Eggplant Grading System Including Rotary Tray Assisted Machine Vision Whole Fruit Inspection

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Abstract

Because the capability of inspecting all sides of each fruit has become a highly desirable feature of a grading system, a new type of rotary tray was developed, as a part of a grading line, to flip a fruit over during quality inspection by color and monochrome machine vision systems. Each grading line consisted of 348 rotary trays and ran at a speed of 38.1 m/min. Since this grading machine had 6 lines, it was capable of sorting a total of 504,000 fruits per day. However, the processing rate of this grading system has reached only 85% of the expected level, because of the operator’s fruit unpacking rate. The automated packing and unpacking systems were considered to provide the grading system a fruit tracing capability in addition to labor saving.

[Keywords] eggplant, grading, automation, machine vision, post harvest, inspection, traceability

I Introduction

Because of the ever-growing need to select high quality food products at a fast speed, automated grading of agricultural products has gotten special attention among many farmers associations in Japan. The impetus for this trend can be attributed to the increased health awareness of consumers and the response by producers to the need of assuring product quality. Therefore, automatic inspection has been important in quality control of agricultural products that are delivered to the market. Unlike most industrial products, quality inspection of agricultural products presents specific challenges because some key quality features, such as appearance, cannot be easily defined (for example, some irregularity is known to be acceptable to customers).

Many fruit grading systems, especially for orange fruits, have been installed at cooperative grading facilities at district JAs (Japan Agricultural cooperatives) in Japan. There have been many reports on fruit grading systems with machine visions in the world (Aleixos et al., 2002; Miller and Delwiche, 1991; Okamura et al., 1991; Rehkugler and Throop, 1986; Sarkar and Wolfe, 1985; Tao et al., 1990). Fruit reception, preprocessing, sorting, packing and shipping are usually conducted for producers at the JAs in the respective districts. Recently, advances of fruit sorting technologies, such as image processing and near infrared analysis, have been used for precise fruit inspection (Kohno, 2003; Lu and Ariana, 2002; Sagara, 1998). It is, however, still uncommon to have machines that can inspect all sides of every fruit, because there is frequently some part of a fruit that is not “seen” by the inspection system.

An orange fruit grader which had a NIR system for measuring sugar content and granulation, X-ray imaging system for inspecting rind puffing, and six cameras for viewing all sides of each fruit was developed in Japan (Njoroge et al., 2002) and has been widely distributed in many agricultural districts, in west Japan, where large amounts of citrus fruits are produced. The grader had a roller pin-conveyor, which turned orange fruits over to expose all sides of a fruit. This mechanism can handle fruits whose skins are not easily damaged such as orange, kiwifruit, and potato; however, it is not suitable for peach, pear and apple, which have delicate skin and unstable fruit shape to be spun. A robot system which could hold 12 fruits at a time using suction pads attached to a three degree of freedom manipulator and inspect all sides of each fruit by 12 TV cameras was developed and installed
for inspection of deciduous fruits at a JA in Nagano Prefecture, Japan (Kondo, 2003).

To date, reports on all-side inspection systems for elongated fruits, such as eggplants and cucumbers, have been readily available. This article describes an eggplant fruit grading system installed at a JA in Okayama, Japan. The grading lines, equipped with rotary trays and machine vision capability, that are designed to flip over each eggplant fruit during inspection are emphasized.

## II Materials

Eggplant is a popular fruit vegetable in Japan. "Senryo" is the most widely cultivated eggplant variety in Nadasaki, Okayama, Japan. Its reputation of high quality fruit is well known. Its fruit has a dark purple color and soft skin with high gloss. The eggplants are usually produced in greenhouses and shipped to markets during the nine months from October to June every production year. There are 141 eggplant producers belonging to the JA. Their total cultivation area is more than 30 ha. The number of eggplant seedlings produced in a year is more than 200,000 in the district. On average, 170 ton of eggplant fruits are produced per ha of greenhouse area in a season, while the sales revenue reaches an annual total of approximately 13 million US dollars (1,300,000,000 Japanese yen).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Eggplant fruit weight and size classified for shipping</th>
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<tbody>
<tr>
<td></td>
<td>Weight (g)</td>
</tr>
<tr>
<td>S</td>
<td>&lt; 62</td>
</tr>
<tr>
<td>M</td>
<td>62-82</td>
</tr>
<tr>
<td>L</td>
<td>82-102</td>
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<tr>
<td>L2</td>
<td>102-122</td>
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<tr>
<td>L3</td>
<td>122-142</td>
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In the JA in Okayama, eggplant fruits are sorted into five sizes (S, M, L, 2L, and 3L) in weight or length and width as shown in Table 1 and four grades (A, B, C, and D). The criteria for grading eggplant fruits are mainly based on color, shape, size, bruise, disease, and gloss of skin. The fruits are shipped to various market places in Japan in three different size boxes (2 kg, 5 kg, and 10 kg) and plastic bags depending on market preference.

