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DETECTION OF INTERNAL DEFECT IN PICKLING CUCUMBERS USING LASER SCATTERING IMAGE ANALYSIS

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ABSTRACT Internal physical damage such as carpel separation or hollow centers in pickling cucumbers is difficult to detect by human inspectors, and the current inspection procedure would require cutting open the fruit, which prohibits evaluation of individual cucumbers. Our recent research has demonstrated that hyperspectral transmittance imaging technique can provide an effective means for internal defect detection in pickling cucumbers. However the technique is still expensive and cannot meet the speed requirement in commercial cucumber processing facilities. Therefore, an alternative technique using laser scattering imaging to inspect internal quality of cucumbers was investigated in this research. A diode laser with the center wavelength of 808 nm was used in the experiment. Fifty fresh pickling cucumber samples were subjected to mechanical load to simulate stress caused by mechanical harvesting and subsequent handling. Scattering images generated at 0, 30, 45, 60, and 80 degrees of laser incident angle relative to the optical axis under transmittance mode were acquired from the pickling cucumbers before and two hours after mechanical stress was applied. Image processing and analysis algorithms were developed and tested on the acquired images to distinguish defective from normal cucumbers. Detection accuracies decreased as the incident angle increased. The best detection accuracy of 96% was achieved with 0 degree incident angle. The laser scattering technique could provide a cost effective way for rapid detection of internal defect of pickling cucumbers.

Keywords: Laser scattering, image analysis, nondestructive, quality, internal defect, cucumbers

INTRODUCTION Internal defects in cucumbers often occur in the form of watery or soft tissue and carpel separation or hollow center due to adverse growing condition and improper harvest, transport, handling, and processing. External defect can be detected visually, however damage that occurs inside the cucumber such as carpel separation is difficult or impossible to detect visually unless the fruit is cut open. Currently manual inspection via visual examination and hand touch is still commonly practiced for detecting bloaters or pickles with internal defect. This method is, however, slow, unreliable and labour intensive (Ariana and Lu, 2008a). A number of destructive methods for detecting defects caused by mechanical injury on cucumbers have been investigated; they include peroxide evaluation (Hammerschmidt and Marshall, 1991) and ethylene production (Miller et al., 1987). However these methods are not suitable for rapid determination of individual cucumbers or pickles and cannot be integrated into commercial lines.

We have recently developed a nondestructive method for internal defect detection in pickling cucumbers based on hyperspectral images acquired under transmittance mode (Ariana and Lu, 2008b). While the technique is effective, it is still expensive and cannot meet the speed requirement for commercial cucumber/pickle processing lines. One alternative approach to achieve fast and cost effective detection is to use a multispectral imaging configuration with a few wavebands (e.g., up to four bands) coupled with a broadband light and bandpass filters. This approach, although simpler than the hyperspectral imaging approach, is still not most economical in hardware design. Another alternative would be to use monochromatic illuminations, such as lasers or light emitting diodes (LEDs). Laser diodes and LEDs are now very affordable, and they are much more energy efficient than broadband illuminations. Inspection of agricultural products using laser illuminations was investigated in several studies. A prototype multispectral imaging system coupled with customarily designed lasers at four different wavebands was built to detect the firmness of apples (Lu and Peng, 2007). The technique is fast and relatively easy to implement, and it could meet the requirement for online sorting and grading of apple fruit. Qing et al. (2007) investigated laser backscattering imaging for predicting soluble solids content and firmness in apple fruits using laser diodes at five wavebands. Baranyai and Zude (2009) studied laser light propagation in kiwifruit using backscattering imaging and Monte Carlo simulation.

The objective of the study was therefore to evaluate the feasibility of laser scattering imaging to detect internal defect in pickling cucumbers.

MATERIALS AND METHODS

Cucumber samples 'Journey' pickling cucumbers were hand harvested from the experimental field of Michigan State University in Oceana County, Michigan in the summer of 2008. Only those cucumbers of 37-55 mm diameter (commercial size 3) free from external defect and irregular shape were selected for the experiment. Prior to the experiment, several harvested cucumbers were sliced and visually inspected to ensure that the cucumbers were free from internal defect that may have been caused by adverse growing condition and/or improper handling. A total of 50 fresh cucumber samples were selected for the experiment.

