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Review

Automation on fruit and vegetable grading system and food traceability

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In recent ten years, operations in grading systems for fruits and vegetables became highly automated with mechatronics, and robotics technologies. Especially, machine vision systems and near infrared inspection systems have been introduced to many grading facilities with mechanisms for inspecting all sides of fruits and vegetables. In this paper, automation technologies of several types of fruit and vegetable grading systems are described, while their potentials to give producers and consumers product information are discussed from a view point of food traceability.

Introduction

Because of the ever-growing need to supply high quality food products within a short time and of demanding recent food safety and security, roles of automated grading of agricultural products are increasing among many farmers associations in many countries. For example, vision based online fruit grading systems are common in European countries and in USA (Aleixos, Blasco, Navarron, & Molto, 2002; Guedalia, 1997; Heinemann, Varghese, Morrow, Sommer, & Crassweller, 1995; Leemans, Magein, & Destain, 1998; Miller & Drouillard, 1997; Moltó, Blasco, & Benlloch, 1998; Rehkugler & Throop, 1986; Sarkar & Wolfe, 1985), while each orange is graded by 6 color cameras and a NIR inspector at more than 100 facilities in Japan (Njoroge *et al.*, 2002; Sagara, 1998). In addition, many fruit grading facilities were constructed in the last two years in Korea. The impetus for this trend can be attributed to increased awareness by consumers about their health well-being and a response by producers on the need to provide quality and safety guaranteed products. Agricultural products have uncertain shape and different size and colors even if they are same variety unlike most industrial products. Quality inspection of such 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.

Nondestructive inspection methods have been widely distributed in this post-harvest field with mechatronics. Especially, machine vision technologies have been comprehensively distributed even in our life such as cell phones and automobiles and become to play the important role of quality control for agricultural products with other automation technologies. It can be said that operations in grading systems for fruits and vegetables became highly automated with the machine vision, near infrared, and robotics technologies in these ten years. Not only in newly developed grading facilities with robots but also in conventional mechanism facilities, the technologies have been introduced.

Another effect which the automation technologies are introduced in many grading facilities is to guarantee safety and security of food, because automation systems can record much grading information on agricultural product qualities. They can measure color, size, shape, external defect, sugar content, acidity, and other internal qualities (Njoroge *et al.*, 2002). In addition, producers' operation records (for example, when, where, and what kind of chemicals were sprayed, what kind of fertilizers were conducted) can be accumulated in a database. This information is disclosed to consumers for risk management and for food traceability as well as to producers for precision agriculture to get higher quality larger amount of yield with minimum input. In this paper, an orange grading system, an eggplant grading system, a leek preprocessing and grading system, and a robotic grading system are described, because they are different types of product shapes and properties that make different processing in their grading procedures. Simultaneously, traceability systems accompanied with the grading systems are discussed.

Orange grading system

Orange grading operations have been mechanized from a couple of decades. At the first stage of the mechanization, plates with holes of orange fruit sizes were used for sorting (FAO, 1989; Reyes, 1988). Machine vision and near infrared

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(NIR) technologies have been utilized and improved with engineering design to convey fruits to detect fruit size, shape, color, sugar content and acidity since about ten years ago (Kohno, 2003; Lu & Ariana, 2002). The system inspects fruit with color CCD cameras installed at six different positions on a line to provide all side fruit images with lighting devices. The light devices are made by halogen lamps or LEDs fitted with PL (polarizing) filters to eliminated halation on glossy fruit surfaces (Kondo, 2006). The near infrared inspection systems consist of halogen lamps and a spectrophotometer to analyze absorption bands of transmissive light from fruits. Furthermore, an X-ray imaging system is sometimes installed on each line to find internal defects such as rind-puffing (Njoroge *et al*., 2002).

Labor intensive work of hand-sorting, traditionally considered the only accurate method for fruit grading is completely eliminated by having a fully automated conveyance system that ensures that oranges are fed to the sensor at a constant speed. Unmanned line inspection has helped to solve the problem of labor shortage caused by advanced age of populations common at most production areas and shortage of successors. Specially designed roller pins, turn over the fruit at 180° ensuring that a full view is acquired by the cameras. Basically two inspection stages of the system can be identified; external fruit inspection and internal fruit inspection stage.

