Proceedings of the International Conference for Agricultural Machinery & Process Engineering
October 19-22, 1993, Seoul, Korea

AUTOMATIC VISUAL FEATURE EXTRACTION AND MEASUREMENT OF MUSHROOM(*LENTINUS EDODES L.*)†

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Abstract

In a case of mushroom(*Lentinus Edodes L.*), visual features are crucial for grading and the quantitative evaluation of the growth state. The extracted quantitative visual features can be used as a performance index for the drying process control or used for the automatic sorting and grading task. First, primary external features of the front and back sides of mushroom were analyzed. And computer vision based algorithms were developed for the extraction and measurement of those features.

An automatic thresholding algorithm, which is the combined type of the window extension and maximum depth finding was developed. Freeman's chain coding was modified by gradually expanding the mask size from 3X3 to 9X9 to preserve the boundary connectivity. According to the side of mushroom determined from the automatic recognition algorithm, size, thickness, overall shape, and skin texture such as pattern, color(lightness), membrane state, and crack were quantified and measured. A portion of the stalk was also identified and automatically removed, while reconstructing a new boundary using the Overhauser curve formulation.

Algorithms applied and developed were coded using MS_C language Ver. 6.0, PC VISION Plus library functions, and VGA graphic functions as a menu driven way.

Key Word : Computer Vision, Mushroom(*Lentinus Edodes L.*),
Automatic Measurement, Automatic Thresholding

Introduction

In the field of agriculture, computer vision is essential to mechanize agricultural operations and to automate the correlated industrial processes. Related to food production and the improvement of a breed, computer vision research has actively progressed worldwide with an emphasis on rather higher priced agricultural products. Most computer vision research so far has focused on automatic harvesting and grading of fruits and vegetables such as tomato, apple, orange, peach, etc.[2,4,7,15,17,19,20,21,23-26] And lots of research have been reported on agricultural processing and even guidance control of the field machinery.

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†This research was partly supported by the Korea Science and Engineering Foundation and the Administration of Rural Development.

Research concerning the quality inspection and grading of dried mushrooms (*Lentinus Edodes L.*) has not been reported yet. Tillet et. al. (1989) reported harvesting pine mushrooms using vision system coordinated robot. Maturity of a mushoom was estimated first by its size and matured ones were picked by robot utilizing their centroid coordinates.

In general, a dried mushroom has rather good market value compared to other agricultural products. And the amount of mushroom consumption increases worldwide annually. At present, most production operations of a mushroom depend on human labor. Since visual features of a mushroom are rather complicated compared to other agricultural products, especially the quality evaluation wholly depends on the expert and its grading is classified into even 16 levels. In the process of drying, drying performace has been evaluated by measuring the moisture content and visually inspecting external features.

This paper aims to develop the system and algorithms which automatically extract and quantify the visual features of a mushroom which human expert qualitatively estimates such as size, shape, brightnes(color), skin texture, thickness, etc.

Image Measurement

For image input, a black and white CCD camera(Sony Inc.) was used and PFG frame grabber(Image Technology Inc.) was used to digitize and store the incoming video signal to 8-bits of accuracy at a rate of 30 frames per second. As host computer IBM PC compatible 386 DX was used. 13" analog RGB monitor(ECM Inc.) and VGA monitor was used for image and text/graphic output respectively.

The undesirable light effect from the outside was cut off and a front lighting system was set up using a ring type fluorescent lamp(20W). 1.5mm thick white acrylic plate was used to obtain somewhat uniformly diffused illumination.

Geometrically distorted nonlinear error in the input image caused by the imaging device was measured using sample patterns to determine the proper size of the measurement window. Two sample patterns having 108(12x9) and 380(20x19) circular dots were used.

1. Unit pixel size

First, the image of a black square(6cmx6cm) was captured to obtain the size of unit pixel. Since image segmentation is sensitive to thresholding, size of unit pixel was determined by averaging results obtained under various threshold values from 70 to 130. Noise effects due to thresholding such as irregular boundary, small hole, missing corner, and isolated point were smoothed using 8-neighborhood logical operation.[5,6] The horizontal to vertical ratio was 1.225.