Each cucumber was subjected to rolling between a bench top and a 30-cm square board supporting a 10 kg load for 30 s to introduce internal damage.

Imaging system An imaging system with laser illumination was assembled for this experiment. The system consisted of: (1) a CCD camera to capture scattering images of cucumbers (model Sensicam QE, The Cooke Corp., Romulus, MI, USA), (2) an 808 nm diode laser with the maximum power of 500 mW (model BWF-808-450E, BWTek Inc., Newark, DE, USA), and (3) a rotational stage mounted with a collimating lens that delivers laser power through a fiber optics. The imaging sensor in the camera had 1376 × 1040 pixel resolution and was thermoelectrically cooled using peltier element to -12^{o}C. The laser's collimating lens was such positioned that it aimed at the axis of rotation for the sample holder as the laser beam was rotated around the cucumber, which was held at its two ends by a mechanical device (Fig. 1). Transmittance mode was chosen because it was found more effective for internal defect detection compared to reflectance mode (Ariana and Lu, 2008a). Laser power output was set to 20 mW. Scattering images of individual cucumber samples were captured at the laser's incident angles of 0, 30, 45, 60, and 80 degrees relative to the camera's optical axis (Fig. 1) to determine the effect of incident angle on internal defect detection.

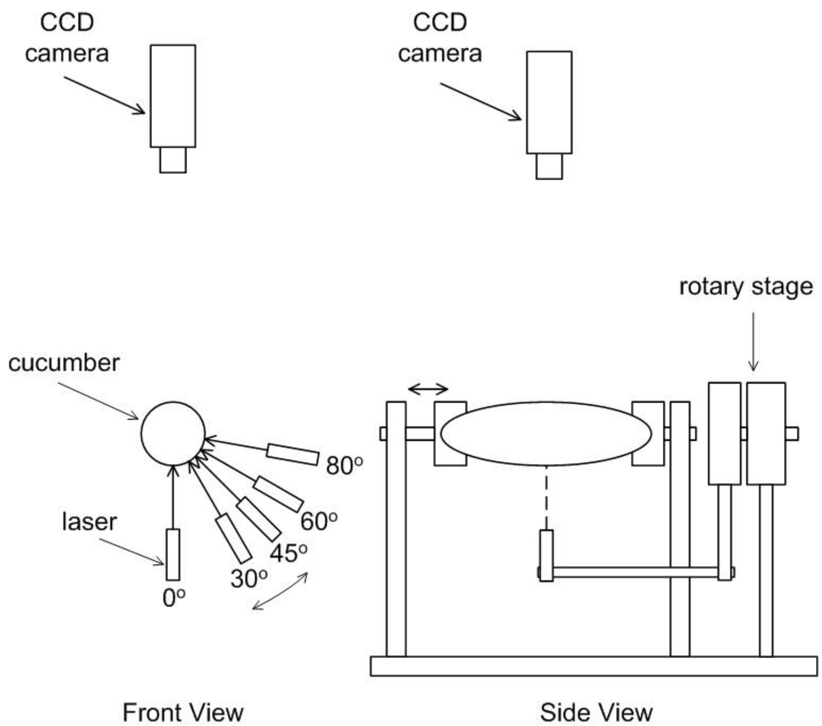


Figure 1. Schematic diagram of laser scattering experiment for detecting defective cucumbers.

Image acquisition and analysis Scattering images were captured using an inhouse program developed using Matlab software (The MathWorks Inc., Natick, USA); the program controlled the camera and the rotational stage to automate image acquisitions at different laser's incident angles. The camera was set at the 4×4 binning mode, which resulted in 260×344 pixel images. The camera's exposure time was set to 40, 30, 20, 5, and 1 ms for laser incident angles of 0, 30, 45, 60, and 80 degrees respectively. Different camera exposure times for different incident angles were used in order to maintain adequate signal levels for the images acquired. Individual cucumbers were imaged before and two hours after mechanical stress was applied. After imaging, the cucumbers were sliced diagonally into six pieces of approximately the same thickness for visual inspection of internal quality. Grade 0 or 1 was assigned to each slice for normal and damaged endocarp (seed cavity) respectively. A normal slice (grade 0) was characterized by seeds being intact within the seed cavity; a defective slice (grade 1) was characterized by the formation of water-soaked lesions in the endocarp (seed cavity) and/or hollow center (Fig. 2).

