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FIRMNESS DETERMINATION USING COMPUTER MACHINE VISION SYSTEM

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Summary. The objective of this study was to use light transmitted through a fruit to determine its firmness. The system developed in this study was capable of rapid acquisition of light transmission light a fruit and gave a relatively good prediction of apple firmness. The results show good correlation from 0.40 to 0.90 between mean gray level and fruit firmness. The best parameters were acquired by mean gray level with fruit firmness. Depth of transmitted light had lower correlation and other vision parameters had poor relationships.

Key words: apple, firmness, vision system, nondestructive

INTRODUCTION

Firmness is a very important indicator of fruit maturity and overall quality. Firmness measurements in fruit and vegetables have been used for over 60 years as an index of the quality [Abbott et al., 1976; Bourne, 1979]. Various testing methods have been reviewed by [Harker et al. 1996 and Pitts et al. 1997]. Firmness is commonly measured with a penetrometer where a cylindrical probe is pushed into the test fruit. The force required to give a predetermined penetration is recorded. The results are quickly obtained, but values are dependent upon the operator, to the extent that variations in readings of 200% have been recorded between different operators [Bourne, 1966]. Other test methods claim to be non-destructive. Small impact devices using accelerometers have been developed. Fruit may be dropped a short distance onto a force transducer, or a small impact is given by a light instrumented projectile without producing apparent damage [Chen and Tjan, 1998].

There are benefits in using computing systems since they are non-destructive [Duprat et al., 1995]. Recently, optical techniques have received considerable attention for nondestructive sensing of fruit quality, as a rapid, online, method of obtaining many attributes. Flesh color is an important determinant of quality and maturity in many crops. McGlone et. al. [1997] studied the potential of using light scattering for predicting the firmness of kiwifruit. They found that use of reflectance at more then one location improves firmness prediction. Choi et. al. [1997] found that wavelengths in the region between 700 and 2500 nm may be needed in predicting firmness of apple fruit. A *NIR* sensor was developed that covers the spectral region from 900 to 1700 nm and meets the online sorting speed requirements. Lammertyn et. al. [1998] used visible and near infrared spectroscopy as a nondestructive technique for measuring quality of Jonagold apples. A relation was established between the reflectance spectra recorded and fruit parameters such as the stiffness factor and elastic modulus of the flesh. Lu and Ariana [2002] used *NIR* spectroscopy for nondestructive sensing of apple fruit for multiple quality attributes. The proposed *NIR* sensing technique can be used for determination of sugar content, but not so accurately for firmness.

The objective of this study was to use transmitted light through a fruit to determine its firmness.

MATERIALS AND METHODS

Six apple cultivars were used in this study, Gala, Fiesta, Sampion, Jonagolg, Ligol, and Golden Delicious. The apples were picked from trees on six dates (every five days apart, before harvest ready and after) from Albigowa Orchard Experiment Station. When apples achieved ripeness, they were put into cold storage for five months at 0° C and 90% RH. Prior to testing fruit were removed from storage at least 15 hours before measurements to allow them to reach room temperature (20°C). Three measurements were taken on each apple.