Fig. 1 shows a whole inspection system on an orange grading line. After dumping containers filled by oranges, fruits are singulated by a singulating conveyor. Singulated fruits are sent to the NIR inspection system (transmissive type) to measure sugar content (brix equivalent) and acidity. In addition, it can measure the granulation level of the fruit which indicates the inside water content of fruit. The second inspection is X-ray imaging for internal structural quality. Rind-puffing, a biological defect is detected from the image.

In the external inspection stage, color images from six machine vision sets under random trigger mode, are copied to the image grabber boards fitted on the image processing computers whenever a trigger occurs. The four cameras are set for acquiring side images, while the two cameras are from top. The final camera acquires a top image of each fruit after fruit turning over because both top and bottom sides are inspected. All the images are processed using specific algorithms for detecting image features of color, size, shape, and external defect. Output signals from image processing are transmitted to the judgment computer where the final grading decision (usually into several grades and several sizes) is made based on fruit features and internal quality measurements.

Image PCs process to extract features from acquired color images as follows:

1) RGB composite data (R, G, and B) are converted into a simple chromaticity (R′, G′, and B′) and into color value (C) as Eqs. (1)–(4).

$$R' = R/(R+G+B) \tag{1}$$

$$G' = G/(R+G+B) \tag{2}$$

$$B' = B/(R+G+B) \tag{3}$$

$$C = (R-G)/(R+G) \tag{4}$$

2) fruit size is measured by area occupying fruit and by a equivalent circle diameter after binarization based on the color information.
3) fruit shape is measured by several evaluation indices such as circularity factor, complexity, occupancy, ratio between maximum length and breadth, deformation from gravity center, degree of symmetry, and others.
4) defect detection can be a challenging algorithm, because there are defects even human cannot find easily such as a rot. However, usual way is two steps: the first step is discrimination of healthy parts from the other parts based on color information. The second step is judgment based on sizes and positions of extracted part by edge detection operators. Using this software, all fruits are graded into three or four grades

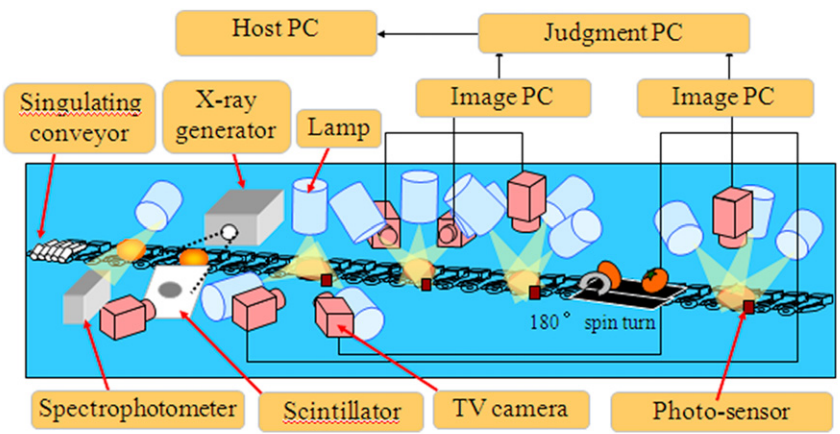

Fig. 1. A whole orange fruit grading system on a line manufactured by SI Seiko Co., Ltd., Japan.

(for example, A, B, C, and D) and into several sizes (SS, S, M, L, LL). This means that 20 sorting lines are necessary in case of 4 grades and 5 sizes.

The line speed is usually 60 m/min and 5 or 6 fruits are processed in a second per line. The image resolution is 0.3 mm/pixel (VGA class) and 80–100 ms per three images are necessary including image acquisition time. An important feature of the system design is that it is adaptable to the inspection of many other products such as potato, tomato, persimmon, and other round shape fruits with adjustments only to the processing codes. This type of conveyors and grading systems are the most widely distributed in the world so far, because it can give product information human cannot measure. Human operator number was drastically reduced after introducing this system, but several operators are still working due to checking the defects TV cameras and NIR inspector cannot detect. Although this system performance is still inferior to human ability to detect defects, this has much superior on measure fruit color and size.

