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Multi-Channel Vision System for On-Line Quantification of Appearance Quality Factors of Apple

S. H. Lee, S. H. Noh

Abstract: An integrated on-line inspection system was constructed with seven cameras, half mirrors to split images, 720 nm and 970 nm band pass filters, illumination chamber having several tungsten-halogen lamps, one main computer, one color frame grabber, two 4-channel multiplexors, and flat plate conveyer, etc. A total of seven images, that is, one color image from the top of an apple and two B/W images from each side (top, right and left) could be captured and displayed on a computer monitor through the multiplexor. One of the two B/W images captured from each side is 720nm filtered image and the other is 970nm. With this system an on-line grading software was developed to evaluate appearance quality. On-line test results with Fuji apples that were manually fed on the conveyer showed that grading accuracies of the color, defect and shape were 95.3%, 86% and 88.6%, respectively. Grading time was 0.35 second per apple on an average. Therefore, this on-line grading system could be used for inspection of the final products produced from an apple sorting system.
Keywords: Machine vision, Sorting, Apple, NIR, NIR imaging, Defect

Introduction

Appearance quality factors of fruit consist of color, shape, surface defect, etc. To quantify these individual factors many researches have been done with machine vision. For color grading of apple, parameters or indices such as the normalized rgb values(Miller and Delwiche, 1989), normalized Hue histogram(Tao et. al., 1995), and reference color chart(Ng etc. 1998) have been developed to minimize the illumination effect instead of using RGB values themselves.

Color difference in visible region(Leemans, et. al., 1998; Heinemann, et. al., 1995; Miller and Delwiche, 1989) and filter images in NIR region(Rehkugler and Throop, 1986; Delwiche et. al., 1990; Singh and Delwiche, 1994, Suh and Sung, 1997) has been tried to detect the surface defect such as scab, bruise and cuts. It has been reported that detection accuracy depends on the kind of defect, color difference between the defect and the surrounding sound region, and uniformity of illumination on the whole surface of fruit. NIR filter image which is independent of color has been suggested as a powerful method in detecting the scab, cuts and bruise.

Shape is one of important appearance quality factors but not many researches have been done to quantify the shape factors. Kuhn et. al.(1982) reported that at least five images from different angles were required to characterize the shape of apple. Recently, laser structured illumination has been adopted for shape discrimination with three-dimensional image.

Machine vision is the most powerful method to evaluate the appearance quality of fruits and vegetables but only on-line system for color grading has been commercialized in Korea. Shape and surface defects are manually inspected at packinghouses. The aims of this research are to construct a multi-channel machine vision system which is capable of inspecting color, defect and shape of Fuji apple at one time, to develop more efficient on-line algorithm to evaluate appearance quality, and to evaluate the performance of the on-line machine vision system.

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Materials and Methods

1. Materials

'Fuji' apples used for test were purchased from fresh fruit market. According to the Korean grading standard for apples, the first grade should have less than two scabs of 3 mm diameter in size and none of bruise and cuts. The biological status of bruise and cuts in apple varies with time lapse, so bruise and cuts were made artificially. The bruises in apples were made by impacting apple lightly with a steel hammer five times, and were left for one hour before testing. The cuts were made with a sharp object and were left for one hour, too. Performance of the multi-vision system was evaluated by classifying the color into 3 grades, and the shape into the 'normal' and 'abnormal'.

2. Selection of significant wavelength for defect detection

Many researches have been conducted to identify significant wavelength for detection of defect using spectrophotometric approach, but those wavelengths obtained from spectrum analysis have a limitation in applying to machine vision system because signal characteristics of spectrophotometer are different from that of the machine vision sensor and the simulation of spectrum is not identical to camera system.

To investigate the most effective wavelength band in detecting defects, a B&W machine vision was used to get NIR filtered images. A total of 15 bandpass filters having different peak wavelengths in the range of 720 to 1000 nm were adopted for test. Effective bandwidth of those filters was 10 nm. A filter holder was made for easy exchange of filters. For uniform and strong illumination, 16 halogen lamps (Luxtex, 200W) were placed around the sample.

