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Bruise Detection Using Complexity for Oorin Apples

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The complexity of binary image for apples as normal, bruised around center, bruised around edge, and bruised around both edge and center were analyzed. A multi-threshold method (thresholds determined by area rates 0.3, 0.4, ...0.7 for complexity rates analysis) was used successfully for bruise classification. Leaving out apples with bruising around the edge, apples were classified 85.7 % correctly.

Key words : Oorin apple, bruise, image processing

Introduction

Post harvest sorting and grading of apples are difficult and labor intensive components of the apple industry. Current research on automatic fruit grading is divided into two branches. One is maturity grading, the other is damage detection.

The extensive use of mechanical systems for harvesting and processing products, especially in the case of soft fruits, may lead to an increase in the number of damaged and bruised fruits. Among all kinds of damages (bruise, scar, cut, russet, bird eating, etc.), as much as 10-30 % of bruises may be caused by handling.

According to a properties analysis of Fuji and Oorin[1], bruises on Oorin apples could be detected using color images. This paper analyzed green images of Oorin apples taken by CCD camera, and built a bruise-detecting algorithm.

Image processing system and binary image

The image processing system used in this study is shown in Fig. 1. It consists of two parts, a lighting box and an Olympus digital image processor.

The influence of curved apple surface on gray level — A green color image of a yellow ball was used in order to check the influence of a spherical surface shape on gray level. The three dimensional gray level distribution of the green color image is shown in Fig. 2. They are symmetric, so a gray level of twenty pixels from the center of the ball was investigated. The relation between gray level and pixel position is shown in Fig. 3. It shows that when pixel distance (r) from the

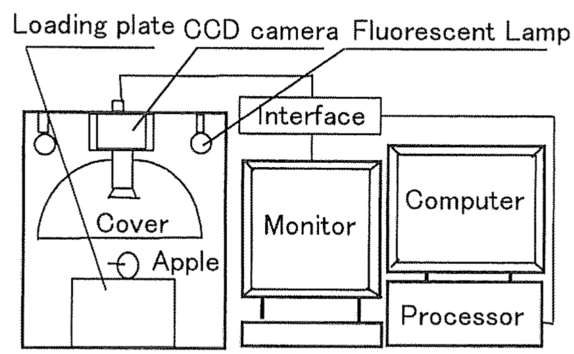

Fig. 1 Color image Processing system.

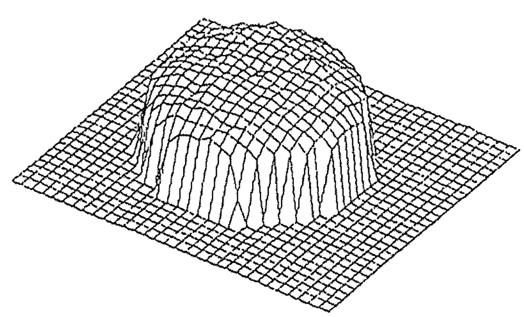

Fig. 2 Three-dimensional gray level distribution of green signal on a yellow ball.

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center of the ball has the following relation with radius (R) of the ball, then it can be suggested that there are no gray level changes.

$$r < 0.7R \tag{1}$$

The effect of ball shape is too small to be considered. A bruise inside this circle is called bruising around the center, outside this circle is called bruising around the edge.

Bruised area's position — Presume the apple to be a ball, the position for possible bruise area is shown in Fig. 4. It assumes the line stem and calyx as X axis. The CCD camera which takes images turns around X axis every 90°, so that four images can be taken. If two other images were taken from the stem and calyx directions respectively, for an apple, there were able to take six images in total to detect bruises.

The bruised areas can be at two positions of an image. One is around the edge of an apple image, another is around the center. Bruised areas happening around stem and calyx are not discussed here; concerning stem and calyx, more complex analysis will be necessary.

According to Fig. 4, bruise 1 is around the center of the image, bruise 2 is around the edge of the image viewed from the Z axis direction. Turn 90° around the X axis clockwise, to view from the Y axis direction, and we can see that bruise 2 is around the center, and bruise 1 is around the edge of the image. Bruise 3 can be seen clearly around the stem area viewed from the X axis direction.

