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A dual-view computer-vision system for volume and image texture analysis in multiple apple slices drying

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ABSTRACT

The present study assessed the ability of a low cost dual-view computer-vision system (CVS) to measure volume and color co-occurrence image textural features of apple slices to find the end of drying process by comparing physical texture parameters and moisture content. Apple slices were dried at three different temperatures (40, 60 and 80 °C) and their volumes were measured with both the CVS and a caliper. The physical texture parameters and image textural features were measured according to the moisture content. While the CVS can be used to measure the volume of the apple slices during the drying process, the volume was not a good indicator of the end of drying because of porosity development. The peak force and initial slope of physical texture showed a significant correlation with H3, H5 and S2 and H3, H5 and S11 of image texture features, respectively. Eleven image texture features correlate well with the moisture content ($R^2 > 0.9$) and also had a high correlation between each other. The uniformity of intensity (I1) of image feature was a good indicator of the end of drying because of the close correlations with moisture content. The drying times according to the moisture content and the uniformity of intensity were 4.31 ± 0.313 h and 4.42 ± 0.125 h, respectively.

1. Introduction

Process control is of great importance in the food industry and determining the end of the drying process is critical in commercial food drying. The conventional technique used for determining the end of the drying process is to monitor the moisture content and terminate the drying process when moisture content reaches equilibrium. Temperature dependent correlations also exist between water activity and moisture content (Thompson, 1972). Prothon and Ahrné (2004) have used the Guggenheim, Anderson and De Boer (GAB) model to correlate moisture content with water activity in apples during osmotic dehydration (Eq. (1)). The GAB model is as follows:

$$X = \frac{X_0 k C a_w}{[(1 - k a_w)(1 - k a_w - k C a_w)]} \quad (1)$$

where X is the moisture content (% dry basis), a_w is the water activity, X_0 equals the mono-layer water and k and C are constants.

The use of computer-vision technology has rapidly increased in the fields of quality inspection, classification and evaluation in processing a large number of food products (Sun, 2004). Computer-vision technology produces fast and objective results and is a non-destructive and cost effective technology that can cater to the needs of the demanding food industry (Brosnan and Sun, 2004). Basically, a computer vision system (CVS) consists of digital or video camera(s) for image acquisition, standard settings illuminants and computer software for image analysis (Brosnan and Sun, 2004). The geometric reproducibility of food is one of the most imperative factors in the food drying process as the volume of food changes during the drying process. Image distortion is any deviation in the image from the rectilinear projection. The most common distortion is radial which can be classified into two categories; barrel and pincushion distortion. A full frame fish-eye lens is commonly used to obtain a wide field of view at a lower cost (Shah and Aggarwal, 1996) because a fish-eye lens is able to map a wide object onto a small image sensor. However, the use of a fish-eye lens usually creates barrel distortion because the image magnification decreases with distance from the optical axis (Shah and Aggarwal, 1996). The correction of lens distortion is more important in the volume measurement of multiple objects as it requires more accurate distances between the objects and camera. A single camera CVS can estimate the bulk volume of simple objects, such as cylinders or axisymmetric products (Wang and Nguang, 2009), while computed tomography (CT) using multiple laser lines or silhouette, or three-dimensional (3D) imaging using mirror(s) or a rotational object with single camera is essential for the food (Ruff

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et al., 1995; Imou et al., 2006; Nishino et al., 2000; Pintavirooj and Sangworasil, 2002; Lee, 2002; Lee et al., 2006). However, the CT is expensive and requires the extensive resources for processing (Russ, 2005) and rotation or mirrors are not suitable methods for the 3D imaging of multiple objects. The 3D imaging volume intersection using perpendicular dual view CVS is a more cost effective method for the bulk volume measurements of 3D sliced objects instead of four camera system (Chalidabhongse et al., 2006).

Unlike the RGB color space which was device dependent, the International Commission on Lighting (CIE, Commission internationale de l'Eclairage) $L^*a^*b^*$ color space is able to estimated human visual perception. Mathematical conversions from RGB to $L^*a^*b^*$ have been developed but require the use of standard illuminants during image capture which may not always be available. Several studies have been concentrated on the color reproducibility of food with low cost using alternative standard illuminant instead of standard illuminant D65 (Segnini et al., 1999) and modeling methods (León et al., 2006). Also, non-uniform illumination can distort color measurements and inhibit the ability to accurately detect edges within a digital image.

Texture, defined as a sensory property detected by humans using senses of touch and pressure, is a multi-parameter attribute related to the structure of the sample (Szczesniak, 2002). Crispness is a desirable characteristic of snack foods for consumers (Fillion and Kilcast, 2002; Joshi et al., 2007; Roudaut et al., 2002). The relationship between food texture perception and food structure is important to understand and develop texturally attractive foods (Wilkinson et al., 2000). For fried tortilla chips, the perception of crispness which is a parameter of texture was directly related to porosity which is a parameter of structure (Kawas and Moreira, 2001). Crispness and texture have been quantified by both instrumental and sensory approaches (Roudaut et al., 2002). Puncture tests on potato chips using a texture analyzer demonstrated that crispness was a function of water activity, while mechanical analyses of crackers indicated that the initial slope of a force–deformation curve was a good indicator of crispness (Garayo and Moreira, 2002; Katz and Labuza, 1981). Peak force, mechanical work and cohesiveness were also significant indicators of crispness for popcorn (Katz and Labuza, 1981). Therefore, based on the results of previous research, peak force, area under the curve (mechanical work) and initial slope measurements of the force–deformation curve were used as crispness indicators for dried apple slices in the current study.