2. Measuring window

Because of the nonlinear attributes of a camera lens, display device and other hardware, input image is geometrically distorted, especially, at the corner and edge. Fig. 1 shows the distorted amount at the quarter portion(upper left) of the input image obtained from the vision system used. To improve the measurement accuracy and to overcome limitations of specifying measuring window, some compensation process is required. Details on the compensation process refer to Hwang and Lee(1992).

However, as shown in fig. 1, the distorted amount can be ignored around the center. Besides, considering processing speed on the input image, a square measuring window(150 pixel x 150 pixel) was set up with pixel coordinate (180,164) of the upper left corner.

3. Real valued information

To obtain the geometrical information of mushroom, Freeman's chain coding[22] and Kitchin's(1981) coding algorithm was applied and modified to extract boundary and to obtain directly real scaled geometrical informations such as perimeter, area, moment, centroid, roundness, complex ratio, etc. Details on the derived formula refer to Hwang and Lee(1992).

Prerequisite for chain coding is the connectivity of the image boundary. However, disconnectivity usually occur in the binarized image after thresholding. To handle up to 3 pixel disconnectivity while preserving the tracing efficiency, 3x3 search mask was extended to 5x5, 7x7, and 9x9 based on the direction of the previous chain vector. For the image having disconnected boundary fig. 2 shows a process of pixel generation via 7x7 extended mask.

Visual Feature Extraction

Primary qualitative visual features for a dried mushroom are overall size and shape, color and pattern of the front skin, thickness, rolled shape and rate of the back side, color and state of membrane around stalk, and crack. Where, the back side represents a side having a stalk.

Those qualitative features are to be converted into quantitative ones. In this section, we present the efficient algorithm to extract and quantify the qualitative visual features. A portion of algorithm adopts the inference method based on the experimental result. And arbitrarily chosen dried mushrooms were used for the experiment.

1. Automatic thresholding

Image segmentation via thresholding wholly depends whether specified threshold value is adequate or not to obtain the desired segmented image. Since it is not desirable to set threshold value manually especially for tasks requiring atomatic visual data acquisition and processing, it is very important to automatically decide an optimum threshold value which can exhibit certain desirable features for a given image.

Various algorithms are known in determining automatically optimum threshold such as simple image statistical method which minimizes weighted sum of group variances[22], moment preservation method[28], maximum entropy method[1], background window extension method[12], etc.

In this paper, automatic thresholding algorithm which utilizes window extension and maximum depth finding based on histogram mode separation were developed to sequentially extract overall size, shape, and skin texture of a mushroom.

Window extension method selects threshold value according to the histogram variation resulted from extending size of the measuring window. Extending window size enlarges number of pixels which belong to the background, while keeping number of object pixels same. Window extension is simple and as size of measuring window gets smaller, the processing efficiency increases.

In general, if intensity levels of the object and the background are apparent, a mode of histogram shows bimodal. In this case, as far as intenities between the object and the background do not significantly overlap, selecting threshold value as the valley point gives near optimum segmentation. Maximum depth finding method is based on the histogram mode separation. To determine a threshold value, two peak probability density functions, one for the object and the other for the background, are connected straight. And in the range specified by the corresponding two peaks, search the gray value which gives the maximum differnce between the straight line and the histogram.

Two methods mentioned above work good only for the bimodal type of histogram. They are not proper to segment the texture of the object. In a case of dried mushrooms, a mode of the histgram is not confined to bimodal but rather trimodal both for the front and the back side because of the skin state.

Developed combined type automatic thresholding first segments a mushroom from the background via window extension. And then for the histogram excluding background, it segments skin patterns of the front and the back via maximum depth finding. In a case that histogram of a mushroom appears to be unimodal, a maximum depth between the histogram and the line connecting the window threshold value and the peak value is assigned as final threshold value.

Window extended from size of 150 pixel by 150 pixel square whose upper left corner coordinate is (180,164) to size of 200 pixel by 200 pixel square whose upper left corner coordinate is (155,139). Two corresponding histograms were averaged at every three gray levels to surpress undesirable noise effects. And gray value was selected at which the compared difference between the two exceeds the predefined values of roughly 10 pixels.

Maximum depth was determined from the averaged histogram obtained from the non-extended window. Two local peaks of histogram were obtained by sign converion of slopes.

