Algorithms Development in Detection of the Gelatinization Process during Enzymatic 'Dodol' Processing

Azman Hamzah, Mohd Marzuki Mustafa & Aini Hussain

Department of Electrical, Electronic and Systems Engineering
Faculty of Engineering, Universiti Kebangsaan Malaysia
43600 UKM Bangi, Selangor Darul Ehsan, Malaysia

Abstract. Computer vision systems have found wide application in foods processing industry to perform quality evaluation. The systems enable to replace human inspectors for the evaluation of a variety of quality attributes. This paper describes the implementation of the Fast Fourier Transform and Kalman filtering algorithms to detect the glutinous rice flour slurry (GRFS) gelatinization in an enzymatic 'dodol' processing. The onset of the GRFS gelatinization is critical in determining the quality of an enzymatic 'dodol'. Combinations of these two algorithms were able to detect the gelatinization of the GRFS. The result shows that the gelatinization of the GRFS was at the time range of 11.75 minutes to 14.75 minutes for 24 batches of processing. This paper will highlight the capability of computer vision using our proposed algorithms in monitoring and controlling of an enzymatic 'dodol' processing via image processing technology.

1 Introduction

Food quality is one of the main drivers or success determinant of the food processing industry [1]. In general, the term of food quality always refers to the food overall quality, which was predefined before processing. A food characteristic is acceptable to consumers such as its external texture, flavor and appearance in terms of size, shape, color, glossiness and consistency. Manufactured food is also susceptible to contamination that may occur during manufacturing process and ensuring quality means minimizing manual handling and labor intensive processing. In the food industry, some quality evaluation is still performed manually by trained inspectors, which is tedious, laborious, costly and inherently unreliable due to its subjective nature [2].

'Dodol' is a taffy-like food delicacy popular in Sri Lanka, Malaysia, Singapore, Indonesia, Philippines especially in the Ilocos Region in Luzon and in the Lanao provinces of Mindanao and in India especially in the Region of Goa [3].

There are different versions of dodol available in Asian food stores. In the production of the 'dodol', texture is a very important food quality factor that

needs considerations. Unfortunately, the shelf life of the 'dodol' produced in normal practice and with a traditional formulation can only last for up to 2 weeks due to mould growth and hardening of the texture. Therefore, by adjusting the formulation and cooking time and method, a well-textured 'dodol' could be produced. The traditional processing technique needs to be improved by adding an enzyme, which has a direct influence on the rheological characteristics of 'dodol' [4]. A new formulation and processing technique of 'dodol' that is by adding the *multogenic amylase enzymatic* will able to improve the 'dodol' texture**.** This new technology in 'dodol' production will prolong the 'dodol' shelf life and helps maintaining its texture and elasticity for up to 6 months if stored at a room temperature. The critical stage of processing this type of 'dodol' is the gelatinization of the GRFS, since correct gelatinization onset shall determine the quality of the enzymatic 'dodol' produced. Therefore, it is very important to determine the optimal stop time of the GRFS heating process. If the heating process stops prematurely or too late, the product will not comply with the enzymatic 'dodol' specification resulting in a too soft or too hard a texture. In normal practice, a trained food operator will control the gelatinization process manually. It is done by visual inspection and decision is made based on their experience.

Visual inspection is an interaction process involving the products, eyes and brain, which can now be implemented for food quality control using digital cameras, image analysis techniques and classification algorithms implemented as computer software [1]. Computer vision can be used as an objective, consistent, quantitative, non-contact and non-destructive methods for evaluating and classifying foods quality during processing [5,6]. Image processing and analysis are recognized as being the core of computer vision [5,7]. Image processing involves a series of image operations that enhance the quality of a tedious human inspection tasks. Computer vision has proven successful for the objective, online measurement of several food products with applications ranging from routine inspection to the complex vision guided robotic control [8,9]. The objective of this research work is to apply computer vision technology into food quality monitoring and controlling. This involves specifically computer vision that will be used to detect the GRFS gelatinization process in real time.

The rest of this paper is outlined as follows. Firstly, we present the introduction followed by the methodology used and specifically highlight the algorithms involving the Two Dimensional Fast Fourier Transform (2D-FFT) and Kalman filtering (KF) techniques. These two algorithms when combined were able to detect the gelatinization of the GRFS based on the monitored image sequences. The results obtained will be presented, thoroughly discussed and conclusion will be drawn.

