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# Development of an Automatic Fruit Grader using Computer Image Processing

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## ABSTRACT

This study was intended to examine feasibility of sizing and color grading of Fuji apple with black/white image processing system, to develop a device with which the whole surface of an apple could be captured by one camera, to develop an algorithm for a high speed sorting, and to examine the effects of blurring on the performance of the experimental fruit grader.

Key Word: Fruit grader, Image Processing, Sizing. Coloration, Blurring, Apple

## INTRODUCTION

Fruit sorting has been done mostly by man and recently weight sizer has begun to be prevailed in Korea. Manual sorting requires great skill and the sorting results vary with individual sorter's emotional condition and decision yardstick. Also, weight sizer is limited to sorting by weight only. In order to increase additional value of the final products, color grader by machine vision is employed in some countries. One color grader developed in Japan detects the color level of a fruit by sensing the skin color of stem end side of the fruit and the other type in Netherland by rolling the fruit. The former is not applicable to the fruit samples having nonuniform color distribution on the whole surface like those produced in our country and the latter might have significant error depending on rolling direction.

The aim of this study was in developing a fruit sorter detecting not only the size but also the color of whole surface simultaneously by using a computer based on black/white image processing system. Primarily, emphasis was placed on identifying feasibility of color detection by a monochromatic CCD camera equipped with a band pass filter and developing a high speed algorithm for sizing and color grading.

## MATERIAL AND METHODS

Material

Test sample used for experiment was Fuji apple which is a main variety cultivated in Korea. The skin color of this apple is developed from green to yellowish red with maturation and stem end side is normally daker than the blossom end. The shape is circular.

Experimental Apparatus

(1) Image processing system: The imaging processing system used for this study was consist of a black/white CCD camera(PULNiX TM-545), frame grabber(PCVision Plus), host computer(IBM compatible PC/AT, 12MHz, w/o co-processor), and color displaying monitor(EMC 1311U, Kichener). An interference band pass filter having 550nm peak wave length(ORIEL Model No.57570) was adopted to the camera.

An illumination chamber(Fig.1) was made with white arcryl in shape of a tunnel and fluorescent lamps(10W) were placed outside the arcryl. Two pieces of plane mirrors were placed on both sides of the sample so that the whole surface image could be captured by the camera. The image frame is devided into three regions, one for the image directly captured from the top side of the sample and the others for those from the mirrors. The image from the top side was named as "direct image" and those from the mirrors were "reflected images", respectively.

(2) Conveying equipment: A flat belt conveyer(Fig.2) having a speed controller was used for analyzing the effect of blurring on sizing and grading depending on conveying speed of a sample.

Development of Algorithms

(1) Pixel classification: Sorting capacity and accuracy of a sorter using the computer based on image processing system is mainly dependent on how to classify and compute the pixels corresponding to the material. In this study, graticule method was used for analyzing the size and coloration of a given sample. By establishing the graticules in the image frame, the relative size of a material($A_v$) can be obtained by the ratio of the number of graticules($a_p$) covered by the material image to the total number of graticules($A_p$) fixed in the given frame. That is,

$$A_v = \frac{a_p}{A_p} = \frac{\text{cross sectional area of the material}}{\text{given area of the frame}} \qquad (1)$$

In order to recognize the graticules corresponding to the material from the background, a threshold value should be given. In this study, that value was determined by an automatic thresholding algorithm and it was found that the value did not change significantly if the illumination is stable.

(2) Color detection: It was assumed that the degree of coloration of a

sample is proportional to the average gray values of the graticules corresponding to the material. The average gray value and the number of graticules of each image in each window, that is, one direct and two reflected, were computed, respectively. With these data, an area weighted average gray value($G_f$) was computed as follows.

$$A_f = A_d + A_r + A_l \tag{2}$$

$$G_f = \frac{(G_d \times A_d) + (FG_r \times A_r) + (FG_l \times A_l)}{A_f} \tag{3}$$

Where, $A_f$ = area ratio of the whole image
$A_d$ = area ratio of the direct image
$A_r$ = area ratio of the reflected image to the right mirror
$A_l$ = area ratio of the reflected image to the left mirror
$G_d$ = average gray value of the direct image
$FG_r$ = compensated average gray value of the reflected image to the right mirror
$FG_l$ = compensated average gray value of the reflected image to the left mirror

Accuracy of the sizing and grading and execution time increase with the total number of graticules established in the frame.

