DETECTION AND CLASSIFICATION OF DEFECTS ON APPLE USING MACHINE VISION *

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ABSTRACT

This study was carried out to develop tools to detect defects of apple using machine vision. For the purpose, 6 kinds of frame for color images, R, G, B, H, S, and I frame, and a frame for near infra-red image(NIR frame) were tested first to select one which is useful to segment defect areas from apple images. After then, several methods to classify kind of defect for the segmented defect areas were developed and tested. Five kinds of apple defect - bruise, decay, fleck, worm hole and scar were investigated. The results are as follows;

NIR frame was selected as the best one among the 7 kinds of image frame, and R, G and I frames showed favourable result to segment areas of apple defect. Various features of the segmented defect areas were measured to classify the defect areas. Eight kinds of feature of the areas - size, roundness, axes length ratio, mean and variance of pixel values, variance of real part of spectrum, mean and variance of power spectrum resulted from spacial Fourier transform were observed for the segmented defect areas in the selected 4 frames. Then procedures to classify defects using the features were developed for the 4 frames and tested with 75 - 113 defects on apples. The test resulted that NIR and I frames showed high accuracies to classify the kind of defect as 77 % and 76 %, respectively.

Key word : machine vision, apple defects, detect, classification

INTRODUCTION

Detection of defects is necessary to sort agricultural products, especially in sorting fruits. Since the job needs lots of labor to perform, mechanization of the job is urgently needed. But this is very difficult to perform because defects of agricultural products have various shape and color as well as various size.

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Several techniques have been tried to develop this defects detection device and machine vision is known as the most promising one. Various cameras and image processing tools were used for the purpose. Delwiche et al.(1988) tried to detect defects of peach using a machine vision system consisted of a line-scanning camera. Throops et al.(1989) tried to detect watercores of apple using an area-scanning camera. They tried to measure density of apple to judge the watercoree by measuring intensity of light that was passed through an apple. The study resulted that existence of watercore could be detected at high confidence but size of watercore could not be measured.

Researchers using machine vision systems to detect the defects have tried with color vision systems and near infra-red cameras recently. Shearer and Payne(1990) detected defects of bell pepper using a color vision system and could detect the defects at an accuracy of 63 %. Delwiche et al.(1990), Miller and Delwiche(1991) and Wulfsohn et al.(1993) reported that images captured in near infra-red light was very effective for detecting defects of fruits.

In the process to detect defects of apple by a machine vision, segemntation of defect area from an apple image is the first step to perform. Fuji apple, a major variety in far east Asia, has so irregular distribution of various color on its surface that distinguishing defect area from an image of apple is very difficult. Hence color vision system was considered as necessary one for this study and several techniques were checked to find out better method for the segmentation.

Defects of apple are caused by bruise, damage by blight disease or harmful insects and mechanical demages etc. and are generally classified as bruise, decay, fleck, worm hole and scar etc. Defect areas segmented are needed to be classified as their kind and size in order to sort out apples unacceptably defected to a sorting standard.

This study was carried out to detect the apple defects using machine vision system. Objectives of this study in detail were to find out an effective method to segment defect areas from apple surface images, to extract features from each segmented defect area for its classification and to develop a method to classify the defect areas systematically using the extracted features of the areas.

MATERIALS AND METHODS

1. Segmentation of Defect Area

Color machine vision used in this study was consisted of a personal computer, a frame grabber, two cameras and a lighting chamber. The computer was an Intel 486 CPU operated IBM compatible one. The frame grabber was made by Imaging Technology Company in USA (model : CFG). One of the camera used was a normal color video camera made by Sony in Japan (Model : CCD-F380). The other camera was a CCD b/w camera made by Pulnix Company in USA (Model : TM-745E). This CCD camera was used to obtain NIR images. The camera had a infra-red cut filter which was detachable. In order to get NIR image the infra-red cut filter was separated and a bandpass filter having a bandwidth of 750±20 nm was mounted on the camera. The lighting chamber had a lighting source of three triple-wavelength N type fluorescent lamps (FL 20S EX-N/18) made by Kumho Electric Company in Korea. Algorithms for image processing with the hardware was almost the same as the one explained in a paper of Suh(1992).

The color vision system generated color images with three basic color frames, R, G and B, which were convertible to the color frames of H, S and I (hue, saturation and intensity) through software routines. Hence, any color image grabbed by the system could be splitted into R, G and B frames or H, S and I frames. Besides the six color frames, image of near infra-red (NIR) in light intensity (b/w) frame could be captured by the system with the b/w camera with the NIR filter. So seven kinds of frame of image could be acquired from a scene by the vision system used.