2   Materials and Methods

2.1   Experimental Set-Up

The automated modules of the machine vision for the detection of the GRFS gelatinization are image acquisition, computer hardware and software, electronic interfacing and the 'dodol' cooker. The arrangements of the equipments used are schematically shown in Figure 1. In this research work we use normal lighting from the laboratory as a source of the illumination to the machine vision system. This is to let the machine vision system working as a normal illumination condition, i.e., as an actual food processing condition. The capacity of the 'dodol' cooker used in this experiment is 500 grams of the glutinous rice flour.
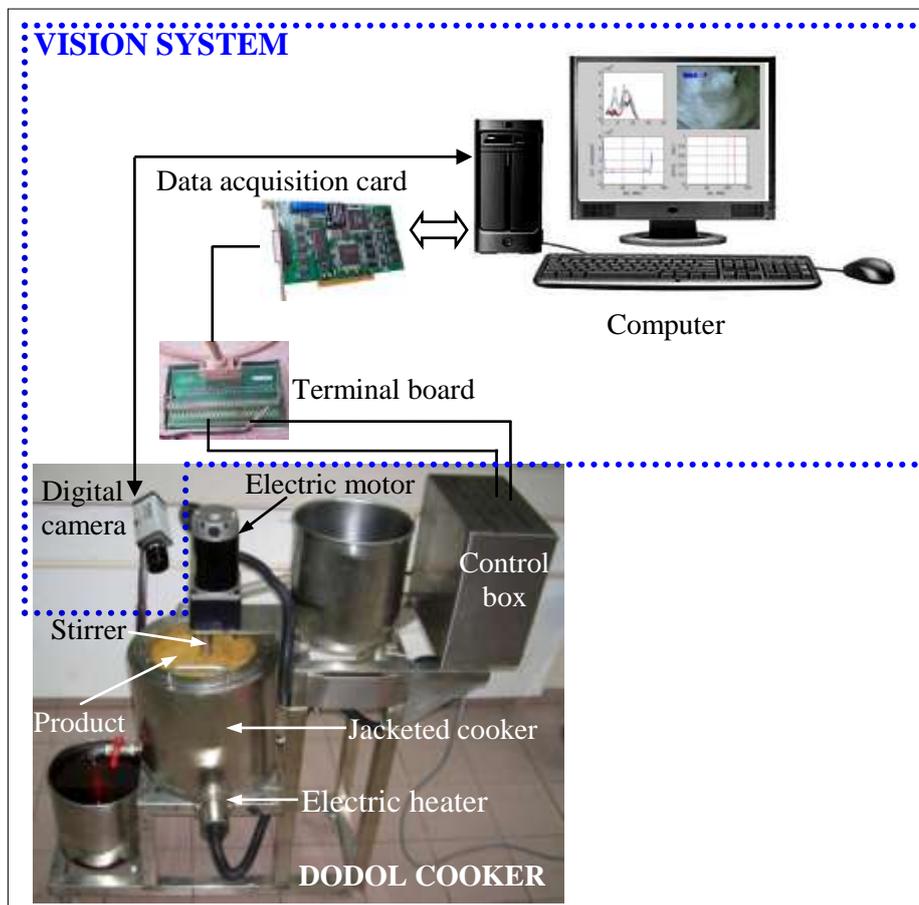

Figure 1   The experimental set-up.

2.2   Glutinous Rice Flour Slurry Gelatinization

The ingredients to develop the gelatinized GRFS are 500g of glutinous rice flour and 1500ml of plain water. The glutinous rice flour is first diluted completely into the plain water and then poured into the cooking pot. The cooker is then set to 'on' for the heating process at the temperature of 100°C and stirring the GRFS at a speed of 23 rpm. Figure 2 shows the flowchart of the enzymatic 'dodol' processing and for the purpose of this paper, we will focus only on the development of the gelatinized GRFS.
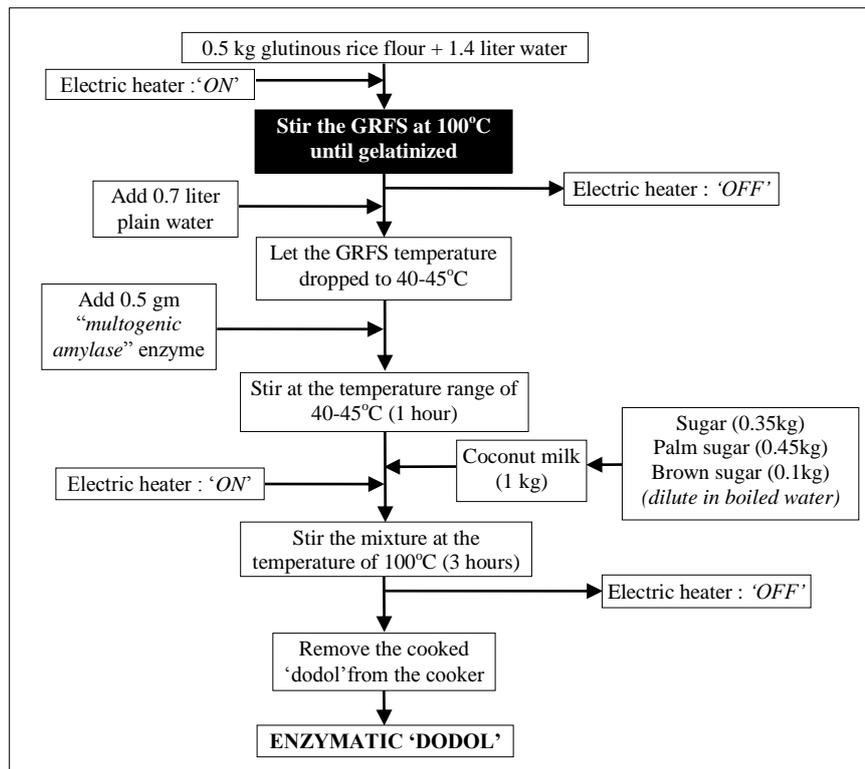