Fig. 3 shows the histograms of the captured input gray level images of front and back sides of typical dried mushrooms. The combined type automatic thresholding scheme is applied as shown in fig. 4. Fig. 5-a shows the input image displayed on RGB monitor and fig. 5-b shows the segmented binary image obtained from the window extension. Fig. 5-c represents results of the combined type automatic thresholding.

2. Size and shape of cap

Overall size and shape of a mushroom cap can be extracted regardless of the front or back side image. In a dried mushroom, however, a stalk is not raised up vertically but lies usually along radial direction. When measuring the cap size, a portion of stalk located outside of the cap should be removed.

For given input image, window extension part of the developed automatic thresholding segments a mushroom from the background regardless of the front or back side. And resulting binary image was smoothed again to remove noise effects. Boundary of a mushroom was obtained via chain coding. With information on area and moment with respect to x and y axis obtained from chain coding, centroid of a mushroom was computed. And the extracted boundary was divided into 60 pieces so that each piece have equal number of pixels. Radial distance from the centroid to each divided point was computed and compared with the distance of the opposite directional radial line. If the magnitude difference of the two radial lines exceeds 0.17 times of the opposite radial length, boundary was identified to have a portion of a stalk to be removed.

Part of a stalk is detected again precisely using the fixed length contour trace algorithm[14] and removed. Removed boundaries are specified by shifting backward and forward 9 segments each from the stalk point along the boundary as shown in fig. 6. Considering the continuity of the boundary curvature, the Overhauser curve formulation[3] was applied to regenerate the boundary of the removed stalk portions. Since generating Overhauser curve requires four points, two points were selected by shfting 5 segments forward and backward from the end points of the stalk region defined previously.

The Overhauser formulation generates a cubic polynomial curve between P2 and P3 as shown in fig. 7 from P1, P2, P3, and P4. Second order polynomial curves are assumed in connecting P1, P2 and P3, P4. By blending linearly two second order polynomial curves, a cubic polynomial parametric curve *C(t)* is generated. Given P1, P2, P3, and P4, *C(t)* is defined as following.

$$C(t) = [t^3, t^2, t, 1] = \begin{bmatrix} 0.5 & 1.5 & -1.5 & 0.5 \\ 1.0 & -2.5 & 2.0 & -0.5 \\ 0.5 & 0.0 & 0.5 & 0.0 \\ 0.0 & 1.0 & 0.0 & 0.0 \end{bmatrix} \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \end{bmatrix}$$

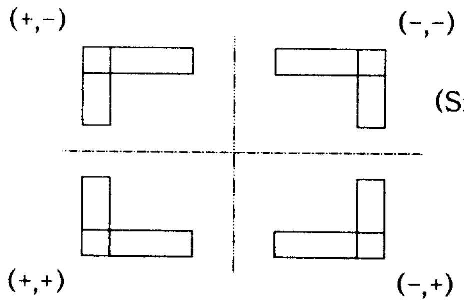
Once new boundary is regenerated, chain coding was executed again and area, centroid, and perimeter of a mushroom were revised. Overall size of a mushroom was estimated by averaging 10 radial lengths excluding the maximum and the minimum magnitude obtained from the centroid to 12 equally spaced perimeter pixel coordinates. Overall shape of a mushroom was quantified by the roundness and complex ratio defined as follows.

$$Roundness = \frac{4 \cdot \pi \cdot Area}{Perimeter} \qquad Complex\ ratio = \frac{(Perimeter)^2}{Area}$$

3. Recognition of front and back side

Since visual features of a mushroom should be extracted separately for the front and back side, recognizing automatically to which side a given mushroom image belongs is very important to automatically select forthcoming processes. The recognition process was performed utilizing the previous information on the stalk.

Once a stalk is identified, the stalk coordinate was utilized to determine locations of two rectangular masks among four possible locations. Let Dx and Dy denote the amount obtained by substracting the centroid coordinate from the identified stalk coordinate. One side of the rectangular mask has 8 pixels and the other side has varying magnitude which is two thirds of average radius. Centroid of two rectangular masks were located 90 degree apart at the distance of one third of average radius from the centroid of a mushroom. According to the sign of Dx and Dy, a quadrant to which two search masks belongs was determined as follows.



