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Image Processing For Food Structure Analysis

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ABSTRACT. *Based on past research a hypothesis was formulated that the sensory crispness of extruded products such as corn puffs is dependent on both the mechanical properties and the internal physical structure of the extrudates. Therefore, image processing techniques were developed to extract various features from images of extrudate samples. A method of dissecting the samples and highlighting the cell structure was established to reveal the internal cell wall patterns to the video imaging system. Numerous parameters related to the internal structure were derived from the digitized images using mathematical algorithms. Samples were classified into groups based on the above parameters.*

INTRODUCTION

Crispness, along with other characteristics such as colour, smell, and moisture content, is considered an important factor influencing the sensation gained at the time of food consumption. Crispness could be described as a sensation caused by the auditory and tactile stimuli at the time of chewing. The person's sensation of the crispness depends on the loudness and pitch of the noise emitted (Vickers, 1981). This heavy dependence on auditory sensations makes it difficult to describe or measure crispness effectively. Various approaches have been taken by researchers to gain a better understanding of crispness and to establish successful measurement methods.

The relationship of food crushing sounds to crispness has been studied by several researchers. The mechanism which generates the crushing sound is the breaking and vibration of the walls of porous foods (Vickers, 1988). Therefore, a study of the distribution and geometry of inner walls may provide information on the crispness of the product. This approach requires a way to observe the pores formed inside the food sample and a scheme of extracting pertinent structural data.

A cross-section of the product must be examined to obtain data on the structural parameters of inner walls and pores. The fineness of the object under observation in this study (extruded cornmeal) prevents any manual measurements on its geometry. Image processing provides the capability of acquiring an image of the object, enlarging it to a suitable size if necessary, enhancing its features related to the property being studied, and extracting relevant data. Therefore, the use of image processing techniques in determining the crispness of extruded food could be of considerable importance to the advancement of food manufacturing studies.

LITERATURE REVIEW

Image processing techniques have been used in both agriculture and in the food industry to automate processes and to provide visual monitoring capability. Current image processing technology can perform these tasks by extracting visual information from computer image analysis systems and automatically extracting data related to the process.

Alahakoon and Heymann (1991) used a B & W video image processing system in parallel with sensory panel ratings in a colour intensity evaluation study. Two groups of samples with varying intensities were prepared by mixing cranberry juice with water and cocoa powder with sugar powder. Variations in the colour intensity of the food samples were estimated by the relative grey level of the video image and the data were compared to those obtained from a sensory panel study. Results showed that such image processing techniques could be used in place of sensory panel studies in evaluating colour intensity properties of food.

Barrett *et al.* (1992) attempted to characterize the stress-strain relationships of puffed extrudates using Instron data and vision based data. They analyzed two groups of extrudates maintained at three humidity levels. The Fourier transform was used to extract power spectrum data from the stress-strain curves generated by the Instron machine.

The technique of manipulating the grey levels in the acquird picture has been often used in numerous other applications of digital image processing in agriculture and food science. Decisions can be made by looking at the image in place of the original object or a picture of the object. Various processing routines can be utilized to enhance its characteristics, making it easier to identify special features. In addition, the computer itself can be used to detect and classify regions in the acquired image depending on the grey level value of pixels. This processing technique can provide more uniform and consistent classifications than the human eye and is one of the best advantages in digital imaging technology.

Therefore a research study was proposed with an overall objective of developing a relationship between the crispness of extruded food and its internal structure using image processing techniques. This paper describes the methods developed to obtain internal structural data from extruded cornmeal, in this study.

MATERIALS AND METHODS

Equipment hardware and software

An APV Baker[1] MP 50/25 corotating twin screw extruder (APV Baker Inc., Grand Rapids, MI) was used to extrude the samples for this experiment. Cornmeal (degermed yellow cornmeal, Lauhoff Grain Co., Danville, IL) was used as the raw material.

A Black and White (B & W) video camera (COHU model 4815) was used to acquire images of the extrudate samples. The captured images were displayed on a video monitor (SONY model PVM-1271Q). An IBM personal computer AT equipped with a frame grabber board (Data Translation DT 2851) and an auxiliary frame processor board (Data Translation DT 2858) served as the host machine for the vision system.

A collection of basic software routines (Data Translation IRISTutor, DT-IRIS Subroutine Library) provided with the image processing hardware was installed in the host computer. Most image processing operations were performed by utilizing these subroutines in user written programs. Programs were developed was done in Fortran and QuickBASIC (Microsoft QuickBASIC, version 4.5) languages.