## III Eggplant grading system

A grading system installed at a JA in Okayama serves as a cooperative agricultural facility to automatically grade eggplants. The system mainly consists of several stations: 1. reception of containerized fruit from producers, 2. unpacking of containers and feeding of fruit to the conveyor line, 3. inspection of fruit appearance and surface gloss by TV cameras, 4. packing of fruit manually and labeling of boxes, and 5. closing, and palletizing of boxes for shipping to market. Figure 1 shows an overview of the entire grading system. Fruits shipped in containers from growers are received at the reception station (A) and conveyed to the fruit feeding point (C). Fruits are removed from containers and fed to the grading lines (D) through the inspection system (E) where fruit images are acquired by TV cameras. Based on the extracted features from the images, the fruits are sorted and sent to fruit packing lines (F). The fruits that are manually packed into boxes are sent to the box closure station (G) where the boxes are sealed. The boxes are sorted based on the labels on the boxes by machine vision before they are sent to a storage location (H). The boxes are conveyed to the box packing station (I) and then shipped in a palletized form (J).

Empty boxes are created at the box manufacturing station on the 2nd floor (B). They are provided to pack-
ing operators at the fruit packing lines through over-head lines above the fruit conveyer lines. The inspection system (E) contains innovative rotary tray assisted machine vision systems that enable the inspect of all sides of each eggplant fruit. The purpose of this paper is to describe the key components of the grading system. Emphasis is given to the rotary tray assisted machine vision fruit inspection system.

1. Fruit reception

Figure 2 shows fruit containers at the reception station where fruits are deposited by growers. Figure 3 shows an example of a container holding fruits that are to be inspected and graded using the automated system. Eggplant growers are expected to have pre-screened their fruits before the fruits are delivered to the automatic grading facility. The prescreening result is checked by an operator at the fruit reception station. After that, a JA assigned grower number, the number of containers, their weight, and the date and time are entered into a database. There are 141 eggplant growers in the district managed by the JA. On average, over a nine month production period, each grower delivers approximately 150 kg of eggplants per day.

2. Fruit transfer from container to conveyor

Fruit containers from the reception station are sent to six fruit feeding lines through free roller conveyors. At each line, an operator removes the containers from the roller conveyor and manually picks fruits from each container and place them on a soft sponge padded roller conveyor. The soft sponge on the rollers prevents fruits from being damaged during conveying. Each roller on the conveyor has a diameter of 20 mm and a length of 300 mm without sponge padding. The sponge padding increases the roller diameter to 40 mm. The conveyor moves at a speed of 12 m/min. Normally, each operator is capable of handling more than four fruits at a time when transferring them from a container to the conveyor. Each fruit feeding line is followed by a fruit singulating conveyor that transports each pre-oriented fruit individually onto a rotary tray. A series of connected rotary trays forms a grading conveyor. A rotary tray presents two opposite sides of a fruit to two separate machine vision systems at two locations along a grading conveyor, as well as deposits the fruit onto one of the sorting conveyors based on the fruit grade determined by the machine vision systems (Figure 4). The machine vision system consists of three color cameras and two monochrome cameras at each inspection systems. A NIR camera is used for checking orientation and position of the fruit transported from the singulating conveyor. Improper oriented fruits are supposed to be immediately released on a returning conveyor which brings back to the section of fruit feeding.

Figure 5 shows fruits that are being moved towards the singulating conveyor. The brush partitions on the singulating conveyor separates each fruit onto a rotary tray of the grading conveyor (Figure 6). The fruit feeding conveyor, singulating conveyor, and grading conveyor are driven by the same motor. The timing of fruit delivery from the fruit feeding conveyor to the singulating conveyor is synchronized with that from the singulating conveyor to the rotary tray by use of sprockets as reduction gears.