Figure 2 Enzymatic 'dodol' processing flowchart.

2.3   Image Acquisition

A Logitech digital camera is used to acquire the GRFS gelatinization images. The images from this camera have a resolution of 320 x 240 pixels. During the gelatinization process, a camera that is mounted above the cooker pot will

capture the gelatinization process image continuously. The captured images are sent to the computer and are then processed by the computer software in every 5 seconds for the image preprocessing, processing, feature extraction and making the decision for the gelatinization processing system.

2.4   Interfacing Computer Hardware and the Cooker

The computer software was developed using MATLAB ver. 6.5 and the Graphical User Interface (GUI) program as shown in Figure 3 processed the images from the camera. To enable the vision system and the cooker works at a real time, the computer hardware was interfaced with the cooker using the data acquisition card, i.e., ADLINK series PCI-9118DG. The card was connected to the cooker via terminal board to supply the electrical signal with the strength of 5V to the solid-state-relay (SSR) in the cooker control box. If the GRFS is still not gelatinized and the data acquisition card has not received any information from the software, it will not give any electrical signal to the SSR. This condition will let the cooker continue the gelatinization process. Hence, when the GRFS gelatinized and the software detects this phenomenon, the data acquisition card will give the electrical signal to the SSR to switch *'off'* the electrical heater. After the electric heater is switched *'off'*, the cooker stirrer continues stirring the gelatinized GRFS until the temperature dropped to the range of 40-45°C. When the gelatinized GRFS reached this temperature, 0.5 gm of the *multogenic amylase enzymatic* will be added and the stirring process will be done for the next 1 hour.
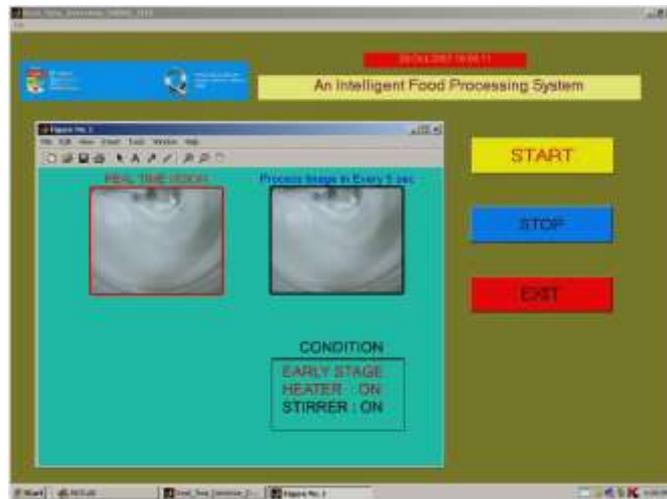

Figure 3   GUI of image processing algorithm.

2.5 Image Database Development

Before the machine vision system can be implemented as a real time system, the the database of GRFS gelatinization process images has to be developed. All the images will be used for algorithms development, training and testing. The Ulead Video Studio Version 10.0 software was used for image acquisition. The captured image is saved in the computer hard disk (PC: Intel Pentium 4 processor, 2.53 GHz) in an Audio Video Interleave (AVI) format. The frame rate for the video was 30 frames/seconds and the gelatinization process was sampled in every 5 seconds. The stored images are then saved as individual images in Joint Photographic Experts Group (JPEG) format with resolution of 320 x 240 pixels. Upon completion, the individually stored images are subjected to further image processing procedures.

In this work, twenty-four batches of the gelatinization of the GRFS were conducted and shown in Table 1 below. Based on the results, we observed the overall processing time and the gelatinization of the GRFS occurred at a different time for a different batches. Therefore, it is impossible to control it using the time setting. A better alternative is to automate the process of detecting GRFS gelatinization using a computer vision application.