However, when a stalk was not identified, a square mask was formed whose size is half of an average radius of a mushroom. Since a quadrant having a stalk shows relatively low intensity compared to other quadrants, using the average intensities of four quadrants of a square mask the quadrant which a stalk resides was identified. With the binary image obtained from the combined type threshold, the recognition of the front and the back side was performed by checking intensities of two rectangular masks. When average intensity of either mask was above the predefined value say 0.9 it was recognized as back side. Fig. 8 shows the sequence of the front and back side recognition.

4. Color and texture of front Skin

Once given image is identified as front side, color and texture information was extracted. Color and texture of the front skin of a mushroom is affected by the growing environment and the drying process. Color of the front skin ranges from an ivory white to dark brown. Since color of a mushroom skin can be characterized as white and brown, intensity distribution allows a black/white monochrome image to easily substitute the colored image.

From the coordinates on the boundary pixels obtained from the stalk removal process, the initial gray valued mushroom image was divided into four quadrants. Overall whitenesss was obtained from averaging two quadrants excluding quadrant having maximum and minimum intensity among four quadrants. High quality muahroom such as Hwago has turtle shaped skin and dark brown spots uniformly distributed over the skin, while overall color is close to ivory white.

To extract a local crack and severe wrinkle on the front skin, average intensities of four quadrants and overall average intensity of the front skin were obtained from the binary image generated by the combined type thresholding. To quantify the degree of local crack and wrinkle, amount of deviation per quadrant obtained after substracting average intensity of each quadrant from the overall average intensity was used.

Texture of the front skin was analyzed via statistical approach[6] including relative position of pixels having equal or nearly equal intensity values with respect to each other.

5. Thickness and rolled skin state of back side

Thickness of a mushroom cap is an important factor in evaluating mushroom. However, it is impossible to measure the thickness from a single two dimensional image viewed from the top. Thickness is almost proportional to the rolled amount of the front skin, though correlation between the two features was not computed.

After stalk removal process was done, using the centroid and boundary coordinates acquired by chain coding, rolled skin amount was measured from the back side image obtained from combined thresholding. In measuring the rolled skin amount, stem portions should be avoided. First, boundary pixels were divided into 60 segments to have each segment equal number of pixels. Once a stalk was identified previously, 8 segments before and behind the identified stalk coordinate were not considered in measuring as shown in fig. 9-a. In a case that stalk is feeble and is not identified, stalk position was identified by radially scaning slected region from the centroid as shown in fig. 9-b. And a size of the scanning region was adjusted with respect to the average radius of a mushroom. And the combined threshold value was temporally increased to some degree to search stalk portion more efficiently.

Image smoothing was applied to the binary image obtained after combined type thresholding to remove noise of the inside membrane. Amount of the rolled skin was traced in radial direction from the selected boundary pixels to the centroid by evaluating continuity of pixels on the scan line. To select the proper pixel on the radial scan line, simple digital differential analyzer(SDDA) scan line conversion algorithm was used shown in fig. 10. From results of sets of radial scan, average, variance, and number of disconnectivity which quantify the amount, shape, and crack of the rolled skin respectively were computed.

6. State of membrane

Membrane of the back side shoud stand in order neatly free of severe crack and folds as shown in fig. 11 and color should be bright. Inspecting the state of membrane standing is almost impossible using two dimensional plane image. From the fact that membrane in good standing looks bright, the average intensity value inside the boundary defined previously was computed using input gray level image.

Previously identified region occupied by the stalk was excluded and a square region whose side is one eighth of average radius was formed around the centroid and that region was also excluded also for the intensity scan. Intensity scan is performed along the x axis from the inside boundary pixels identified from the thickness quantization to the centroid axis and average intensity value was obtained to quantify the state of membrane.

Software Development

Algorithms mentioned above were coded using Microsoft C language ver. 6.0, ITEX PC Vision Plus library function, and VGA graphic functions as a menu driven way[9,10,17]. Input and output image was displayed RGB monitor as well as VGA color monitor. Display window consists of three parts such as graphic image display, histogram output, and text output. Fig 12 shows a sequence of graphic output at each processing step. Block diagram of the developed software is shown in fig 13.