When a fruit is placed onto a rotary tray, its orientation may not be appropriate for machine vision inspection. Some part of the fruit may be placed outside of the rotary tray and the fruit orientation may be changed due to the combined effect of the irregularity of the fruit shape and the dropping action. The fruits may be out of the field angle of the machine vision systems and the rotary tray may not be able to close. A NIR camera is used to check the fruit position and orientation on a rotary tray as shown in Figure 4. The camera is connected to an image processing unit and the information obtained from an image is sent to a host PC through LAN. Improperly orientated fruits will be dropped before approaching color TV grading.
3. Inspection by color and monochrome cameras

After all the eggplant fruits are properly placed on rotary trays, their appearance and surface gloss are inspected by both color and monochrome machine vision systems. Two sets of machine vision systems with each set containing three color cameras and two monochrome cameras are used along the grading conveyor. One set is used to inspect one side of a fruit and the other set is used to inspect the opposite side of the fruit. The fruit is turned over by its holding rotary tray while traveling between the two sets of machine vision systems (Figure 4). Color cameras A and B capture fruit images from $+45^\circ$ and $-45^\circ$ angles from normal above a fruit. Color camera C acquires an image of the end of the fruit because this part of the fruit is not covered by cameras A and B. This image acquisition process is repeated using color cameras D, E, and F. The six color cameras are programmed to measure color, size, shape, and defect of each fruit.

One of the most important defects of an eggplant is “dullness” of fruit surface. Dull surfaces frequently indicate that there is firm flesh under the skin due to slower growth rate of the fruit. A fruit with firm flesh is considered low quality. Monochrome cameras A and B are used to measure the extent of gloss on a fruit surface from its calyx side and fruit end side, respectively. Kondo and Kakemizu (2000) demonstrated that a pair of monochrome cameras and three long straight lighting devices enabled to measure the extent of gloss on a fruit surface. An identical set of the
monochrome cameras is used after a fruit is turned over.

The RGB signals from the color cameras are captured by image grabber boards. Three image grabber boards and a DIO (Digital Input/Output) board are installed in a microcomputer; therefore, the images from three color cameras are processed by one CPU. The signals from two monochrome cameras are acquired by the R and G channels of image grabber boards. Two image grabber boards and a DIO board are installed in another microcomputer; therefore, a single CPU is used to work with four monochrome cameras. The data from all the cameras are sent to a host microcomputer. The host computer issues a command, based on a set of predetermined image feature criteria, to each rotary tray regarding which of the sorting conveyors the inspected fruit is to be released to.

4. Rotary trays

As mentioned above, the grading conveyor consists of a series of rotary trays. Each rotary tray is capable of holding and presenting an eggplant fruit to be inspected by two identical machine vision systems at two different locations along the grading conveyor. It is also capable of making a 180° upside-down rotation while traveling between the two machine vision systems. The purpose of this rotation is to allow image acquisition of two opposite sides of a fruit.

The rotary tray was specially designed for the "Senryo" eggplant grading facility and mainly consisted of two cover plates (top and bottom of the tray) and other side plates. Figure 7 shows the top view of a cover plate and a front view of the entire rotary tray on the grading conveyor. A cover plate is made up of one center plate and two guide plates. The center plate is pressed by two flat springs so that it can accommodate various sizes of eggplant fruits. The fruit sizes may vary from 30mm to 80mm in diameter. The flat spring applies 5N of force when pressing on an 80 mm diameter fruit. A cover plate is lined on its inner side by sponges to provide stability when holing an eggplant fruit.

The front view in Figure 7 is a composite drawing that also illustrates when the cover plate is open (left half of the view) and closed (right half). Figure 8 shows three different plates (Z shaped, polygon, and circular) used on each side of a rotary tray. Figure 7 shows the relative locations of the three plates (viewed from their edges), as well as a short main shaft on each side of the rotary tray (the main shafts terminate at the polygon plates). Referring to Figure 8, the circular plate that is affixed to the main shaft of a rotary tray serves to rotate the tray 180° at a time. The polygon plate is also affixed to the main shaft and rotates together with the circular plate (i.e. there is no relative motion between the circular plate and the polygon plate at all times). The two cover plates of a rotary tray are connected on each side by a Z shaped resinous plate and two metal fittings with long elliptic slots as shown in Figure 8. The center shaft of a cover plate slides along the elliptic slots when the cover plate is in the process of opening or closing. One of the two edge shafts of a cover plate is inserted into a hole on a Z shaped plate (at S-A1 or S-B1). During the opening and closing actions of the cover plates, there are relative motions between the cover plates and the Z shaped plate, as well as between the Z shaped plate and the polygon plate. There are four locations (S-A1, Z1, S-B1, and Z2) on the Z shaped plate and two locations on the two cover plates (S-A2 and S-B2) serving as catch points. Depending on the geometric status of the rotary tray, two to four of the catch points S-A1, S-B1, S-A2, and S-B2 may rest on several of the C shaped notches (C-A1, C-B1, C-A2, and C-B2). The movement of C shaped notches is governed by their respective cams. There are moments that catch point Z1 may rest on S-B2 (and likewise Z2 may rest on S-A2) to totally expose the eggplant to the machine vision...
system. When the entire rotary tray is being turned over 180°, both cover plates are in the closed position and the entire assembly of cover plates, Z shaped plates, polygon plates, and circular plates rotates together as one single unit. At this moment, S-A1, S-A2, S-B1, and S-B2 are resting on C-A1, C-A2, C-B1, and C-B2, respectively. A total of 22 spiral springs are used for all the cams and movable parts on the two sets of side plates (eleven on each set: one on circular plate, eight on polygon plate, and two on Z shaped plate).