Table 1 Image numbers and overall processing time.

Batch	Image Numbers	Overall processing time	Batch	Image numbers	Overall processing time
A	201	16 min. 45 sec.	M	198	16 min. 30 sec.
B	149	12 min. 25 sec.	N	206	17 min. 10 sec.
C	203	16 min. 55 sec.	O	165	13 min. 45 sec.
D	192	16 min. 0 sec.	P	196	16 min. 20 sec.
E	156	13 min. 0 sec.	Q	173	14 min. 25 sec.
F	187	15 min. 35 sec.	R	196	16 min. 20 sec.
G	185	15 min. 25 sec.	S	206	17 min. 10 sec.
H	182	15 min. 10 sec.	T	158	13 min. 10 sec.
I	218	18 min. 10 sec.	U	161	13 min. 25 sec.
J	164	13 min. 40 sec.	V	194	16 min. 10 sec.
K	206	17 min. 10 sec.	W	172	14 min. 20 sec.
L	157	13 min. 5 sec.	X	239	19 min. 55 sec.

2.6 Image Pre-Processing

The purpose of image pre-processing is to improve or to enhance the digital images. It is important for correction of geometric distortions, removal of noise, grey level correction and correction for blurring [10]. In this study, the images were captured using a Logitech digital camera and therefore are subjected to

various types of noise such as the light intensity. In general, noise can degrade the image quality and subsequently provide incorrect information for further image processing. Therefore, to improve the image quality, pre-processing operations are needed to remove or reduce degradations in the captured images.

The original color image as shown in Figure 4(a) is first converted from RGB (red, green, blue) image to grey-level image as in Figure 4(b) using the MATLAB image processing tool box command, i.e., *G=rgb2gray(II)*. In order to remove the image noise and reduce detail levels and to enhance the image structures the Gaussian low-pass filter (GLPF) smoothing operator for two dimensions as in Eq. 1 was applied.

$$G1(u,v) = \frac{e^{\frac{-(u^2+v^2)}{2\sigma^2}}}{\sum_{u=0}^{R-1}\sum_{v=0}^{C-1} e^{\frac{-(u^2+v^2)}{2\sigma^2}}} \tag{1}$$

After image smoothing, the resulted image looks like the image shown in Figure 4(c). Next, the image will then increase its brightness for the purpose of next image processing and analysis, Figure 4(d). The brightness operation of the GLPF image was done using the Eq. 2.

$$G2(u,v) = \frac{G1*a(R*C)}{\sum_{u=0}^{R-1}\sum_{v=0}^{C-1} G1_{u,v}} \tag{2}$$

(a) RGB   (b) Grey-level   (c) GLPF   (d) Brighten
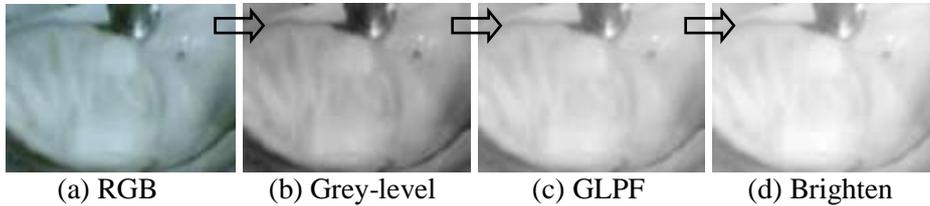
Figure 4 Image conversion.

2.7   Region of Interest (ROI)

A region of interest, often-abbreviated ROI, is a selected subset of samples within a dataset identified for a particular purpose. It is sometimes of interest to process a single sub region of an image, leaving other regions unchanged. This is commonly referred to as area of interest (AOI) processing. In this work, ten regions of interest with the size 50 x 50 pixels were chosen as shown in Figure 5. For the purpose of classification, the following selected regions of the image were processed and analyzed.
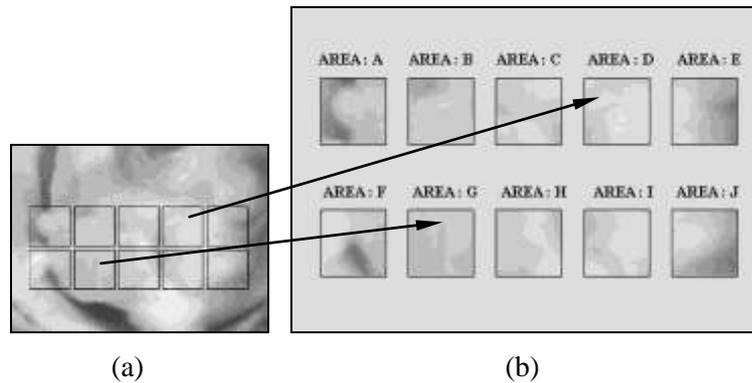
(a)   (b)

Figure 5 Image with ten AOI to be considered.