## RESULT AND DISCUSSION

### Evaluation of Measurement Error

The total number of pixels were measured 10 times with two pieces of rectangular paper having the area of $20cm^2$ and $40cm^2$, respectively. As the result, the measurement error was found to be negligible. Also, the relative measurement error in the total number of pixels ranged from 0.74 to 1.31% when the $40cm^2$ piece of paper was located 5cm apart from the center line of the camera to the right, left, upside and downside, respectively.

Measurement error in gray value was examined with six kind of colored papers and two apples by varying the focusing point of the camera. The relative error in gray value was 0.25 to 2.00% within the vertical variation of 10cm.

### Correlation between Weight and Area Fraction

Fig. 3 shows the correlation between the weight of apples and their area fractions computed by Eqn.(2). According to this result it is proved that the area fraction is significantly correlated with the weight and that counting the whole image is better than counting the direct image only.

### Feasibility of Color Differentiation

The gray value of the black/white image processing system mainly depends on the brightness rather than the color. To investigate the effect of the 550nm band pass filter on the color differentiation, variations in gray values were measured with 5 sample groups having different coloration.

Table 1 indicates that gray value of the group A which has relatively the darkest red color among the five group is the smallest and the value inceases as the color chages from red(group A) to green(group E). Also, it is noticed that the gray values of the reflected images are smaller by 14 to 23 than those of the corresponding direct image. Further tests were made with the samples having more various colors to identify the correlation between the gray values from the direct image and those from the reflected. The correlation coefficient was greater than 0.98.

The correlation between the gray values and "L", "a", and "b" values of Hunt color scale were investigated by mearsuring 50 locations of apples with the image processing system and Hunt colorimeter(MODEL: Minolta CR-200), respectively. This result(Fig. 4) showed that highly significant correlations exist between the "a" value and gray value as well as between the "L" value and gray value.

In view of these results it was concluded that the gray value obtained from the image processing system can be used for color grading of Fuji apples.

Effect of Blurring on Sizing and Grading

When the sample moves at fast speed, blurring of the image may cause the sizing and grading errors. Relative errors in area fractions and average gray values as compared with those of stationary state were analyzed by varying the conveyer speed from 5.1cm/sec to 25.1cm/sec. Although the relative error increased with the speed(Table 2), it was showed high correlation between the stationary and the conveying(Fig. 5) states. This result indicates that the error due to blurring can be compensated, if necessary, and the separation lines in sizing and grading should be determined on the basis of the values acquired at conveying state.

Sorting Accuracy and Capacity

One hundred apples were classified into 8 classes by weight and 4 grades by color. The separation lines of color grades were primarily determined on the basis of the area weighted average gray values measured at stationary state and were compensated for each conveying speed. Tests for sorting accuracy were made by comparing the computer's grade to the predetermined grade of each sample. The test speeds of the conveyer were 5.3cm/sec, 15.2cm/sec and 25.1cm/sec, respectively.

Accuracies for sizing and color grading ranged from 68 to 72% and from 79 to 80%, respectively, indicating no signifcant difference depending on the speed. One thing noted here is that there was no sample erred more than one class. Tables 3 and 4 show the results of sizing and grading tests at conveying speed of 25.1cm/sec.

It took 0.27 to 0.33 second(DOS time with PC/AT, 12MHz) to compute the final grade of a sample including the time required for capturing the image.

The computing time was increased a little bit with the size of sample. On the basis of the DOS time the theoretical capcity is estimated about 10,000 apples/hr. If the effect of blurring is considered, the actual capacity should be lower than that. One of the important factor concerned with the blurring is the shut speed of the camera. The shut speed in this study was fixed at 1/30 sec.

## SUMMARY AND CONCLUSION

Feasibility of sizing and color grading of Fuji apple was examined with a black/white image processing system equipped with 550nm band pass filter and a computer algorithm for high speed sorting was developed using graticule method. The whole surface of an apple could be captured with one camera by placing two mirrors on both sides of the sample. The sorting accuracy and capacity of the experimental sorter was eavaluated by identifying the effect of blurring on sizing and grading.