For a point P on the ball, if the images were taken from X, Y and Z directions or from the inverse direction, there must exist at least one image that the pixel position from center (r) has the following relation with the radius (R) of the ball:

$$r \leqq 0.816R \tag{2}$$

Here, $r = \sqrt{r_1^2 + r_2^2}$ or

$r = \sqrt{r_1^2 + r_3^2}$ or $r = \sqrt{r_3^2 + r_2^2}$

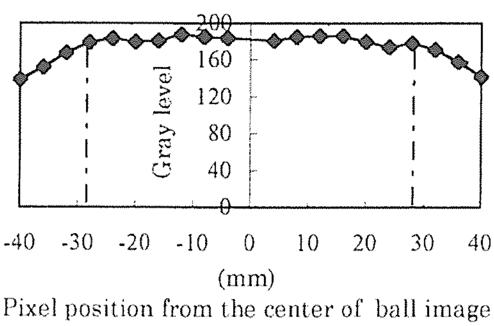

Fig. 3 Gray level changed with pixel position.

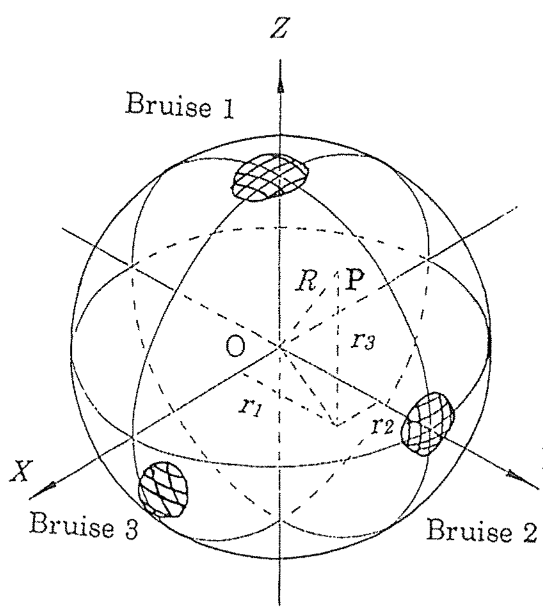

Fig. 4 Possible bruise areas on apple.

Materials and analysis method

Material — 147 Oorin apples were used for image analysis and detection of bruised areas by the above image processing system. Among these 147 apples, ten normal apple images, ten apple images with bruising around the center, ten apple images with bruising around the edge, ten apple images with bruising both around center and edge were captured for image analysis. The other 107 apples including 43 normal ones, twenty-eight with bruising around the center, sixteen with bruising around the edge, twenty with bruising around both the center and the edge of the image were used for detection by the program made according to the analysis results. Images of bruised apples were all captured within one hour of bruising.

Gray level distribution — Gray level distributions of green signal image are shown in Fig. 5. It shows that the bruised part has a lower gray level than the normal part (c more than a and d more than b), and if the apple is heavily bruised, the distribution of gray level was divided into two parts, as shown in Fig. 5(d). There are no large differences between the distribution shape of normal and that of bruised apple when the apple is lightly bruised. The pixels which have low gray level belong to the black background.

A three dimensional graph of gray distribution for normal and bruised apples is shown in Fig. 6. It shows that normal and bruised apples have their own special properties in the gray level. From the outside to the center of an apple, a normal apple changed its gray level gradually and evenly, but a bruised apple changed its gray level suddenly when there was a bruise happened.

Complexity of binary image — Complexity of binary image is defined with the following formula[2]:

$$c = \frac{4\pi a}{l} \quad (3)$$

where,

c: complexity of binary image.

a: area of the binary image not including holes.

l: perimeter of the binary image including inner holes.

Concerning the equal gray level lines, it was considered that complexity is a suitable and simple way to make bruise detection realization from normal apples.

Complexity of normal and bruised apple analysis — For an apple, the complexity changed when the binary image changed with the threshold. Binarization was processed under the following condition:

$$f(x, y) = \begin{cases} 1 & f(x, y) \geq t \\ 0 & f(x, y) < t \end{cases} \quad (4)$$