A series of experiments were carried out to select a frame which gave the best result to segment defect areas. The seven kinds of frame were tested with the 5 kinds of defect - bruise, decay, fleck, worm hole and scar, of various size and shape on Fuji apple.

To segment areas of defect on an apple image, a method of thresholding pixel value using input LUT (look up table) was used. A desirable condition for a frame to segement defect areas was having big difference in pixel values between the various defect areas and normal apple image. Hence a method to select the best frame was to choose a frame which resulted the difference as much as possible to the all kinds of apple defect. The experiment was performed with 131 normal apple surfaces and 20 defects of the 5 kinds of apple defect each.

2. Features of the Segmented Area

The segment defect areas needed extraction of their feature to classify. The features of defect area could be extracted from their geometric or optical informations.

Geometrical features of size, roundness and axes length ratio were derived from the defect area. Roundness of the area was determined by an equation below. If the area shaped like a circle, the value is close to 1. Axes length ratio was calculated from the maximum and the minimum distance from geometric center of the area to each pixel of boundary of the area.

$$R = 4\pi \ A / L^2 \quad \text{------------------------------------} \quad (1)$$

where, R = roundness of defect area

A = area of defect

L = exterior boundary length of defect area

Optical informations of defect area were obtained from pixel values of the area. Average, variance and gradient of the pixel values were calculated. Characteristics of texture of the area were analyzed by frequency domain analysis using Digital Fourier Transform of the pixel values. One dimensional Fourier Transform was performed along a line of the maximum distance obtained from the geometric analysis. Results of this transform were spectra to spatial frequency. These spectra were described in real and imaginary parts, and a power spectrum could be obtained from the data. From the results of Fourier Transforman, a meam and variance of spectrum of real part and power spectrum were calculated.

3. Classification of Defects

Several systematic inspection procedures to classify the defects using the geometric and optical informations of the segmented defect areas were developed. The procedures were developed using the tree structured tracking method checking the extracted features with which the segmented defect areas could be distinguished from each other. The developed procedures were tested for their validity with the 5 kinds of apple defects classified by human eye. The test was performed with 113 samples of apple defects, 11 - 32 samples for each kind of apple defect.

RESULTS AND DISCUSSION

1. Segmentation of Defect Area

Ranges of pixel value distribution for the 5 kinds of defects and normal apple surface in R, G and B frames and H, S, I and NIR frames of machine vision were shown in Fig. 1 and 2. The ranges of pixel value distribution showed $x \pm 2s$, where x and s are mean and standard deviation of observed pixel values in each frame, respectively.

In R frame, most of pixel values of bruise, decay, fleck and worm hole were less than 110 and pixel values of scar were in a range of 128 - 217, while pixel values of normal surface were greater than 208. Hence defect areas in R frame were easily segmented because very small range of pixel values of defect area in R frame were overlapped with pixel values of normal surface. In G frame, pixel values of bruise, decay, fleck and worm hole were less than 49 and pixel values of scar were in a range of 115 - 137, while pixel values of normal surface were in a range of 24 - 210. Since about a half of the range were overlapped with pixel values of scar area, defect areas of the 4 kinds of defect could be easily segmented but only a part of scar areas were possible to be segmented in G frame. In B frame, pixel values of decay, fleck and worm hole were less than 135 and pixel values of bruise and scar were in a range of 79 - 209 while pixel values of normal surface were in a range of 94 - 187. Hence most of pixel values of bruise and scar were overlapped with pixel values of normal surface. Hence defect areas of the first 3 kinds could be easily segmented but segmentation of bruise and scar were difficult in B frame.

In H frame, most of pixel values of bruise, fleck and worm hole were greater than 206 and pixel values of decay were in a wide range of 80 - 256 and pixel values of scar were less than 43, while pixel values of normal surface were distributed in the whole range of 0 - 256. Hence H frame showed the worst result to detect apple defects. In S frame, the range of pixel values of the 5 kinds of defect except worm hole were overlapped with the range of pixel values of normal surface. So this frame also showed the worst result to detect the defects. In I frame, most of pixel values of bruise, decay, fleck and worm hole were less than 78 and pixel values of scar were in a range of 158 - 189, while pixel values of normal surface were in a range of 127 - 203. So segmentation of the defects was possible except scar, of which only about an half could be segmented in I frame.

