Microwave cold-spot detection

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This article describes how computer vision is effectively used for image processing in the food industry. We shall see in detail how cold spots are identified through computer vision in packaged foods during the microwave sterilisation process.

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1. Introduction

Today's consumers are on the lookout for high-quality readymade foods. With their purchasing capacities growing at a fast pace, food production houses are pressed with the fact for improving quality of food. Microwave sterilization is a thermal method that delivers high quality and shelf-stable foods. To ensure the adequate sterility of these high-quality foods, it is necessary to determine the cold and hot spots during microwave sterilization.

The cold spot is an area that receives the lowest thermal energy and the hot spot is the area of highest thermal energy reception. For quality monitoring purposes, the entire food has to be heated thoroughly meaning that there should be a uniform distribution of hot spots in the food. Else it signals contamination in the food and the shelf-storage capacity of the foods is diminished. Thus to meet the stringent requirement of food regulation bodies, there is a need to develop reliable and rapid methods to determine the heating pattern, especially the location of cold spots. Determination of the cold spots is still a challenge to researchers to ensure that the processed foods are safe for consumption.[1], [2], [5].

There are various methods that are used for cold-spot detection, the most promising of them being the usage of Computer Vision analysis as opposed to High Performance Liquid Chromatography (HPLC). These methods are discussed in the proceeding section.

2. Why Computer vision is used for image processing in the Food industry?

The earlier experiments on cold spot identification in microwave food sterilization processes dealt with point temperature measurement methods. In the point temperature measurement methods a point is defined where temperature is measured and this could influence the results of the experiment. Reports obtained can be used to study temperatures in the general region, here the regions being packaged food. The direct measurement of time-temperature log for all points in food packages is not possible in the microwave sterilization as it is a tedious and error-prone process. All this emphasized the need for a reliable method of measuring temperature at the required point, and a definition of that point. Researchers then turned to High Performance Liquid Chromatography (HPLC).[1]

HPLC is used to separate components of a mixture by using a variety of chemical interactions between the substance being analyzed (**analyte** -here it is the amino acids and poly-sugars present in the food) and the chromatography column. The column usually has Chemical Markers present that are an indirect means to evaluate relative heating absorptions in the packaged foods. Commonly used food markers are M-1 and M-2 [3]. These markers react to the analyte (food substance) based on the region's heating. **Thus by analyzing the separate components of the food for the different levels of formations of the Chemical marker, we get to know the relative heating in those areas**. This was a laboratory-intensive and time-consuming process with multiple repeat tests required. Thus the need arose to have an efficient and reliable method to capture the color intensities of the chemical markers depicting 3D heating patterns. 'Automated visual inspection' or 'Visual inspection facilitated by machines' commonly known as **Computer Vision** proved the best possible alternative.

3. Computer Vision

Computer vision is a technology for acquiring and analyzing a digital image to obtain information or control processes by the construction of an explicit and meaningful description of physical objects from images. It replaces human inspectors for the evaluation of a variety of quality attributes of raw and prepared foods. Computer vision applications range from routine inspection to complex vision-guided robotic controls. Computer vision technology provides a high level of flexibility and repeatability at relatively low cost. It also permits fairly high plant throughput without compromising accuracy. Currently, computer vision systems are being developed as an integral part of food processing plants for on-line, real-time quality evaluation and quality control. [2], [5].

4. An experimental setup

Here we refer to the experiment conducted by Pandit et al [1], [2] at the Department of Biological Systems Engineering, Washington State University for the US FDA acceptance of a dependable and reliable microwave sterilization system. Their experiments demonstrated how computer vision could be used effectively to analyze the cold spots in the sterilization process.

4.1 Sample Preparation

Samples used here consisted of either mashed potatoes or strawberries. The samples were placed in air-tight aluminium containers and heated to high temperatures. A thermocouple was fitted to the lid of this container to measure the temperature levels. [1].

4.2 Computer Vision system - hardware

The computer vision system consisted of a light pod, a helical compact fluorescent bulb, a digital camera with right-angle viewing attachment, automatic image acquisition software and a computer vision software installed on a computer. Refer Fig. 1.

