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 0.30 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.

Keywords: 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 vegetables [Brooks et al., 2002].

Sugar content is one of the most significant factors affecting internal fruit quality [Dobrzaniski 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. 1995] 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 systems 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, color, and chlorophyll content. Bellon-Maurel [1992] used the wavelength region between 300 and 1050 nm to build a model for sugar measurement using a CCD camera instead of the standard photodiode detector. Moore 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. [1969] 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.

Ahmad 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 capability to confirm the variety or origin and the estimation of its growth, maturity, and quality of citrus fruits are a major interest of citrus juice industry. A rapid and accurate measurement technique was developed and validated for simultaneous and non-destructive quantifying the sugar content of citrus fruits. A high-resolution Fourier Transform Near-Infrared (FT-NIR) spectroscopy in conjunction with Artificial Neural Network (ANN) was used for predicting the sugar content of citrus fruits. 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, Sampson, Jonagold, Ligol, and Golden Delicious. The apples were picked for testing from trees on one date (five days apart) before harvest and continuing thereafter from Allsopp Orchard Experiment Station. When apples achieved full ripeness, they were put in cold storage for two 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-DC88AP, 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 sources. 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 20 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 0.2% Brix.

![Image]

**Fig 1. Setup of transmitted light system.**

Parameters determined on the base of transmitted light system.

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 following 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 or 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 varities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gala</th>
<th>Sampson</th>
<th>Fiesta</th>
<th>Jonagold</th>
<th>Licol</th>
<th>Golden Delicious</th>
<th>Water</th>
<th>Dilate winter</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey level of red R</td>
<td>0.99</td>
<td>0.93</td>
<td>0.98</td>
<td>-0.50</td>
<td>-0.39</td>
<td>0.40</td>
<td>0.92</td>
<td>0.69</td>
<td>0.74</td>
</tr>
<tr>
<td>Grey level of green G</td>
<td>0.96</td>
<td>0.45</td>
<td>0.38</td>
<td>-0.84</td>
<td>-0.66</td>
<td>0.29</td>
<td>0.50</td>
<td>0.26</td>
<td>0.44</td>
</tr>
<tr>
<td>Grey level of blue B</td>
<td>0.50</td>
<td>0.95</td>
<td>0.97</td>
<td>-0.52</td>
<td>-0.42</td>
<td>0.97</td>
<td>0.91</td>
<td>0.46</td>
<td>0.48</td>
</tr>
<tr>
<td>Intensity</td>
<td>0.89</td>
<td>0.57</td>
<td>0.95</td>
<td>-0.36</td>
<td>-0.44</td>
<td>0.50</td>
<td>0.89</td>
<td>0.40</td>
<td>0.72</td>
</tr>
<tr>
<td>Hue</td>
<td>0.97</td>
<td>0.80</td>
<td>-0.60</td>
<td>-0.84</td>
<td>-0.59</td>
<td>0.86</td>
<td>-0.58</td>
<td>0.24</td>
<td>-0.23</td>
</tr>
<tr>
<td>Mean grey level</td>
<td>-0.98</td>
<td>-0.78</td>
<td>-0.72</td>
<td>-0.56</td>
<td>-0.84</td>
<td>0.73</td>
<td>-0.41</td>
<td>0.43</td>
<td>-0.50</td>
</tr>
<tr>
<td>Depth of transmitted light</td>
<td>-0.63</td>
<td>-0.44</td>
<td>-0.95</td>
<td>-0.62</td>
<td>-0.36</td>
<td>0.65</td>
<td>-0.46</td>
<td>0.42</td>
<td>-0.33</td>
</tr>
</tbody>
</table>

Winter varieties — Gala, Sampson, Fiesta.
Dilate winter varieties — Jonagold, Licol, Golden Delicious.
All the correlations coefficients in bold are significant.

Sugar content of 2000 individual measurements plotted versus mean grey level for all varieties overall harvest 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. A high value of sugar content of apples resulted in a smaller mean grey level. It was probably affected by changes in flesh colour. The relatively high value of correlation coefficient 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 1983).

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 hues 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.
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 Fiestas, grey level blue B had good correlations for Sampson, Fiestas and Golden Delicious, intensity I had good correlations for Fiestas and Gala and grey level red R had good correlations for Gala, Sampson, Fiestas.

This research was funded by grant KBN 6P06H 0352 and grant 2 P0G R 093 30.

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WYZNACZANIE POZIOMU ZAWARTOŚCI CUKRI ZA POMOCĄ SYSTEMU WIZYJNEGO

**Streszczenie.** Cel badania miało być opracowanie systemu do określania zawartości cukru w jabłkach za pomocą komputerowego systemu wizyjnego. Zastosowany system transmisyji światła przez mięsień owocu pozwala na określenie optycznych właściwości wchodzących się w strukturę owocowej jabłka. Dwa parametry, którymi skomponowano i głębokość transmisji światła, zostały wykorzystane jako wskaźniki zawartości cukru w owocach. Uzyskano istotne współczynniki korelacji między danymi cechami w zakresie od 0.30 do 0.98 w zależności od odmiany jabłek. Wyniki te świadczą o możliwości zastosowania komputerowego systemu wizyjnego do oceny zawartości cukru w jabłku metodą nieinwazyjną.

**Słowa kluczowe:** jabłko, poziom cukru, komputerowy system wizyjny