In NIR frame, most of pixel values of all the defect were so different from pixel values of normal apple surface that all the defects could be segmented easily, and this frame was considered as the best frame for the segmntation of defect.

2. Features of the Segmented Area

The features extracted from the segmented area of defects were 8 kinds - geometrical informations of size (SZ), roundness (RDN) and axes length ratio (ALR), mean and variance of pixel values (MPV and VPV) and variance of real part of spacial frequency spectrum (VRS) and mean and variance of power spectrum (MPS and VPS) resulted from Fourier transform of pixel data of a segmented area.

Distribution range of the eight parameters in the segmented area of the five kinds of defect were investigated. The ranges of the parameters of the segmented area were required to be different as much as possible in order to classify the kind of defect clearly. The investigation was performed in four frames of R, G, I and NIR, which showed good results in the segmentation of defect areas. The ranges of the parameters in R frame were shown in Fig. 3 as a sample.

In R frame, bruise and decay were distinguished from the other three kinds of defects clearly by SZ. Decay and bruise could be distinguished by RDN. Fleck, worm hole and scar had some difficulty in distinguishing each other with the other six kinds of defect analysis parameters. Part of fleck and worm hole were possible to distinguish from scar by VPS and most of fleck was distinguished from worm hole by MPS.

In G frame, decay and bruise were distinguished from the other three kinds of defects clearly by SZ like in R frame and decay and bruise were distinguished each other by ALR. Fleck and scar were partly distinguished from worm hole by ARL and most of fleck was distinguished from scar by RDN.

In I frame, decay and bruise were distinguished from the other three kinds of defects clearly by SZ as above. Decay and bruise were distinguished each other by RND or ALR. Among the other three kinds of defect, scar was distinguished from the other by RDN, and part of fleck was distinguished from worm hole by MPS.

In NIR frame, decay and bruise were distinguished from the other three kinds of defects clearly by SZ as above. Decay and bruise were distinguished each other by RDN. Fleck, worm hole and scar were very difficult to distinguish each other. Only some of fleck could be distinguished from the other two by MPS and scar was distinguished from worm hole partly by VPS.

3. Classification of Defects

The procedures to classify the segmented areas were developed for the 4 kinds of image frame, R, G, I and NIR, using the tree structured tracking method. The procedures were developed following the processes to distinguish defects noted above. The developed procedures for the 4 kinds of image frame were tested for their validity and the results were summarized in Table 1, 2, 3 and 4.

Accuracies to detect and to classify the 5 kinds of apple defects correctly in the R, G, I and NIR were 69 %, 67 %, 76 % and 77 %, repectively. Hence image frames of NIR and I were proved as the most desirable frames for the objective of this study. The accuracies in NIR and I frames were higher than those of peach experiments by Miller and Delwiche(1991) and Singh(1993).

It is notable that, in NIR and I frames, only 4 kinds of feature of the segmented area to classify the defects were used among the 8 kinds of feature. The used features were SZ, RDN, MPS and VPS in NIR frame and SZ, RDN, ARL and MPS in I frame.

Bruise and decay are known as important defects which should be detected in apple sorting. The accuracies to detect and to classify bruise and decay were 100 % and 79 % in NIR frame and 91 % and 79 % in I frame, respectively. Hence the machine vision system developed in this study was considered as a tool which is not very accurate but useful for detecttion of apple defects practically.

SUMMARY AND CONCLUSIONS

This study was carried out to develop a tool to detect defects of apple using machine vision. For the purpose, 6 frames for color images, R, G, B, H, S and I, and a frame for near infra-red image (NIR frame) were tested to select one which is useful to segment defect area from an apple image. After then, several procedures to classify kind of defect for the segmented defect area were developed and tested. Five kinds of apple defects - bruise, decay, fleck, worm hole and scar were investigated for the study. The results were as follows;

NIR frame was found as the best one among the 7 kinds of image frame, and R, G and I frames showed favourable result for segmentation of the defect areas. Various features of the segmented defect area were measured to classify the defects. Eight kinds of feature of the area - size, roundness, axes length ratio, mean and variance of pixel values, variance of real part of spectrum, mean and variance of power spectrum obtained from Fourier transform were observed for the segmented defect area in the selected 4 frames. Then procedures to classify defects using the features were developed for the 4 frames and tested with 75 ~ 113 defects on apples. The test showed that NIR and I frames resulted higher accuracies to classify the kind of defect as 77 % and 76 %, respectively.