Helical lights were mounted outside the light pod to maintain an even illumination inside the box. The diffusion light pod was used to prevent the incident monochromatic light source to the object. High quality images were captured by the digital camera. [1]

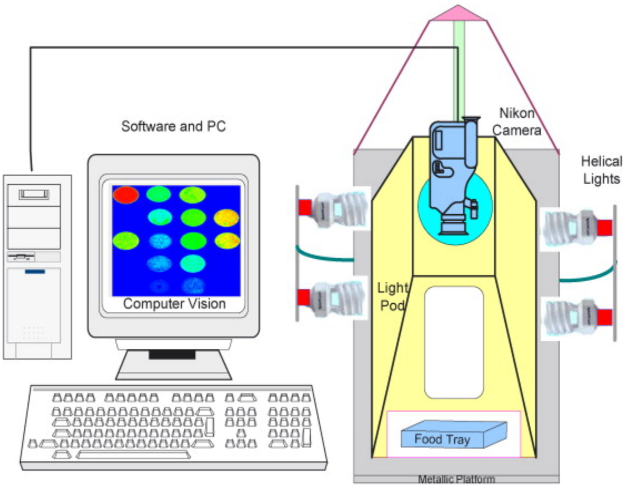


Figure 1. Computer Vision Hardware setup [1]

4.3 Computer Vision system – software

Once the digital images of the packaged foods under various heating tests are made available, they need to be processed through a sequence of steps to be able to reliably detect the cold spots in the foods. Below is the flowchart depicting this image processing sequence (Fig 2) followed by an explanation for each module.

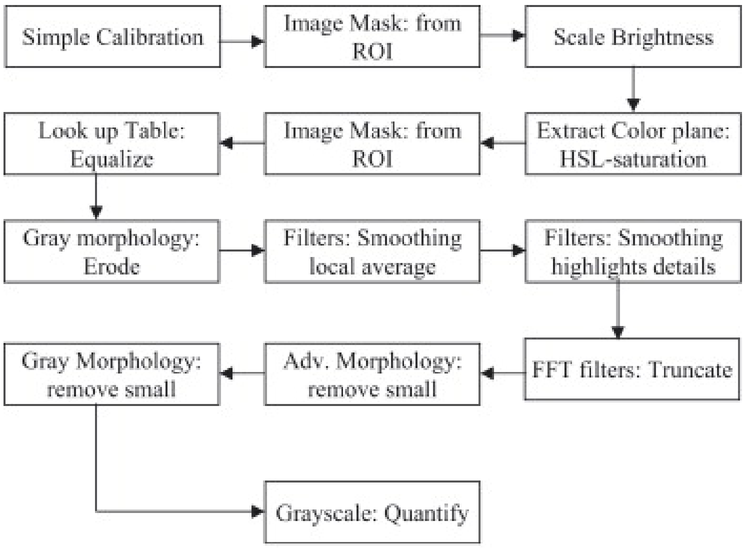


Figure 2. Image processing sequence in Computer Vision [1]

4.3.1 System Calibration

Calibration is the process where the output of a measuring device (here it refers to the pixel coordinates from the digital image taken by the camera) is mapped against a measuring standard (these are the real-world coordinates). This is done to adjust the outputs to a standard thus maintaining levels of accuracy. System calibration was done by scaling in the x and y directions in the coordinate system for the real-world units given by the origin, angle and axis direction. This increased the accuracy and visibility of the trays by reducing the noise (disturbances or aberrations) in the image. [2],[4].

4.3.2 Image Mask: from ROI

The Region of Interest (ROI) is an area of the image we want to focus our image analysis and this is graphically selected from a window displaying the image. ROI can be chosen interactively, programmatically or using an image mask. An image mask is a technique that applies onto the image the value 255 in the area of interest and zero elsewhere. [1], [4].

4.3.3 Scale Brightness

Brightness of the color scale was fixed using the Look up table values. The brightness was adjusted to get better quality color images for color extraction in the next step.

4.3.4 Extract Color planes: HSL Saturation

In this step, the color image is broken down into various sets of primary components like Hue, Saturation and Luminance (HSL). Each component becomes an 8-bt image that can be converted to a gray-scale image. The lightest pixel in the image is assigned the lowest gray-level value and darkest pixel, the highest gray-scale value. HSL is the chosen method in machine vision applications because of the close relationship between chromaticity and human perception of color. [1], [5]

4.3.5 Look up Table: Equalize

Look up tables(LuT) are part of image processing operations where the image details are highlighted in an area containing significant information at the expense of other areas. A LUT transformation converts the input gray-scale values in the source image into other gray-scale values in the transformed image. For example as mentioned in [1], an image (I) in rectangular matrix is:

$$I = f[s_{in}(x,y)]$$

where x is row index and y is column index. The original gray-scale values $s_{in}(x,y)$ can be assigned any value out of the gray-scale set g={0,1,...,255} for an 8-bit image. Resulting set of output values $s_{out}(x,y)$ using LuT would be

$$s_{out}(x,y) = f[s_{in}(x,y)]$$

For each value of g, function f(g) will have 256 possible values in a look-up table, therefore

$$LuT(g) = f(g).$$

Thus the computed output of the LuT function becomes:

$$s_{out}(x,y) = LuT[s_{in}(x,y)]$$

Thus we see that the grayscale values are evenly distributed within a given grayscale range. This is done to increase the contrast in the image. [4].