Eggplant grading system

A new type of elongated fruit grading system, which inspects not only size, shape, color, and defects but also gloss of fruit surface, was introduced to a farmer's association, at Okayama, Japan (Kondo *et al.*, 2007) as a cooperative agricultural facility. 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.

Its grading line consisted of feeding, singulating, grading, and sorting conveyors. Two sets of machine vision systems (3 color cameras and 2 monochrome cameras each set) for grading fruits are installed in it before and after fruits flipping over. A rotary tray was developed (Kondo *et al.*, 2007), as a part of a grading line, to flip a fruit over during quality inspection by 6 color and 4 monochrome machine vision systems.

The color TV cameras measured fruit color, size, shape, and defect as well as the other cameras in grading systems (Chong *et al.*, 2008). Two top cameras were arranged at 90 degree-different locations and the other camera was set at fruit end side to inspect top half of fruit. Software algorithms for measuring color, size, and defect except shape were basically similar with those of the orange grading system. Extracted features on shape after binarization were average of fruit diameters, difference between maximum and minimum diameters letter C bend, letter S bend, and others. As an internal quality inspection, the two sets of monochrome cameras measured fruit surface gloss with three lighting rods (Chong *et al.*, 2008). It is said that more gloss surface fruit is more fresh and soft (higher grades), because cell division speed is higher when it is on tree before harvesting, while slower cell division makes firm fruit with dull surface involving an internal defect. Two cameras were set at calyx side and at fruit end side. All those cameras were VGA class and their resolutions were 0.4 mm/pixel. Fig. 2 shows monochrome image examples from the both sides. From the images, it can be observed that glossy fruit shows very clear boarder line of the lighting rods on its surface, while dull fruit does ambiguous lines. To digitize the degree of gloss, actual calculation of dispersion was conducted within each red ROI (red color region of interest) as shown in Fig. 2. (For interpretation of the references to color in this paragraph, the reader is referred to the web version of this article.)

Based on the color and monochrome images, fruits were sorted into five sizes and four grades. To set the sorting

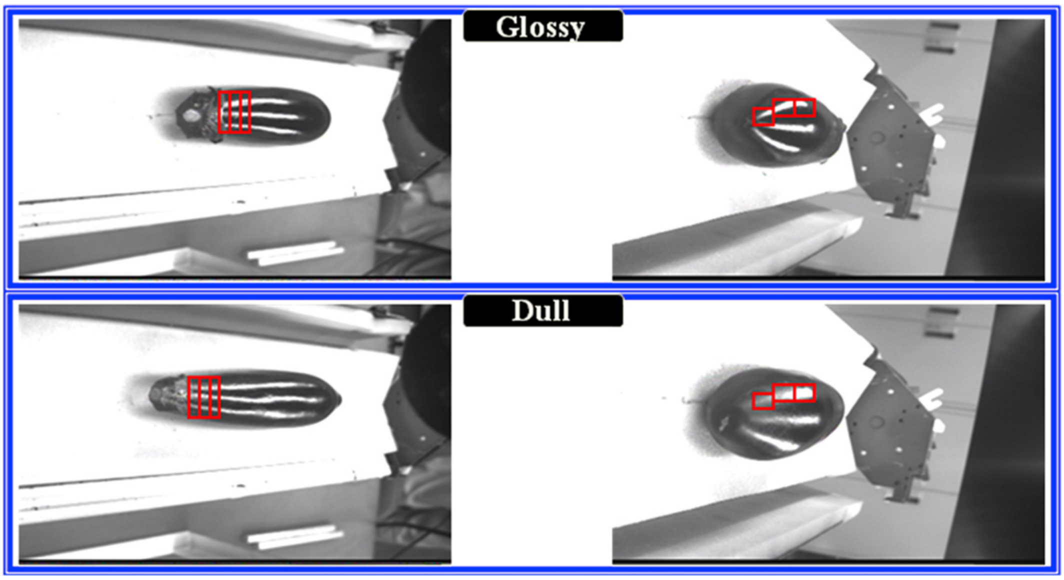

Fig. 2. Monochrome images of two different gloss fruits on rotary trays (left: calyx side, right: fruit end side, upper: glossy fruit, bottom: dull fruit).

lines, it was required that the grading line consisted of 348 rotary trays and the line length was about 30 m. Since this grading machine had 6 lines at an introduced facility and each line speed was 38.1 m/min, it was capable of sorting a total of 504,000 fruits per day. This translated into an estimated potential processing capacity of 40.320 t per day. A couple of operators work for fruit feeding each line and 50–70 operators pack fruits into boxes. This packing operation is still so laborious that takes 30–40 s for packing a 2 kg box.

