Algorithm for Discrimination of Brown Rice Kernels Using Machine Vision

C. S. Hwang, S. H. Noh and J. W. Lee
Graduate Student, Professor and Post-Doc.
Dept. Agricultural Engineering, Seoul National Univ.
Suweon 441-744, Korea

ABSTRACT

An ultimate purpose of this study is to develop an automatic brown rice quality inspection system using image processing technique. In this study emphasis was put on developing an algorithm for discriminating the brown rice kernels depending on their external quality with a color image processing system equipped with an adaptor for magnifying the input image and optical fiber for oblique illumination.

Primarily, geometrical and optical features of sample images were analyzed with unhulled paddy and various brown rice kernel samples such as sound, cracked, green-transparent, green-opaque, colored, white-opaque and brokens. Secondary, an algorithm for discrimination of the rice kernels in static state was developed on the basis of the geometrical and optical parameters screened by a statistical analysis(STEPWISE and DISCRIM Procedure, SAS ver. 6).

Brown rice samples could be discriminated by the algorithm developed in this study with an accuracy of 90% to 96% for the sound, cracked, colored, broken and unhulled, about 81% for the green-transparent and the white-opaque and about 75% for the green-opaque, respectively. A total computing time required for classification was about 100 seconds/1000 kernels with the PC 80486-DX2, 66MHz.

Key words : image processing, brown rice, external quality, classification

INTRODUCTION

In Korea, RPC's(Rice Processing Complex) have been prevailed in rural area under the government financial aids since 1992 for the purpose of improving the post-harvest rice quality, supplying shortage of farm labor and modernizing the rice marketing system.

In order to achieve such a purpose the post-harvest works such as drying, storing, milling and marketing which have been conventionally done by individual farmer basis should be performed together, not by the individual, at the RPC and finally, a joint sale of the final product and an accurate account for each farmer

should be followed.

With regard to these functions of RPC it is essential to evaluate and classify the raw materials brought by each farmer by quality and geometrical characteristics for efficient processing and storing since many rice varieties are grown in Korea.

Quality inspection standard for rough rice includes moisture content, content of foreign material, brown rice yield rate, external quality of brown rice, etc. and the quality of brown rice is determined by composition ratios of the sound, immatured(green-transparent, white-opaque, milky), damaged(germinated, cracked), and discolored.

A mechanical automatic paddy quality inspection system which was recently commercialized in Korea is not suitable for accurate quality evaluation of brown rice since the working principle of the machine is based on thickness grading only. The brown rice samples having similar thickness to the sound kernel such as the cracked, milky and discolored can not be separated out from the sound. Also, it is reported that an optical automatic brown rice quality inspection system developed in Japan can be used for discriminating the sound, discolored, cracked, chalky and greenish but it has disadvantage that broken kernels or unhulled paddy included in the sample can not be separated out.

With the development of computer related industries, the image processing or computer vision system has been applied to classifying and inspecting the agricultural products. Some of the applications for grain quality evaluation are as follows.

Matshuisa and Hosokawa(1978, 1981, 1983) conduced a series of research work to develop quality inspection system of brown rice with image processing technique by employing transmission light. Dekker and Visser(1988) developed an algorithm to discriminate the sound, cracked and broken white rice by using an oblique illumination. An algorithm and illumination method to detect the crack, scars and mold contamination of corn kernel was developed by Gunasekaran et al.(1988). Kim(1989) reported that combined adaptation of sobel and non-maximum suppression operators was the most effective to detect corn crack. Liao et al.(1993) and Ni et al.(1993) developed an on-line computer vision system to classify the corn kernels by neural net based algorithm.

An ultimate purpose of this study is to develop an on-line brown rice quality inspection system using image processing technique which can be used at RPC. In this study emphasis was primarily put on developing an algorithm for discriminating the brown rice kernels produced after hulling process. Specific objectives are as follows.

1) To present the significant parameters necessary for discrimination of the sound, cracked, white-opaque, green-transparent, green-opaque, colored, unhulled,

and broken brown rice kernel by analyzing the geometrical characteristics and color information of each sample.

