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SUGAR CONTENT DETERMINATION USING COMPUTER VISION SYSTEM

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Summary. The objective of the study was to develop a system for determining an apple's sugar content with computer vision. The transmitted light sensing system developed in this study was capable of rapid acquisition of optical properties relating to internal quality of an apple. Two parameters, mean grey level and depth of transmitted light were obtained as indicators of sugar content. The correlation coefficients between sugar content and selected parameters were significant and ranged from 0.50 to 0.98 depending on the variety. The results show that it is possible to use a non-destructive computer vision technique for measuring sugar content in apples.

Key words: apple, sugar content, computer vision system

INTRODUCTION

Computer vision is a rapid, economic, consistent and objective inspection technique, which has expanded into many diverse industries. Its speed and accuracy satisfy ever-increasing production and quality requirements, hence aiding in the development of totally automated processes. This non-destructive method of inspection has found applications in the agricultural and food industry, including the inspection and grading of fruit and vegetable [Brosnan T. *et al.,* 2002].

Sugar content is one of the most significant factors affecting internal fruit quality [Dobrzanski *et al.* 2001]. Recently, reflectance and transmittance spectroscopy have received considerable attention in non-destructive detection of fruit quality. Dull et al. (1992) showed that near-infrared reflectance in wavelengths between 800 and 1000 nm could be used to determine the sugar content in cantaloupe and honeydew melons. Kawano et al. (1992) used a NIR spectrophotometer to measure the sugar content of intact peaches in the spectral region of 680 and 1235 nm. They showed that NIR transmittance could be used to determine the sugar content of mandarins. [Ventura *et al.* 1998] applied diffuse reflectance, coupled with a CCD detector to measure the sugar content of apples in the spectral region of 800 and 1000 nm. Their objectives were to: (1) examine the ability to predict soluble solids in intact apples using computer vision system and (2) obtain information to develop an intelligent fruit quality assessment system.

[Slaughter 1995] determined that visible and NIR-spectroscopy could be used to measure non-destructively the internal quality of peaches and nectarines as characterized by their soluble solids, sugar content, sorbet content, and chlorophyll content. [Bellon-Maurel 1992] used the wavelength region between 800 and 1050 nm to build a model for sugar measurement using a CCD camera instead of the standard photon multiplier detector. [Moons *et al.* 1997] established a relation between NIR-spectra and fruit quality parameters such as acidity, pH and sugar content. No information was found in the literature concerning NIR spectroscopy prediction models for texture and firmness parameters of fruit flesh. [Steinmetz *et al.* 1999] investigated sensor fusion to predict apple sugar content by combining image analysis and near-infrared spectrophotometer sensors. The repeatability of the classification technique was 78% when the two sensors were combined for the 72 samples. The objective of this study was to develop a computer vision system for determining sugar content of apples using a machine vision system for colour assessment and a transmitted monochromatic light system.

[Ahmada *et al.* 2000] evaluated the sugar content of orange fruit using features such as fruit colour, shape and roughness of fruit surface related to the pH. In order to give the consumer a more uniform product, the classification and separation of mixed nuts into lots of uniform shape and size is desirable.

The capacity to confirm the variety or origin and the estimation of sucrose, glucose, fructose of the citrus fruits are major interests of citrus juice industry. A rapid classification and quantification technique was developed and validated for simultaneous and non-destructive quantifying the sugar constituent's concentrations and the origin of citrus fruits using Fourier Transform Near-Infrared (FT-NIR) spectroscopy in conjunction with Artificial Neural Network (ANN) using genetic algorithm, Chemo metrics and Correspondences Analysis (CA) [Jagdish C. *et al.* 2008].

[Yan-de Liu 2007] measured diffuse reflectance spectra were at different testing distances of 0, 2, 4 and 6 mm for apple sugar content prediction. The statistical analysis results for fruit FT-NIR diffuse reflectance spectroscopy have been obtained employing the variance analysis.