Since the transmittance of each filter was different, NIR images were acquired after adjusting the lens iris so that similar gray value(about 15) images could be obtained with each filter. A gray value representing the defect part was obtained by averaging the gray values of 5×5 pixels which cover the defect area. The gray value of the sound part was obtained at neighborhood of the defect area.

A measure of sound and 3 types of defect separability is Mahalanobis distance(Tou and Gonzalez, 1974) :

$$d_m = \frac{(m_1 - m_2)^2}{\sigma^2} \quad (1)$$

where m_1 and m_2 are the class means and σ^2 is the pooled variance.

3. On-line multi-channel machine vision system

The defects in apples are randomly distributed on their whole surface. In order to capture the images from three directions, three sets of cameras were installed at top, right and left sides of an apple sample. One set which consists of three cameras, as shown in Fig.1, was mounted on top side of the apple sample. In this set, two B&W cameras were mounted on the lateral to grab the images reflected from the two half mirrors. One of these cameras is equipped with a bandpass filter having 720 nm peak wavelength for scab detection, and the other is with 970 nm peak wavelength for detection of bruise and cuts. The third camera mounted on the top is a color camera to analyze the color of the stem side of apple. Other two sets of cameras which are mounted at right and left sides of apple are similar to the unit on the top but color camera was not installed.

In order to get uniform illumination, 12 halogen lamps(Luxtex, 200W) were placed around the sample in two layers and also, white acryl palates were placed in front of the light sources to eliminate the regular reflectance from the sample.

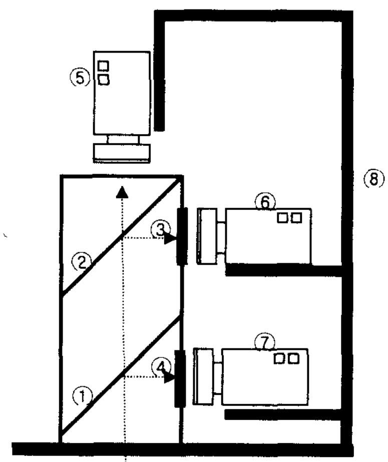
Two units of 4-channel multiplexor were used to integrate video signals from a total of 7 cameras, one color camera and six B&W cameras. Those seven images were displayed on the monitor as shown in Fig. 2, and were used to analyze color of stem side, defects and shape of apple.

For on-line test, apple samples were conveyed on a flat belt conveyor which passing through the center of illumination chamber at maximum speed of 0.5 m/s. A position sensor(BR100-DDT) and digital I/O interface card(AX5008, Axiom) were adopted for capturing the image of the moving apple.

4. Grading algorithm and performance test

Algorithms for color grading, defect detection and shape discrimination were developed independently and combined together for on-line test. The detailed contents of each algorithm could be referred to the reference(Lee, 2000). Primarily, an algorithm to detect the stem part of apple was developed with the color image. Because color characteristics of stem region was different from any other surface of apple. Also, the location of the stem was used for shape discrimination.

For color grading algorithm, it was found that b*/a* of L*a*b* color values was the most effective index among the color values of R, G, B,G/(G+B), H, I, S, Y, I, Q, Q/I, L*, a*, b*, b*/a*, r, g, b, Y, x, g and y/x in classifying each pixel of Fuji apple image into the surface color and the ground color. The ratio of



① 1st beam splitter (R 30, T 70)
② 2nd beam splitter (R 40, T 60)
③ 720nm bandpass filter
④ 970nm bandpass filter
⑤ color camera
⑥ 1st B&W camera
⑦ 2nd B&W camera
⑧ camera stand

Fig. 1 Cut-way view for acquisition system of three images using beam splitter.