Further software binning at 2×2 and 4×4 were applied to the captured images to reduce the image size before subsequent analysis. Contour area analysis was used for the scattering images. Eight levels of pixel values at 30, 40, 50, 60, 70, 80, 90, and 100% of the maximum dynamic range of camera (4096 pixel counts) were selected to create contour lines. Morphological operations ("open") were applied to remove small noises outside the contour area, followed by the "close" morphological operations to remove small noises inside the contour area. Areas of pixels within each contour with their values at least equal to the selected levels were calculated. Discriminant analysis based on size of the contour areas at the eight different levels of pixel values for each laser incident angle was performed to evaluate the detection accuracies of internal defect in pickling cucumbers. Seventy five percent of the normal and defective images were selected randomly as the training set to calculate a pooled covariance matrix in the discriminant analysis. Then the discriminant function values for the rest images (test set) were used to classify each image. An image was classified to a class (normal or defective) if its discriminant value of that class was larger than that of the other class. Classification accuracy was then computed based on the correctly classified test images.

Figure 2. Normal and defective cucumber slices (Ariana and Lu, 2009).

RESULTS AND DISCUSSION Typical laser scattering images of pickling cucumbers at different laser incident angles are shown in Figure 3. At zero degree incident angle, two peaks appeared symmetrically on the images. As the angle became larger, the peaks shifted to the edge of the cucumbers, close to the location where the laser light had hit the cucumbers.

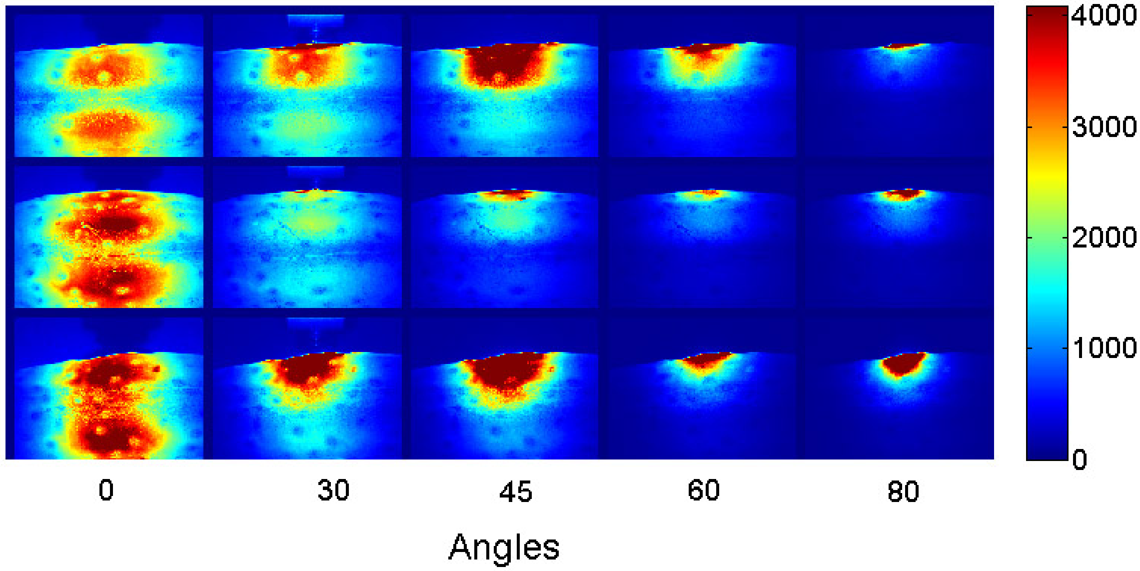
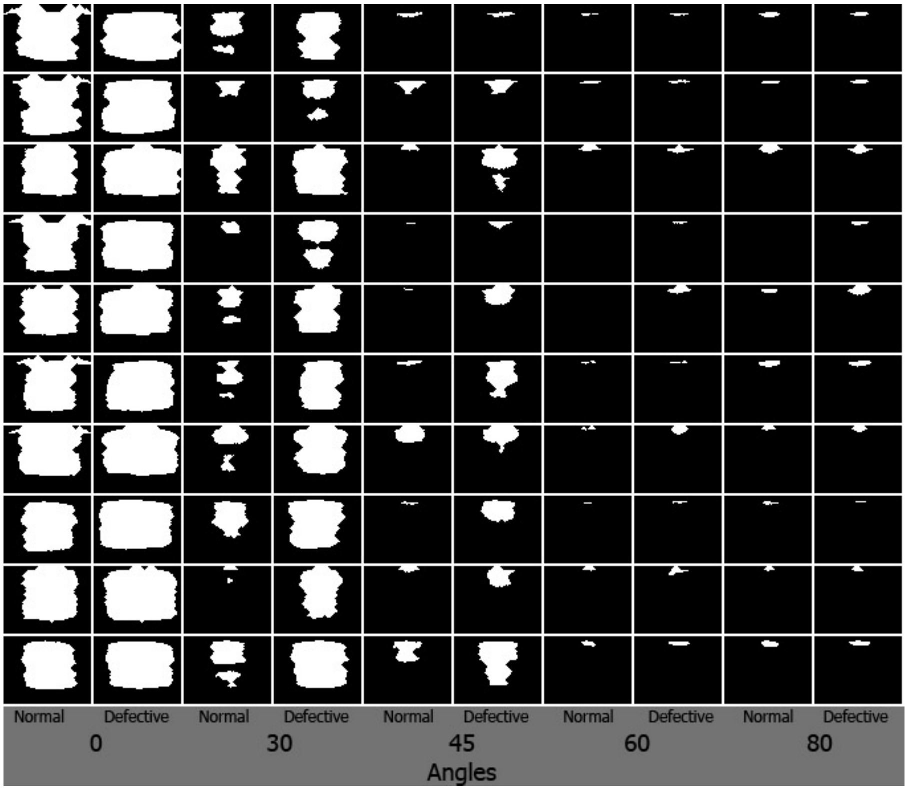