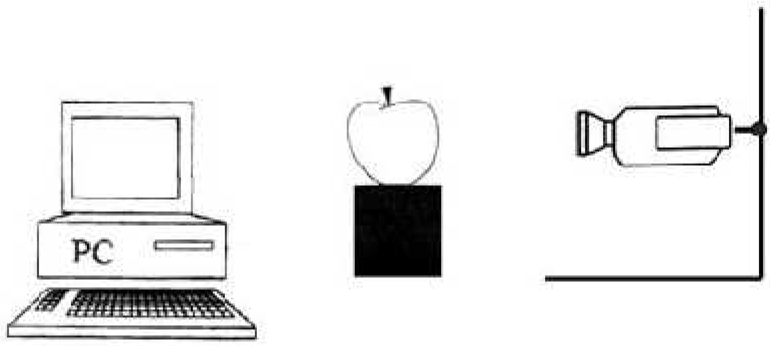
MATERIAL AND METHODS

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

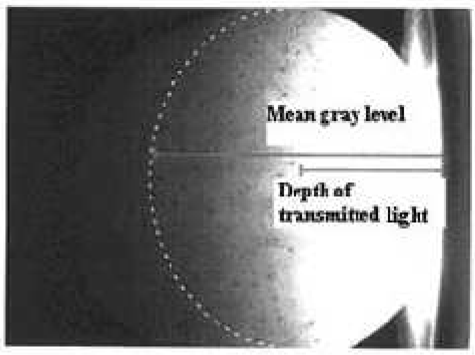
Images were acquired using one CCD camera (Model SSC-DC58AP, RGB Sony) equipped with 25 mm lens, computer with MultiScan program of image analysis, and lighting, which was provided with diffuse light from two halogen lamps [Puchalski *et al.* 2008]. Apples were oriented vertically in the stem- calyx direction and then they were rotated. Eight images of each apple were taken. Images were digitized using a frame grabber, and visualized on the monitor. The camera was mounted at the side of the sample with a working distance of 400 mm.

The experimental setup consisted of a solid-state camera, frame grabber and computer, and light source. 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 (Fig. 1). For determining when the apples were ready to harvest the following measurements were used: firmness and starch index. 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 11 mm in diameter which travelled at a constant speed of 2 mm/s into the peeled apple a distance of 8 mm. 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. Apple juice was then extracted and its sugar content was measured with a refractometer of RR 12 to an accuracy of 0.25% Bricks.



Setup of transmitted light system.



Parameters determined on the base of transmitted light system.

Fig.1. Setup of transmitted light system and determined parameters

The sugar content in the studied apples showed good relationship with light transmittance data. The measurements at several different locations of an apple are recommended to obtain representative values of sugar contents. A better prediction can be obtained with a separate calibration for each apple variety. Model performance was reported as the coefficient of determination, standard error of prediction, average difference between the measured and predicted values, and the calculated model error.

RESULTS

The followings parameters were selected; grey level for red R, grey level for green G, grey level for blue B, hue H, mean grey level M, and depth of transmitted light D.

Sugar content of the tested apples changed significantly during harvest and storage, as a consequence of changing chemical compositions. Correlation coefficients between sugar content of apples and the above parameters are presented in Table 1. Mean grey level M from transmitted light system and Hue from machine vision produced correlation coefficients in the range from 0.50 to 0.98 for all the studied varieties. A potential use of such parameters is to make grading decisions based on the transmitted light through the sample or on an individual fruit basis. Application such as the measurement of apple quality on assessment of sugar content of the fruit may be possible. Depth of transmitted light D, grey level blue B and intensity I, and grey level red R have a limited use i.e., they had good correlations for only some varieties.