The correlation coefficient was 0.995 between the weight of Fuji apple and the area fraction computed on the basis of the projected area of the whole surface. The area weighted average gray values of apple surface were highly correlated with the "L" and "a" values measured by the Hunt colorimeter.

The effect of blurring on the sizing and the color grading increased with the conveying speed of the sample but it could be reduced by using the grading lines calibrated with the speed.

The errors in sizing by 8 classes and color grading by 4 grades ranged from 24 to 32% and about 20%, respectively, but there was no sample erred more than one grade.

The time required for computing the final grade of a sample ranged from 0.27 to 0.33 second in DOS time.

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Table 1. Gray value of direct and reflected images by coloration.

| Groups of apple | Direct image | | Left reflected image | | Right reflected image | |
|---|---|---|---|---|---|---|
| | Gray value | S.D. | Gray value | S.D. | Gray value | S.D. |
| Group A | 69 | 6 | 54 | 5 | 53 | 5 |
| Group B | 87 | 7 | 69 | 7 | 68 | 7 |
| Group C | 110 | 9 | 89 | 11 | 87 | 9 |
| Group D | 126 | 6 | 112 | 5 | 109 | 5 |
| Group E | 130 | 7 | 115 | 5 | 113 | 5 |

Table 2. Effect of blurring on area fractions, average gray value of direct image and mean of average gray values of two reflected images at various conveying speed

(Unit: relative error, %)

| Speed(cm/s) \ Sample | | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | Mean | S.D. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.3 | EAF[a] | 2.21 | 1.83 | 1.65 | 2.98 | 2.30 | 2.38 | 2.35 | 2.31 | 1.97 | 2.62 | 2.17 | 0.28 |
| | $EG_m$[b] | 0.33 | 0.01 | 0.41 | 0.30 | 0.04 | 0.29 | 0.33 | 0.30 | 0.55 | 0.30 | 0.29 | 0.14 |
| | $EG_n$[c] | 0.15 | 0.00 | 0.30 | 0.05 | 0.13 | 0.01 | 0.00 | 0.04 | 0.47 | 0.47 | 0.16 | 0.18 |
| 10.1 | EAF | 2.35 | 2.22 | 1.78 | 2.10 | 2.32 | 1.98 | 2.14 | 2.39 | 2.23 | 2.20 | 2.17 | 0.17 |
| | $EG_m$ | 1.11 | 0.44 | 0.82 | 0.77 | 0.08 | 1.07 | 1.66 | 1.11 | 0.85 | 0.99 | 0.89 | 0.40 |
| | $EG_n$ | 0.58 | 0.22 | 0.61 | 0.52 | 0.36 | 1.46 | 0.97 | 0.60 | 0.90 | 0.62 | 0.68 | 0.33 |
| 15.2 | EAF | 2.21 | 2.23 | 2.41 | 2.33 | 1.99 | 1.93 | 2.90 | 2.39 | 2.72 | 2.08 | 2.22 | 0.24 |
| | $EG_m$ | 1.11 | 1.35 | 1.24 | 1.21 | 0.82 | 1.43 | 2.71 | 1.63 | 1.01 | 2.25 | 1.48 | 0.55 |
| | $EG_n$ | 0.68 | 0.59 | 0.81 | 0.58 | 0.51 | 0.55 | 1.33 | 1.08 | 0.90 | 1.99 | 0.90 | 0.44 |
| 20.0 | EAF | 2.46 | 2.71 | 2.68 | 2.05 | 2.67 | 1.86 | 1.73 | 1.67 | 2.30 | 1.50 | 2.16 | 0.44 |
| | $EG_m$ | 2.26 | 1.93 | 1.20 | 1.99 | 1.66 | 2.54 | 4.59 | 1.75 | 1.43 | 2.55 | 2.19 | 0.90 |
| | $EG_n$ | 1.35 | 1.25 | 0.65 | 1.18 | 1.22 | 2.52 | 2.20 | 1.05 | 1.16 | 2.19 | 1.48 | 0.57 |
| 25.1 | EAF | 2.76 | 2.29 | 3.18 | 2.54 | 3.05 | 2.15 | 1.34 | 1.92 | 2.07 | 1.62 | 2.29 | 0.57 |
| | $EG_m$ | 3.30 | 1.94 | 1.98 | 2.40 | 2.52 | 3.32 | 7.01 | 3.51 | 2.26 | 3.75 | 3.20 | 1.41 |
| | $EG_n$ | 2.01 | 1.06 | 1.05 | 1.50 | 1.55 | 2.75 | 4.13 | 2.25 | 2.00 | 3.07 | 2.14 | 0.92 |