2.8   Feature Extraction

All images were processed using the Image Processing Toolbox v3.2 of MATLAB v6.5 (R13) for Windows XP, developed by Math Works, Inc. (Math Works 1998a, 1999). In MATLAB, the RGB color format is used to read the JPEG images. After setting the specific ROI on the images, each image will be ready for further processing and analysis.

Changes from *thin* to *thicker* glutinous rice slurry due to the gelatinization of the GRFS image can be best described or visualized in term of its image texture namely from the *smooth* to *rough* texture. However, there are no significant differences that can be observed in term of the pixel values at the specific location before and after the gelatinization. Examples of the pixel value changes at the same position in the image are shown in Figure 6. It is difficult to detect and determine the exact time of the gelatinized GRFS if we only rely on the changes of the image of every pixel value.
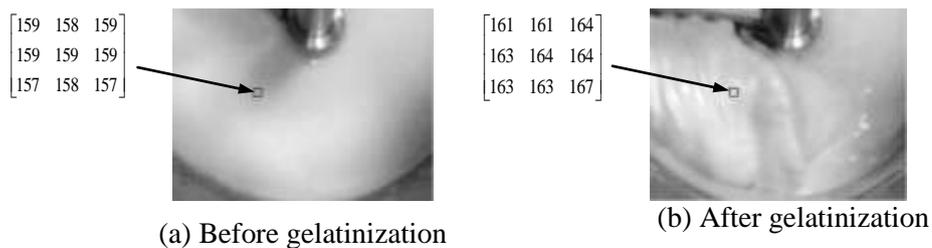

(a) Before gelatinization   (b) After gelatinization

Figure 6 Pixel value changing before and after gelatinization.

Therefore, the 2D-FFT algorithm was applied to all images to enable the system to detect the onset of the gelatinized GRFS. The two dimensional Discrete

Fourier Transform (2D-DFT) of Row by Column image with function *f(x,y)*, is defined by the Eq. 3.

$$F(u,v) = \frac{1}{RC}\sum_{x=0}^{R-1}\sum_{y=0}^{C-1}F(x,y)e^{-j2\pi(\frac{ux}{R}+\frac{vy}{C})} \tag{3}$$

Before computing the 2D-FFT of every region of the image, it is necessary to apply the Fast Fourier Transform (FFT) shift. This is to shift the zero-frequency component of discrete Fourier transform to the centre of the spectrum. Consequently, the spectrums for the region of interest namely area A to area J as in Figure 5 are obtained and shown in Figure 7. Each image has 10 Fourier spectrums.
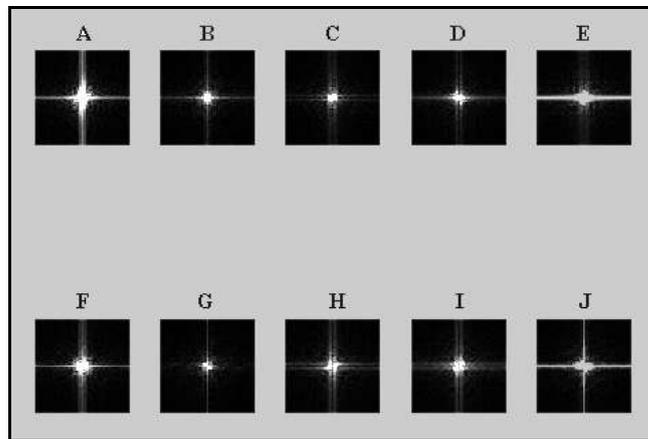
Figure 7 Fourier spectrum for the related ROI as image in Figure 5(b).