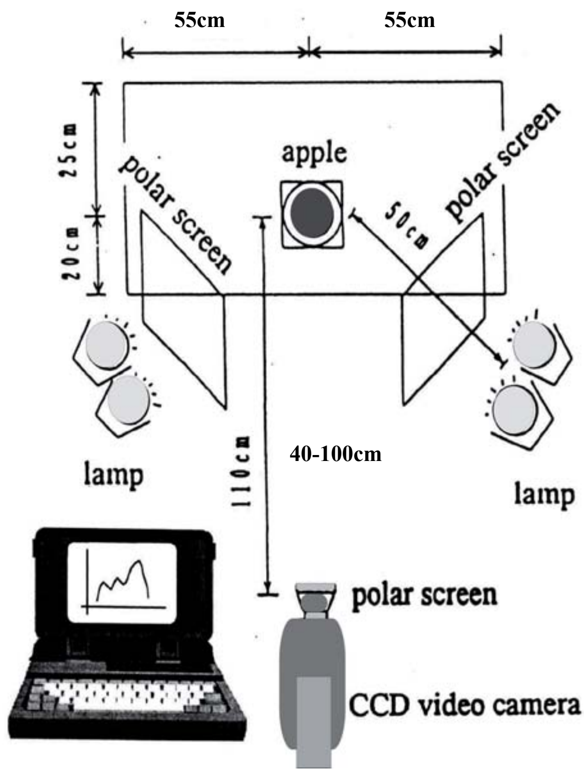
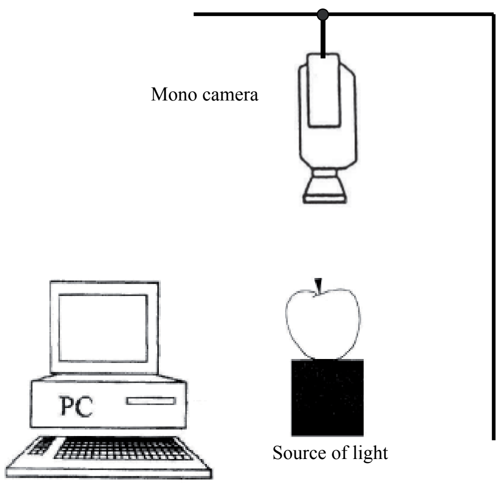


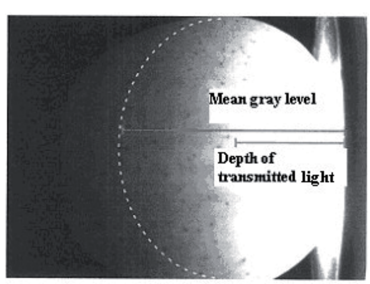
Fig. 1. Machine vision system

Images were acquired using one CCD camera (Model SSC-DC58AP, RGB Sony) equipped with 25 mm lens, computer with MultiScan program of image analysis, and diffuse light from two halogen lamps (Fig. 1). Apples were oriented vertically in the stem- calyx direction and then they were rotated. Eight images were taken around each apple. Images were digitized using a frame grabber, and visualized on the monitor. The camera was mounted on the side of the sample at a distance of 400 mm.

The experimental setup consisted of a solid-state camera, frame grabber and computer, and light source (Fig. 2). The calyx-end of the fruit was illuminated through a 30 mm diameter opening at the top of the light box. The amount of light that was transmitted through the apple was measured by viewing the stem-end with a CCD camera. After acquiring images, firmness was measured at the same location as computer images. The firmness tests were performed directly after the optical measurements. The Magness-Taylor test was carried out with a Zwick Machine using a cylindrical plunger in diameter of 11 mm, which traveled at a constant speed of 2 mm/s a distance of 8 mm into the peeled apple. The force vs. deformation curves were recorded for each apple. The maximum force and the slope of the curve from the origin to 2.0 mm of displacement were used as a measure of fruit firmness. Juice was then extracted from the fruit and its sugar content was measured using a digital refractometer.



Setup of transmitted light system.



Parameters determined on the base of transmitted light system.

Fig. 2. Setup of transmitted light system and determined parameters.

RESULTS AND DISCUSSION

Plots of sugar content and firmness for all varieties are presented in (Fig. 3.) It shows that there is a significant correlation between sugar content and firmness. It is difficult to explain results obtained from six varieties at different development stages. The following image parameters were selected; gray level for red R, gray level for green G, gray level for blue B, hue H, intensity I, mean gray level M, and depth of transmitted light D. Correlation coefficients between these vision parameters and apple firmness are shown in Table 1. The best significant correlations (0.40 to 0.90) were obtained between mean grey level and firmness. Depth of transmitted light was correlated with firmness for all varieties except for Jonagold; however the correlation was lower at 0.58. In some cases, gray level of red show higher correlation coefficient. The remaining parameters could only be useful for some varieties.

