware. The performance test for the grading machine then was conducted, and the result of citrus classification was observed visually to determine the performance of the machine. The testing results showed that the machine prototype could work properly, and the classification of citrus could be done based on the fruit size as conventionally done, added by the skin color of citrus as an improvement to the manual sortation.

Keywords: citrus, evaluation, image processing, automatic grading machine prototype

Introduction

Citrus is one of fruits with high economic value in Indonesia. The Government of Indonesia, through the Ministry of Agriculture, has a program to increase local citrus production to substitute import citrus, and later on to export high quality citrus to other countries. The citrus production has been increasing from year to year since 1999, and in 2006, the volume of production was about five times of that in 1999. The increase of citrus production was achieved due to the extensification and intensification programs. The extensification program increased the harvest area of 25. 2 thousand hectares in 1999 to 67.2 thousand hectares in 2006, while the intensification program was able to increase the production yield per hectare of citrus from 17.83 ton/ha in 1999 to 36.93 ton/ha in 2006. As a result, total production of citrus in Indonesia has increased from 449.5 thousand tons in 1999 to 2.5 million tons in 2006. The complete data was shown in Table 1.

In the near future, high quality product is a must to compete with the same product from other countries in the free trade , as well as in the domestic market. Exporting citrus means to meet the quality standard determined by importing countries, which might be higher than the standard applied for domestic market. Many countries apply Good Agricultural Practices (GAP) called in different names such as Malaysian Field Accreditation Scheme in Malaysia, Fresh Care in Australia, Approved Supplier Program in New Zealand, Assured Produce Scheme in England, and at the end is Global GAP. These regulations are mostly applied to the on-farm activities. There also had been many applications of robotic technologies to agricultural operations such as seedling, grafting, transplanting, spraying, harvesting, grading and other operations (Kondo and Ting, 1998). Kim et al. (2008) developed a hybrid system for harvesting heavy produce using Stewart platform parallel manipulator system in the field of agriculture, such as melon and watermelon. The main goal was to extend the limited workspace of the Stewart platform parallel manipulator to be applied in a multi-purpose robot, by adding two serial joints. It was concluded that the hybrid robot was effective and capable of handling heavy produce, and could be controlled precisely for use in harvesting. Chong et al. (2008b) developed a mobile fruit-grading robot for eggplant, equipped with dynamic location data logging system using odometry approach and integration of incremental motion information from wheel rotation. To get spatial position data, a rotary encoder attached to the wheel provided a location data by measuring traveled distance from a referenced point. The developed prototype worked satisfactorily with relatively low level failure rate despite irregularities in physical characteristics of the eggplant fruits. Qiao et al. (2005) used a mobile fruit grading robot for mapping yield and quality of sweet pepper by creating a database of yield and quality information from the field. The grading unit composed of an electric balance to weight the fruit and a machine vision system to grade fruits by image processing. The robot used three personal computers, one for controlling mechatronic systems, and the other two computers for machine vision. A local network was used for data transmission between the computers. Many researchers tried to use other high technology for agricultural products quality evaluation. Near infrared (NIR) technology used to predict sucrose content and malic acid in the fruit flesh so NIR can be used to measure non-destructively as an opposite of destructive analysis such as HPLC method to measure important content of fruit flesh. The research reports showed that NIR technology had been used to measure sucrose content without cutting off the fruit such as in tomato (Suparlan and Itoh, 2001), and peach (Kawano et al., 1992). In the developed countries, this technology had been applied in sorting and grading machine and other types of quality control machines for agricultural products including fruits. Machine vision today is one of the most essential sensors in many kinds of inspection systems. There are some grading facilities where more than 6 machine vision systems are working for an individual fruit on each line to measure the fruit size, color, shape, and defects. Since the images from the machine vision contain a lot of information and recent technologies on electronics and mechatronics are quickly progressing year by year, wider uses of the machine vision systems is expected in other bioproduction operations (Kondo, 2006). The use of image processing technology in automatic grading machine is expected to increase the accuracy of fruit sorting and grading based on its size and skin color. Fruit condition can be approached from object size to represent fruit size or weight, and the ripeness of the fruit can be represented by skin color, if there is correlation between the two. Another advantage is that image processing can be used also to detect defect such as dried latex in mango, that might be exist on the fruit surface and will downgrade the quality. Kondo (2006) described the problems of imaging the bioproducts and explained a method to avoid the problems. To avoid halation and surroundings reflection on a surface of bioproducts, a halogen lamp with a mirror and a polarizing filter for direct lighting were suggested. For indirect lighting, a dome with several halogen lamps was recommended to be held so that light from the lamps reached the fruit not directly but after reflected on the dome wall. The two techniques helped machine vision to capture images without halation and surroundings reflections. Grading system had been introduced to agricultural cooperative facilities in local production districts for orange, apple, peach, pear, tomato, eggplant, leek, asparagus, and other fruits and vegetables (Kondo, 2009). Recently, robotics and mechatronics had been developed, while machine vision and near infrared technologies had been also innovated (Kondo, 2006). Image processing technology had been applied to detect and locate cherry tomato among the leaves by selecting suitable color signals, and the result of detection was used to design cherry tomato harvesting robot (Kondo et al., 1996). Other examples of image processing application were mushroom harvesting robot (Reed et al., 1995) and watermelon harvesting robot (Tokuda et al., 1995) which utilized image processing to detect and locate mushroom and watermelon, respectively, that were ready to harvest. Kondo et al. (2009b) identified the fluorescent substance in mandarin fruit skin, and investigated the excitation wavelength of the substances to determine the most efficient lighting device specification. It was reported that the fluorescent substance extracted from the peel of mandarin orange had the basic structure of flavones as the mother nucleus. It was also reported that the excitation and fluorescent wavelength of fluorescent substance were 360-375 nm and 530-550 nm, respectively. Chong et al. (2008a) developed and evaluated features extraction algorithm extracting fruit features such as length, diameter, volume, curvature, color homogeneity, calyx color, calyx area, and surface defect. They also studied the feasibility of the developed algorithms and machine vision based grading machine in the grading eggplant fruit. The result of grading in the study showed machine vision could grade the elongated eggplant with an average agreement rate of 78.0%, which was considered feasible.

