DEVELOPMENT OF AN INTEGRATED GRADER FOR APPLES

K. H. Choi, K. J. Lee, D. S. Choi, Y. S. Han

National Agricultural Mechanization Research Institute
Rural Development Administration
Suwon, Kyunggi-Do 441-100, Korea
E-mail : khchoi@rda.go.kr

ABSTRACT

An integrated grader which measures soluble solid content, color and weight of fresh apples was developed by NAMRI. The prototype grader consists of the near infrared spectroscopy and machine vision system. Image processing system and an algorithm to evaluate color were developed to speed up the color evaluation of apples. To avoid the light glare and specular reflection, an half-spherical illumination chamber was designed and fabricated to detect the color images of spherical-shaped apples more precisely. A color revision model based on neural network was developed. Near-infrared(NIR) spectroscopy system using NIR reflectance method developed by Lee et al(1998) of NAMRI was used to evaluate soluble solid content.

In order to observe the performance of the grader, tests were conducted on conditions that there are 3 classes in weight sorting, 4 classes in combination of color and soluble solid content, and thus 12 classes in combined sorting. The average accuracy in weight, color and soluble solid content is more than about 90 % with the capacity of 3 fruits per second.

Key Words: Fruit grader, Image Analysis, NIR Spectroscopy, Quality, Apple

INTRODUCTION

Grading is one of the important fruit processing operations. It evaluates objectively fruits and vegetables based on established grade standards, because well-sorted products command better price in the market. Grading is also a necessary as it becomes the basis for establishing business confidence and trust between the producer, distributor and buyer. In Korea, weight or size is one of the major factors which are usually considered in the grading or sorting operations. The surface color of fruits is another factor considered particularly for apples and tomatoes since early in the 1990s.

As the consumption of fresh fruit increases with high income of the population, the consumer demands for high quality and wide variety of agricultural products. The assessment and grading are needed to satisfy the consumers' demand and also make growers to be more responsive to the needs and demands of the consumers.

Researchers were aware of the importance of sorting fruits and vegetables, so the development of the grader was actively carried out in Korea since 1990's. Grading technologies like nondestructive fruit graders using image processing, near infrared (NIR) spectroscopy, and leading edge technologies have been developed by Korean researchers. Recently, machine vision has been widely used for online apple grading applications, and it provides great potential for detecting color, size and defect in apples. Choi et al.(1997) developed a color imaging system for apple by color and size which could grade 3 apples per second. The said grader is currently available in packing houses in Korea. Also non-destructive fruit sweetness grader using NIR spectroscopy was developed by Lee et al.(1998 a, c).

The purpose of this study is to develop an integrated apple grader which can measure sweetness, color and weight in nondestructive and real-time based. The specific objectives are as followings:

1. Develop the prototype grader for apples which are composed of NIR spectroscopy and machine vision system.
2. Evaluate the grader and the algorithm to grade apples by its sweetness, color, size and weight.

MATERIALS AND METHODS

Integrated Grader

The integrated grader in this study was designed to measure or segregate apples according to color, weight and sweetness. The prototype includes five computer controlled systems: feeding, weight detection, color detection, sweetness detection and discharging system.

Figure 1 shows the schematic diagram of the grader which is a combination of the NIR system, load cell(BCA-15,CAS Co.) and machine vision system placed a line. Fruits are fed manually and conveyed by means of rectangular cups. As the fruit travels through each detection systems, the sweetness, weight, color and size can be measured simultaneously through the NIR system, load cell, machine vision system, respectively.

These systems use two computers which are connected by a series of interfaces. Each system has its own control module. Host computer serves as the commander of the entire grading system. It is responsible for receiving the sensing information of soluble solid content, color and weight from each detection system, determining the final grades, sending the discharging signal to discharging system, and handling all the correspondence among the systems. Once the grader activates, it detects the loaded cups and measures weight, soluble solid content and color.