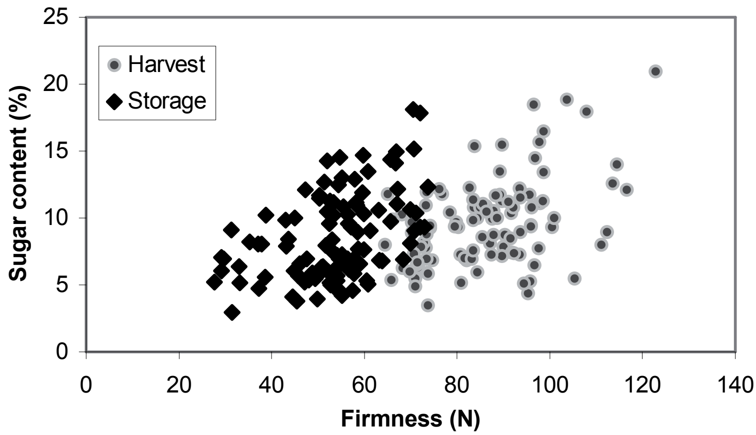


Fig. 3. Firmness plotted versus sugar content for all data of varieties within harvest and storage.

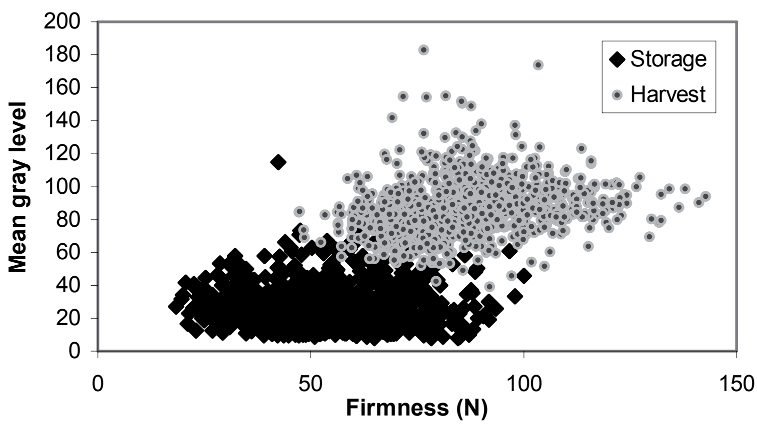


Fig. 4. Firmness plotted versus mean gray level for all data of varieties within harvest and storage.

Table.1. Correlation coefficients between parameters determined from vision system and firmness of apples of the tested varieties

Parameters	Correlation coefficients								
	Varieties								
	Gala	Sam-pion	Fiesta	Jona-gold	Ligol	Golden Deli-cious	Winter	Delate winter	All
Gray level of red	**-0,99**	**0,85**	**0,91**	**0,82**	-0,27	0,33	**0,58**	**0,74**	**0,66**
Gray level of green	-0,47	**0,57**	0,56	0,32	**-0,62**	**0,79**	**-0,89**	0,42	0,28
Gray level of blue	**-0,97**	0,41	**0,78**	**0,78**	-0,52	0,23	0,28	0,46	0,19
Intensity	**-0,87**	0,38	**0,81**	**0,72**	-0,30	0,44	0,16	**0,71**	**0,63**
Hue	**-0,91**	**0,46**	**-0,70**	0,28	-0,39	0,40	**-0,97**	**-0,86**	0,31
Mean gray level	**-0,82**	**-0,83**	**-0,90**	**-0,86**	**-0,40**	**-0,77**	-0,23	-0,35	-0,29
Depth of transmitted light	**-0,54**	**-0,83**	**-0,59**	-0,43	**-0,42**	**-0,51**	-0,25	-0,36	-0,32

Winter varieties – Gala, Sampion, Fiesta
Delate winter varieties – Jonagold, Ligol, Golden Delicious
All the correlation coefficients in bold are significant

Firmness versus mean gray level for all the varieties, harvests, and storage showed significant differences (Fig. 4). The changes in gray level were from 60 to 140 and 10 to 60, respectively for harvest and storage. It was also observed that increased firmness was related to a decrease in mean gray level. Reduced firmness was related to an increase in depth of the transmitted light (Fig. 5). One explanation is that a softening in the structure of apple allows for a greater penetration of light. In general this parameter can be used to distinguish fruits from various harvests and storages. Depth of transmitted light moderately correlated with the firmness level. A more complex algorithm may be needed for using the depth of penetrating light.