2) To develope an algorithm for evaluating the quality of brown rice in static state.

MATERIALS AND METHODS

Experimental Apparatus :

Image acquisition system was composed of image processing unit, illumination device and sample tray as shown in Fig. 1. Color CCD camera(Panasonic, WV-CL110) was used to acquire the image, and an adaptor was attached to the camera to magnify the sample kernel. The digitizer and display module were MVP-AT(Matrox Co.) and 14″ RGB Monitor(Model 38-DO51MA UU). The host computer was the PC 80486-DX2, 66MHz.

Incandescent light was used for diffuse illumination and an oblique light using optical fiber was applied to the longitudinal direction of the grain kernel to detect the crack in the grain kernel. A sample tray was made with black acryl plate to provide a good contrast between the sample and the background. The illumination on the sample tray was maintained so that R, G and B values were 84($\pm$1.2), 83 ($\pm$1.5) and 85($\pm$2.1), respectively for the standard white plate and 25.3($\pm$2.3), 26.9($\pm$1.3) and 30.5($\pm$2.8) for black background. And the intensity of the light was kept around 1300 lux.

The paddy of Ilpoom variety was hulled by the test huller(Satake, THU-35A) and the brown rice was classified into the sound, cracked, white-opaque, green-opaque, green-transparent, colored, unhulled and broken for test runs.

Experimental Procedure :

Image segmentation and chain coding were performed by the predetermined threshold value to extract the grain kernel from the background and subsequently the length, width, area and perimeter were measured as basic parameters. Also, the ratios, length/width, length/area, perimeter/area were calculated.

For analysis of the sample color, average R, G and B values were measured in the rectangular region set up within the grain kernel image(Fig. 2), which were also converted into the rgb, XYZ, xyz, L*a*b* color coordinate values. The parameters to detect the cracked kernel were determined from the analysis of the color information of the image which was obtained under oblique light. The effect of the relative kernel position to the oblique light on the crack detectability was examined.

Significant parameters which affect in discriminating the brown rice samples were selected by statistical analysis. On the basis of this result an algorithm was

developed and its performance was evaluated with the known samples in static state.

RESULTS AND DISCUSSION

Selection of Discriminating Parameters :

Primarily, STEPDISC procedure(SAS) was run to select geometrical and color parameters which significantly contribute to discrimination of each brown rice sample. As the result, length was the most significant among the geometrical parameters investigated and others were selected in the oder of width/area, width, area and perimeter. In case of color information, g value was the most significant and B, L^*, R, G, Y, b^*, b, Z and r were appeared as significant.

Subsequently, DISCRIM procedure which is based on the generalized squared-distance $D_j^2(X_i)$ was run with those significant parameters to find the posterior probability of each parameter. This probability indicates the degree of contribution of each parameter to discrimination of each sample.

The statistical analysis indicated that the unhulled and green-opaque kernels could be discriminated by length with 100% and 95% of posterior probability, respectively(Table 1). Other geometrical parameters such as length, width/area, width and area were also appeared significant for discriminating the unhulled and green-opaque kernels from the other samples.

Similarly, DISCRIM procedure was adopted to analyze the posterior probability of each color information. As the result, posterior probabilities of the color value, g, for the colored, unhulled, green-transparent and green-opaque kernels were 71.7%, 70%.0, 61.7% and 43.3%, respectively(Table 2). The posterior probability of g value for the unhulled kernel was comparatively higher than others but the deviation of g value of the unhulled was relatively large. B, L^8, R, Y and Z values indicated probability of greater than 80% for the white-opaque and relatively low for other kernels as shown in Table 2.

In consideration of the above results, distribution of each parameter value for each sample group(Fig. 3 to 8) and the computing time of each parameter, length and area as the geometrical parameter and g, B, R and r values as the color information were selected as the final parameters to be used for algorithm development for on-line kernel discrimination.