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Table 1. Experimental result of defect classification in R frame

Defects	No. of Sample	Defect Classification in R Frame						Accuracy (%)
		Bruise	Decay	Fleck	Worm Hole	Scar	No Detect	
Bruise	11	7	1				3	64
Decay	19		19					100
Fleck	13			9	4			69
Worm Hole	16			4	12			75
Scar	16	2	3			6	5	38
Avg. (Sum)	(75)							69

Table 2. Experimental result of defect classification in G frame

Defects	No. of Sample	Defect Classification in G Frame						Accuracy (%)
		Bruise	Decay	Fleck	Worm Hole	Scar	No Detect	
Bruise	11	8	1			2		73
Decay	19	2	15			2		79
Fleck	13			8	2	2	1	62
Worm Hole	16			3	10	2	1	63
Scar	16	3	1			9	3	56
Avg. (Sum)	(75)							67

Table 3. Experimental result of defect classification in I frame

Defects	No. of Sample	Defect Classification in I Frame						Accuracy (%)
		Bruise	Decay	Fleck	Worm Hole	Scar	No Detect	
Bruise	11	10	1					91
Decay	19	1	15			2	1	79
Fleck	13		1	8	2	1	1	62
Worm Hole	16			3	11		2	69
Scar	16	1	2			13		81
Avg. (Sum)	(75)							76

Table 4. Experimental result of defect classification in NIR frame

Defects	No. of Sample	Defect Classification in NIR Frame						Accuracy (%)
		Bruise	Decay	Fleck	Worm Hole	Scar	No Detect	
Bruise	131	13						100
Decay	19	4	15					79
Fleck	32		1	24	7			75
Worm Hole	22			10	12			55
Scar	27	3	3	1		20		74
Avg. (Sum)	(113)							77