The objective of this research was to develop a real-time grading machine prototype for citrus using a CCD camera as an image sensor and image processing unit for quality evaluation from the acquired image of the citrus being evaluated.

Table 1. Increase of citrus production in Indonesia during the year of 1999 – 2006.

Year	Criteria		
	Harvest area (ha)	Production (ton)	Productivity (ton/ha)
1999	25 210	449 531	17.83
2000	37 120	644 052	17.35
2001	35 367	691 433	19.55
2002	47 824	968 132	20.24
2003	69 139	1 529 824	22.13
2004	66 071	1 994 760	30.19
2005	62 578	2 150 219	34.36
2006	67 152	2 479 852	36.93

Materials and methods

Five grades of Pontianak citrus (A, B, C, D, and E), obtained from a wholesaler in Kramatjati market, Jakarta were used for samples. At first, some important parameters of visual quality from all grades of citrus were studied. The images of citrus were captured and then an image processing computer program was developed to analyze the captured images. The results of image analysis were observed to determine whether there were parameters that correlate with the weight, sweetness, and firmness of citrus, that will be used for further quality evaluation in the automatic grading process. Visual parameters that figured the actual quality of citrus were then selected to be used for quality parameters to develop a real-time quality evaluation system for citrus. The flow chart to develope computer program was illustrated in Fig. 1. In the next step, hardware for the system was designed and manufactured. The gardening machine prototype consist of a rotating fruit feeder with two pneumatic solenoids that open and close one after another to release one fruit at a time, a belt conveyor to convey the fruit, a color CCD camera located in an image acquisition chamber with lighting system for image capturing, four openings with three pneumatic solenoids that open and close each accordingly to a different fruit grade of citrus, four collecting boxes for graded citrus, a logic control panel for computer interfacing, and a computer with an image frame grabber to process the captured image. The schematic diagram of the automatic grading machine prototype was shown in Fig. 2. Finally, the automatic grading machine prototype was run to test the prototype performance, and the result of citrus classification were also observed visually.

Results

The developed computer program to analyze the still image captured into 400 by 300 pixels image was shown in Fig. 3. The analysis of the area of citrus related to its size , and the skin color in RGB color model related to sweetness and ripeness of citrus were conducted. The relationship of the area of the object and the weight of citrus was analyzed as well as the fruit color, the sweetness checked by refractometer, and the firmness checked by penetrometer. Area of the object indicated close relationship with the weight of citrus (Fig. 4), however the citrus color did not have significant relationship to the fruit sweetness and firmness.