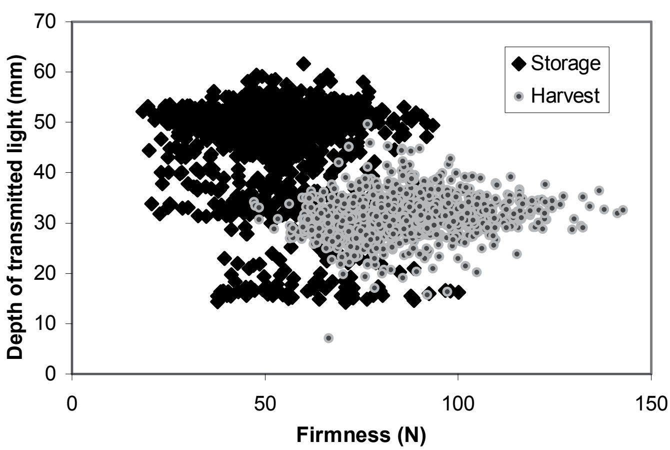


Fig. 5. Firmness plotted versus the depth of transmitted light for all the data of varieties within harvest and storage.

The results of the remaining gray level parameters of red R, gray level of blue B, hue H, intensity I as presented in Fig. 6, 7, 8 and 9 were poorly correlated with firmness. The poor performance of the computer vision system may be explained partially by the measurements principle as well as the reference firmness. Firmness is a measure of the mechanical properties of fruit tissue, which is related to tissue density. Light is also influenced by the density and structure of the fruit tissue. Therefore light should be more closely related to fruit firmness. Relatively poor firmness prediction results were also caused by the larger variability in firmness measurements within individual apples.