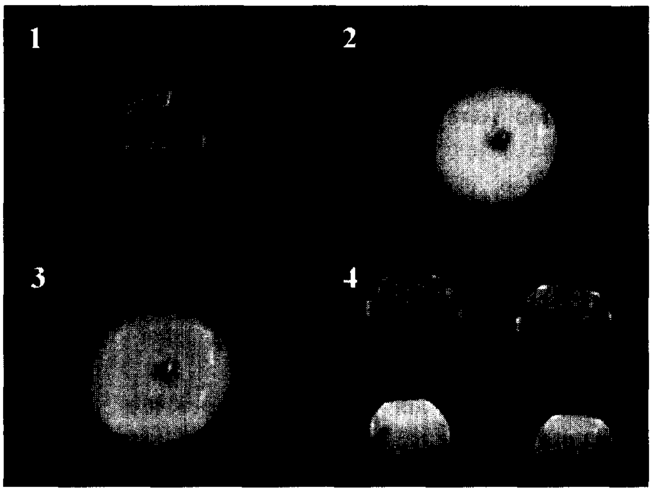


Fig. 2 Display of 7-channel images grabbed by one color camera and six B&W cameras.

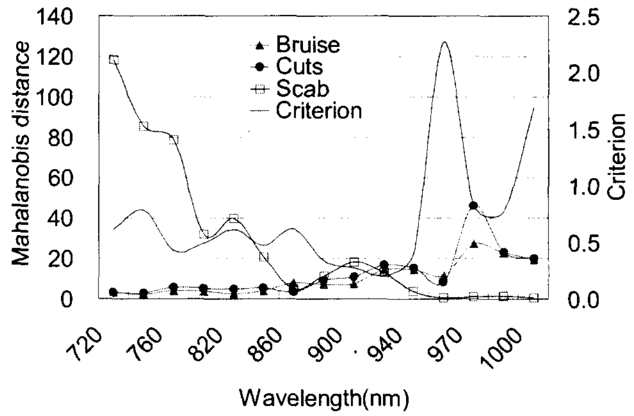


Fig. 3 Mahalanobis distance computed with the filter images of the sound and each defective part of Fuji apple in NIR range, and criteria for discrimination of the defectives from the sound.

the pixel counts classified into the surface color and the ground color was used for color grading.

Three 720 nm bandpass filtered images and three 970 nm bandpass filtered images which were captured from top, right and left sides of the sample were processed by chain coding and labeling algorithm to detect the scab and bruise & cuts, respectively. Local thresholding technique was applied to each image for enhancement of defective parts. Total number of pixels which have gray values below certain level was counted to be used as the decision criteria of defective apple.

Shape was discriminated based on not only the distance between the stem and centroid computed from the top side image but also the ratios of maximum and minimum diameters computed from three images(top, right and left).

For the performance test of the on-line grader, a total of 50 apples moving at 0.5 m/s were used for color and shape grading, and 90 samples(30 for the sound, scabs and bruise & cuts, respectively) moving at 0.2 m/s for defect detection. In the former case, three replications were made.

Results and Discussion

1. Significant wavelength bands for defect detection

NIR filter images captured with 15 different bandpass filters were analyzed to select the most effective band in detecting the defects in Fuji apple. Mahalanobis distances between the sound part and each defective part were computed with the corresponding average gray values obtained from each filter image. Fig. 3 represents the results. In this figure it is noticed that the most effective band is 720 nm for detecting scab, and 970 nm for bruise and cuts, respectively. Scab shows different trend in Mahalanobis distance from the bruise and cuts.

In Fig. 3 the criterion plot indicates the sum of the reciprocals of Mahalanobis distances computed with three types of defect. Therefore, the wavelength band having the smallest value means the most effective band in discriminating the defectives all together from the sound. In this case 920 nm band is the most effective. It is concluded that 920 nm band is possible for discriminating the defects but using two bands, 970 and 720 nm is more efficient for detecting the defects.

2. On-line test for defect detection with NIR imaging

A total of 7 images for each sample grabbed with the multi-channel experimental apparatus were processed. The two filter images(top side) were thresholded by gray value of 150 and the four filter images(left and right sides) by 130. The stem part of the sample was successfully isolated by the algorithm developed in this study.

Table 1. Average accuracies of defect detection for top and lateral side of apple

Defect position \ Defect	Scab	Bruise & Cuts
Top Side (T = 150)	96.7	81.7
Left and Right Side (T = 130)	78.3	70.0

The detection results(Table 1) indicated that scab, bruise and cuts on top side of apple were detected more accurately than those on the lateral. This result may be due to nonuniformity of illumination. Variation in the gray values of lateral side images was relatively larger than that of top side, particularly the bottom part of the apple. As other researchers(Singh, 1994) were pointed out, uniform illumination is a key factor in detection of the defect.