Machine Vision System

Machine vision system is used to measure the color and size of an apple. The system includes the illumination chamber, image input and imaging process unit. Most fruits and vegetables have irregular shape, color and size, so each experiment shows differences among image frames. For an example, images are affected by a location of a light source above or parallel to the spherical fruits. Also it is hard to get accurate image data because of the glare and specular of the reflected light. The half-spherical shaped light chamber was designed and fabricated to provide uniform diffuse illumination without any specular reflection. A round frame was equipped with two layers of 18 incandescent white bulbs of 20W (Dulux EL ECO, Osran Co)as shown in figure 2. The light source is covered by a half-spherical acryl of 3mm in thickness to irradiate the scattered light. It turned out to be very effective in acquiring good images of apples.

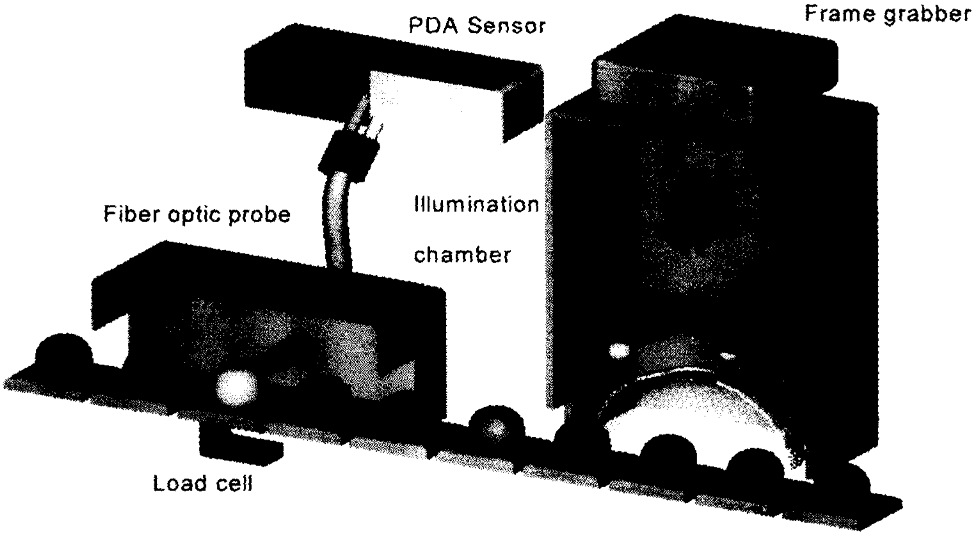

Fig.1 Schematic diagram of the integrated grading system.

The luminous intensity in the chamber was about 11500 lux. Image input and processing unit included a progressive scan color CCD camera(Model TMC-9700, PULNiX Inc.) which has a resolution of 768(horizontal) x 484(vertical) and high speed electronic shuttering due to the interline transfer CCD. Images captured from the camera were sent to the computer via input lines of frame grabber for further processing.

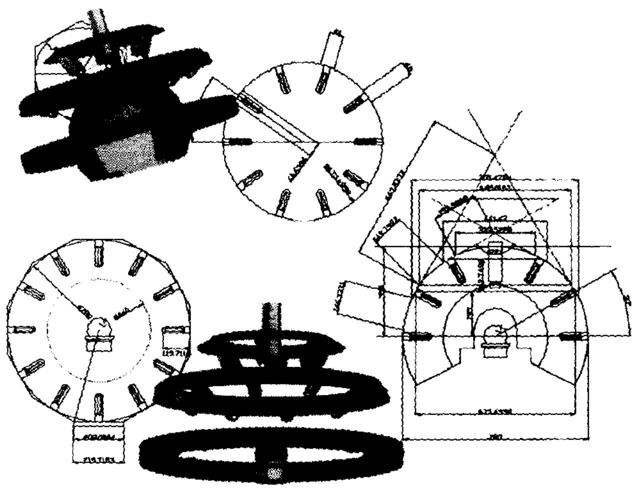

Fig. 2 Design concept of the illumination chamber.

Analog image signals were digitized by a frame grabber(Model IC-PCI, Image Technology) which was inserted in an expansion slot of the industrial computer(Model 610, Advantech Co.) via PCI interface.

Image segmentation and edge detection were performed by predetermined threshold value to extract the fruit from background and subsequently the color was calculated by the algorithm for color analysis. Digital signals were out to D/O of PCL 812-PG board(PC-LabCard, Axiom) to discharge fruits graded by a computer program from the plates on a moving chain to the appointed section.