Conclusion

In this paper, computer vision based algorithms for automatic visual feature extraction and measurent of a mushroom(*Lentinus Edodes L.*) were developed. The developed system can be utilized to sorting, grading, and growth state measuring of mushrooms and performance evaluation of mushroom drying.

Research results are summarized as follows.

① automatic thresholding which is the combined type of window extension and maximum depth finding was developed and the front and back side of a mushroom was automatically recognized.

② Real-scaled geometrical information was extracted directly from chain coding with extended search mask while preserving the connectivity of boundary pixels.

③ Qualitative visual features of a mushroom such as size, shape, skin textures, thickness, etc. were quantified and extracted automatically.

④ Algorithms applied and developed were coded as a menu driven way and intermediate processing results were graphically dispalyed.

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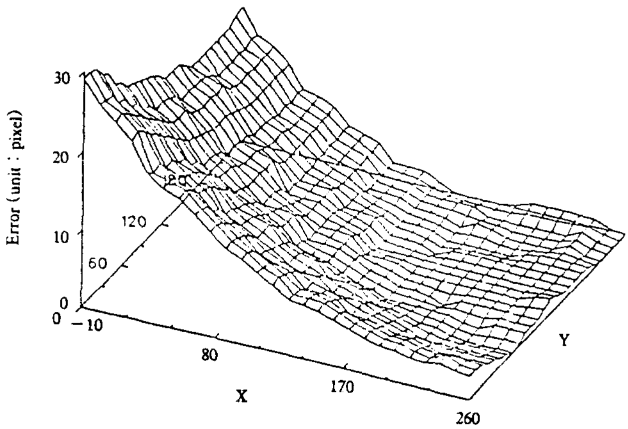

Fig. 1 Distorted position errors of sample pattern dots.

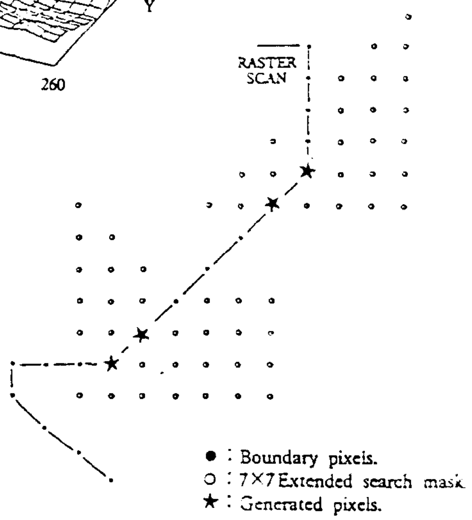

Fig. 2 Chain connection of disconnected boundary pixels via mask extension.