For each image, only the maximum value of the Fourier spectrum summation value was considered. The maximum value was considered because its spectrum value makes a large change in term of energy in that particular Fourier spectrum, i.e., the image texture for the respective ROI become *rougher*. This means that the GRFS has begun to gelatinized. However, the plot of the maximum value of the Fourier spectrum verses image numbers are not consistent for the different batches. Figure 8 shows the plot for batches A, D, J and K. Therefore further analysis were done i.e., KF algorithm is applied to maximum value plot for the purpose of enhancing the result.
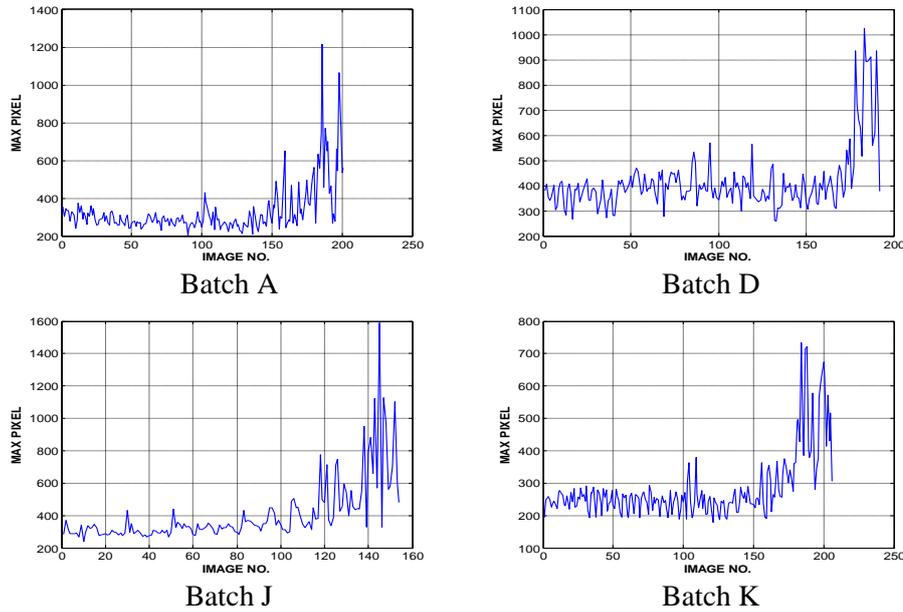
Figure 8 Plot of the Fourier spectrum maximum value for the batches A, D, J and K.

2.9 Gradient Estimation Using Kalman Filter

In 1960, R.E. Kalman published his famous paper describing a recursive solution to the discrete data linear filtering problem measurement [11]. Kalman filter is used in various fields of applications for optimal state estimation, prediction, noise filtering and stochastic optimal control. Kalman filter can be easily programmed on a digital computer. A brief introduction to Kalman filter is given here.

Assume that the evolution of the underlying signals to be observed can be modeled as:

$$x(k+1) = Ax(k) + w(k) \qquad (4)$$

The signal $y(k)$, measured by sensor is assumed to be a linear combination of the state vectors and corrupted by sensor noise. This is represented by the following output equation:

$$y(k) = Mx(k) + r(k) \qquad (5)$$

The discrete Kalman filter equations to estimate the state $x(k)$ are given by the following equation [12]. The symbols (-) and (+) used below represent the prior updated value based on the use of the current measurement.

State estimate extrapolation:

$$\hat{x}_{k(-)} = A\hat{x}_{k-1(+)} \tag{6}$$

Error covariance extrapolation:

$$P_{k(-)} = AP_{k-1(+)}A^T + Q_w \tag{7}$$

Kalman gain matrix:

$$K_k = \frac{P_{k(-)}M^T}{(MP_{k(-)}M^T + Q_r)} \tag{8}$$

State estimate update:

$$\hat{x}_{k(+)} = \hat{x}_{k(-)} + K_k(y_k - M\hat{x}_{k(-)}) \tag{9}$$

Error covariance update:

$$P_{k(+)} = (1 - K_k M)P_{k(-)} \tag{10}$$

Kalman filter can be formulated to estimate derivative of the signal indirectly without the need to directly differentiate the signal [13]. Now let d_k denotes the gradient of the 'maximum value plot (MVP)' of the FFT spectrum for every images at the k_{th} step. The MVP is therefore related to d_k by the following equation:

$$mvp_{k+1} = mvp_{k+1} + T_s d_k \tag{11}$$

Let y_k denotes the calculated value of the MVP and this value will be corrupted by measurement noise denoted by r_k.

$$y_k = mvp_k + r_k \tag{12}$$

We now assume that the gradient of the MVP varies according the following model:

$$d_{k+1} = \alpha d_k + w_k \tag{13}$$

Defining the state vector $x_k = [d_k \quad mvp_k]^T$, and using equation (11) and (13), we form the state transition equation.

$$x_{k+1} = Ax_k + \zeta_k \qquad\qquad (14)$$

where $\quad A = \begin{bmatrix} \alpha & 0 \\ T_s & 1 \end{bmatrix}$ and $\zeta_k = \begin{bmatrix} w_k \\ 0 \end{bmatrix}$

From equation (12), the observation equation is

$$y_k = Mx_k + r_k$$

With these values of matrices A and M, the Kalman filter can be implemented as given in algorithm as equation (6) to equation (10). The performance of the filter will depend on the selection of α , and $\gamma = \dfrac{\sigma^2{}_w}{\sigma^2{}_r}$. These two parameters will be the design parameters to achieve the desired performance.