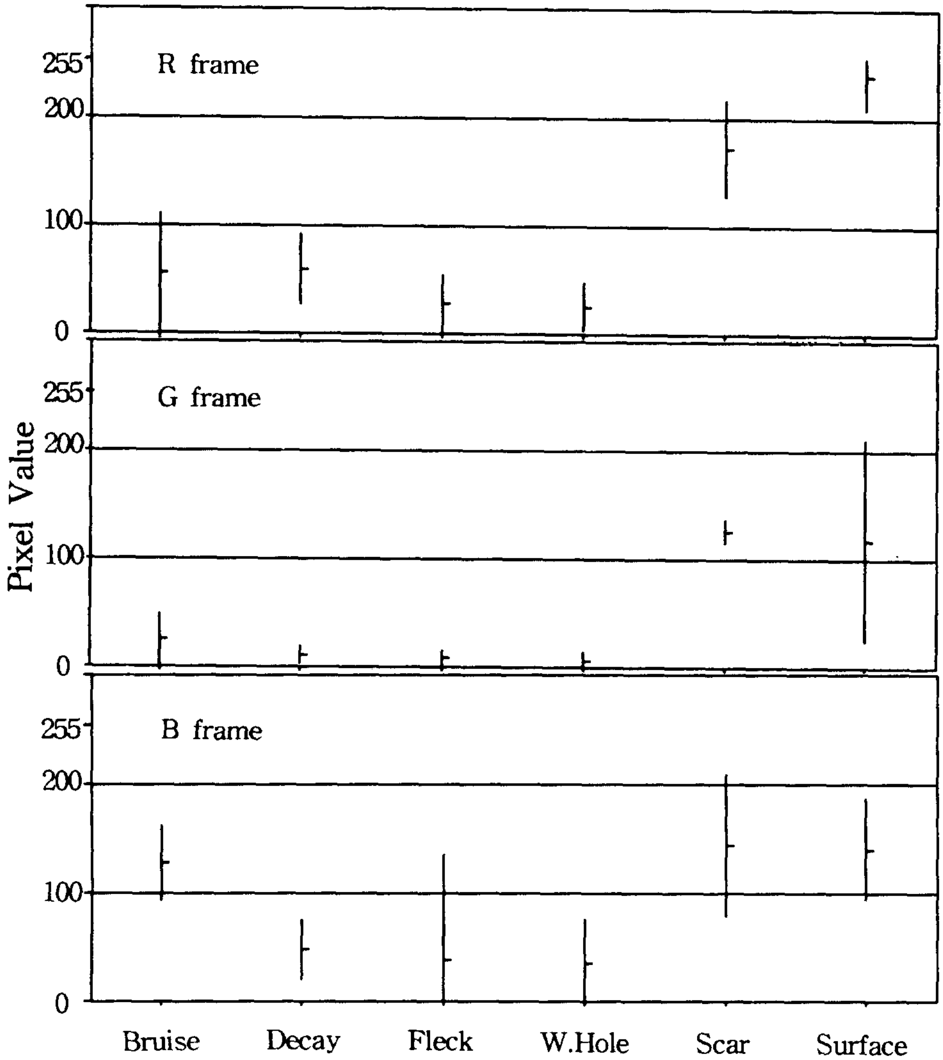

Fig. 1 Ranges of pixel values of five kinds of defect and normal surface of apple in R, G and B image frames.

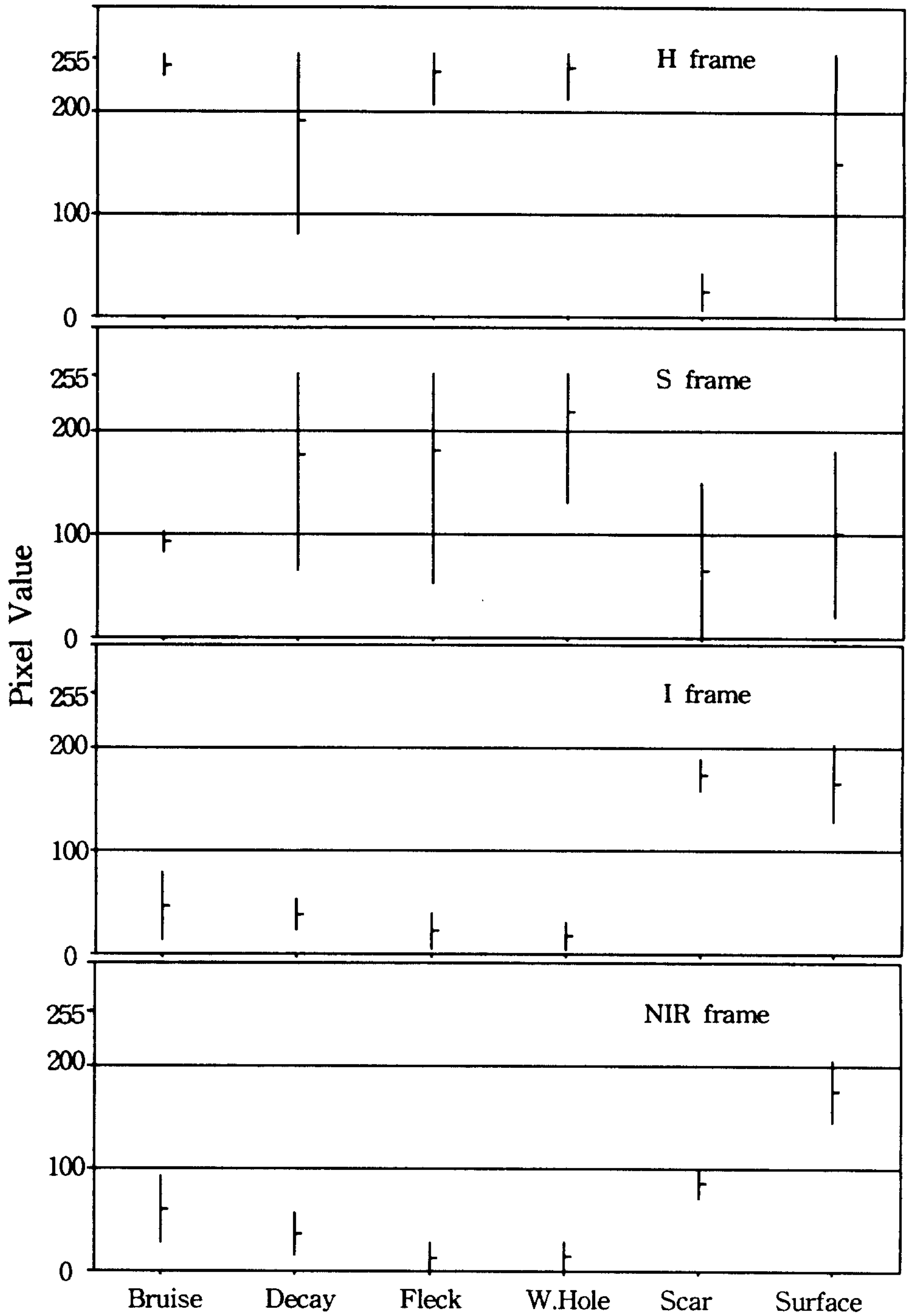

Fig. 2 Ranges of pixel values of five kinds of defect and normal surface of apple in H, S, I and NIR image frames.