Figures 9 shows a series of stages depicting the motions of a rotary tray. Stage (a) is when the rotary tray is ready to accept an eggplant delivered from the singulating conveyor. The fruit will land on the bottom cover plate B and be presented to the first machine vision system. Stages (b) and (c) show that cover plate A is being lifted up by the Z shaped plates and placed over cover plate B after image acquisition. The circular plates and polygon plate stay stationary at this time. Stages (d) and (e) show a 180° turn of the entire rotary tray assembly. At the end of the rotation, cover plate B assumes the top position. Stages (f) and (g) illustrates how cover plate B is opened and dropped in order to expose the “opposite side” of the eggplant to the second machine vision system. Stage (g) is in a similar posture as Stage (a) except that the positions of cover plates A and B are swapped. Stage (h) shows the posture of a rotary tray when an eggplant is being dropped on to a particular sorting conveyor based on the decision made by the machine vision grading algorithm.

Figure 10 is a schematic diagram showing a series of rotary tray motions when traveling through a grading line. At point (1) a rotary tray assumes a posture depicted by Stage (a) in Figure 9. It maintains the same posture that enables the presentation of an eggplant to the first set of inspection cameras. After that, the Z shaped plates of the tray is gradually lifted up by a pair of lifting guides until point (2). At the same time, the open cover plate of the tray is beginning to close due to the motion of the Z shaped plates. A rotary pusher, driven by a main motor that powers
the grading line, along with a downward guide forces the cover plate to close completely at point (3). At this time, the Z shaped plates and the cover plates are tightly locked on the catch points on the polygon plates. The entire rotary tray starts to rotate by 180° through points (4) and (5). This rotation is caused by the releasing of cams that are locking the circular plates (Figure 8). This in turn allows the twin rollers (Figure 7) that are concentrically attached to the outside of circular plates to roll by contact on the surface of the guide track. This rotational motion stops when the circulate plates are reengaged by the cams (180°
later). At this point, a pair of clicks trigger the cams on the polygon plates to free the upper cover plate and the Z shaped plates from the catch points. The upper cover plate is then opened by the lowering action of the Z shaped plates through points (6) and (7). The eggplant is now ready for inspection by the second set of cameras. After the second inspection, the open cover plate is lifted up by another pair of lifting guides. The tray stays in this posture until it arrives above an appropriate sorting conveyor determined by the result of inspections. The lower cover plate will then be opened, by a pair of rotary solenoids hitting the left cams of polygon plates at point (8), to release the eggplant (Kamata, 2000). After releasing the eggplant, the lower cover plates are closed by another pair of lifting guides placed after each sorting conveyor. This rotary tray is then returned to point (1) to get ready for receiving an eggplant from the singulating conveyor and repeat the cycle as shown in Figure 10.

The total length of the grading line depends on the number of the sorting conveyors that are needed to separate eggplants into different quality grades. The grading system in Okayama has 14 sorting conveyors (seven pairs of sorting conveyors) and the distance between the pairs is 3,750 mm. The total length of the grading line is 32,220 mm which requires 348 rotary trays per line.

5. Fruit packing and labeling

Fruits released from rotary trays are conveyed by the sorting conveyors to human operators who are in charge of packing the fruits into boxes. Figure 11 shows a 2 kg box filled with eggplant fruits. The dimensions of a 2 kg box are 475, 240, and 75 mm in length, width and height. The number of fruits packed in a 2 kg box depends on the fruit size: 16 fruits for size 2L and 3L, 25 for L, 30 for M, and 35 for S. The 2 kg boxes are the most popular for eggplant shipment in Japan; however, 5 kg and 10 kg boxes are also used. These boxes are mechanically made on-site (on the second floor of the grading facility as shown in Figure 1). During the busy season (April and May), 5 packing operators are needed along each sorting conveyor. This means that a total of 50 to 70 packing operators are on duty at any given time when the grading system is in operation. The time required to pack a box depends on operator's skill and fruit size. On average, it takes 30 to 40 seconds to pack a 2 kg box.