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[1] Trade names are provided solely for the purpose of information and those should not be considered as recommendations made either by the Department of Agricultural Engineering, University of Missouri-Columbia or by the Agriculture Research Service of the U.S. Department of Agriculture.

Sample preparation

In producing the extruded food samples, it was decided to use a minimum number of additional ingredients in order to reduce the complexity of the cooking process. The screw speed and feed rate were changed as shown in Table 1. After the extruder controls were adjusted to the desired setting for a certain batch, sufficient time was allowed for the extruder to stabilize. Extrudate samples were collected 5 minutes after stable operating conditions were reached, with the sample collection process taking less than 20 seconds per batch. The corn puffs were dried in a fluidized bed drier for 5 minutes and allowed to cool to room temperature before being sealed in polyethylene bags.

The moisture content of each batch was measured by weighing 24 samples from each batch. The samples were then vacuum dried (AOAC, 1984). Since there were no significant ($p<0.05$) differences in moisture content among batches after the initial drying, no additional drying was required. The extrudate samples produced as described above were used in all subsequent steps of the research.

Table 1. Screw speed and feed rate combinations used to prepare samples.

Sample group	Screw speed (r/min)	Feed rate (kg/s)
1	400	1.20
2	350	1.06
3	300	0.91
4	250	0.76
5	200	0.60
6	150	0.45

Image analysis

In order to extract internal structural information, it was necessary that the samples be processed before presentation to the image processing system to highlight the features under investigation.

Dissecting of samples

The overall shape of corn puffs could be best approximated by cylindrical tubes with hemispherical end caps. The signs of structural formations inside the corn puff indicated by the outmost surface were not of sufficient contrast to be detected by a B & W video camera. It was necessary to observe the interior cells and cell walls to investigate the internal structure. Since the extrudates were very brittle, it was impossible to cut the samples into two halves without causing wall breakages.

It has been widely observed that the crispness of cereals decreases with increasing moisture. Since this implies a decrease in the brittleness of product walls, the moisture content of the extrudate was increased prior to cutting. Saturated salt solutions were used to provide constant humidity environments to control the relative humidity of the test materials (Sauvageot and Blond, 1991). Three salts; Magnesium Nitrate ($Mg(NO_3)_2$), Sodium Chloride ($NaCl$) and Potassium Chloride (KCl); which had water activity (A_w) values of 0.528, 0.753 and 0.843 respectively, were selected for this purpose. Saturated solutions of each salt were prepared, and corn samples were placed inside airtight desiccators containing the solutions. Two weeks were allowed for the samples to reach the equilibrium moisture level and were then dissected with a scalpel blade.

This method greatly reduced the number of breakages during cutting. The best results were obtained with the KCl solution, which humidified the samples to 0.843 A_w. Almost no breaking or cracking noises were heard during cutting as opposed to the very distinctive 'crackly' sound when the samples were cut without humidifying. The amount of extrudate broken from the walls was reduced by two orders of magnitude when compared to that collected when cutting dry samples. The cut surface was smooth and flat.

Highlighting of edges

Colouring with a felt tipped pen was attempted after several other highlighting methods such as burning the uncut sample, burning the sectioned sample, and pressing the sectioned sample on an ink pad. Immediately after cutting, the edges of the sectioned walls were painted by sliding the felt tip of a pen over them. The resulting appearance was better than that obtained with the other methods mentioned above. Since the painting was done after the sample was moistened, no absorption or dispersion of the ink occurred.

Camera and lighting

The camera was equipped with a zoom lens (Pentax-M Zoom 80 mm - 200 mm) with the use of a Pentax K-C adaptor. Once the image size was set to the best magnification, the camera position and the zoom lens settings were not changed throughout the experiment.

Providing proper lighting to the sectioned and coloured sample was an important consideration. Since brightness levels are transferred to numbers during the quantization of a scene, uniform lighting over the sample was essential for accurate digital representation of the different parts of the object.

It was expected that a circular light would provide uniformly distributed illumination over a sample of the size of an average corn extrudate and minimize shadows. A circular ring-type fluorescent light (General Electric, 20 W, 25 cm dia.) was mounted above the sample in a horizontal plane. A wooden box was used as an enclosure for the bulb and the sample (Figure 1). The enclosure was designed to prevent direct rays of light from reaching the camera which was mounted above the box.