Leek preprocessing and grading system

Leeks are one of the longest vegetables and often grow in sandy fields. They are transported immediately from the fields to agricultural facilities. Because soils or sands are attached to their surface, they should be peeled as well as their roots and leaves are cut before grading. To peel outer skin properly, it is required to cut the plate between stem and root, which locates at the end of the stem. Because the plate is a couple of mm thickness, mechanical precise position determination is essential. In case that it is cut at a stem side position, inner stalks come out and market value becomes down because inner stalks dry out soon. On the other side, if it is cut at a root side position, it is not able to easily peel the skin because the outer skin is stopped peeling at the plate. Since the plate positions at the end of the stem, it is necessary to discriminate the stem from root whose color is whitish and similar with stem color. It was found, however, that spectral reflectance of stem was higher than that of root in ultraviolet region (UV-A). From these reason, two identical monochrome TV cameras (B/W cameras) whose sensitivities include ultraviolet region to detect the plate were set as shown in Fig. 3 for leek skin peeling.

A color TV camera was also necessary for detecting a point between leaves and stem in order to start blowing for peeling by compressor air pressure in preprocessing operations, because a color of the point was a boarder between green and white colors. Peeling operation procedure of a preprocessing machine is shown in Fig. 3. Several human Operators manually feed leeks on the line of the preprocessing machine after removing outer leaves. Although the figure does not show, leeks are automatically cut into about 60 cm length on the line. Sandy soils are attached to the leek surfaces fed to the machine, because they are transported immediately from fields. Before detecting the plate between stem and root, sandy soils attached to lower stem are blown away by air pressure and long roots are roughly cut. To precisely cut at the plate between stem and root, twice trials are conducted with two sets of B/W cameras and servo-cutters as shown in the upper layer (Root cutting section) of Fig. 3. During the cutting operation, a color camera detects a point between green leaves and white stem to peel outer skin. Based on an image from the color camera, the point of each leek position is adjusted on tray to blow at a proper position, while leaves are held by a holding plate as shown in the lower layer (Peeling section) of Fig. 3. Then, high pressure air from a compressor is blown to the points of 21 leeks through nozzles and they are peeled out at a time by moving nozzles with peeling plates.

After peeling, three B/W cameras measure white stem width and bend and leaf number, while two color cameras detect stem length and defects. Two right images of two B/W cameras as shown in upper Fig. 4 were acquired at