Table 1. Correlation coefficients between mean parameters determined from vision system and sugar content of apples of the tested varie

Parameters	Correlation coefficients Varieties								
	Gala	Sampion	Fiesta	Jonagold	Ligol	Golden Deli-cious	Winter	Dilate winter	All
Grey level of red	**0.99**	**0.93**	**0.98**	-0.50	-0.39	0.40	**0.92**	**0.69**	**0.74**
Grey level of green	**0.96**	0.45	0.58	**-0.84**	**-0.65**	0.29	0.50	0.26	0.44
Grey level of blue	0.50	**0.95**	**0.97**	-0.52	-0.42	**0.97**	**0.91**	**0.46**	0.48
Intensity	**0.99**	**0.,87**	**0.95**	-0.36	-0.44	0.50	**0.89**	0.40	**0.72**
Hue	**0.97**	**0.80**	**-0.60**	**-0.84**	**-0.59**	**0.86**	-0.38	0.24	-0.23
Mean grey level	**-0.98**	**-0.78**	**-0.72**	**-0.50**	**-0.84**	**-0.70**	-0.41	0.43	-0.50
Depth of transmitted light	**-0.63**	-0.44	**-0.95**	**-0.62**	-0.36	**-0.65**	-0.46	0.42	-0.33

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

Sugar content of 2000 individual measurements plotted versus mean grey level for all varieties over all harvests and storage are presented in Figure 2. There are significant differences between measurements within storage and harvest. Mean grey levels changed from 60 to 140 and 10 to 45, respectively for harvest and storage. It is evident that using mean grey level is possible to distinguish harvest and storage conditions. This demonstrates that mean grey level is a good indicator of sugar content. High value of sugar content of apples resulted in smaller mean grey level. It was probably affected by changes in flash colour. The relatively high value of correlation coefficient found for mean grey level must take into account that measurement should be performed on the same location of the fruit. The reason of this is that the variability of the sugar content on the same fruit extends up to 2° Brix.

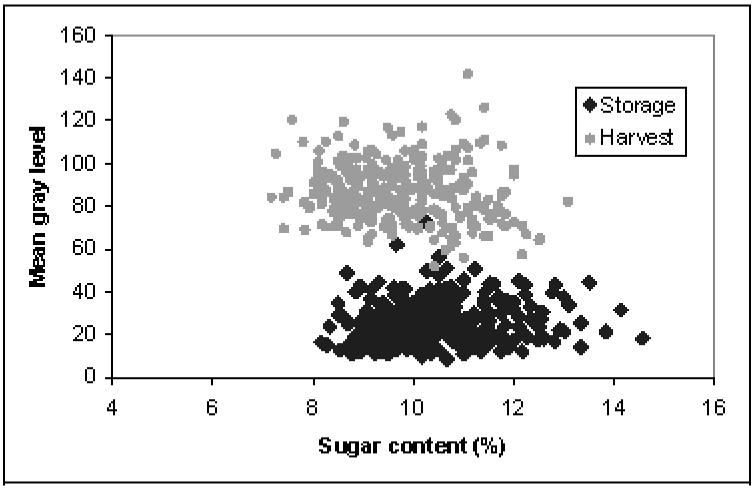


Fig. 2. Sugar content plotted versus mean grey level for all the data of varieties within harvest and storage

Depth of transmitted light (Fig.3) produced lower separation ranging from 25 to 40 and 40 to 55, respectively within harvest and storage. The reason for this is that the depth of transmitted light is multiple factor which depends i.e., on colour and texture (Mohsenin 1986).

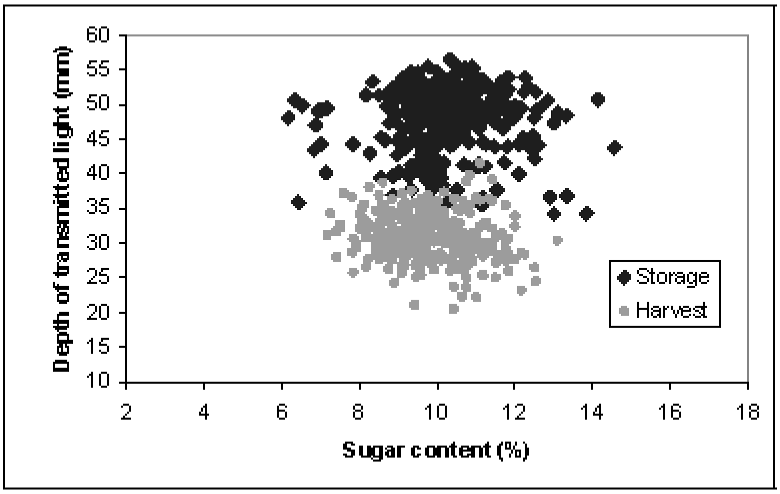


Fig. 3. Sugar content plotted versus depth of transmitted light for all data of varieties within harvest and storage

