Image Processing for Stress Cracks in Corn Kernels

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ABSTRACT

A n image processing algorithm was developed for detecting stress cracks in corn kernels using a commercial vision system. White light in back-lit lighting mode with black-coated background having a small aperture for the light provided the best viewing conditions. The kernel images, when processed using the algorithm developed, produced white streaks corresponding to the stress cracks. Double stress cracks were the easiest to detect. Careful positioning of the kernel over the lighting aperture was necessary for satisfactory detection of single and multiple stress cracks.

INTRODUCTION

Physical and mechanical stresses developed in corn kernels as they are harvested, dried, stored, and handled induce various quality defects. Defects such as surface splits, starch cracks and chip-offs, caused by mechanical stresses, are external and are easily detectable. However, stress cracks, caused by a combination of thermal, moisture and mechanical stresses, are internal and not readily identifiable.

Stress cracks can be defined as very fine fissures in kernel endosperm underneath the pericarp. Gunasekaran et al. (1985) investigated the size characteristics of stress cracks with the help of scanning electron microscope pictures. They concluded that a typical stress crack is about 53 μm in width and half the kernel thickness in depth. The stress cracks were also found to propagate from the center of the kernel and may not extend to the surface underneath the pericarp.

In general, kernels with stress cracks have lower mechanical strength (Gunasekaran and Paulsen, 1985) and break more readily upon subsequent handling than non-stress-cracked kernels. Amount of broken corn along with foreign matter is a major corn grading factor.

At present, corn kernels are examined for stress cracks by candling the kernels with a bright light source from below. This procedure is time consuming and fatiguing to the human eye. Gunasekaran and Paulsen (1986) investigated several nondestructive testing techniques for stress crack evaluation. Light reflectance measurement using a helium-neon laser light (632.8 nm) was found insufficient for stress crack detection because reflectance is a surface phenomenon (Gunasekaran et al., 1986). However, optical imaging has been found to be suitable for stress crack evaluation (Gunasekaran, 1985; Gunasekaran and Paulsen, 1986). Optical imaging or image processing is a relatively new technique that holds promise for automatic, on-line quality evaluation and control of wide-ranging materials (Gagliardi et al., 1984; Kahwati and Law, 1985). This method essentially duplicates the condition as the eye sees an object. A typical image processing system receives light from a source; converts the light into an electrical signal proportional to the intensity of the light received; processes the analog electrical signals into a digital form usable by a computer; measures and analyzes various characteristics of the digital data representing the image; and interprets the image data to obtain useful information. The resolution of the digital image depends on the number of pixels (picture elements) digitized for each scan line and on the number of scan lines used. Proper lighting conditions are very important for processing speed and efficiency (Berlage et al., 1984; Gagliardi et al., 1984; Paulsen and McClure, 1985).

Image processing applications in agricultural engineering are rapidly expanding. Quality evaluation of various biological materials such as apples (Graf et al., 1981); brown rice (Matshuista and Hosokowa, 1981); fish (Shimatachi et al., 1982); seed contaminants (Berlage et al., 1984); and tomatoes (Sarkar and Wolfe, 1985) has been achieved by image processing. Image processing has also been used as an aid to automatic fruit and vegetable harvesting (Whittaker et al., 1984; Sites and Delwiche, 1985).

This article presents the application of image processing technique for detecting stress cracks in corn kernels.

OBJECTIVES

The objectives of this investigation were:

1. To determine optimal condition for viewing stress cracks in corn kernels using a computer vision system.
2. To develop an image processing algorithm to identify the presence of stress cracks in corn kernels.

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SYSTEM DESCRIPTION

A commercial vision system, Intelledex V200*, was acquired and subsequently upgraded. It was developed with special hardware to interface with cameras and display monitors and with software to implement processing algorithms and drive a vision-to-robot interface. Fig. 1 shows a block diagram of the system hardware.

A Hitachi KP-120 solid state video camera was used for image acquisition. A C-mount to bayonet adaptor allowed use of 35-mm SLR photographic lens system. The camera was mounted on a vertically adjustable stand for necessary magnification and resolution. The stand also provided support for lighting sources.

