NOTE

Use of Computer Vision for Real Time Estimation of Volume Increase During Microwave Baking

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ABSTRACT

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A novel estimation method for real time measurement of the volume expansion of materials being baked in microwave ovens is described. The method incorporates the capabilities of computer vision systems. The results obtained with this method compared favorably with volume measurements derived by the standard rapeseed displacement technique. The method provides the product development scientist with the tool necessary to study the rapid expansions experienced during microwave baking.

With the ever growing consumer use of foods that are prepared and/or reconstituted in microwave ovens, there is an increased demand for new products in this category. This creates a need for novel research and development tools that are easily used by the product development scientist.

This note addresses the problem of real time measurement of volume expansion of food items being baked in microwave ovens. Because microwave heating rates are rapid, these products normally rise and collapse before the investigator has any reasonable chance of measuring their volume. Since the final volume is an important attribute of most baked products, there is a need to understand how the volume increase occurs so that product development and formulation can proceed on some rational basis.

The recent availability of moderately priced computer vision systems provides a solution to the problem. Detailed discussion of these devices and the algorithms that are utilized to analyze images may be found in the literature (e.g., Ballard and Brown 1982, Baxes 1984, Rosenfeld 1984). These devices have the capability of "grabbing" an image and analyzing it in real time. As a result, even the very rapid volume changes that products undergo in a microwave oven may be measured and analyzed in a reproducible and meaningful manner. The intent of this research note is to describe such a device.

MATERIALS AND METHODS

A schematic representation of the equipment used to measure volume change during microwave cooking of a bakery product is shown in Figure 1. Typical volume data collected at 2-sec intervals during this microwave process is depicted in Figure 2.

The equipment consists of three major components: 1) A commercial computer vision system (model P256, International/Robomation Intelligence, Inc., Carlsbad, CA), 2) a digital black-and-white television camera (model KP120, Hitachi Denshi America Ltd., Woodbury, NY) equipped with a 50-mm, F1.4 lens (Nikon Inc., Instrument Division, Garden City, NY), and 3) a modified microwave oven (Litton Generation II, Memphis, TN.)

Microwave Oven Modification

The microwave oven was modified to provide a bright, backlit image to the television camera. First, the "smoked glass" false front on the oven door was removed. A 3 × 11 in. hole was cut in the back of the oven cavity. To avoid arcing, the paint was removed from the edges of the hole to ensure good electrical contact. The hole was covered with a 3/16-in. mesh screen held in place with an aluminum "picture frame" attached to the oven cavity with carriage bolts. The combination of small-screen mesh

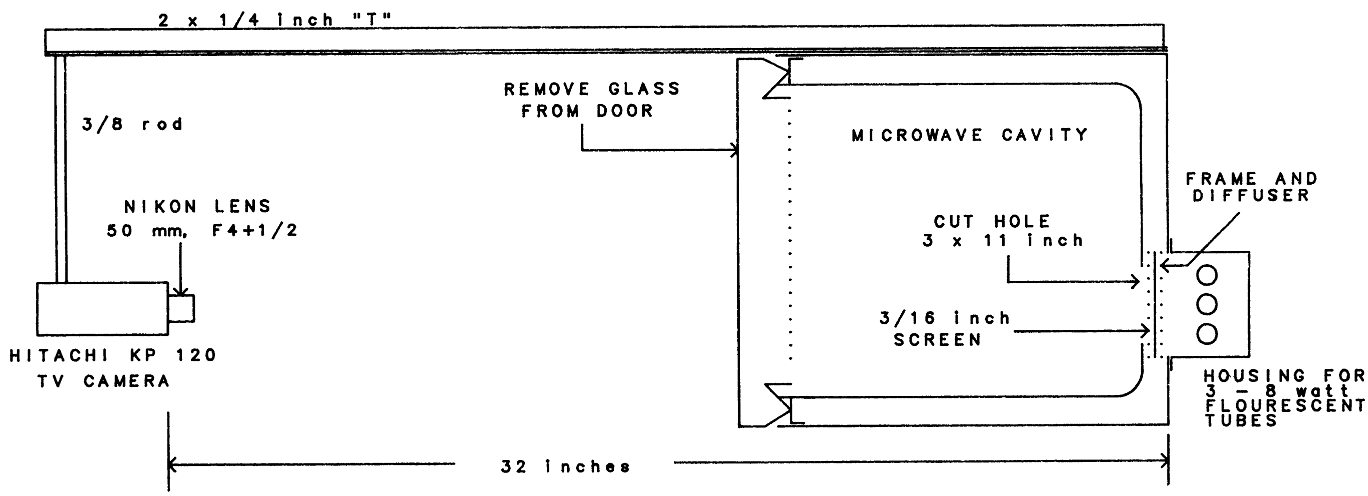

Fig. 1. Experimental apparatus (not to scale).