The separation capability from harvest and storage was also determined using hue with the differences between them being lower than for mean grey level and hue (Fig.4). The remaining parameters, grey level red R (Fig.5), grey level blue B (Fig.6) and intensity I (Fig.7) show similar values for harvest and storage and so they cannot be used to assess fruit quality on the basis of individual measurements. Grey level red R for storage (Fig.5), grey level blue B, and intensity I for all harvests (Fig.6 and 7) had a low correlation to the sugar content. Relatively poor sugar content prediction may also be caused by the selection of the reference method since there was a large variability in these measured parameters within individual apples.

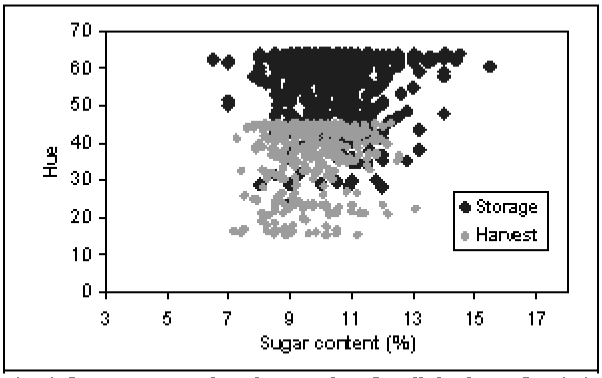


Fig. 4. Sugar content plotted versus hue for all the data of varieties within harvest and storage

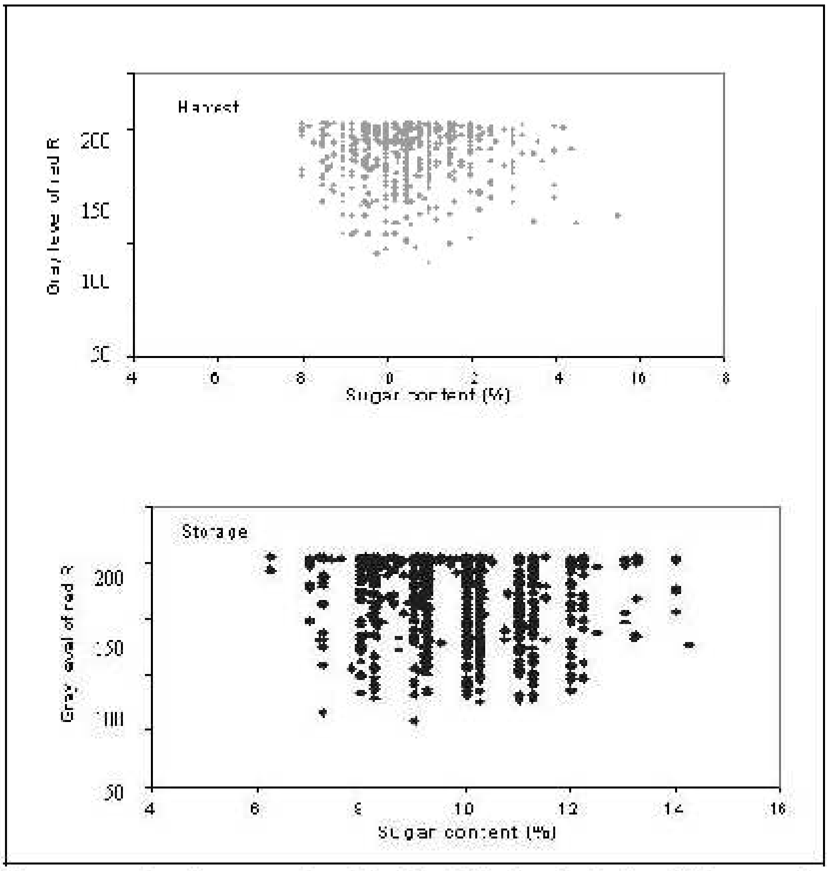


Fig. 5. Sugar content plotted versus grey level of red for all the data of varieties within harvest and storage