Detection of the Cracked Kernel :

It was impossible to discriminate the cracked kernel from the whole with diffuse illumination only. Through the references(Dekker and Visser, 1988) and preliminary tests it was found appropriate to use the variation in light intensity to the longitudinal direction of the kernel which was appeared when an oblique light

was beamed to the kernel with optical fiber.

Fig. 9 shows example images of whole and cracked kernels which were obtained under the oblique light having the angle of about 20° to the horizontal. From these images it was found that for the sound kernel the G value in the longitudinal direction changes smoothly but for the cracked kernel sharply at the crack point regardless of the direction of the embryo to the light source as shown in Fig. 10. Accordingly, the maximum difference in G value to the longitudinal direction was defined as a crack-index and used for detection of the cracked kernel.

Table 3 shows detectability of the cracked kernel depending on location of the kernel embryo to the oblique light and the angle between the oblique light and the longitudinal axis of the kernel. The crack is detected with relatively high accuracy when the embryo was placed and the detectability was decreased with an increase in the angle between the oblique light and the longitudinal axis of the grain kernel.

Algorithm for Discriminating Rice Samples :

On the basis of the meaningful parameters determined by the statistical analysis an algorithm was developed to discriminate rice kernels into the sound, cracked, white-opaque, green-transparent, green-opaque, colored, broke and unhulled. The flow chart of the algorithm is presented in the Fig. 11 and the following is the description on the algorithm.

① Check if the kernel belongs to the unhulled, green-opaque or broken kernel by the length and area index of grain kernel.

② Check if the kernel is white-opaque by R value unless the kernel is one of three kernels in ①.

③ With B, r and g values check if the kernel is colored.

④ With g value, check if the kernel is greenish. If it is, examine the kernel whether it is green-opaque or green-transparent by the area index of the kernel.

⑤ If the kernel is not greenish, discriminate the kernel into the sound or cracked by Crack-Index.

Performance of the Algorithm :

Accuracy of the algorithm developed in this study was tested with each sample of 100 kernels which were classified by human eye. Each kernel was placed so that the longitudinal axis of the kernel was coincide with the oblique light direction, and embryo was placed arbitrarily. The reference values of those parameters used for discriminating each kernel were determined primarily on the basis of geomtrical and color coordinate values of each sample group and adjusted by experiment.

Table 4 shows that the discrimination accuracy of the algorithm is ranged from 90% to 96% for the sound, cracked, colored, broken and unhulled, about 81% for the green-transparent and white-opaque and about 75% for the green-opaque, respectively.

The computing time required for discrimination of sample kernels including the image capturing was about 100 sec. per 1000 kernels with the PC 80486-DX2, 66MHz.

SUMMARY AND CONCLUSIONS

An ultimate purpose of this study is to develop an automatic system for brown rice quality inspection using image processing technique. In this study emphasis was put on developing an algorithm for discriminating the brown rice kernels depending on their external quality with a color image processing system equipped with an adaptor magnifying the input image and optical fiber for oblique lightening.

Primarily, geometrical and optical features of images were analyzed with various brown rice kernel samples including unhulled paddy such as the sound, cracked, green-transparent, green-opaque, colored, white-opaque and broken. Secondary, geometrical and optical parameters significant for identifying each rice kernels were screened by a statistical analysis(STEPWISE and DISCRIM Procedures, SAS ver. 6). Based on these results an algorithm for discrimination of the rice kernels in static state were developed and finally, its performance was evaluated. The results are summarized as follows.

1. Significant geometrical parameters for discrimination of brown rice kernels including unhulled paddy were analyzed as length, width/area, width, area and perimeter and color parameters were as g, B, L*, R, G, Y, b, Z and r.

2. It was ascertained that the cracked kernels could be detected when the incident angle of the oblique light was less than 20°. The difference in G value to the longitudinal direction of the kernel was found to be used for crack detection but detectability was significantly affected by the angle between the direction of the oblique light and the longitudinal axis of the rice kernel and also, by the location of the embryo with respect to the oblique light.

3. An algorithm for on-line discrimination of rice kernels were developed by using the parameters, area, length, g, B, R and r .