3   Results and Discussions

After applying gradient estimation using Kalman filter to the plot of the maximum value for the Fourier spectrum as in Figure 8, the gradient estimation graph as in Figure 9 is plotted. To enable the machine vision systems to automatically determine the correct time for switching *'off'* the electric heater, we have set a threshold value for the gradient estimation to be 50 and the time to be 12 minutes. The time 12 minutes is equivalent to the image number 140 from the starting of the gelatinization process since the gelatinization-processing image is taken every five seconds. The data acquisition card will give the electrical signal to the SSR to switch *'off'* the electrical heater once this condition is met and detected by the computer software. The electric heater status plot for switching *'off'* the electric heater is shown in Figure 10.

Additionally, we found that the changes in the GRFS image before and after gelatinization can be detected, based on the image texture. The FFT algorithm combined with the KF algorithm was able to provide better detection of the gelatinization onset of the GRFS. Figure 11 shows an example of the sequences of the GRFS gelatinization for the batch A. From this image sequence it can be seen that the gelatinization will start only at the image 153, i.e., at 12 minutes 45 seconds. Figure 12 shows the GRFS gelatinization time for 24 batches of processing. It was found that the use of combination of FFT and KF algorithms enable detection of the onset of the gelatinization process. The gelatinization starting time was in between the range of 11.75 minutes to 14.75 minutes.
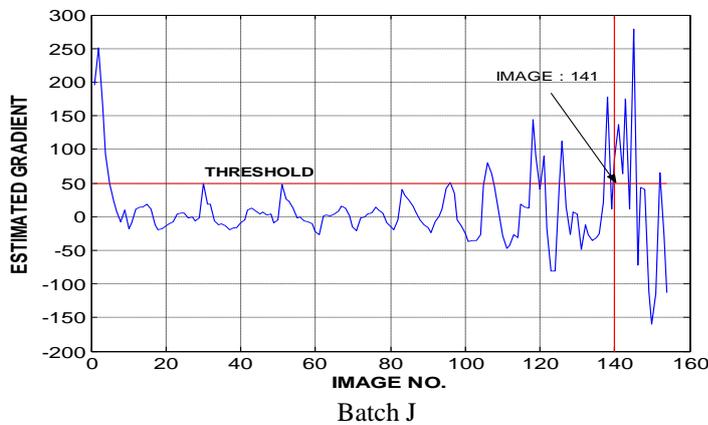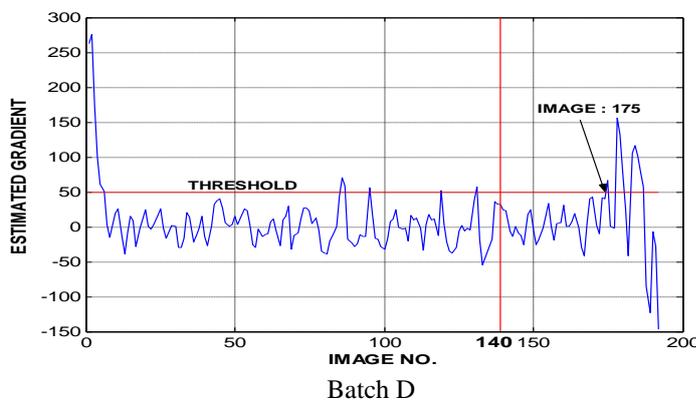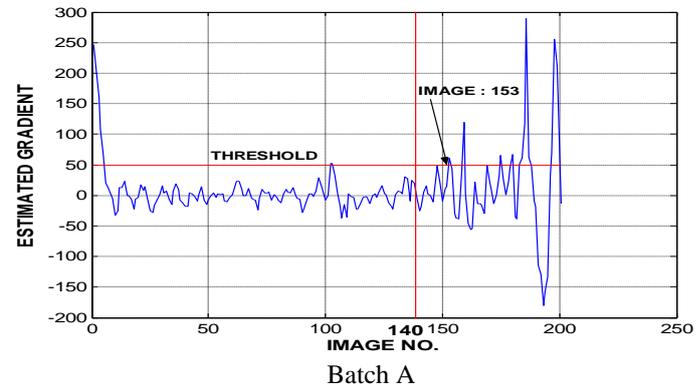
Batch A