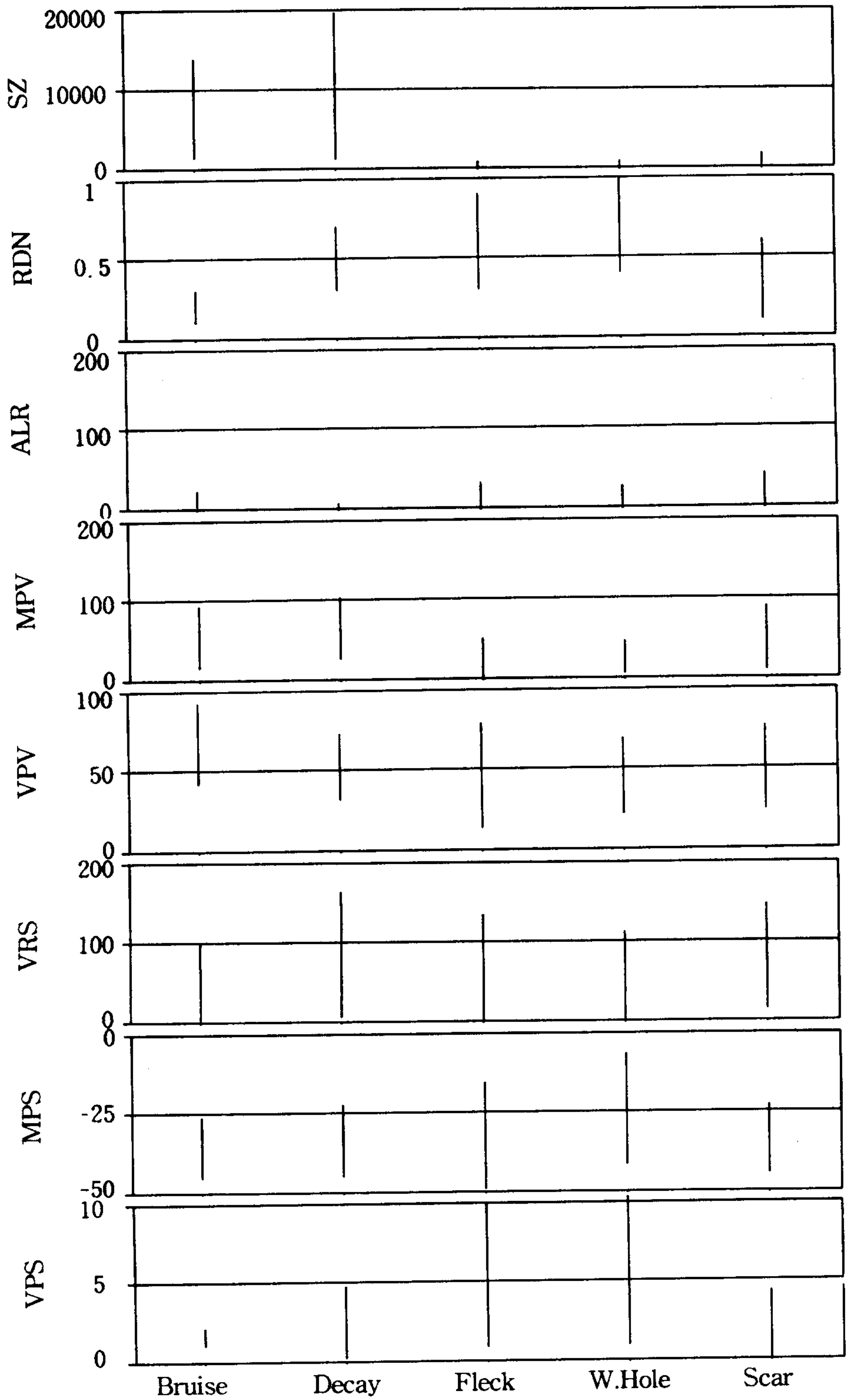

Fig. 3 Ranges of values of extracted features for the segmented area in R frame.