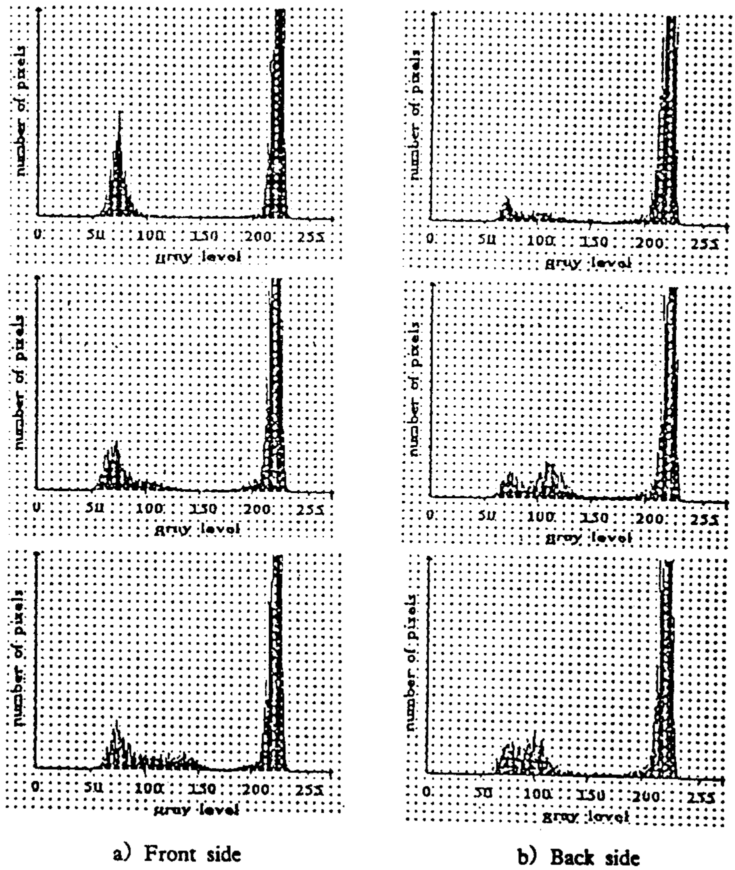

Fig. 3 Histograms of typical dried mushrooms(*Lentinus Edodes L.*).

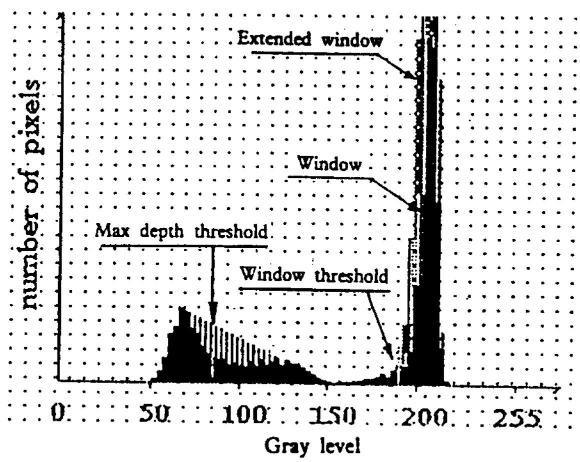

Fig. 4 Combined type automatic thresholding.

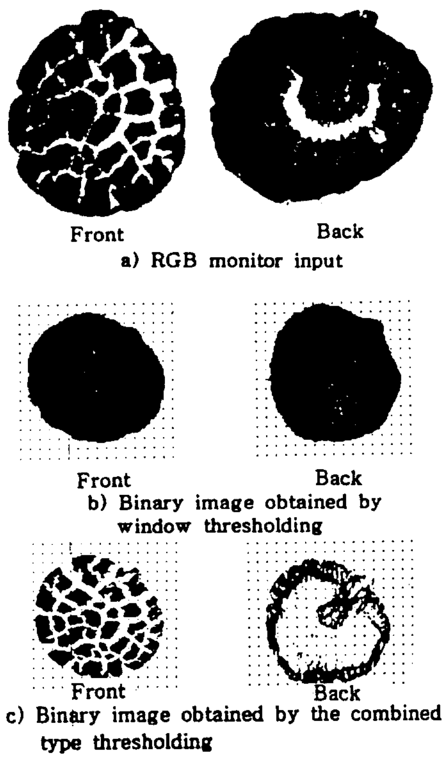

Fig. 5 Monitor input image and binary image after thresholding.

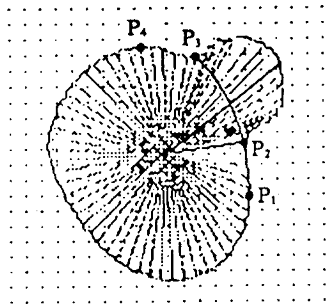

Fig. 6 Stem removal and boundary generation.

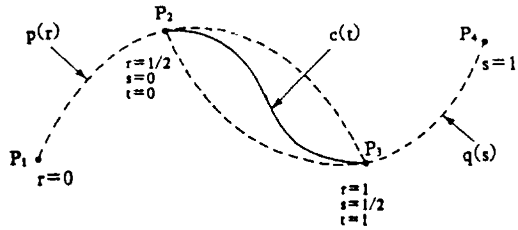

Fig. 7 Curve generation via Overhauser curve formulation.

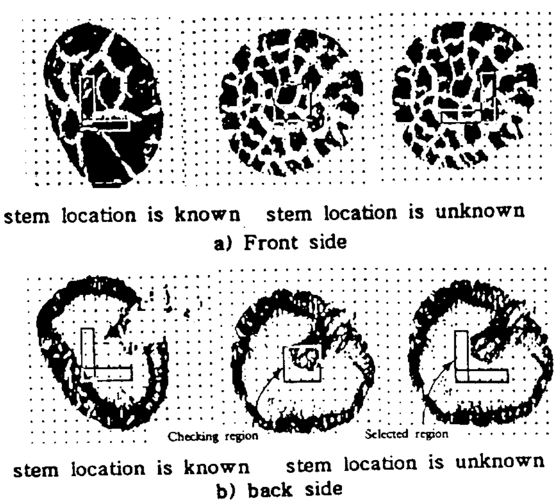

Fig. 8 Recognition of front and back side by checking two masks.