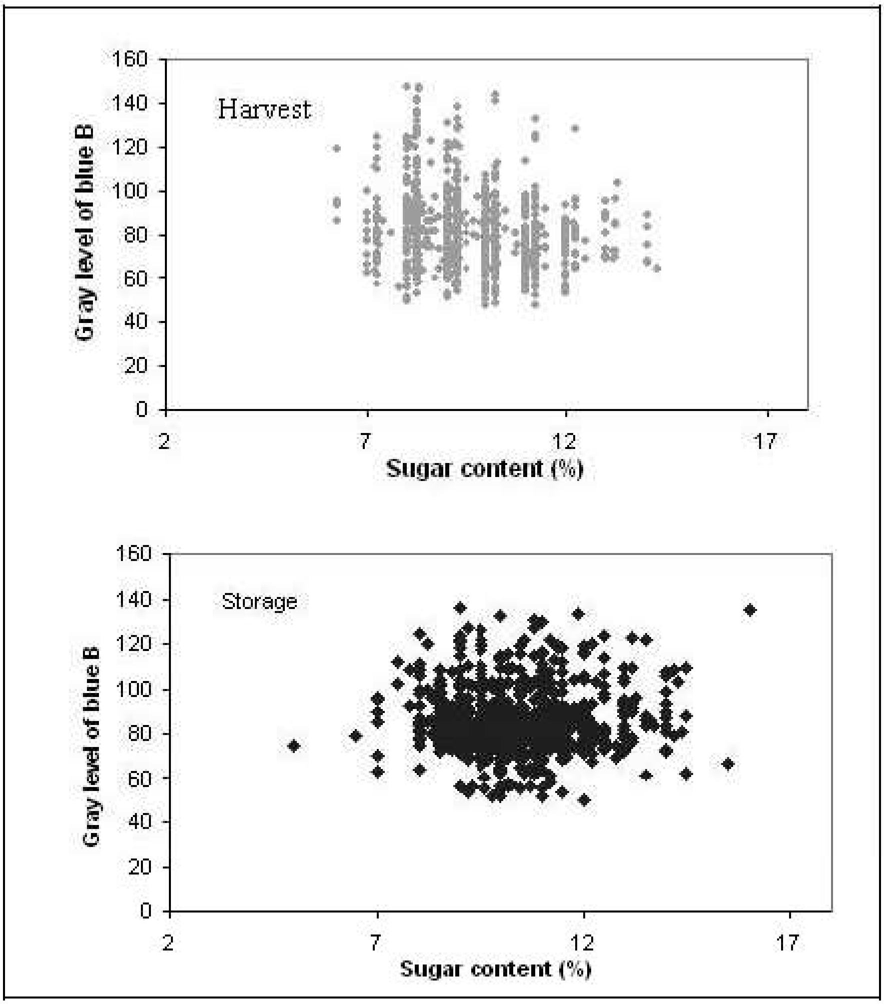


Fig. 6. Sugar content plotted versus grey level of blue for all the data of varieties within harvest and storage