4.3.6 Gray morphology: erosion and dilation

These are fundamental functions for most morphological transformations which help in removing or enhancing isolated features. Basically a pixel is compared to those surrounding it. The transformation keeps the smallest pixel values during erosion and maintains the largest pixel value during dilation. Thus dilation increases the brightness of pixels surrounded by proximate pixels with a higher intensity, while erosion reduces brightness of each pixel that is surrounded by proximate pixels with a lower intensity.

In erosion, the value of output pixels is set to the minimum of coefficients $s_{in}(x,y)$ as

$$s_{out}(x,y) = min[s_{in}(x,y)]$$

and in dilations, output pixels have values set to the maximum value of coefficients $s_{in}(x,y)$ as

$$s_{out}(x,y) = max[s_{in}(x,y)]$$

This is done to delineate between objects to facilitate quantitative inspections. [1],[6].

4.3.7 Filters: smoothing local average

Since the pixels are now of varying brightness intensities after having performed the morphological transformations, averaging of these intensities of pixels is performed. This would normalize the intensities across the image thereby increasing the contrast. [1], [2], [5]

4.3.8 Filters: smoothing highlight details

After averaging over pixel intensities in the image, the next step involves smoothing highlighted details like boundaries or edges that would help in clearly demarcating the objects within the image. Filtering improves the quality of the image by calculating the new pixel value of highlighted areas using the original pixel value and those of its proximities. This method of image filtering is called **'Convolution'** wherein filtering of the image occurs using a weighted sum of the neighbouring pixels. [1], [5]

4.3.9 FFT filters: truncate low pass

Fast Fourier Transform (FFT) is used to convert an image into its frequency domain. An image can have extraneous noise, such as periodic stripes, introduced during the digitization process. In the frequency domain, the periodic pattern is reduced to a limited set of high spatial frequencies.

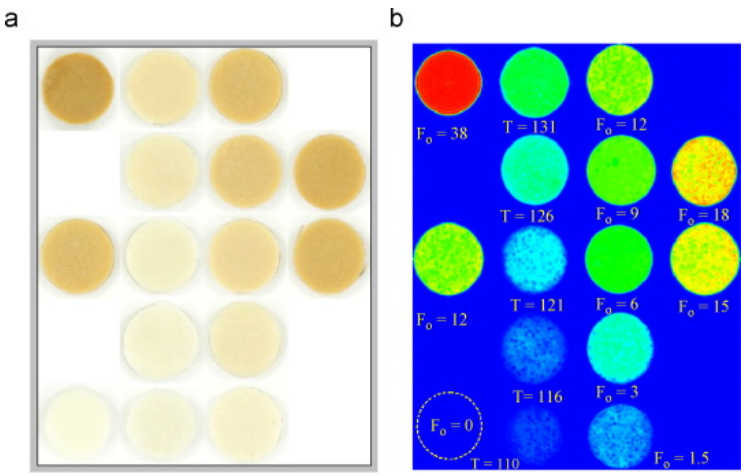
A low pass frequency filter attenuates or removes high frequencies present in the FFT (Fast Fourier's Transforms) plane. This filter suppresses information related to rapid variation of light intensities in the spatial image. For example, the frequency components above the ideal cut-off are removed whereas the frequency components below it remain unaltered. This generally helps in smoothing the sharp edges. [1], [5]

4.3.10 Advance morphology: remove small objects

These morphological transformations extract and alter the structure of objects in an image. We can use these transformations to prepare objects for quantitative analysis, observe the geometry of regions, and extract the simplest forms for modeling and identification purposes. The advanced morphology functions are conditional combinations of fundamental transformations such as the binary erosion and dilation. This function eliminates tiny holes isolated in objects and expands the contour of the objects based on the structuring element. [1], [6]

4.3.11 Quantify

Now the images are given a pictorial color base to depict three-dimensional heating pattern. In this study, red color of the spectrum represented the hot area having higher microwave thermal treatment and is shown as ridge regions while deep blue color represented the cold area having less thermal treatment and was shown as depressed regions. During the quantification step, the color intensities are assigned numerical values. The color palette used in this experiment [1] assigned the number 0 to deep blue and 255 to dark red. Thus the spectrum from deep blue to dark red was used to compare varying degrees of color intensities. [2]



a) Original Sample **b) Computer Vision patterns**

Figure. 3. Computer vision patterns for mashed potato samples heated to a set temperature of 121°C for different F0 (thermal lethality of target microorganisms) [1]

4.4 Detection of the heating patterns using Computer Vision

We have seen the various steps involved in computer image processing to detect hot and cold regions depending on color intensities arising out of heating patterns. The heating patterns are traceable due to the reactions of the chemical markers to different levels of heating.