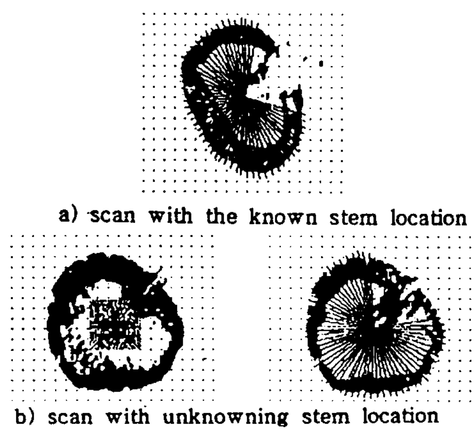

Fig. 9 Extracting rolled state of back side.

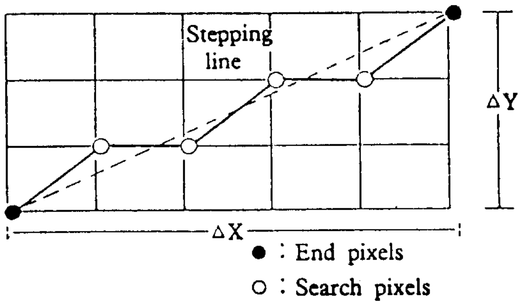

Fig. 10 Pixel scan via simple DDA algorithm.

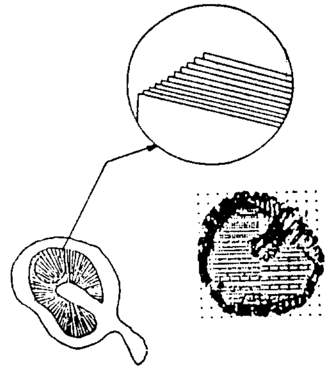

Fig. 11. Extracting membrane state of the back side.

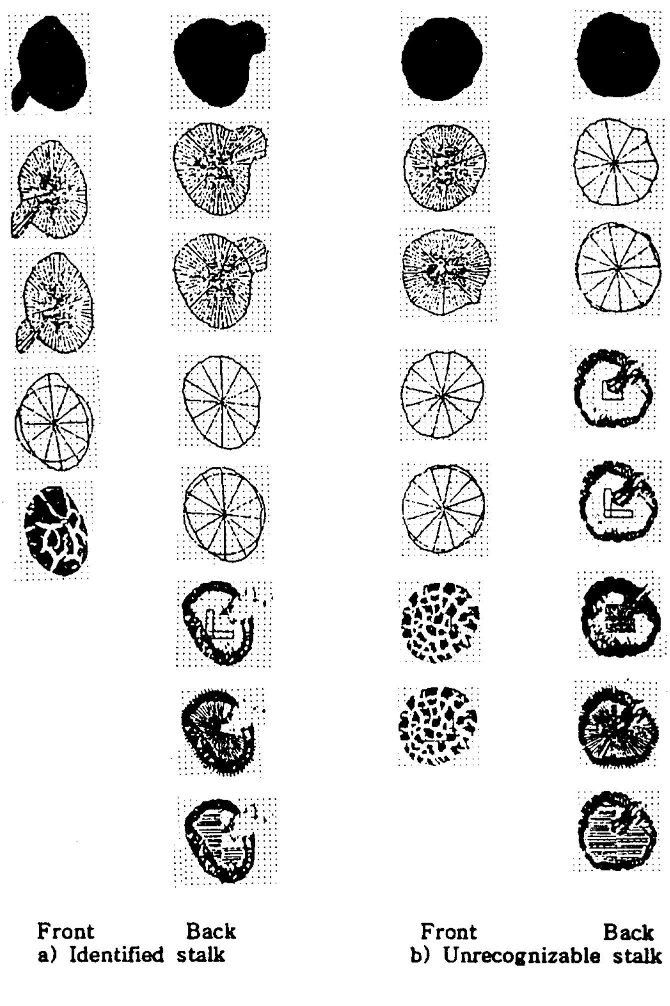

Fig. 12 Computer grapic output of the visual feature extraction.