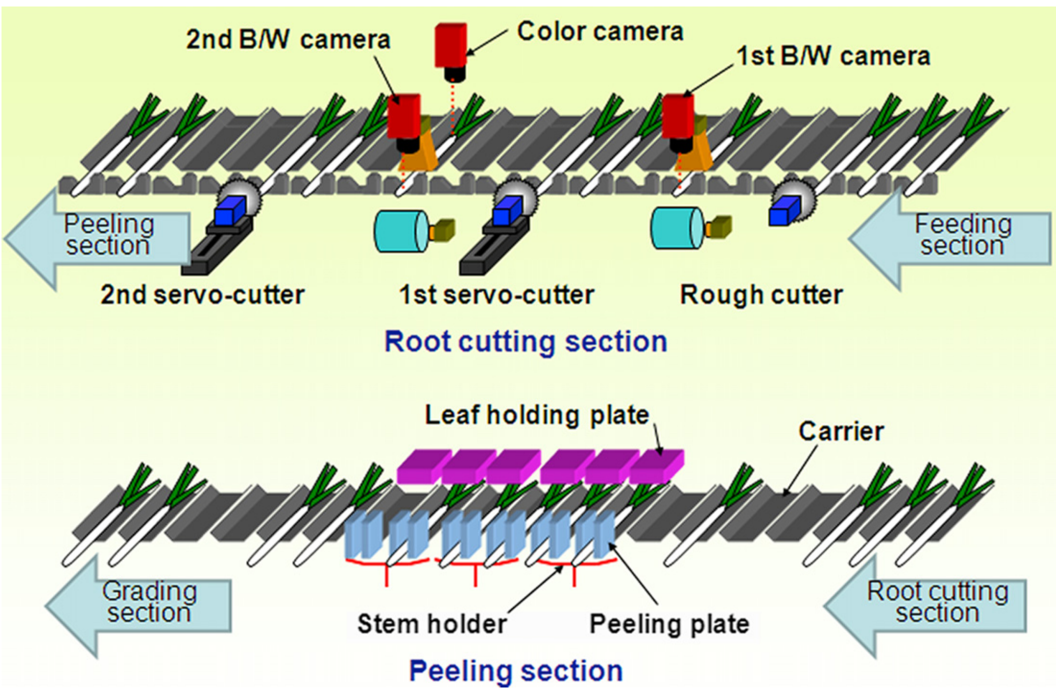

Fig. 3. Root cutting section (upper) and peeling section (bottom) in a leek preprocessing and grading facility manufactured by SI Seiko Co., Ltd., Japan.

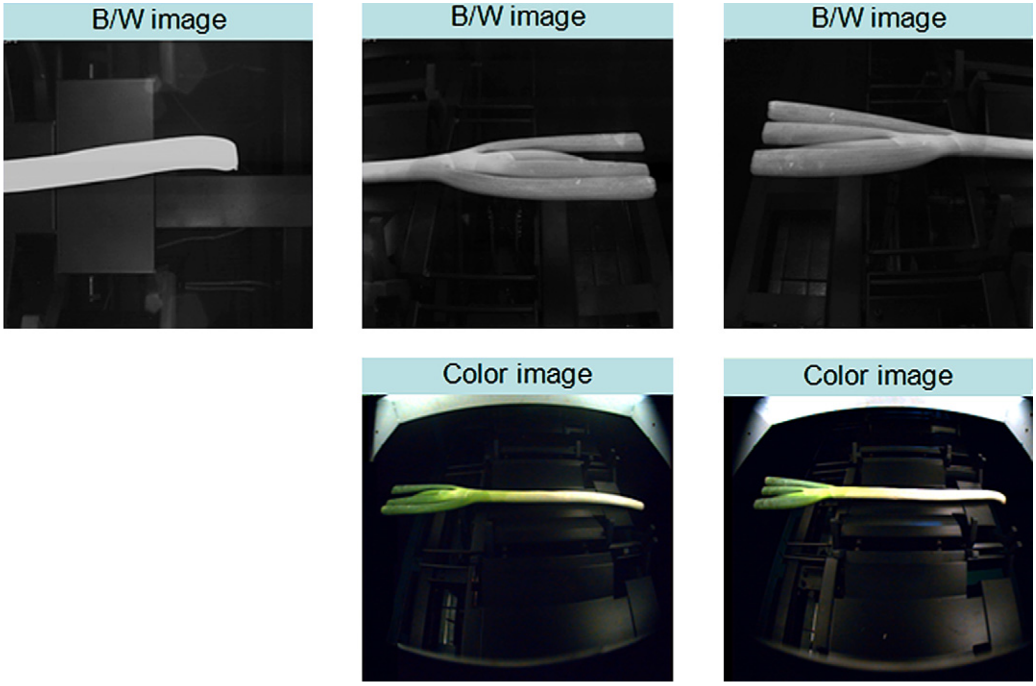

Fig. 4. Images at grading section.

two different-angled locations as well as two color images in bottom Fig. 4, because only one camera cannot exactly measure stem bend and defects. In a different model of this grading system, another set of cameras is arranged to acquire another set of images from bottom after leeks are turned over by a hanging mechanism. Each leek weight can be measured by a load cell installed to a tray. Based on the inspection results and weight, they are graded into a couple of levels. The most important evaluation indices are white stem length and width, because the longer white stem is better for eating. A couple of leeks are bound by a binding machine (manual feeding type) accompanied with the grading system according to a set weight and are manually packed in box for shipping by operators.

This line speed is 30 m/min and 10,000 leeks are processed in an hour. Ten operators work for feeding leeks to this system and a few operators check peeling, while several operators bind and pack them. This preprocessing and grading system was developed in 2002 and is now being distributed in Japan. 40% operators were reduced in the facility and laborious operations were eliminated after introducing this system.