In the vision system, the analog camera image is sent to the system computer. The computer consists of three modules: (a) camera/monitor interface, (b) digitizer/display module, and (c) processing module. The camera/monitor interface module passes information between the digitizer/display and the camera and monitor. It also controls the gain, timing, and selection of camera from which the image is produced.

The digitizer/display module converts the analog camera signal to a digital form that the computer can process and store. Each of the 256 camera scan lines is digitized into a series of 256 discrete picture elements (pixels). Each pixel in this 256 x 256 array has a 6-bit value (range: 0-63) representing the average light intensity over its area. A value of zero is black while a value of 63 is white. The hardware digitizes an image in 0.0167 s. The module has 64 k x 6 bits of static random access memory (RAM) which is used for storing a single digitized image. This image buffer or display RAM holds a single frame for processing or display.

PROCEDURE

Sample Selection

Corn kernels of four varieties namely, FRB73 x Mo17, FRB73 x Va22, Mo17 x H100, and (FR4A x FR4C) x Mo17 were used in this investigation. These corn genotypes are grown popularly in the Midwest. The kernels for the experiment were drawn at random from high-temperature dried samples and grouped as those with no, single, double, and multiple stress cracks (Fig. 2). About 25 kernels of each variety and of each stress crack category were viewed individually under the vision system to obtain the images.

Illumination

The need for proper lighting conditions for efficient image processing has been well established. In this investigation the kernels were illuminated using different lighting modes such as front-lighting, back-lighting, and side lighting.

Front-lighting, (illuminating from above the kernels) and back-lighting (illuminating from below the kernel) were provided using the Schott, Model KL1500 fiber optic light source. This light source had a maximum of 150 W power rating and provided a maximum light intensity of about 10 Mix at the fiber optic light guide. A ring light guide mounted on the camera lens was used to obtain a shadow free diffuse lighting for front-lighting. For back-lighting, a flexible fiber optic bundle of 4.5 mm diameter was used. Light intensities at the kernel surface, when illuminated with white light, were measured to be 48.3 klx and 32.3 klx under front and back-lighting modes, respectively. A Wollensak Fastax WF327 type light meter was used for light intensity measurements.

The wavelength of the light used for illumination was

* Mention of trade names in this publication is solely for the purpose of providing specific information and does not constitute endorsement by the University of Delaware and the USDA over others of a similar nature not mentioned.
varied using insert filters at the light source. While using white light, the wavelength received by the camera lens was controlled by mounting a suitable filter over the camera lens. A series of filters namely, violet (Wratten 34A, 370 nm); blue (Wratten 47 B, 450 nm); green (Wratten 61, 515 nm); and red (Wratten 70, 610 nm), were used. For side-lighting a pair of incandescent lamps (18 W) mounted at 45° angle on either side of the kernel were used.

The kernels were placed directly under the camera over different backgrounds of frosted glass plate, milky white glass plate, and black-coated wooden plate. These backgrounds were used with each of the above lighting modes to determine the best viewing conditions. The black-coated wooden plate used with back-lighting had a 2.4 mm diameter opening for the light to pass through. Fig. 3 shows a kernel being viewed with back-lighting over the black-coated wooden plate background. This figure also shows the ring light guide mounted on the camera lens for front-lighting.

Image Processing

Image acquisition and processing were performed using a variety of processing algorithms available with the vision system. The algorithm used for stress crack evaluation is similar to high-pass filtering. The pixels representing stress cracks had significantly different gray scale values than the pixels of the rest of the kernel surface. Therefore, gray scale levels of the pixels representing the stress cracks were extracted first by creating an image supressing the gray scale levels of the stress crack part and subtracting this newly created image from the original image. The high-pass filtering used in the image processing algorithm passes high frequencies in the gray scale value, i.e., it passes the pixels with large change in gray scale value (derivative) in relation to the neighboring pixels but not necessarily those pixels with high gray scale values. Following is the sequence and brief description of each of the step:

VDIG is a mode command and does not perform any processing function. It switches the signal shown on the monitor to the current image in display RAM. This step is required only to see the actual processing of the image.