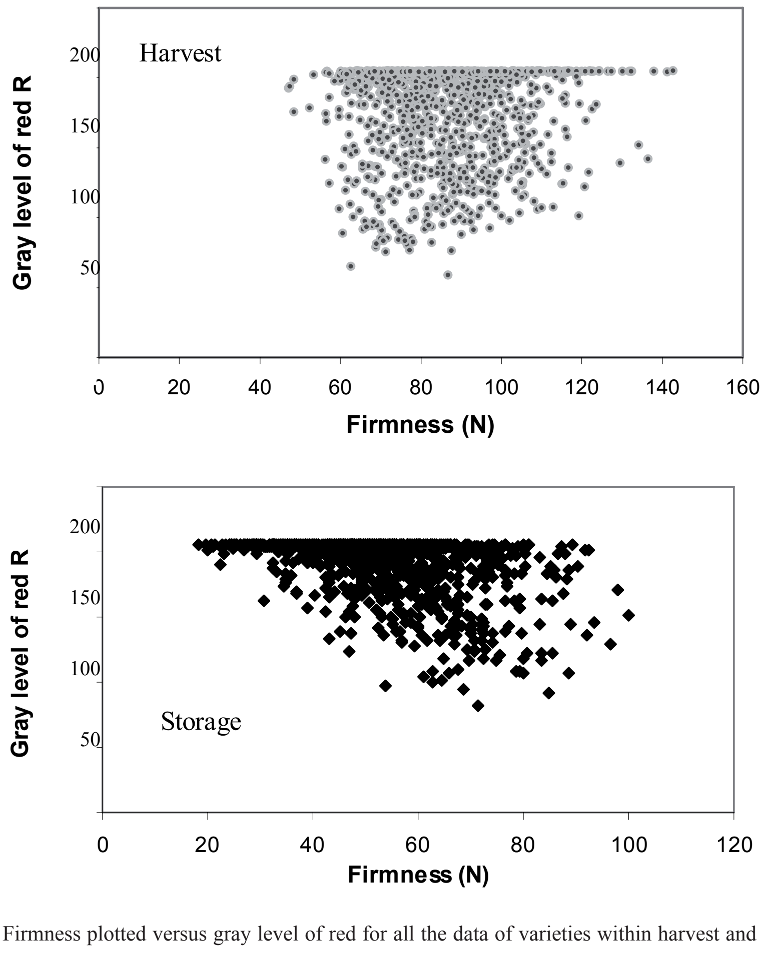


Fig. 6. Firmness plotted versus gray level of red for all the data of varieties within harvest and storage.

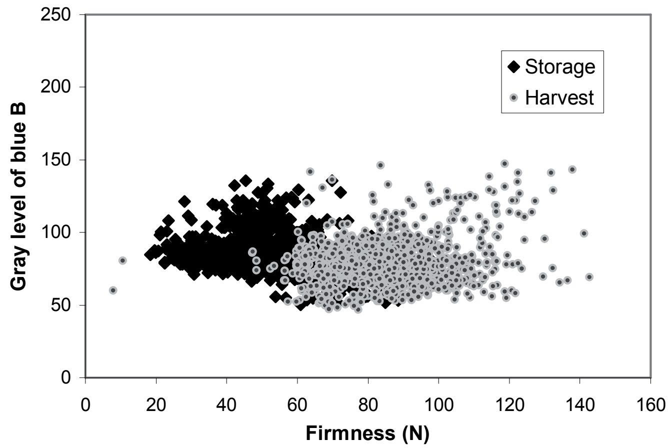


Fig. 7. Firmness plotted versus gray level of blue for all the data of varieties within harvest and storage.

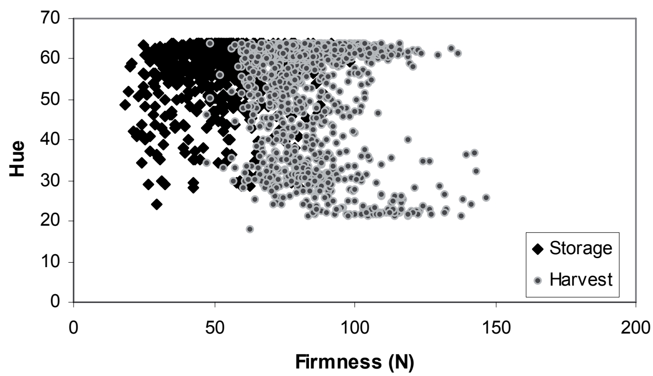


Fig. 8. Firmness plotted versus hue for all the data of varieties within harvest and storage.

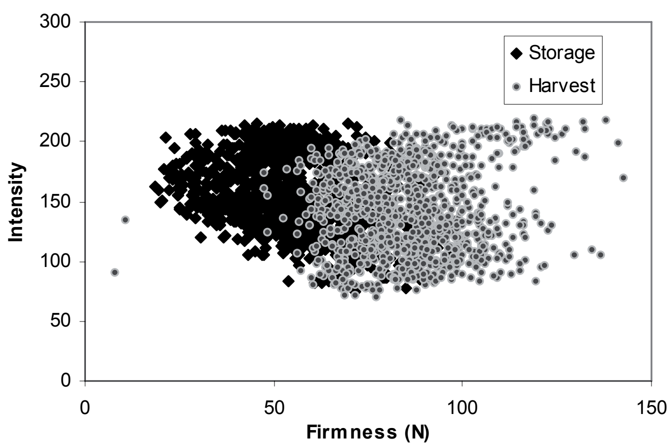


Fig. 9. Firmness plotted versus intensity for all the data of varieties within harvest and storage.

CONCLUSIONS

The transmitted light system developed in this study was capable of rapid acquisition of data and gave a relatively good prediction of firmness of apples for some parameters. The best parameter, mean gray level had correlations from 0.40 to 0.90 with fruit firmness. Depth of transmitted light was moderately correlated with firmness while the other vision parameters were poorly related.

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