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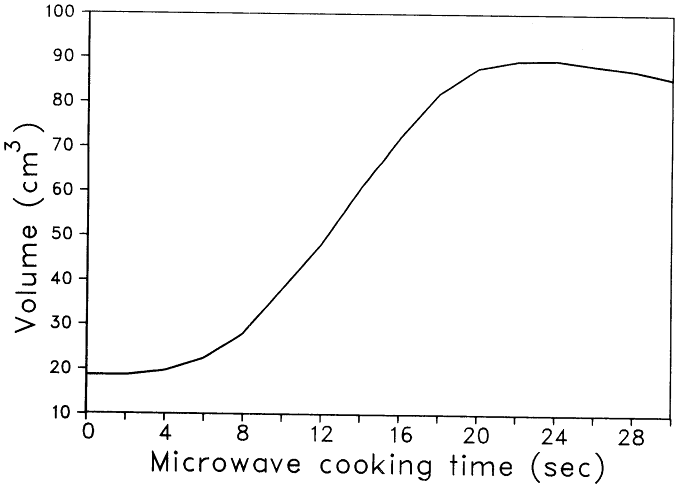

Fig. 2. A typical volume increase during microwave baking.

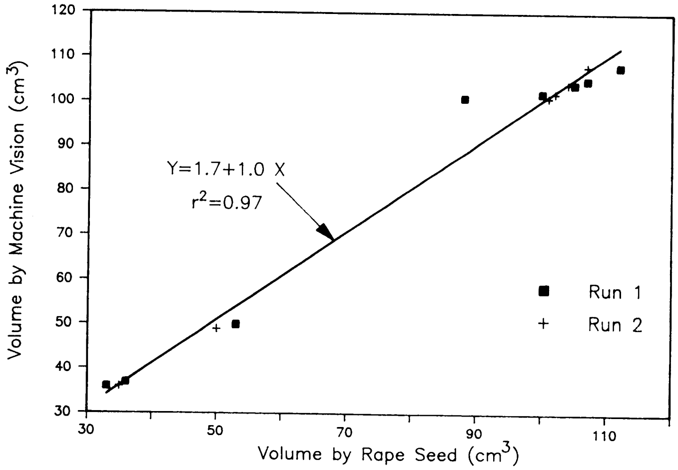

Fig. 3. Correlation of machine vision volume with rape seed displacement volume.

size and good electrical connection between the screen and frame and the oven cavity prevented microwave leakage and arcing. Finally, three standard 8-watt fluorescent bulbs and a translucent diffuser were mounted behind the screen, outside the oven. These bulbs provided a bright visual background for viewing through the oven door. This image was recorded by the computer vision system.

Camera Positioning and Lens Focusing

The modifications to the oven deliver a bright, high-contrast image to the camera. Combined with the correct focusing of the lenses and positioning of the camera, this provides a sharp image that has few artifacts and is readily interpreted by the vision system.

The camera lens aperture was set at F4.0 ± a half stop. This, combined with proper focusing, results in a depth of field that is shallow enough to focus on the object in the oven and not on the screen in the oven door. As a result, the product appears in sharp silhouette and the door screen remains invisible. The camera position was chosen so that the image of the baked product, at maximum expansion, filled most of the viewing field. This maximized the sensitivity of the measurements.

Vision System

The vision system's computer digitizes the image received from the camera. The image is resolved into 256 (horizontal) × 240 (vertical) pixels (picture elements). The digitizing limits the accuracy of any measurement to about 0.42% (i.e., 1/240 pixels) of full scale.

Measurement

The digitized image was further analyzed through the use of a simple set of algorithms, many of which are built into the hardware of the vision system. The image was interpreted using the following procedure. The image was converted to a binary form (i.e., from 256 grey levels to black and white) and inverted so that the silhouette of the baked product appeared white on a black background. The projected area of the baked product was measured by counting the number of white pixels in the binarized, inverted image. The image was scanned to locate the position of the highest white pixel, which yields an estimate of the baked product height. The results were printed and the entire procedure was repeated once per second. The repetition frequency was arbitrarily chosen; the system has enough computing capabilities to repeat this procedure at a far greater rate. For real-time monitoring, five to 10 measurements per second are possible.

Calibration of the output of the device was obtained by substituting a 0.75 in. (height) × 1.5 in. (diameter) wooden block for the baked product. Executing the algorithm on the block yielded the following relationships between pixel height and the projected cross-sectional transverse area:

$$\text{Height (cm)} = 0.0476 \times (\text{pixel height}) \quad (1)$$

$$\text{Area (cm}^2) = 0.0024 \times (\text{pixel area}) \quad (2)$$

Estimation of Baked Product Volume

The volume of the baked product can be geometrically approximated. For instance, for a cylindrical product the volume can be estimated by the following formula:

$$\text{Volume (cm}^3) = (\pi/4) \times \text{area}^2/\text{height} \quad (3)$$

RESULTS AND DISCUSSION

The accuracy and precision of the method described above was tested by two sets of experiments (1 and 2). Commercially available products were baked in a conventional oven to various degrees of volume expansion, then cooled to ambient temperature, placed in the test unit, and measured for five scans at 2-sec intervals without microwave power. The volume from each scan was estimated using equation 3. The average volume of the five scans was reported as the volume from "machine vision". Those products were also measured by the standard method of rapeseed volume displacement. Figure 3 illustrates the correlation between the two methods. There was no significant difference in the results between the two runs (1 and 2). This shows the precision of the method. The relationship between volume measured by rapeseed displacement and volume determined via machine vision was:

$$\text{Volume (test system)} = 1.0 \times \text{volume (rapeseed)} + 1.7 \quad (4)$$

The correlation coefficient (r^2) for this relationship was 0.97. A slope of 1.0 and the low intercept of equation 4 show the compatibility of these two methods. The correlation established illustrates the usefulness of the rapid technique that has been proposed. The technique described herein can be readily modified and expanded for different sizes of products and other real time measurements.

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