VSNAP acquires the real-time digitized image of the object under the camera and writes it into the display RAM.

VTHRESH operates based on the threshold gray-scale value used (the numeral following the command). All the pixels with gray-scale value less than the threshold are set to the binary value of zero (black); the rest are set to one (white). Thus, VTHRESH produces a purely black and white image.

The images obtained using the above steps showed white streaks corresponding to the presence of stress cracks; but they also contained some spurious streaks which could be mistaken for stress cracks. To eliminate these spurious streaks the image-smoothing step, VENHANCE was repeated several times before VSUBTRACT operation. Additional VENHANCE operations eliminated the spurious streaks, but it also eroded the streaks representing stress cracks. After several trials, repeating VENHANCE three times was found to be optimal.

In order to obtain a better stress crack recognition, a contrast enhancement algorithm (VMAP) was added to the program prior to VENHANCE operation.

VMAP enables remapping of any or all pixel gray-scale values to new values as specified. In the program used, all pixels with gray-scale values less than a chosen lower limit (XL) were set to zero. The pixels with gray-scale values greater than (XL + 32) were set to 63. Those pixels with gray-scale values from XL to (XL + 31) were remapped as 2x(l-XL), where I is the gray-scale value of the current pixel. This operation has the effect of doubling the contrast of those pixels with gray-scale values from XL to (XL + 31). The lower limit XL was chosen to be 20 by examining the gray-scale histogram of the original image.

The program with VMAP eliminated the spurious streaks and spots within the kernel boundary more effectively. However, this also caused the streaks representing the stress cracks to split and shorten. Therefore, an image-structuring algorithm VDILATE was added to the program.

VSIMAGE stores the digitized image in an image buffer. This original image is later used in the VSUBTRACT step to extract the stress cracks.

VENHANCE performs an image enhancement operation on the contents of display RAM. Each pixel in the image is arithmetically averaged with its eight surrounding pixels and a new pixel value is obtained. The action is similar to low-pass filtering; and has the effect of smoothing the contrast of the pixels representing the stress cracks that have significantly high gray-scale value compared to their surrounding pixels.

VSUBTRACT numerically subtracts the gray-scale value of each pixel of the current VENHANCED image from the corresponding pixels of the original image stored in the image buffer (obtained by VSIMAGE). As mentioned above, this has the effect of passing those pixels with large rate of change or derivative of gray scale value. Change in gray scale value is usually large at places of discontinuity like a crack.

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VCOMPRESS compresses the image in display RAM into bit plane zero. A bit plane is a contiguous 8 kbyte
block of RAM located in a saved image buffer. The vision system has bit planes 0 to 7 representing 64 k RAM. VCOMPRESS is necessary for the VDILATE operation.

VDILATE algorithm dilates contents of bit plane zero by a linear structuring element. Dilation of an image by a structuring element can be defined as the union of the translations of all points in the image to all points in the structuring element. The software allows use of 8 structuring elements, each in a different direction. For stress crack detection, structuring elements in any two opposite directions were found most suitable.

A BASIC program of the final version of the processing algorithm is given in the Appendix.

RESULTS AND DISCUSSION

Front-lighting generally produced lower contrast images than back-lighting. Therefore, even though the stress cracks were visible on the monitor with front-lighting, the information was lost in the processing steps. This is expected because front-lighting images are similar to light reflectance measurements; and reveal only the surface characteristics. Images obtained with side-lighting were similar to those obtained with front-lighting. Even though side-lighting is expected to reveal more of inner characteristics than front-lighting because of the body reflectance (Gunasekaran et al., 1986), it was not sufficient to bring out the stress cracks. Back-lighting, on the other hand, produced images with high contrast between stress cracks and the rest of the kernel surface. Thus, the images obtained with back-lighting, when processed, exhibited bright streaks representing the stress cracks. Back-lighting used in the experiments is similar to the candling procedure currently in use for stress crack detection. The frosted glass and milky white plates used as backgrounds for placing the kernel did not give good results because of huge light dispersion around the kernel. The black-coated wooden plate with a 2.4-mm opening helped to eliminate the light dispersion and provided a better contrast for stress cracks than other two backgrounds.