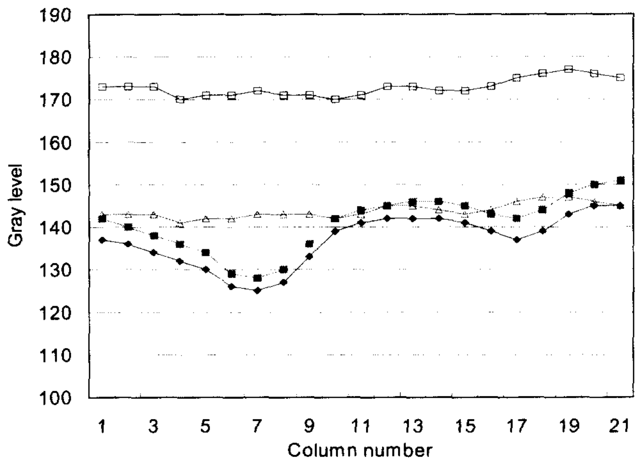


Fig. 4 Effect of image normalization on distribution of gray level.

3. Modification of illumination settings and algorithm for defect detection

To improve uniformity of illumination, semi-sphere chamber was made with white acryl to provide uniform light intensity. Also, the belt conveyor which was black color originally was coated with silver color, and pieces of flat silver plates were placed on both sides of the belt conveyor to strengthen the illumination at bottom side of the apple. On the other hand, gray values of the lateral images were normalized by the average gray value as follows.

① calculate the average gray value of apple image(M_a)
② calculate the average gray value of a horizontal line(M_h)
③ correct every pixel value in the horizontal line $New\_P(x, y) = P(x, y) - M_h + M_a$
④ correct the marginal pixel value in the horizontal line $New\_P(x, y) = P(x, y) + | x_{center} - x |/4$
⑤ repeat ②–④ for every horizontal line

Table 2. Error of the vision system in detection of bruise & cuts with filter images before and after modification

Status	Before modification (%)	After modification (%)
Type I error	23.4	6.8
Type II error	36.7	16.0

Figure 4 shows the test results after modification of illumination settings and the algorithm. It is noted that the difference in gray value between the sound part and the defective part was enlarged after normalization of the gray values.

With this modified settings and algorithm, tests for defect detection were carried out with 35 sound apples and 50 bruise & cuts apples conveyed at 0.2 m/sec. In Table 2 the type I and the type II errors represent misclassification of the sound apple to the defected apple and vise versa, respectively. Modification reduced the type I error by 16.6 % and the type II error by 20.7%.

4. Color and shape grading

Performance of the algorithms for color grading and shape discrimination was tested with 50 apples moving at 0.5 m/sec. Color was classified into 3 grades and shape was into the normal and abnormal. Three replications were made. As the result, accuracies of color grading and shape discrimination were 95.3% and 86.0%, respectively, on the average as compared with human sorting. Relatively low accuracy in shape discrimination was thought to be due to low resolution of the lateral images of apple.

Conclusions

A multi-vision system consisting of one color camera and six B&W cameras was implemented to evaluate the appearance quality of fruit such as color, shape and defect(scab, bruise and cuts). Primarily, it was found that color grading of Fuji apple could be successfully done with b*/a* of L*a*b* color values, and the deformed shape was discriminated by the distance between the stem and the centroid of apple image and by the ratios of maximum and minimum diameters of the top, right and left side images of apple. The scab could be most effectively detected with 720 nm band pass filter image and the bruise and cuts with 970 nm bandpass filter image. One of the key factors for successful detection of defects was uniformity of illumination.

The on-line test results with Fuji apple showed that accuracies of color grading, shape discrimination and defect detection were 95.3%, 86.0% and 88.6 %, respectively. Processing speed was about 0.35 second per apple. Based on these results, it is concluded that the multi-vision system developed in this study could be used for inspection of Fuji apples at packing houses.

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