NIR System

In order to estimate soluble solid content in a nondestructive and real-time based, the sweetness grading system based on NIR reflectance method, which was developed by NAMRI, was adopted for this system. The system consists of a light source, light detection unit, fiber optic and others.

Light source used a 250W crystal-tungsten halogen lamp which ejects a visible and NIR ray evenly. Light detection unit used monochromater (Multi Spec TM77400, Oriel Instrument) and PDA(Insta Spec TMII Oriel Instrument) to detect the reflected light on moving sample. It also used a bifuricated fiber optic probe to guide the light from the light source to the sample and the reflected light to monochromater at the same time. The Multiple Linear Regression(MLR) model was used to estimate soluble solid content of apples. The MLR model using wavelengths between 800nm and 1100nm predicted an unknown sample with determination coefficient of 0.781, SEP of 0.798 Brix, and bias of 0.264 Brix.

The NIR system used in this study is described detaily explained in detail in the report of previous studies (Lee et al., 1998 a, b, c; Choi et al., 1998).

Performance Test

'Fuji' fresh apples used in the test were harvested at Kyungbuk province in 1999. A total of 75 apples were randomly chosen so that sizes and colors varied.

In order to estimate the color accuracy of the system, the reproducibility test was conducted with the following considerations that there are 3 pixel intervals(full pixel or 1-pixel, 3-pixel, 5-pixel) and 3 replications. Three apples per second were fed into the system. The color data were measured, calculated the deviations between replications and considered their means and standard deviations as errors. Weight accuracy was calculated by comparing the system results and digital scale results.

The classification tests were carried on the condition that there are 3 grades in weight sorting, 4 grades in combination of color and soluble solid content, and thus 12 grades in combined sorting.

RESULTS AND DISCUSSION

To classify apples by color, L* a* b* color system was used. Two-layer neural network used to convert RGB to L* a* b* as shown in figure 3. A total of 113 standard color papers from the color chart(DIC/color guide) were selected, measured the L* a* b* by colorimeter and compared with the data from the camera to test the efficiency of the machine vision system. The neural network was verified using 100 standard color papers containing the colored apples and non-colored apples and not including previous 113 papers. Also to improve the calculation speed, look-up table, considering color conversion, was used as a reference.

RGB of apples fed into a computer was input into a neural network and revised. It is converted into L* a* b* and segregated fruits into colored and non-colored apples. If the colored ratio is over 70%, the fruit is classified as grade 'A' and if a colored ratio is between 40% and 70%, it is grade 'B' and a ratio under 40% is grade 'C'. Image processing tool for Window NT 4.0 software was developed using Microsoft Visual C++ 6.0 at NAMRI.