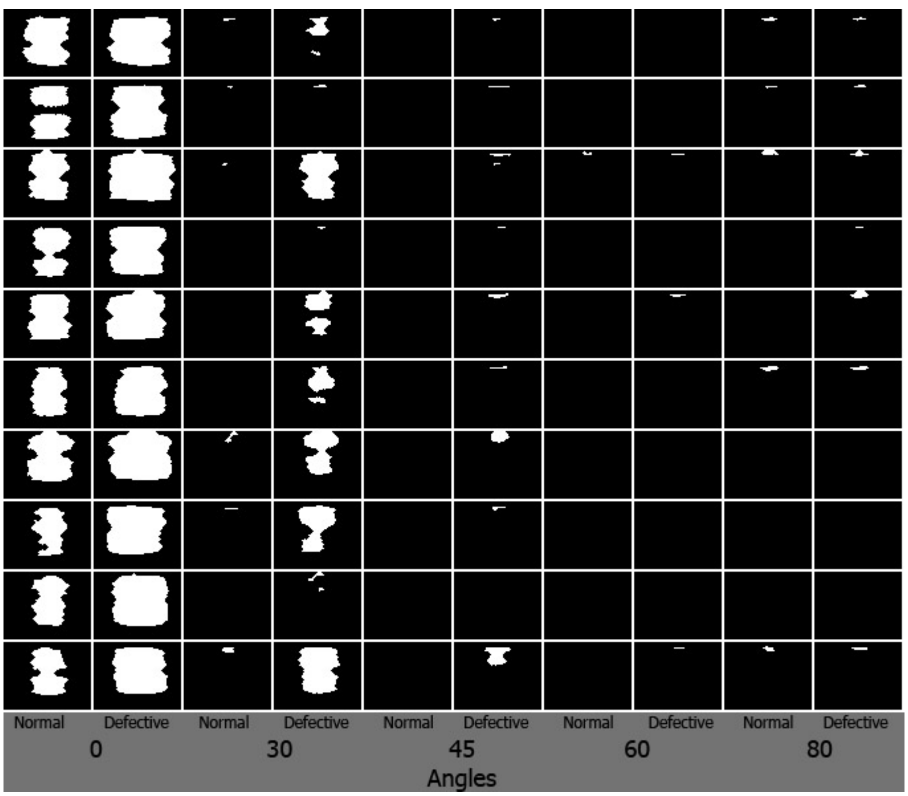
Figure 3. Laser scattering images at 0, 30, 45, 60, and 80 degrees of incident angle.