Robotic grading system for peach, pear, and apple fruits

A grading robot for deciduous fruits such as peaches, pears, and apples to automatically provide fruits from containers and to inspect all sides of fruit was developed (Kondo, 2009) and was introduced into local districts as commercial models. Although it is not easy to define "robotic" compared with the other grading systems described before, a machine with manipulator(s) like human arm(s) is called "robot" in this paper. Fig. 5 shows a fruit grading robot system installed at JA Shimoina, Japan.

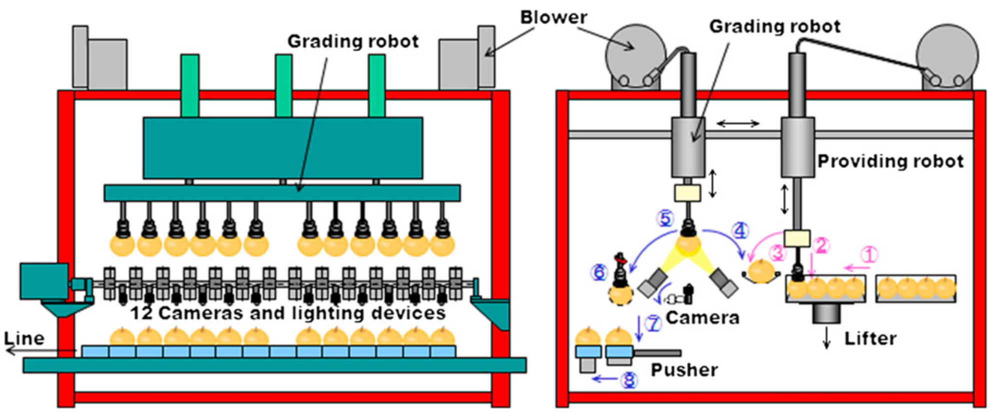

Fig. 5. A fruit grading robot system manufactured by SI Seiko Co., Ltd., Japan (Left: front view, Right: side view).

The robot system consists of two 3 DOF manipulators, in which one is a providing robot, while the other is a grading robot with 12 machine vision systems. After container comes under the providing robot (1), 12 fruits are sucked up by suction pads at a time (2) and are transported to intermediate stage making space toward vertical direction on this page between fruits (3). The grading robot picks 12 fruits up again (4) and 12 bottom images of the fruits are acquired during the manipulator moving to trays on a conveyor line (5). Just before releasing the fruits to the trays (7), 4 side images of each fruit are acquired by rotating the suction pads for 270° (6). The fruits are pushed out onto a line (8) and top images are acquired by another color camera stationed on each line. Software algorithms of machine vision are similar with that of the orange grading system. Fruit color, size, shape, and defect are measured.

The providing robot has a 3 DOF Cartesian coordinate manipulator, while the grading robot has two prismatic joints and a rotational joint and both manipulators have 12 suction pads as end-effectors. All actuators are electric motors and the maximum speed of each robot is 1000 mm/s. Since each robot cycle was set into 4.2 s for handling 12 fruits, this robot system can grade three fruits per second and applied to 11 varieties of deciduous fruits, peaches, pears, and apples. Because 4 sets of robotic grading systems were introduced in the JA, Japan, the maximum fruit reception capacity of the facility was about 40,000 fruits in a day. To suck fruits properly, 30 kPa vacuum force was applied for sucking peach fruit, while 45 kPa was for pear and apple fruits by use of a blower for 6 suction pads. No damage was observed even after twice sucking peach fruits by both robots.

A NIR inspector with halogen lamps (semi-transmissive type) installed on each line measures sugar contents and internal qualities of fruits such as rotten core after an image acquisition by the top camera. This NIR inspector is different from the one used in the orange grading system and light from halogen lamps goes through half bottom fruit and is received by a spectrophotometer was installed under the line. Based on both external and internal inspection results from machine visions and the NIR inspector, fruits are sorted into several grades and several sizes using criteria as shown in Table 1. This table shows five criteria for color, three for shape and three for defect and some of them are two different criteria for top half and for bottom half of fruit.