where,

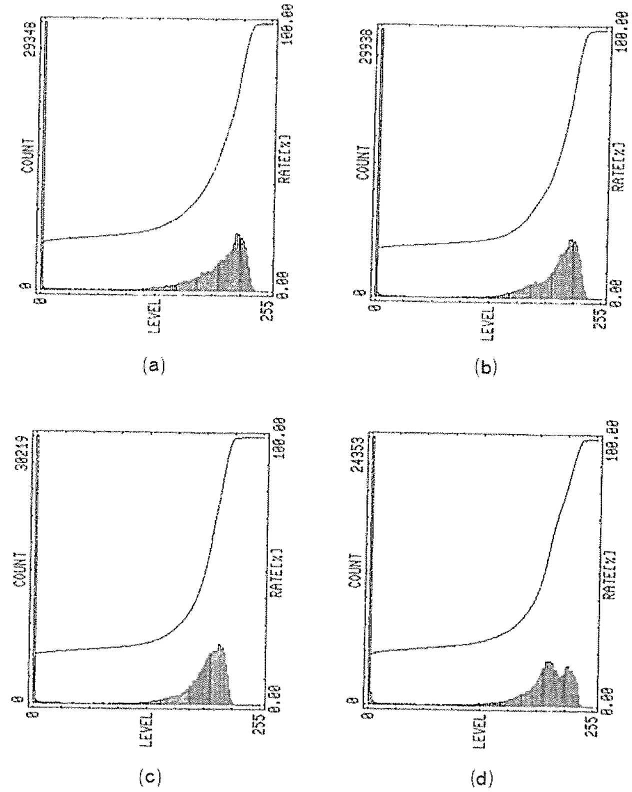

Fig. 5 Gray level distribution of the green signal on an apple.
(a) Normal, (b) Normal, (c) Bruised, (d) Bruised

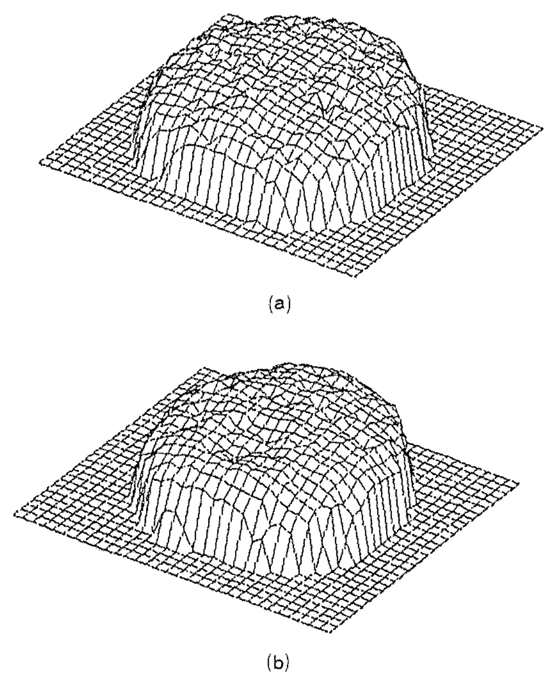

Fig. 6 Three-dimensional distribution of gray level for green signal on an apple.
(a) Normal, (b) Bruised

$f(x, y)$: gray level at pixel (x, y)

t: thresholds for binarization, they are 100, 160, 168, ...232.

When the gray level is 100, the whole apple was chosen, with the threshold increasing and the effect of bruise, the chosen areas decreased gradually following the change of the perimeter. So the complexity changed with those two factors.

Because every apple has its own gray level distribution and its own original shape complexity, it is impossible to make a standard suitable to all apples just by absolute complexity. So the relationship between area rate and complexity rate was calculated.

The area rate (r_a) and complexity rate (r_c) are defined with the following formulae:

$$r_a = \frac{a_i}{a} \tag{5}$$

$$r_c = \frac{c_i}{c} \tag{6}$$

where,

a: binary image area of apple when threshold is 100.

a_i: binary image area of apple when threshold is 160, 168, ...232.

c: binary image complexity of apple when threshold is 100.

c_i: binary image complexity of apple when threshold is 160, 168, ...232.

The relationship between area rate and complexity rate concluded according to the above four groups of samples is shown in Fig. 7.

Fig. 7 shows that normal apples had the same kind of relation as that of bruised around edge between the complexity rate and area rate, but differences were found between normal apples and two kinds of bruised apples (with bruise around center, and with bruise both around center and edge). For both normal and bruised apples, when area rates are larger than 0.75($r > 0.866R$), they have almost no differences. When area rates are lower than 0.3, almost no relation exists between area rates and complexity rates. This means that beyond this range, it is impossible to detect the bruise using complexity rate.

Detection method and results

Flowchart of bruise detection algorithm is shown in Fig. 8. C is a regulation constant.