Note: a) Relative error of area fraction.
b) Relative error of average gray value of direct image.
c) Relative error of mean of average gray value of reflected images.

Table 3. Comparison of sorting between by area fraction($A_f$) at conveying speed of 25.1cm/sec and by weight of apple.

| $A_f$ \ Weight | I | II | III | IV | V | VI | VII | VIII | Total |
|---|---|---|---|---|---|---|---|---|---|
| I | 3 | 4 | | | | | | | 7 |
| II | 1 | 5 | 1 | | | | | | 7 |
| III | | 3 | 6 | 4 | | | | | 13 |
| IV | | | 3 | 5 | 1 | | | | 9 |
| V | | | | 2 | 14 | 2 | | | 18 |
| VI | | | | | 2 | 20 | | | 22 |
| VII | | | | | | 6 | 10 | | 16 |
| VIII | | | | | | | 3 | 5 | 8 |
| Total | 4 | 12 | 10 | 11 | 17 | 28 | 13 | 5 | 100 |

Table 4. Comparison of sorting by the area weighted average gray value between at each conveying speed and in stationary state of apple.

| Grade by speed \ Grade in stationay state | | I | II | III | IV | Total |
|---|---|---|---|---|---|---|
| 5.3cm/sec | I | 13 | 1 | | | 14 |
| | II | 7 | 29 | 3 | | 39 |
| | III | 1 | 6 | 28 | 1 | 36 |
| | IV | | | 2 | 9 | 11 |
| 15.2cm/sec | I | 15 | 1 | | | 16 |
| | II | 6 | 32 | 2 | | 36 |
| | III | | 3 | 30 | 7 | 40 |
| | IV | | | 1 | 3 | 4 |
| 25.1cm/sec | I | 16 | | | | 16 |
| | II | 5 | 27 | 1 | | 33 |
| | III | | 9 | 28 | 1 | 38 |
| | IV | | | 4 | 9 | 13 |
| Total | | 21 | 36 | 33 | 10 | 100 |

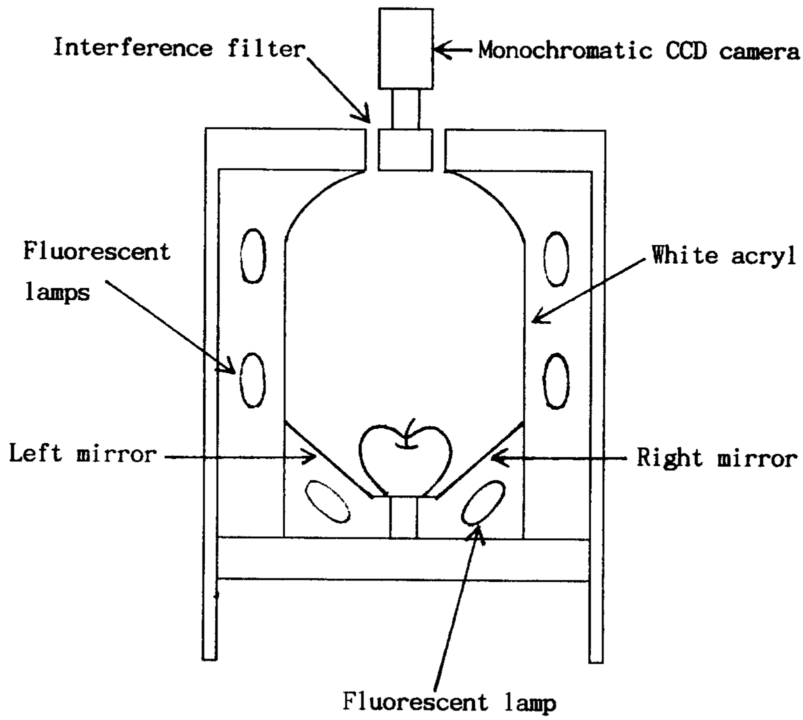



Fig. 1. Cut-away view of the illumination chamber.