The sorting and grading machine was manufactured and the prototype was pictured in Fig. 5. The real-time image processing program utilized two visual parameters, size and skin color. The size was chosen based on the results of image analysis of captured images, which was found to have correlation with the weight of the citrus as discussed earlier,

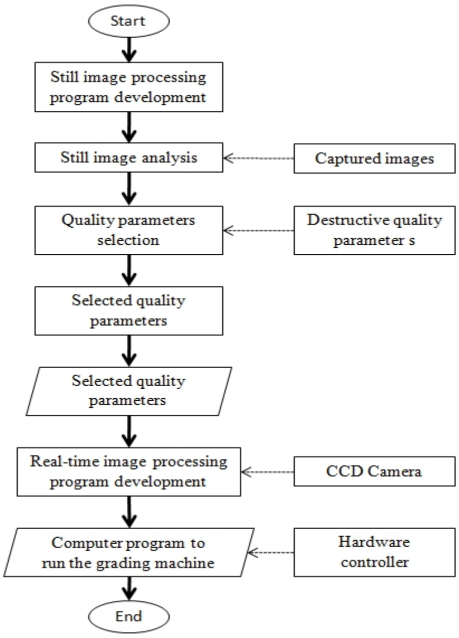

Fig 1. Flow-chart of developed computer program to run the grading machine prototype.

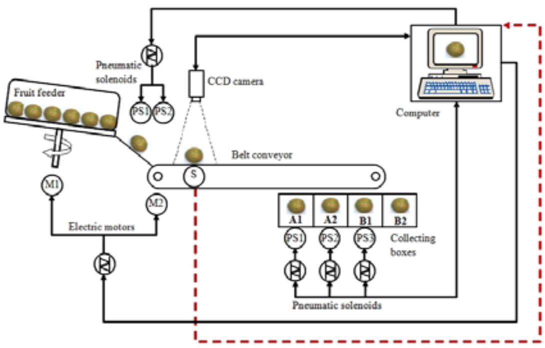

Fig 2. Schematic diagram of the automatic grading machine prototype.

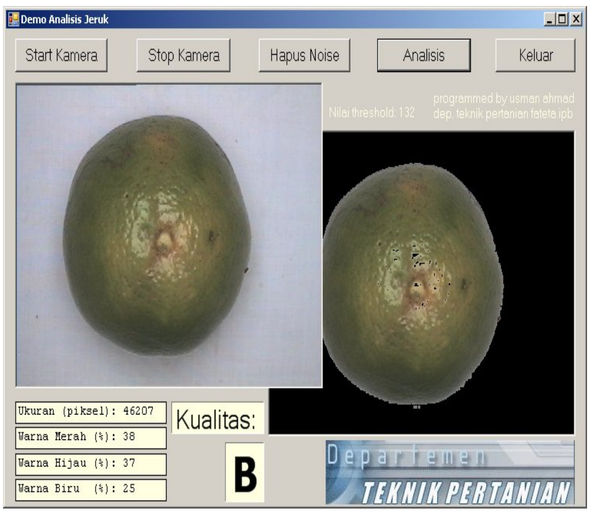

Fig 3. Still image processing program developed for image analysis

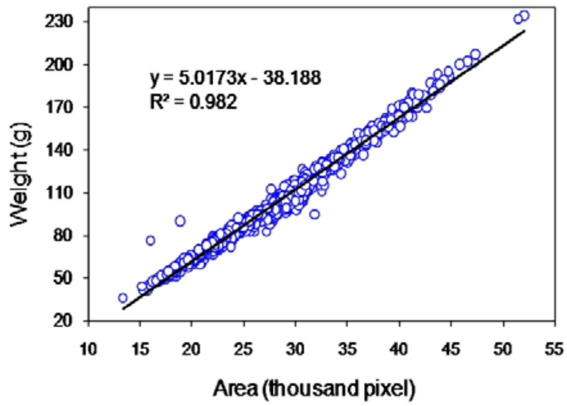

Fig 4. Relationship between weight of citrus with area of the object

Fig 5. Developed prototype for automatic sorting and grading machine of citrus

while the skin color was chosen to obtain uniformity visual appearance of each grade. The rotating fruit feeder and the belt conveyor were actuated by two different electrical motors, which were controlled by the developed computer program. Two pneumatic solenoids were used for the feeder that open and close one after another to release one fruit at a time, and three pneumatic solenoids were used to open and close the three openings for A1, A2, and B1 grades, which were controlled by the developed computer program. The fourth opening for B2 grade was left to be open. A photo sensor was placed in the image acquisition chamber to detect the passing fruit. Actually, citrus of a given size could be divided into three grades according to fruit color as shown in Fig. 6. But in this study, the computer program was modified to divide the fruit color into two grades because the prototype had only four openings for grading counting for two different sizes (A and B), and two different fruit colors (yellow and green), resulted in four grades.