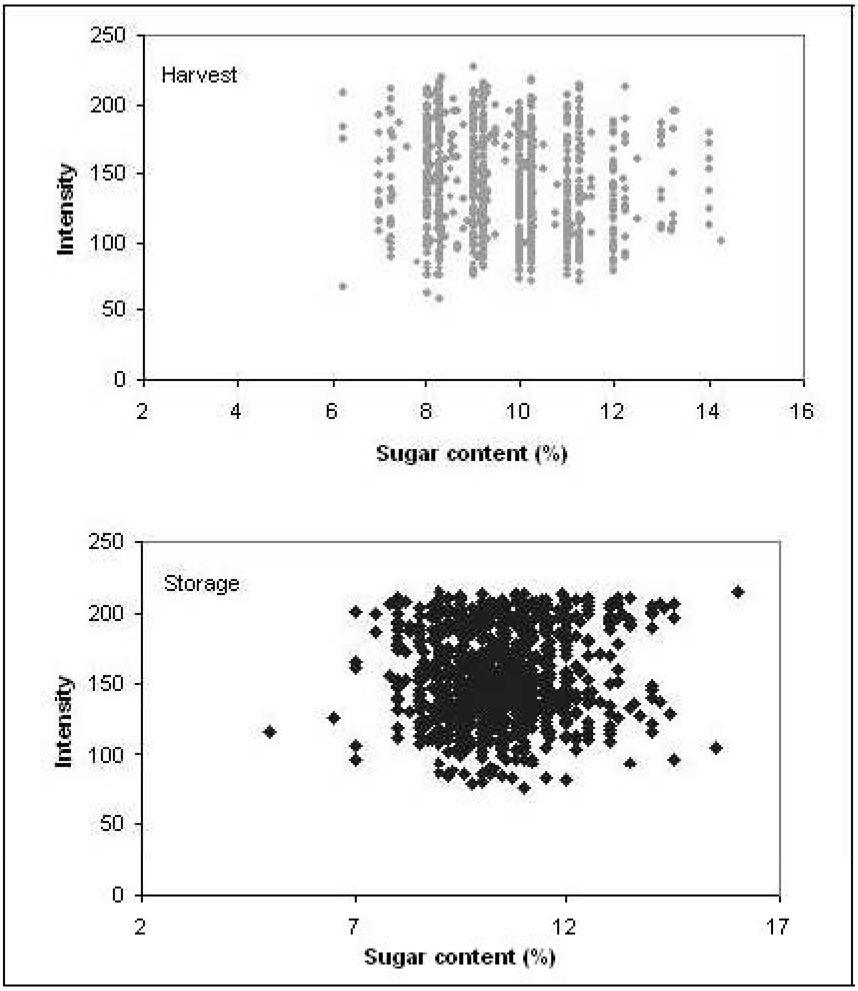


Fig. 7. Sugar content plotted versus intensity for all the data of varieties within harvest and storage.

CONCLUSIONS

1. The results of this study show that it is possible to use a non-destructive technique for measuring sugar content in apples.
2. The transmitted light sensing system developed in this study was capable of rapid acquisition of optical properties related to internal quality of apples.
3. Two parameters, mean grey level and depth of transmitted light were good indicators of sugar content. The correlation coefficients between sugar content and these parameters were significant, ranging from 0.50 to 0.98 depending on variety.

4. Depth of transmitted light D had good correlations for Fiesta, grey level blue B had good correlations for Sampion, Fiesta and Golden Delicious, intensity I had good correlations for Fiesta and Gala and grey level red R had good correlations for Gala, Sampion, Fiesta.

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WYZNACZANIE POZIOMU ZAWARTOŚCI CUKRU ZA POMOCĄ SYSTEMU WIZYJNEGO

Streszczenie. Cel badania miało być opracowanie systemu do określania zawartości cukru w jabłkach za pomocą komputerowego systemu wizyjnego. Zastosowany system transmisji światła przez miąższ owocu pozwala na określenie optycznych właściwości wiążących się ze strukturą wewnętrzną jabłka. Dwa parametry tj. poziom szarości i głębokości transmisji światła zostały wyselekcjonowane jako wskaźniki zawartości cukru w owocu. Uzyskano istotne współczynniki korelacji między badanymi cechami w zakresie od 0.50 do 0.98 w zależności od odmiany jabłek. Wyniki te świadczą o możliwości zastosowania komputerowego systemu wizyjnego do oceny zawartości cukru w jabłku metoda nieniszczącą.

Słowa kluczowe: jabłko, poziom cukru, komputerowy system wizyjny