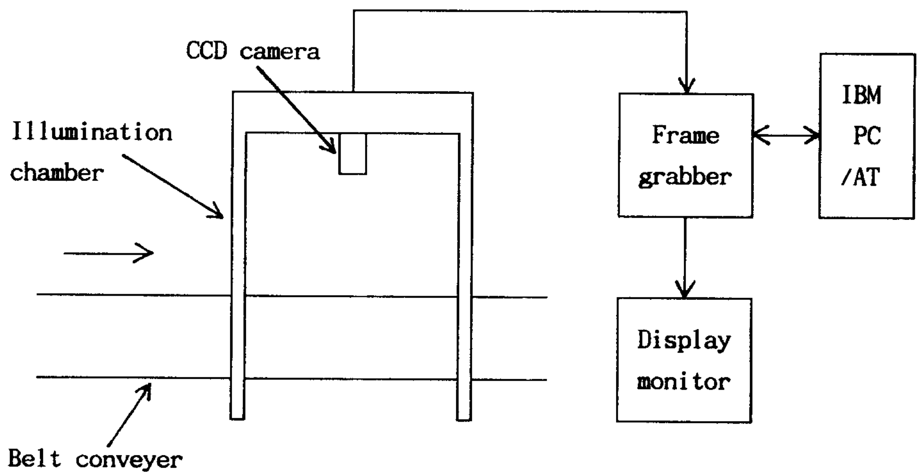
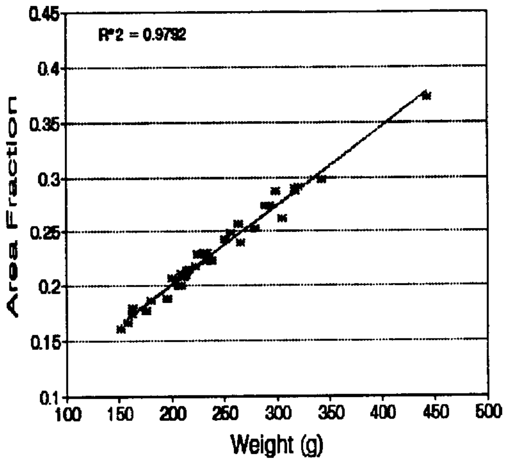
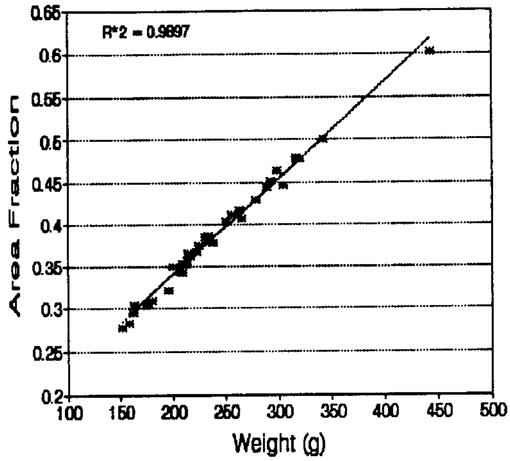



Fig. 2. Layout of the experimental fruit grader using black/white image processing system.