Representative binary images displaying the filled contour areas for normal and defective cucumbers are shown in Figure 4a and 4b for pixel levels of 30% and 50% respectively. At zero degree incident angle, the area for defective cucumbers consistently appeared larger than that for normal cucumbers. This indicates that light transmittance and scattering was more significant in the defective cucumbers than in the normal cucumbers. A similar trend was also observed at the incident angles of 30 and 45 degrees, although the filled areas at these angles were much smaller compared with those at zero degree incident angle. At 60 and 80 degree incident angles, high inconsistencies in the filled contour areas between normal and defective cucumbers were noticed, which suggested poor classification for the two classes.

Classification results based on the area of filled contour at different pixel levels are presented in Table 1. The highest classification accuracy was achieved at 0 degree incident angle with a total accuracy of 96% at the minimum pixel level of 50%. The high classification results were expected because the areas of filled contour between normal and defective were distinctly different and consistent (Fig. 4). Classification accuracy decreased as the incident angle increased. Under transmittance mode, the path that the photons go through the cucumber tissues decreases as the incident angle increases. Therefore, the photon interaction with the tissues becomes less, resulting in lower defect detection ability. Furthermore, the highest classification accuracies of 96.0, 88.0, 84.0, 60.0, and 64.0% were obtained at 50, 30, 30, 40, and 50% minimum pixel level for the incident angles of 0, 30, 45, 60, and 80 degrees, respectively. In most cases, classification accuracies were higher as pixel level was lower, which suggested the significance of scattered photons for internal defect detection.



(a)



(b)

Figure 4. Filled contour areas of normal and defective pickling cucumbers at pixel values of at least (a) 30% and (b) 50% of the camera's maximum value.

Table 1. Classification accuracies based on the contour area.

Angle (degrees)	Minimum Pixel Level (%)	Classification Accuracy (%)		
		Normal	Defective	Total
0	30	92.3	91.7	92.0
	40	92.3	91.7	92.0
	50	100.0	91.7	96.0
	60	84.6	91.7	88.0
	70	84.6	91.7	88.0
	80	84.6	91.7	88.0
	90	84.6	91.7	88.0
	100	84.6	91.7	88.0
30	30	84.6	91.7	88.0
	40	76.9	91.7	84.0
	50	76.9	91.7	84.0
	60	84.6	83.3	84.0
	70	84.6	75.0	80.0
	80	84.6	66.7	76.0
	90	84.6	58.3	72.0
45	30	76.9	91.7	84.0
	40	76.9	83.3	80.0
	50	76.9	66.7	72.0
	60	76.9	50.0	64.0
60	30	7.7	91.7	48.0
	40	38.5	83.3	60.0
	50	30.8	75.0	52.0
80	30	53.8	50.0	52.0
	40	53.8	66.7	60.0
	50	61.5	66.7	64.0

CONCLUSION

Results from this preliminary study showed that laser scattering image analysis had great potential for internal defect detection. The best classification accuracy of 96% was achieved when the laser was positioned at 0 degree incident angle relative to the optical axis under transmittance mode and the areas of filled contour were calculated at 50% of the camera's maximum pixel value. The ability to detect internal defect was lower as the incident angle increased. Further study on this technique with more cucumber samples is needed and other image processing algorithms for laser scattering classification of defective cucumbers should be investigated. In addition, study on dual waveband design should be considered because it may improve the system reliability by eliminating or reducing the effect of light source fluctuations.

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