4. Discrimination accuracies of the algorithm were ranged from 90% to 96% for a sound, cracked, colored, broken and unhulled, about 81% for green-transparent and white-opaque and 75% for green-opaque, respectively. A total computing time required for classification was about 100 seconds per 1000 kernels with the PC,

80486-DX2, 66MHz.

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Table 1. Posterior probability for discrimination of rice kernels by geometrical parameter.

parameter	Posterior probability of correct discrimination (%)						
	sw*	cr	wo	go	gt	co	uh
Length	50.0	25.0	20.0	95.0	18.3	36.7	100.0
Width/Area	55.0	3.3	6.7	100.0	8.3	18.3	81.7
Width	6.7	25.0	6.7	63.3	16.7	41.7	81.7
Area	11.7	53.3	20.0	90.0	25.0	40.0	85.0

* Description of the kernel type
  sw : sound whole kernel   cr : cracked kernel
  wo : white-opaque kernel   go : green-opaque kernel
  gt : green-transparent kernel co : colored kenel
  uh : unhulled kernel

Table 2. Posterior probability for discrimination of rice kernels by color parameter.

parameter	Posterior probability of correct discrimination (%)						
	sw*	cr	wo	go	gt	co	uh
g	28.3	60.0	20.0	43.3	61.7	71.7	70.0
B	58.3	31.7	80.0	46.7	35.0	18.3	50.0
L*	23.3	41.7	83.3	5.0	50.0	15.0	40.0
R	31.7	46.7	86.7	18.3	28.3	45.0	10.0
G	21.7	35.0	76.7	35.0	21.7	28.3	40.0
Y	31.7	35.7	83.3	5.0	50.0	15.0	40.0
b*	1.7	28.3	46.7	55.0	1.7	48.3	11.7
b	53.3	28.3	10.0	56.7	3.3	35.0	0.0
Z	58.3	31.7	80.0	46.7	35.0	18.3	50.0
r	55.0	10.0	41.7	31.7	3.3	60.0	66.7

[1] Description of the kernel type is the same as in Table 1.

Table 3. Accuracy of crack detection according to the angle between the direction of optical fiber light and the longitudinal axis of grain kernel (%).

Angle between the optical fiber light and the longitudinal axis of kernel									
0°		22.5°		45°		67.5°		90°	
I [1]	II [2]	I	II	I	II	I	II	I	II
86(%)	96	34	50	6	10	0	0	0	0

[1] when the kernel embryo is toward the optical fiber light.

[2] when the kernel embryo is opposite to the optical fiber light.

Table 4. Accuracy of the rice kernel discrimination by image processing system as compared to the manual (%).

IPS [1] / Human [2]	whole	cracked	green-transparent	green-opaque	colored	unhulled	white-opaque	broken
whole (100)	90	5	·	·	·	·	5	·
cracked (100)	4	92	1	1	·	·	2	·
green-transparent(100)	4	7	82	5	2	·	·	·
green-opaque (100)	·	2	13	75	·	·	·	10
colored (100)	·	5	·	·	91	·	·	4
unhulled (100)	·	·	·	·	4	96	·	·
white-opaque (100)	2	10	·	·	6	1	81	·
broken (100)	1	·	·	2	·	·	3	94