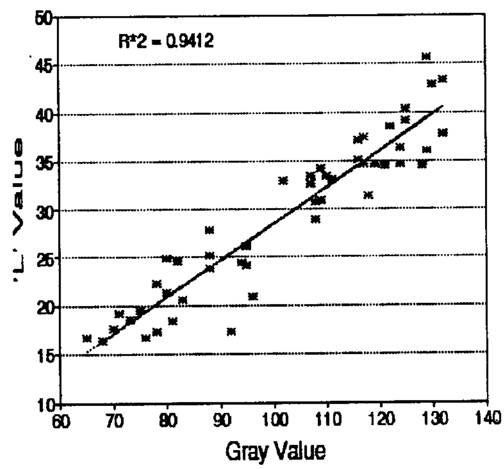



(a)

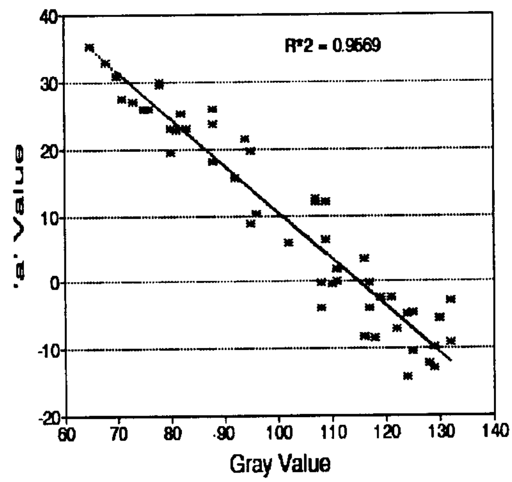



(b)

Fig. 3. Correlation between weight and area fraction of apple.
(a) weight vs. area fraction of the direct image
(b) weight vs. area fraction of direct and two reflected image

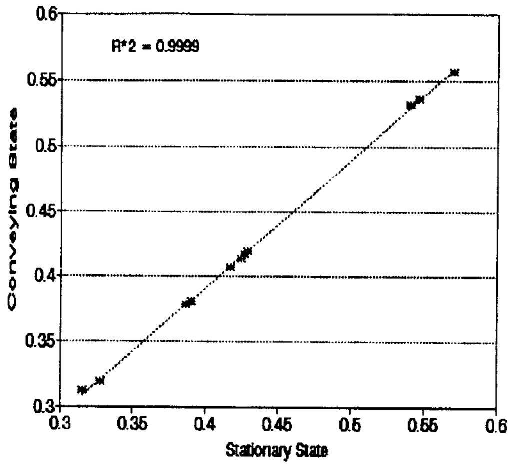



(a)

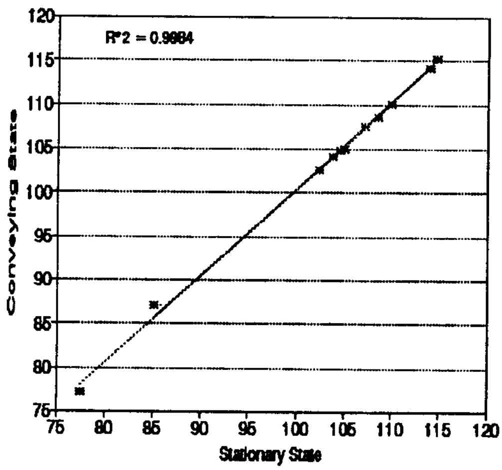



(b)

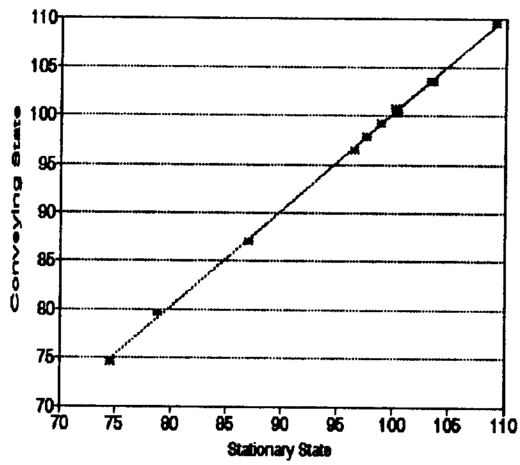
Fig. 4. Correlation between the gray values and 'L' and 'a' values of Hunt color scale.
(a) gray value vs. 'L' value
(b) gray value vs. 'a' value




(a)




(b)




(c)

Fig. 5. Correlation of area fraction and average gray values between stationary state and conveying state at the conveying speed of 15.2 cm/sec.
(a) area fraction of the whole image
(b) average gray value of the direct image
(c) mean of average gray values of two reflected images