This arrangement provided uniformly distributed light over the sample, while eliminating the shadows of walls appearing inside the voids. The shadow which appeared around the sample was completely eliminated by placing the sample 2.5 cm above the bottom surface of the box.

Software development

Computer programs were necessary for both the image analysis and Instron analysis sections of the research. Image processing programs were developed for image acquisition and other basic operations, and to implement advanced processing routines.

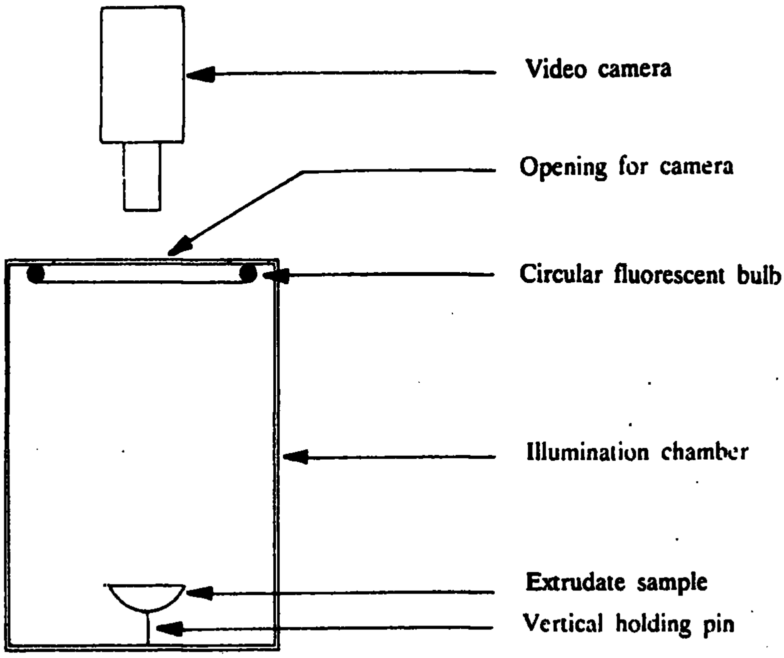

Figure 1. Presentation of the sample to the video camera (not drawn to scale).

Image acquisition and processing operations

Image acquisition was done via the DT 2851 frame grabber board. A program was written in Fortran to display the video camera output on the monitor, to acquire any given scene into the memory provided on the auxiliary frame processor board and to save an acquired image to disk.

Since it was hypothesized that the arrangement of walls and voids contributed to the crispness properties of extruded food, attempts were made to extract wall area and total area of the cross section as a preliminary step. Wall area was obtained by:

1. acquiring an image with a white background,

2. performing global thresholding between the grey levels 0 and 70, and

3. counting the number of white pixels in the thresholded image.

The number of pixels thus obtained directly represented the area covered by sectioned walls. A similar but more complicated process which involved image enhancement operations was developed for estimating the sectioned wall area of the sample.

RESULTS AND DISCUSSION

Derivation of useful parameters

Mathematical routines were developed to derive various parameters from the images. Two basic parameters extracted were the wall area (WALL) and the total area (TOTAL). In developing application-oriented image processing routines to investigate the variation of a certain parameter, it is necessary to identify a property which exhibits that variation and can be easily detected and estimated using image processing techniques. Total area and wall area were two such parameters in this study that showed a clear variation based on the sample groups (Figure 2, Figure 3). Since the image analysis scheme was very sensitive to those two features, promising results could be obtained by using the area measurements to classify the samples into respective groups.

Other parameters based on the Fourier transform (Gonzalez and Wintz, 1987) and spatial dependence matrix (Haralick *et al.*, 1973) were also derived to be used in subsequent analyses performed to study the capability of the image data to classify the samples into corresponding groups.

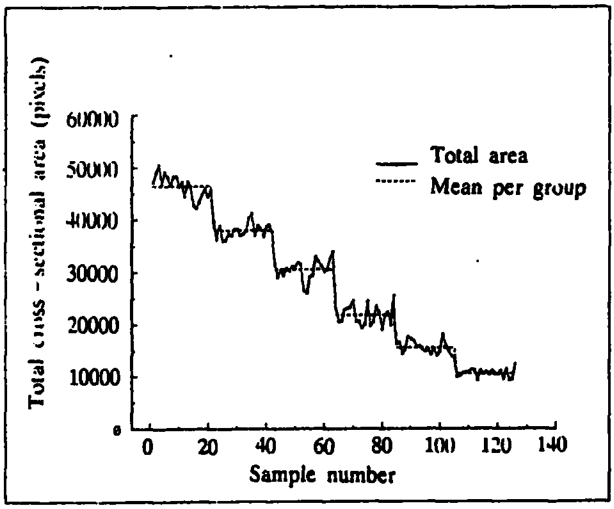

Figure 2. Variation of the parameter TOTAL, the total cross-sectional area of sample.