[1] Discriminated by image processing system
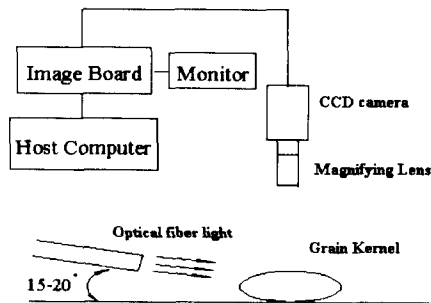
[2] Discriminated by human
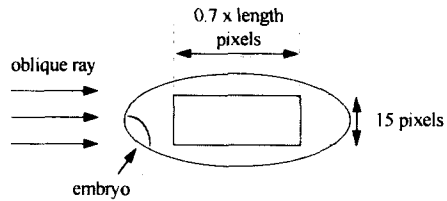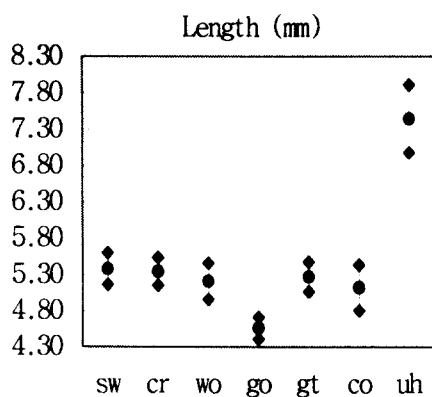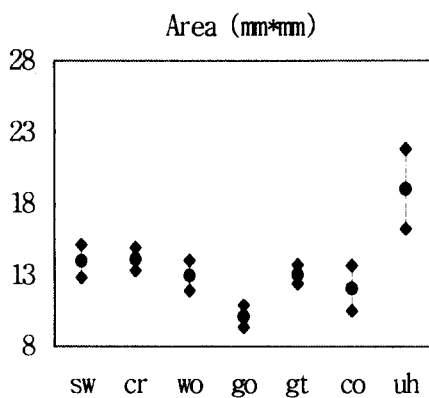

Fig. 1. Image processing system.

Fig. 2. Rectangle set up within the kernel to measure color information.

Length (mm)

sw: sound, cr: cracked, wo: white opaque, go: green transparent

Fig. 3. Range of length for each kernel.

Area (mm*mm)

gt: green transparent, co: colored uh: unhulled

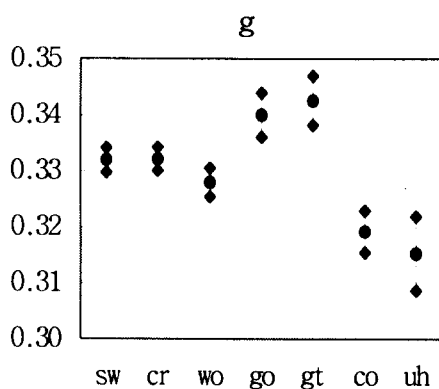Fig. 4. Range of area for each kernel.

g

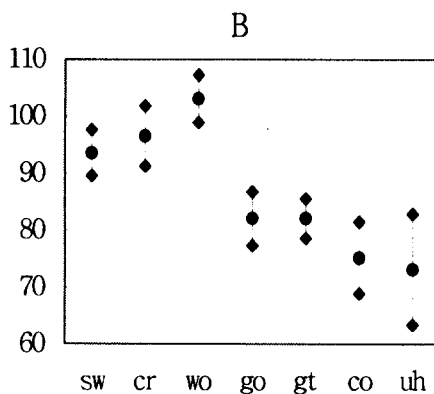Fig. 5. Range of g for each kernel.

B

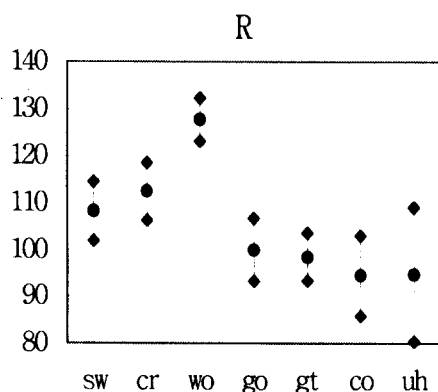Fig. 6. Range of B for each kernel.
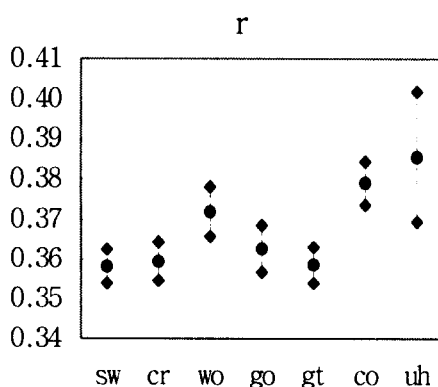
R