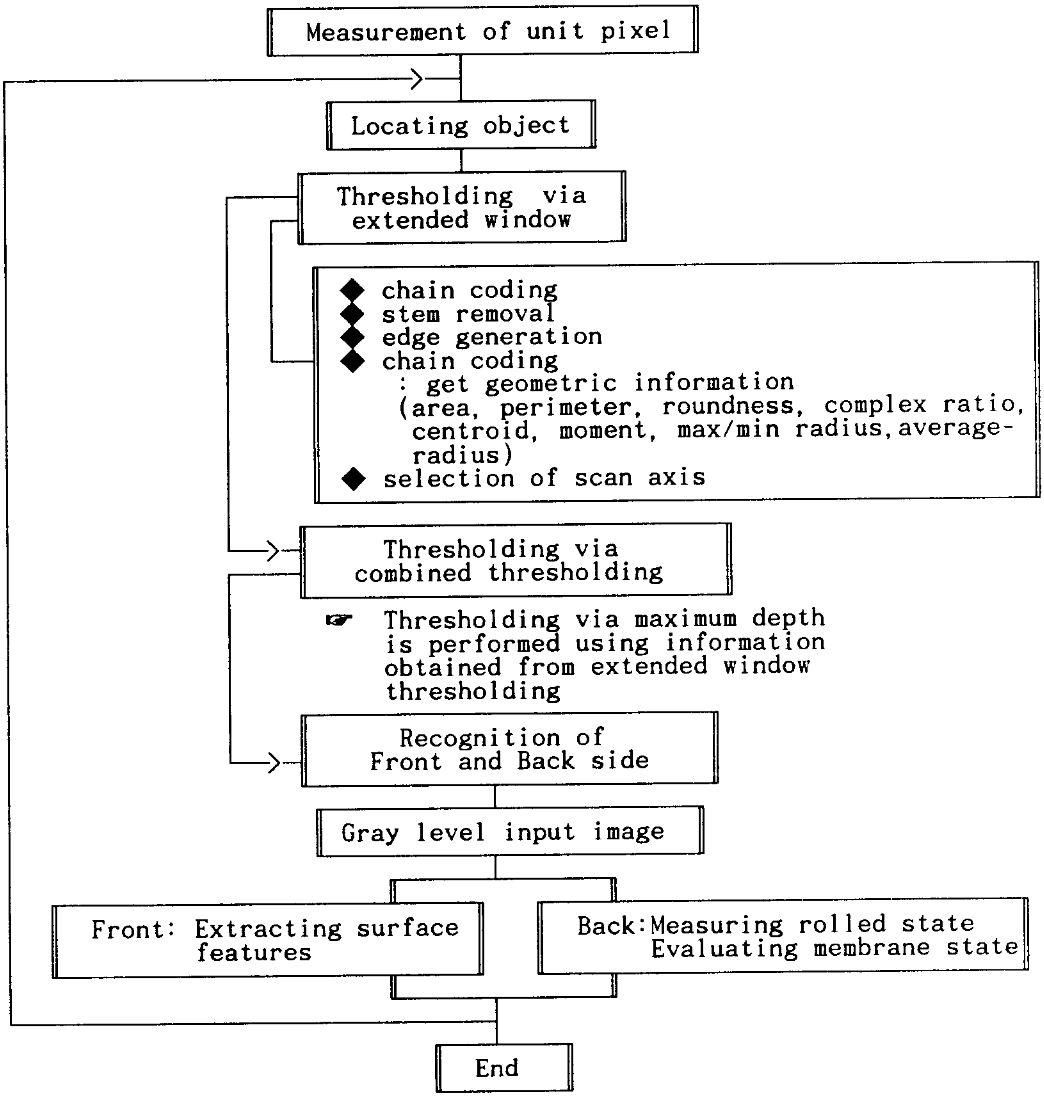

Fig. 13 Block diagram of the feature extraction and measurement.