After a box has been packed with fruits, red color stamps are applied to proper places on two labels printed on one side of the box to indicate the grade and size of the fruits, as well as the identification number of the packing operator (Figure 12). The grade and size are marked on the left hand side (L enclosed by a circle in this example). The numbers and letters (S, M, L, 2L, and 3L) are for sizes. The enclosing square, enclosing circle, and prefix A are for grades A, B, and C, respectively. D grade fruits are packed into plastic bags. The operator's identification number is shown by the two marked digits (28 in this example) on the right hand side. The capacity of the box (2 kg in this example) is also indicated on the box.

6. Box closure and transfer

The packed boxes are sent from the sorting conveyors onto two conveyors that deliver the boxes through box closing and sealing machines. As soon as five boxes are stored in a lane at the storage, they are automatically moved to a final stage. The five boxes are transferred onto a palette after they are stacked and strung together at the box packing station.

IV Results and discussions

1. Performance of grading system

The grading system started working from 2002 and it was found that the rotary tray conveying system made it possible to inspect two opposite sides of each fruit by two sets of machine vision systems. Since the grading conveyor travels at 38.1 m/min and every
rotary tray occupies a space of 190.5 mm in the traveling direction, it is possible, by design, to process 3.3 fruits per second per grading line. This facility, with 6 grading lines, has a rated capacity of inspecting 504,000 fruits per day (based on seven hours of daily operation). At this rate, 20,160 boxes weighing 40.320 t per day may be inspected and shipped from the facility (assuming that all fruits are of L size and are packed in 2 kg boxes). This design capacity is expected to be able to handle the day to day fluctuation in eggplant production since it is nearly double of the average production rate of 21.15 t/day (i.e. 150 kg/day per producer x 141 producers). However, based on the result of actual operation, the processing rate of this grading system has reached only 34 t per day, because the operator's fruit unpacking rate at the feeding station was only 85% of the expected level.

2. Further automation

A total of four conveying devices are used to handle individual fruits in this grading system. They are fruit feeding conveyor, singulating conveyor, grading conveyor with rotary trays, and sorting conveyor. This leaves two key operations for further development in automation within the grading system: (1) picking fruits from containers and placing them on to the feeding conveyors (i.e. fruit feeding operation) and (2) removing fruits from sorting conveyors and packing them into shipping boxes (i.e. fruit packing operation). Of the two operations, automating the latter operation will enable more labor saving, as well as provide a means of recording information on the quality of each fruit while it is placed in a shipping box. This will in turn improve the traceability of eggplants in the food distribution system, which is increasingly important in addressing the issues related to food quality and safety.

References


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コメント

【読者のコメント】
システムの期待処理能力に対して、実際の処理能力が下回ったのは、作業者の unpacking 作業に依存していたようですが、この課題に対する具体的な解決策があるのでしょうか。

Packing 作業の自動化とトレーサビリティ情報を加えるためにも推進するような記述があります。トレーサビリティ情報の付加には、unpacking の部分の自動化も重要と思われますが、いかがお考えでしょうか？

【コメントに対する著者の見解】
おっしゃるとおり、unpacking 作業もトレーサビリティ情報付加のためには自動化が必要です。当初は、マシンビジョンならびにロボット 3 台程度を用いて unpacking 作業とトレイへ loading する作業をさせるため、予備実験も行いましたが、簡単な利用できるロボットの機構上の制約、コスト、作業効率の問題で実現していません。ロボットでコンテナからのハンドリングが可能となれば、別途丸形果実用に開発された選果ロボットのようにロボットが果実を保持したまま、外観計測を行うことも考えられ、システム全体が大きく変わる可能性を含んでいると思います。

【読者のコメント】
本システムが実際の共同集荷場にすでに導入されているため、本論文は非常に説得力がある。また設計作業能力の 85％ とはいえ人間一人の数十倍もの作業スピードを期待できる能力を実現している点も高く評価すべきものである。基礎研究を行う研究者に対して現場を意識させ、現場につながる技術開発あるいはプレゼンテーションの必要性を訴えていると思われる。

【コメントに対する著者の見解】
高い評価ありがとうございます。今後は、本論で記述いたしましたが、果実供給部ならびに箱詰め部の自動化、ロボット化の検討が必要と考えています。このような選果施設の現場においては、まずその施設が成り立っている地域の診断を行った上で、ロボット、マシンビジョンなどのハイテクロジを、地域ニーズに合わせて適切に導入することが必要です。今後、そのような地域診断に基づくテラーメード型ロボットならびに新技術の導入が、成功の鍵と言えるでしょうし、そのような研究が増加することを期待しています。