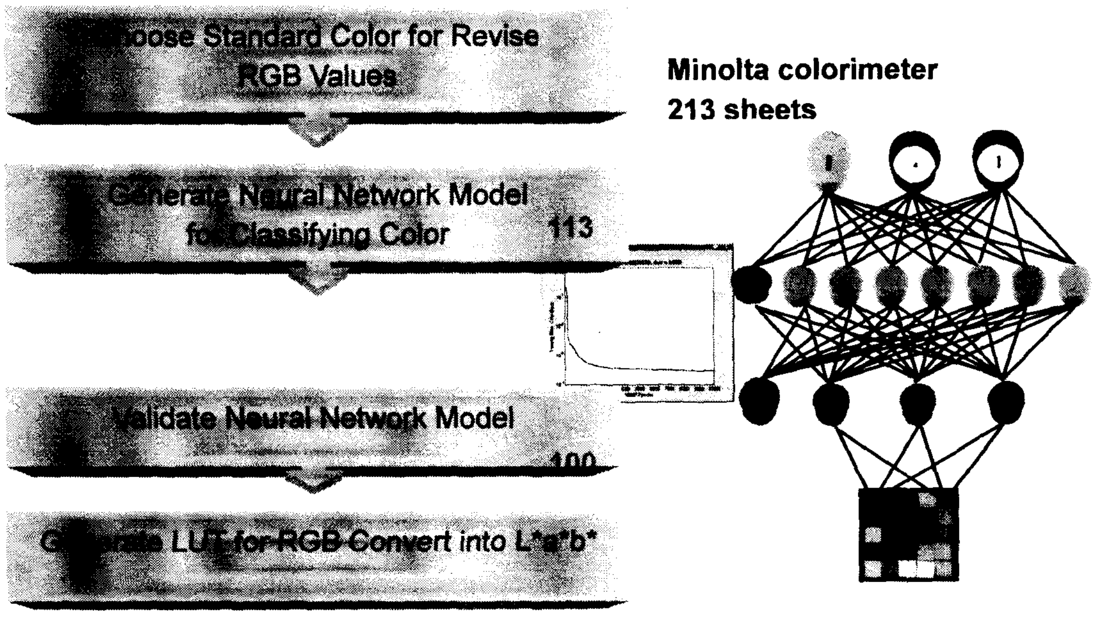

Fig. 3 Two-layer neural network used to recognize the color.

Firstly, the image processing background set-up file to create the cameras input state during the experiment and the camera set-up file to adjust the output of the camera were prepared. A white board was used for adjustment of camera so that the average of RGB was 250. Main menu consists of few files such as a ROI concerned set-up file for clipping; an individual grading file for grading and recording of sugar content, color and weight; an overall grading file; an outlet set-up file for operating a solenoid through a port defining an overall grade; a neural network input data set-up file for saving a neural network weight and bias; an image processing set-up file for saving values of background threshold and colored threshold; and an users file for entering a users information.

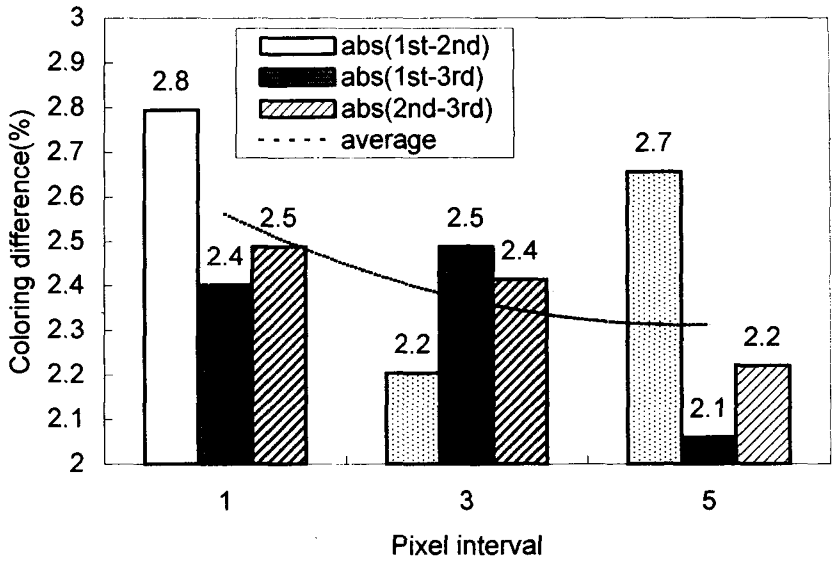

Fig. 4 Coloring difference between replications in case of pixel intervals.