Another robot with twelve 3 DOF Cartesian coordinate manipulators packs fruits into a cardboard box. The boxes are stored in a storage and they are palletized by an articulated robot just before shipping. Since all the operations in this facility were automated or robotized, it was observed that 10 operators were replaced by this robot system and that about 40 operators were saved that could contribute intelligent farming, enlarge management scale, and enable cultivation management for higher quality production.

This robotic grading system can extract exact information compared with the traditional grading systems because manipulators precisely handle fruits during all the procedures from providing operation to packing operation. Most of recent grading systems possess a database to accumulate the extracted features from images of each fruit and vegetable such as color, size, shape, defect, and other external features as well as internal quality data from NIR inspection system or X-ray imaging system such as sugar content, acidity, granulation, and rind-puffing. The product data from the grading robots can be linked with reception data (producer ID, field ID, received date, product variety, product number) and packing data (issued product ID, operation date and time, packing robot ID or operator ID) of products which are stored in a database. It is possible to input data of farming operations such as fertilization, irrigation, chemical spray, harvesting date and time, and

Table 1. An example of criterion set for grading pear.

Nansui pear	Criteria for fruit appearance grade, Sep. 24, 2002				
	Grade A	Grade B	Grade C	Grade D	Grade E
Color					
Hue (whole)	135–175	175	130–180	0–190	
Hue (top)	135	135	130		
Hue (bottom)	175	175	180	190	
Reddish area (bottom)	58	63	68	80	
Saturation (whole)	268	270	272	280	
Shape					
Roundness (top & bottom)	110	115	120		
Complexity (top & bottom)	120	130	157		
Deformativity (side)	130	180	320		
Defects					
Serious defect (top)	4	20	50		
Serious defect (bottom)	6	30	70		
Medium defect (top)	12	25	100		
Medium defect (bottom)	15	30	130		
Slight defect (top)	15	40	110		
Slight defect (bottom)	30	60	160		

field information as well as climate and weather information and geographical information at local districts as production information. It is not difficult to collect such data and accumulate them in a database every year by growers associations, because many producers have relation with products shipped to a cooperative facility.

This collected production information in the database can be sent to distribution stage if some ID was issued for the products such as serial number, barcode, two dimensional code, or RF-ID. During distribution, transportation methods, environmental condition, case, distance, time, packing information can be added to the production information. Distributors send the products with the information to retailers and the products are finally sold to consumers. At this stage, price, time until sold, consumers' voices can be added to the information. Hence, the many kinds of information are linked from production to consumption and are stored in a database even after products are sold to consumers. This whole information set can complete the food traceabilty which is able to be referred by not only consumers, but also distributors and producers.

It is technically traceable when product ID on shipping box and fruit positions in the box are kept when the box is packed by a packing robot, because all the product data are linked with the fruit positions in a shipping box with product ID. It is, however, not easy to completely trace back to all production stage if human packed fruits manually in traditional systems like the eggplant grading system, because the data are unlinked on the packing operations (Kondo *et al*., 2007).

There are several purposes to construct the database of agricultural products (Kondo & Ninomiya, 2007): 1) Risk management, 2) Information release to consumers, 3) Product management, 4) Intelligent farming guidance. From those viewpoints, the automated grading systems play an important role, because they can precisely collect the external and internal information. Especially, recent robots working for grading and packing operations can handle each fruit and vegetable so that the information can be corresponded to each fruit and vegetable. For producers, the information can be used for future effective production of higher quality products. This means that the database accumulated every year can be a part of DSS (decision support system) as actual data of farming guidance to achieve precision agriculture.

Conclusion

It can be said that roles of automated grading systems as follows: 1) Efficient sorting and labor saving, 2) Uniformization of fruit quality, 3) Enhancing market value of products, 4) Fair payment to producers based not only on quantity but on quality of each product, 5) Farming guidance from grading results and GIS (Geographical Information System), and 6) Contribution to the traceability system for food safety and security. The most important difference of the automation systems from the conventional machines is to be able to handle a lot of precise information. To handle the comprehensive data on agricultural products and foods, understanding of diversity and complexity of biomaterial properties is required and sensors to collect data should be often designed based on the properties. Through the traceability system in which all the data of producers, distributors, and consumers are linked and opened to them, it is expected that mutual information exchange among them makes more effective procedure at each stage and produces more safety and higher quality products.

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