Heating patterns in each tray are divided into a number of rectangular grids and the color values in each grid are analyzed. Thus the grid with the lowest color value (corresponding to blue regions showing cold spots) was selected amongst all grids to be the cold spot region of the microwave sterilization process. Refer Fig 3 for the computer vision-generated heating patterns. [1]

5. Result Validation

To validate the accuracy of the hot and cold spots determined by the computer vision system, multiple tests were repeated for same and different temperatures. The measured temperature confirmed that the temperature measured at the perceived hot spot was indeed always higher than the cold spot for all tests, as shown in Fig 4.

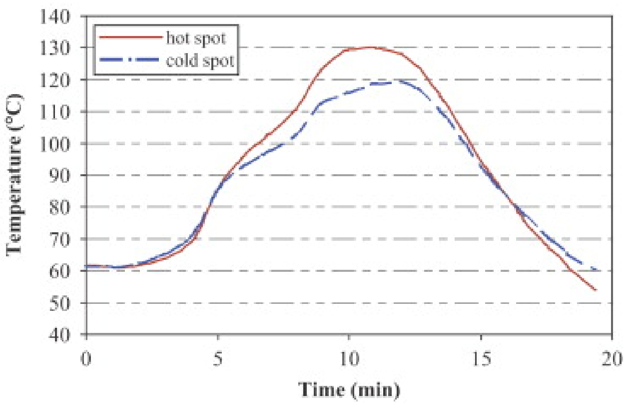
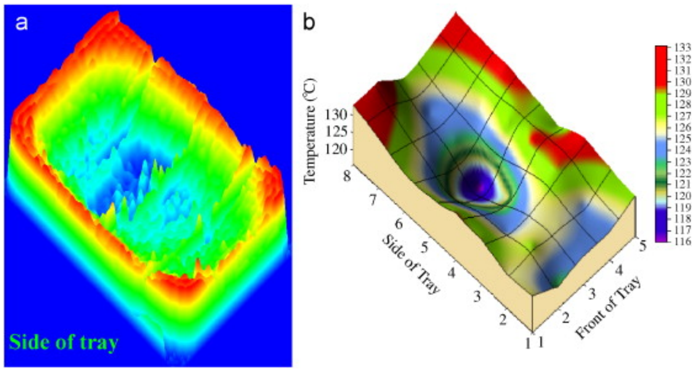


Figure 4. Validation of cold and hot spots locations specified by computer vision method [1]

To confirm that the computer has identified the heating areas correctly, similar tests were carried out but now with optic sensors instead of computer vision. In each of the tests, four pre-calibrated optic sensors were placed in a sample tray during the microwave sterilization process. One of the sensors was always inserted at the cold spot identified by the computer vision method while the others were placed in three different locations. Compiling all the measured temperatures from these tests, a temperature profile is created for different points evenly distributed in the middle layer of a tray. Computer vision patterns and temperature mapping, of middle layers, obtained using fiber optics are compared in Fig. 5. It shows that heating pattern and cold spot location obtained by both the methods were concordant. This indicates that the novel computer vision method reliably revealed the cold spots in foods and thus could be used to study general heating patterns in foods after microwave sterilization processes. [1], [2]



(a) Heating pattern by developed computer vision method.
(b) Temperature distribution measured by fiber optic probes.
Figure 5. Matching of the experimental and developed method heating patterns for the middle layer of a tray with mashed potato [1]

6. Conclusion

Based on the experimental results obtained, it can be seen that the system provided by computer vision proves reliable to identify hot and cold spots in a food sample. The locations of the hot and cold spots given by the computer vision validated well with the temperature measurements using fiber-optic probes. Thus this confirms that the computer vision system along with the Chemical markers could accurately identify cold spot regions in microwave processed foods. Due to the cost effectiveness, fast speed and accuracy this method proves best for the evaluation of cold spots in the microwave sterilization process.

7. References

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