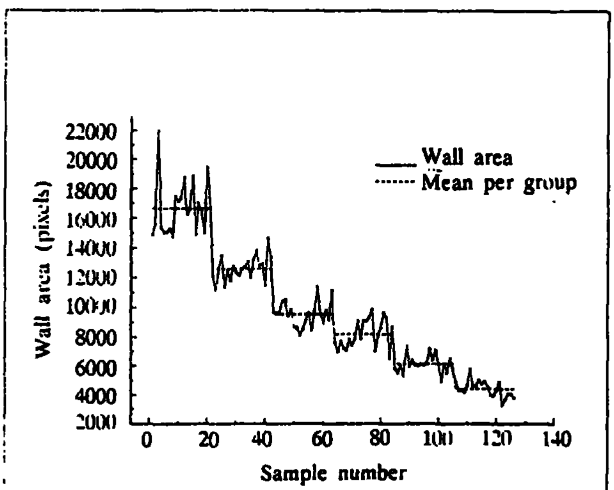

Figure 3. Variation of the parameter WALL, wall area of the sectioned sample.

Classification analysis

As an initial step for understanding the behaviour of vision-based features, an analysis of variance was performed to identify the parameters which exhibited significant differences among the six groups. The parameters WALL, TOTAL, F2, F3, F4, F5, F6, WHTMEAN, and WHTVAR could be identified as the vision-based features that showed significant ($p<0.01$) differences. These variables indicated varying levels of separation among the six groups when tested individually using the Duncan's multiple range test (SAS Institute, 1985). Classification effects given by all the above parameters are included in Table 2.

Table 2. Classification performance of the parameters (letter indicate the grouping based on Duncan's multiple rage test ($p<0.05$).

Parameter	Mean value per group					
Name	1	2	3	4	5	6
F1	0.43 a	0.46 b	0.46 ab	0.46 ab	0.46ab	0.44 ab
F2	0.12 a	1.03 a	1.46 ab	3.02 bc	5.22d	3.22c
F3	3.41 ab	3.01 c	3.09 bc	3.31 abc	3.44 a	3.63 a
F4	0.941 a	0.945 b	0.945 b	0.948 c	0.952 d	0.951 cd
F5	4.4 ac	4.08 b	4.15 bc	4.34 abc	4.44 a	4.61 a
F6	6.99 ab	6.32 c	6.45 bc	6.91 ab	7.09 a	7.51 a
F7	0.723 a	0.716 a	0.717 a	0.716 a	0.723 a	0.720 a
F8	-1.01 a	-0.97 b	-0.97 b	-0.97 b	-0.97 b	-0.98 ab
BLKMEAN	9.42 a	10.79 b	10.75 b	10.82 b	11.58 b	10.87 b
BLKVAR	61.15 a	82.78 ab	86.88 abc	103.39 bc	124.84 c	101.59 bc
WHTMEAN	5.47 ab	5.24 a	5.31 a	6.16 bc	6.72 cd	7.27 d
DENSITY	0.303	0.304	0.320	0.344	0.280	0.402
FPEAK	271.4 ac	274.3 ac	265.0 c	317.2 a	395.5 b	313.5 ac
FVOL	6676.1 a	666.9 ab	695.5 ab	646.1 bc	620.2 d	631.5 cd
MOMENT	1842.7 a	1837.8 a	1835.5 ab	1821.3 bc	1795.8 d	1810.5 cd
WALL	16643 a	12625 b	9536 c	8192 d	6134 c	4425 f
TOTAL	46364 a	37983 b	30460 c	21751 d	15543 e	10554 f

SUMMARY AND CONCLUSIONS

Data were collected on six batches of extruded cornmeal produced with different process parameter combinations. Numerous vision-based parameters were computed to investigate the classification performance (Table 2). These parameters were later used to predict the sensory crispness of each sample group.

A technique for dissecting extruded corn puffs with minimal structural damage was developed. Humidifying of samples by placement in a desiccator with a saturated Potassium Chloride (KCl) solution increased the moisture level enough to prevent wall breakage when cutting the sample with a scalpel blade.

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