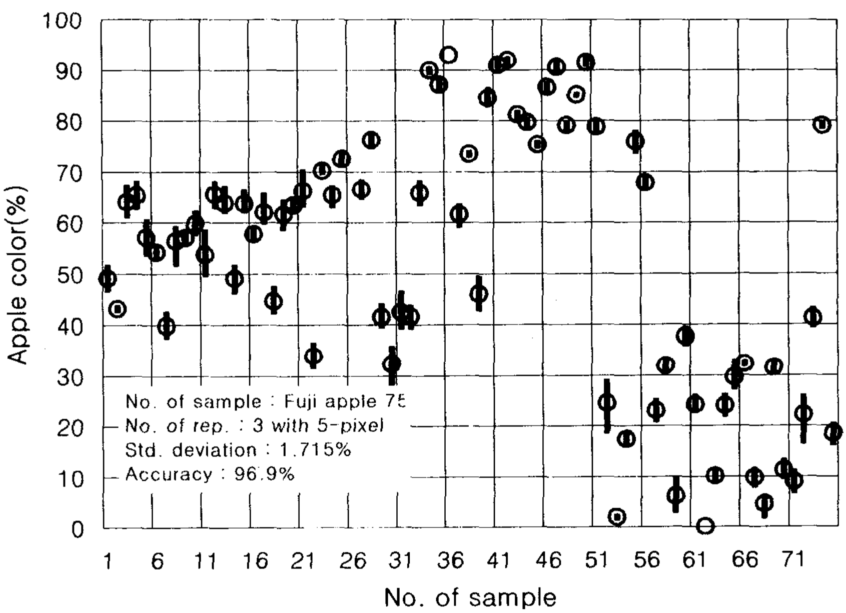

Fig. 5 Coloring distribution with 3 replication tests at 5-pixel intervals.

The color differences for 3 pixel intervals and 3 replications were less than 2.1-2.8% of color as shown in figure 4. It was found that there is no significant difference between the color from apples for pixel interval. In this study images with 5-pixel were processed to classify the color.

Figure 5 shows the coloring distribution with 3 replication tests at 5-pixel intervals. The prototype system was able to correctly classify 90.7% of apples for color in the specified condition of 3 grades.

The average sugar content error and accuracy were under ± 1 Brix and 90%, respectively, and this system can evaluate 3 apples per second. Results of weight evaluation showed the standard deviation of 11g which was little high. Probably it was affected by the vibration and signal noise of the system.

In order to observe the performance of the grader, the tests were carried on 3 grades in weight sorting, 4 grades in combination of color and sweetness, and a total of 12 grades in combined grading. The overall accuracy in size, color and sweetness is more than 90% with the capacity of 3 fruits per second per line. Although the grader was developed mainly for apples, it can be easily applied to other fruits and vegetables with minor modification.

CONCLUSIONS

This study aimed to develop an integrated apple grader which measures soluble solid content, color and weight in a nondestructive and real-time based. The prototype grader consists of the near-infrared spectroscopy and image processing system.

Fruits are feed manually and conveyed by means of rectangular cups. As the fruit travels through each detection systems, the soluble solid contents can be measured by the NIR system, and the color and weight also measured simultaneously by imaging system and load cell. Image processing system and an algorithm to evaluate color and size were developed to speed up the color evaluation of apples. A half-spherical illumination chamber was developed to detect the color images of spherical-shaped agricultural products like apples more precisely. It turned out be very effective in obtaining good images of apples. A color revision model based on neural network was developed. The sweetness grading system based on NIR reflectance method, which was developed by Lee(1998) of NAMRI, was adopted in this system.

The average accuracy in size, color and soluble solid content is more than about 90% with the capacity of 3 fruits per second per line under lalieratery conotitions.

REFERENCES

1. Choi, K., J.Y. Son, J.T. Hong, Y.K. Cho. 1997. Development of an apple sorter using color image processing system. RDA Journal of Farm Management & Agri-Engineering 39(1):55-63(In Korean).
2. Choi, K. and K.J. Lee. 1998. Nondestructive technology to measure sugar content in fruits using NIR spectroscopy. International Seminar on Technology Development for Nondestructive Quality Evaluation of Agricultural Products. National Agricultural Mechanization Research Institute(In Korean).
3. Lee, K. J., W.R. Hruschka, J.A. Abott, S.H. Noh, B. Park. 1998a. Predicting the soluble solid of apples by Near Infrared Spectroscopy(I) -Mulple Linear Regression Models-. The Korean Society for Agricultural Machinery 23(6):561-570(In Korean).
4. Lee, K. J., W.R. Hruschka, J.A. Abott, S.H. Noh, B. Park. 1998b. Predicting the soluble solid of apples by Near Infrared Spectroscopy(II) -PLS and ANN Models-. The Korean Society for Agricultural Machinery 23(6):571-582(In Korean).
5. Lee, K. J., J.A. Abott, W.R. Hruschka, K.H. Choi, B. Park. 1998c. Comparison of statistical methods for calibrating soluble solid measurement from NIR interactance in apples. Proc. of ISAIP '98 : 98-111