Filters of varying wavelengths used both at the light source and at the camera lens diminished the light intensity reaching the lens and hence produced a lower contrast image than with white light. Therefore, it was determined that using white light (no filters) in the back-lighting mode with black-coated plate having a small aperture as the background to be the optimal lighting and viewing condition.

The original images of the kernels with single, double, multiple stress cracks and the corresponding processed images are shown in Fig. 4, 5, and 6, respectively. In the processed images the outer lines partially define the kernel periphery; and the stress cracks are represented by the lines inside the kernel boundary. The algorithm performed very satisfactorily in extracting the stress crack details in 90% of the kernels examined. The success rate was determined by comparing the visual evaluation of the kernels for stress cracks with the corresponding evaluation of the vision system using the same set of kernels. Of the three stress crack categories, double stress cracks were the easiest to detect. This is possible because most double stress cracks branch out on either side of the kernel surface, which become highly visible when light is directed at the center of the kernel.
times, to account for all of the stress cracks.

In all three stress crack categories the faint ends of the stress cracks were not obtained as lines. Also, some of the lines representing stress cracks were not continuous; some faint cracks were not detectable. This was due to the image-smoothing step in the algorithm, which tended to erode the less contrasting portions of the image (the ends of stress cracks). Therefore, further improvements in the processing algorithm and/or illumination conditions are necessary to obtain complete stress crack details.

In all the figures shown here, the kernel edges are represented by streaks similar to the stress cracks. They are shown to provide better visualization of the kernel boundary. However, these edges can be removed by providing a light seal around the kernel periphery.

CONCLUSIONS

1. White light in the back-lighting mode with a black-coated background having a 2.4-mm diameter aperture for the light produced images showing high contrast between the stress cracks and the rest of the kernel surface.

2. An image processing algorithm was developed to produce the effect of high-pass filtering and thus extracting the pixels representing the stress cracks as streaks or lines.

3. The algorithm performed very satisfactorily in detecting stress cracks in 90% of the kernels examined.

4. Double stress cracks were the easiest to detect by centering the kernels over the lighting aperture.

5. Single and multiple stress-cracked kernels required careful positioning over the lighting aperture in order to obtain complete stress crack details.

6. Further improvement in the processing algorithm and/or illumination condition is required to obtain information about very fine cracks and complete crack length.

References


APPENDIX

BASIC program to implement the image processing algorithm for detecting stress cracks in corn kernels in the Inteledex V200 vision system.

Fig. 6—Original and processed images of a multiple stress-cracked corn kernel.
140 'Store contrast enhanced image in image buffer zero.
150 'VENHANCE the image three times.
170  
180  VSIMAGE 0  
190  FOR I = 1 To 3: VENHANCE 1: Next I  
200  
210  'Subtract gray-scale value of each pixel of the VENHANCED image  
220  'from corresponding pixels of the image stored in buffer zero  
230  '(VSIMAGE) and add 20. A value of 20 was chosen arbitrarily to  
240  'make the image appear good to the viewer. This, however, will  
250  'not affect the end result. You can choose any value.  
260  
270  VSUBTRACT 20, 0  
280  
290  'Choose a threshold value of 22 (this value is relative to the  
300  'number 20 used in the VSUBTRACT step). VTHRESH converts all  
310  'pixels of gray-scale value less than the threshold value to pure  
320  'black (0) and the rest of the pixels to pure white (63).  
330  'Compress the VTHRESHed image in bit plane zero.  
340  
350  VTHRESH 22  
360  VCOMPRESS 0  
370  
380  'Restructure the cracks using two directly opposite linear  
390  'structuring elements. Repeat VENHANCE three times.  
400  
410  FOR I = 3 To 4: VDILATE: NEXT I  
420  FOR I = 1 To 3: VENHANCE 1: NEXT I  
430  END