Discussion

From the results of still image processing, area of the object was found useful to classify the fruits based on the size. Classification rules referred to Indonesia Standard for citrus (SNI 01-3165-1992) as shown in Table 2. The rules of classification then were inserted to the real-time image processing program. Although skin color had no correlation with taste, it was used to separate the citrus into color grades

Tabel 2. Criteria for weight of citrus at various grades onverted to pixel for area of the object in image

Class	Weight (g/pc)	Area of the object (pixel)
A	≥ 151	≥ 37919
B	101 – 150	27687 – 37715
C	51 – 100	17455 – 27483
D	≤ 50	≤ 17251

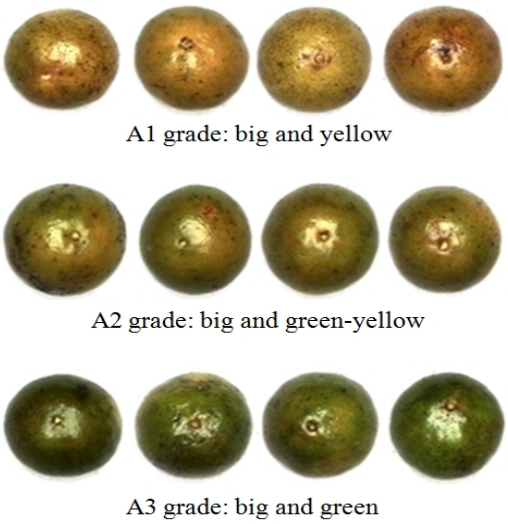

Fig 6. Citrus of the same size divided into three grades based on skin color.

for better visual display, in combination with the size grading. Though, by applying area of the object and skin color, the citrus was classified on the size and skin color to get different grades. For example, A1 grade was for big and yellow citrus, A2 grade for big and green-yellow, A3 grade for big and green, and so on, instead of based on the size only (Fig. 6). However, image of citrus was captured from top side only and this meant the judgment was still unfair. Using multiple cameras could solve the problem, but it would cause the system become more complex. Kondo et al. (2009a) developed a machine vision system for tomato cluster harvesting robot, which was expected to recognize and harvest tomato in cluster, instead of single fruit to speed the operation. The machine vision system consist of two identical color TV camera, four lighting devices, and two image capture boards. The system could recognize tomato cluster with a success rate about 65%, and needed to be improved mainly in stem recognition. The developed hardware components and the real-time image processing program were then put together into a single machine, and the prototype was tested to observe if all the hardware components worked well, and the result of citrus classification were also observed visually to determine the performance of the machine. All the installed hardware components were interrelated managed by a single computer program, which was also performing image processing for quality evaluation. Since the program for image processing also controlled the hardware, the result of image processing was immediately used as required information for judging each citrus quality, thus to separate them accordingly to their respective grade when they were transported through the belt conveyor. The graded citrus was removed by opening one of the three openings according to its quality and it would fall in to one of the collecting boxes, A1, A2, or B1 grade. For B2 grade, all the three openings would stay close and the citrus went through the fourth opening that was always open, as default condition. A photo sensor was placed in image capturing chamber, and would send a signal to the system to stop the electrical motor and halt the conveyor if there was a fruit in the chamber. When the belt conveyor stopped, CCD camera captured and analyzed the image of the fruit. The real-time image processing software then was synchronized to run all the hardware attached to the control system in the sorting and grading machine. During testing, only four output grades were considered: A1 (big and yellow), A2 (big and green), B1 (small and yellow), and B2 (small and green). In the future, if skin color was proved important for classification, more than four output grades could be considered and the modification of the system mechanism could be easily done. The results of performance testing showed that the automatic sorting and grading machine prototype for citrus worked accordingly to the designed function. However, the capacity was about 700 fruits/hr or approximately 7-8 kg/hr. This was typical problem for machine vision. To overcome this problem, researcher sometimes put multiple cameras to increase the accuracy and capacity. Kondo (2009b) reported that round-shape fruit such as citrus needed to be inspected from all sides to get accurate result of quality evaluation and a machine vision system that could suck 12 fruits by suction pads at a time and inspect all sides of the fruits by 12 TV cameras was developed. The system could process more than 9000 fruits per hour, which was quite reasonable for industry. Another problem that caused low performance of the machine was the slow movement of belt conveyor. Speeding up the electrical motor for the belt conveyor was possible to eliminate this problem, but the fruit tended to slip from the fruit position on the belt conveyor, and when it entered the image acquisition chamber it was not in the center of image frame anymore for camera to capture. Besides, the slip caused the ununiformity distance between two fruits and sometimes two fruits entered the image acquisition chamber at the same time which caused trouble in image processing. Rough surface belt conveyor to avoid the slip was needed to overcome this problem.

Conclusions

From this research, important information had been obtained and can be concluded as follows:

1. Image processing could be used to classify citrus into several quality classes based on the area of object to represent fruit size according to the quality standard issued by the government. Skin color could also be used as additional parameter to get more uniform color of citrus after classification.
2. The developed prototype for automatic grading machine with image processing as quality evaluation method had been performed accordingly to the designed function. However, the capacity was small and the prototype needed improvements before implementation in the field.

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