Image texture is the perceived changes in scattered light from structural changes in the surface of an object (Russ, 2005). A common method used to evaluate statistical texture analysis is the gray-level co-occurrence matrix (GLCM) (Zheng et al., 2006). Since Haralick et al. (1973) applied the GLCM to the classification of land-use categories, there has been numerous application of the GLCM technique in different agricultural product including apple. The co-occurrence matrices of MRI image were used to characterize apple ripening among different apple varieties (Létal et al., 2003). Kavdir and Guyer (2002) used the GLCM of spectral image for apple sorting. The GLCM has been used for classification of grade of apples after dehydration (Fernández et al., 2005). This study used the hue-saturation-intensity (HSI) color planes for generating matrices instead of single GLCM (Shearer and Holmes, 1990).

The present study aims to: (i) determine the moisture-desorption isotherm of the apple tissue, (ii) investigate the possible use of a low cost perpendicular dual-view computer-vision system (CVS) to evaluate visual characteristics of apple slices, such as volume and image textural features, and compare these to moisture content and other food quality characteristics, (iii) assess the drying time according to volume from the CVS and (iv) assess the drying time according to image textural features measurement as well as correlations between image textural features and physical texture parameters.

2. Materials and methods

2.1. Common procedures for all experiments

The drying experiments were performed in a tray dryer (model: UOP8, Armfield Ltd., Ringwood, UK) which was modified for drying in the temperature range of 40–80 °C. A photographic region was illuminated by two light emitting diodes (LED; Model Number: TL-BW3N8B-0.5W, TSD Co., Guangdong, China; Color: White 6000–6500 K, Viewing Angle: 120°). The LEDs were fixed on the approximate center of the ceiling directly above the photographic region with chromaticity values of $x = 0.33$ and $y = 0.33$ and light intensity of approximately 400 lux in the center of the region. A top camera (model: Unibrain Fire-I, Unibrain Inc., San Roman, CA, USA) was placed 20 cm above the top tray. Initially, the same camera was used for the side view but it did not show good relationship between pixels and thickness even after correction for lens distortion. Therefore, a different side camera (model: DFK31AF03, The Imaging Source LLC, Charlotte, NC, USA) and CS mount lens (model: T2Z3514CS, CBC (AMERICA) Corp., Commack, NY, USA) which brought higher resolution and easy control of the depth of field were pressed up against the glass window, 14 cm from the center of the dryer, which located the two cameras at a 90° angle to each other. Both were interfaced using an IEEE 1394 Firewire interface card. The tray dryer's middle of top tray was modified to connect a scale (model: WSB-8015, Omega engineering Inc., Stamford, CT, USA) which was able to communicate with PC via RS-232C (Fig. 1).

For each experiment, the tray dryer was primed at the specified temperature (40, 60 and 80 °C) and the velocity of the air was set at 0.9 m/s. The tray dryer was considered primed when a controller virtual instrument (VI), was made using a LabVIEW version 8.5.1 (National Instruments Corp., Austin, TX, USA) program, indicates a stable reading (±0.5 °C). The air velocity was measured with a vane type thermo-anemometer (model; WDCFM8912, General Tools & Instruments, New York, NY, USA) with resolution of 0.1 m/s prior to the experiments. The lights inside were turned on 10 min prior to the experiment to ensure a consistent light spectrum.

Locally purchased (Truro, NS, Canada) fresh apples (Empire) were sliced to 2 mm using a food slicer (model; FS150, Waring, Odessa, FL, USA) except for the volume measurement. Apple slices were selected from the center of the apple and separately weighed on a scale (model: Symmetry ECII-4000, Cole–Parmer Canada, Montreal, QC, Canada). After the initial measurements, all apple slices were immediately moved to the tray dryer. The LabVIEW VI monitored and recorded the temperature, humidity and weight throughout each experiment and the VI also recorded images for further analysis. Linear regression analysis and linear models were used for regression analyses and modeling if they fit well.

2.2. Methods to determine moisture-desorption isotherms

The tray dryer was primed at 40, 60 or 80 °C. Three apple slices were placed on a tray attached to a scale and fifteen slices were placed on Teflon sheets on the stationary tray in the dryer for sampling. The LabVIEW VI recorded the temperature and humidity and displayed approximate moisture content every 2 min. Samples were taken at various moisture contents for water activity measurements throughout the drying process. The dried apple samples were ground into powder with a coffee grinder and placed in a water activity meter (model: ms1 Set aw, Geneq Inc., Quebec,