Fig. 7. Range of R for each kernel.
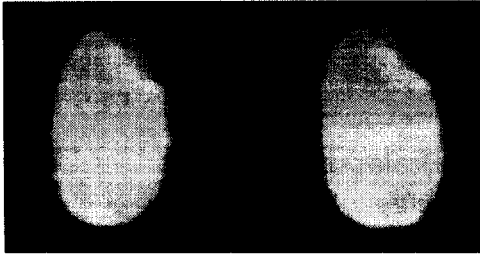
r

Fig. 8. Range of r for each kernel.
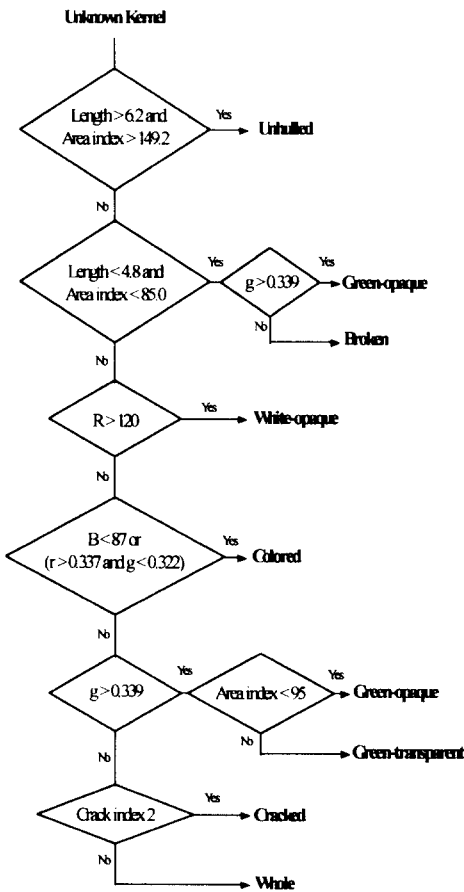
Fig. 9. Images of whole and cracked kernel.

Whole Kernel

embryo is OPPOSITE to the light

embryo is TOWARD the light

Long axis of kernel

Cracked Kernel

embryo is OPPOSITE to the light

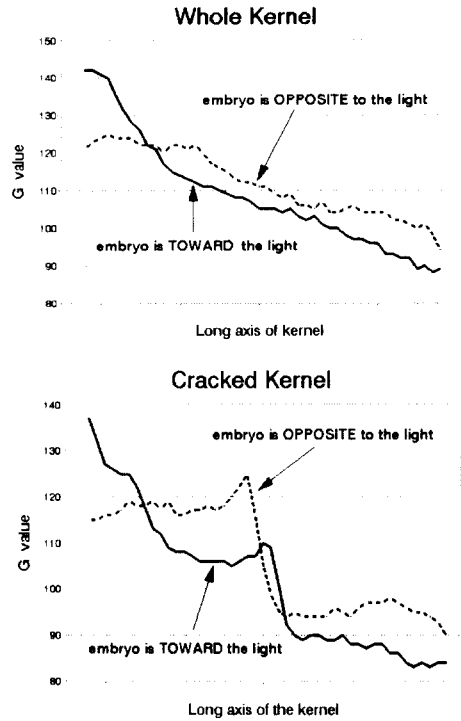embryo is TOWARD the light

Long axis of the kernel

Fig. 10. Profiles of G values along the longitudinal axis of whole and cracked kernel.

Unknown Kernel

Length>6.2 and Area index>149.2 — Yes → Unhulled

No

Length<4.8 and Area index<85.0 — Yes → g>0.339 — Yes → Green-opaque

No → Broken

No

R>120 — Yes → White-opaque

No

B<87 or (r>0.337 and g<0.322) — Yes → Colored

No

g>0.339 — Yes → Area index<95 — Yes → Green-opaque

No → Green-transparent

No

Crack index 2 — Yes → Cracked

No → Whole

Fig. 11. Flow-chart for discrimination of rice kernels.