According to the gray level distribution graph, some of the bruised apples have the same kind of

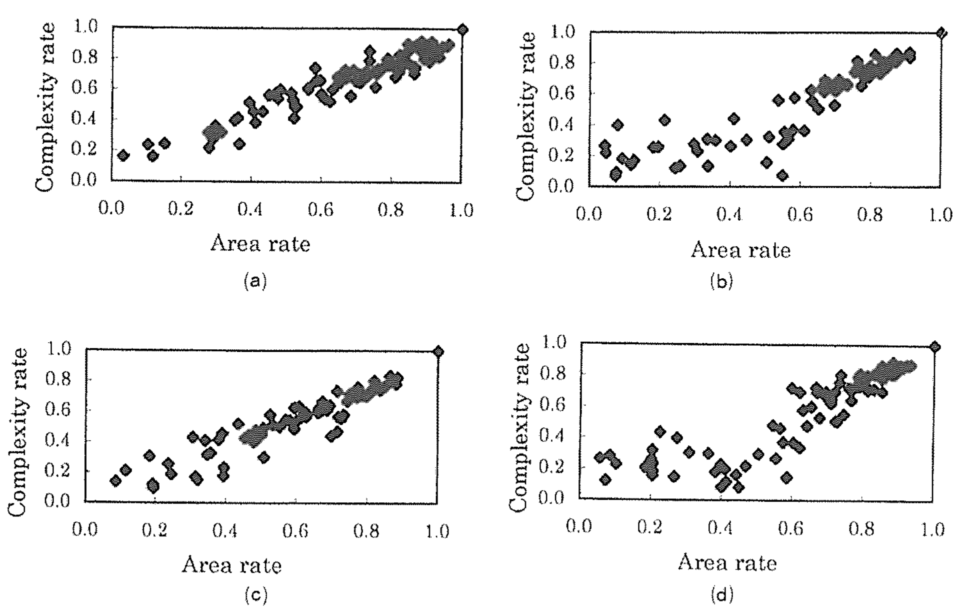

Fig. 7 Relation between relative complexity rate and relative area rate.
(a) Normal, (b) With bruise around center, (c) With bruise around edge, (d) With bruises around center and edge

Table 1 Apple detection results using complexity method

Apple	Classified as normal	Cassified as bruised	Total	Detected rate
Normal	34	9	43	79.1%
Bruised around C	2	26	28	92.9%
Bruised around E	10	6	16	37.5%
Bruised around C and E	2	18	20	90.0%

C: center, E: edge

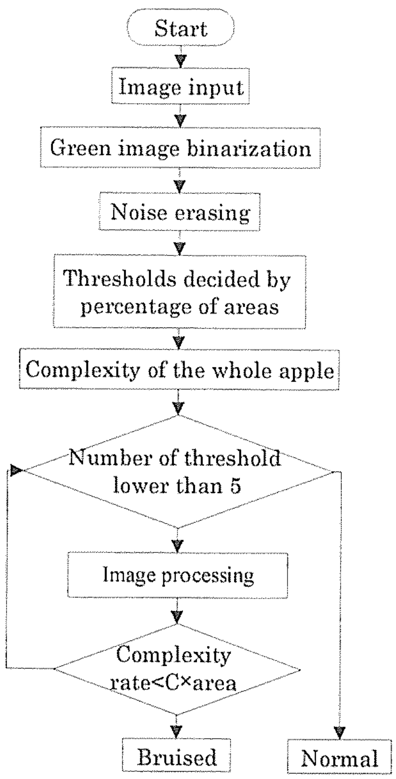

Fig. 8 Flowchart of bruise-detection algorithm.

distribution as normal ones, but just have a wider area around maximum. Some of the distribution was divided into two peak values. In order to make the program suitable for these two types of apples, five thresholds were chosen absolutely when area rates were around 0.7, 0.6, ...0.3. When the area rate is 0.7, the distance from the center of the image r is $0.837R$.

Results — The complexity and area were calculated for bruise detection for each apple. No matter where the bruise happened, they can be divided into normal and bruised apples. Detection results for 107 sample apples are shown in Table 1. It shows that the average detection rate for apples is 85.7 % leaving out bruise around edge.

Discussions

It is impossible·to detect the bruise when the bruise is at the position $r > 0.837R$ using the above algorithm for image with bruise around edge. But according to the analysis of Fig. 3 and Fig. 4, it will be detected out from images viewed from other directions. Apples with bruise around stem and calyx were not analyzed here. More research on bruising around stem and calyx need to be done.

Here bruises were made by dropping, so the bruised area was big. More research on small sized bruises should be undertaken.

It is shown in the analysis that complexity is a feasible method for bruise detection.

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複雑度により王林リンゴの損傷判別

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本研究は、王林リンゴのgreen画像を2値化し，その2値化画像を分析した．損傷果を検出するために，2値化画像の面積の変換による，画像の複雑性をもとに，正常部及び損傷部（損傷部は画像の真中辺り，エッジ辺り，真中とエッジ辺りとも）の画像を分析した．この画像種類複雑性の分析結果によって，多しきい値方法を使用して，正常部と損傷部は85.7％の精度で判断できだ．