Batch D

Batch J

Figure 9   KF refine the plot of the maximum value of Fourier spectrum for the batches A, D, J and K. A threshold value of the estimated gradient is 50 and the image is 140 and is shown with a red line.
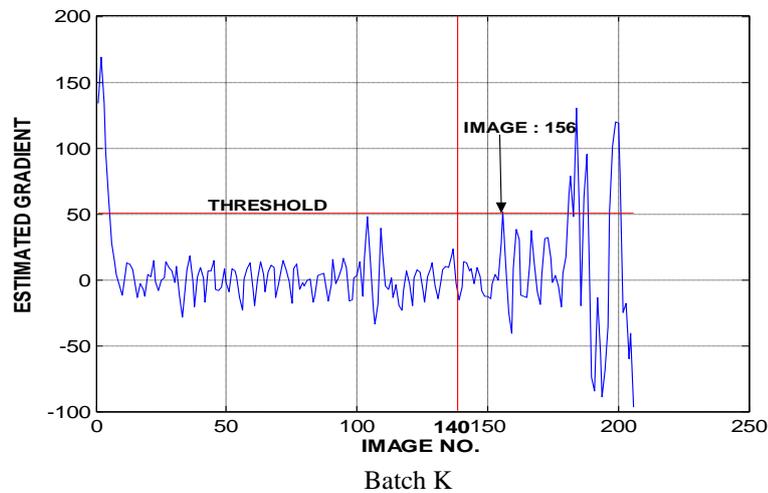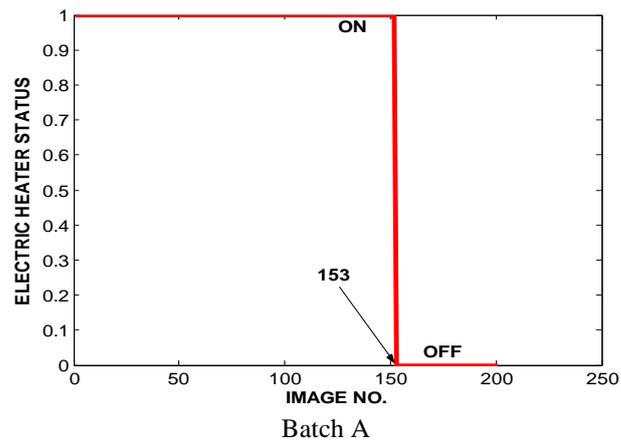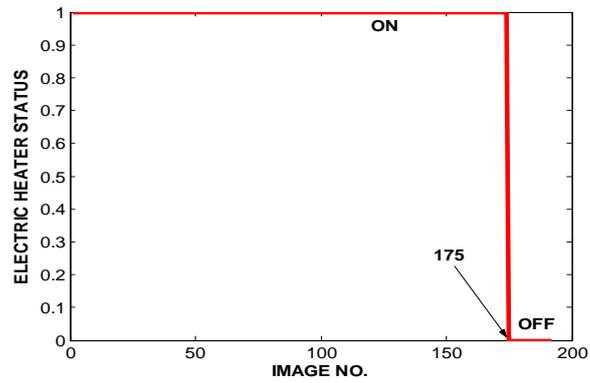
Batch K

Figure 9 (*continued*) KF refine the plot of the maximum value of Fourier spectrum for the batches A, D, J and K. A threshold value of the estimated gradient is 50 the image is 140 and is shown with a red line.
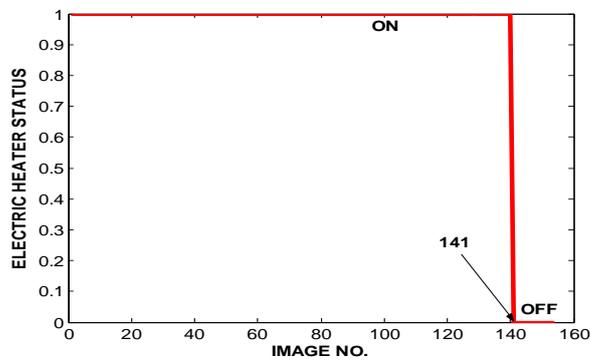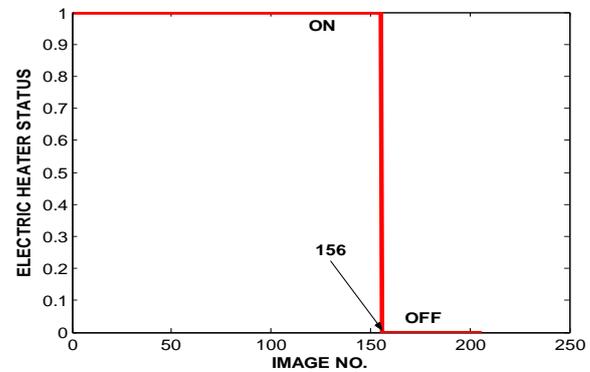

Batch A

Figure 10 Switching *'off'* the electric heater after GRFS gelatinization for the batches A, D, J and K.

Batch D

Batch J

Batch K

Figure 10 (*continued*) Switching *'off'* the electric heater after GRFS gelatinization for the batches A, D, J and K.
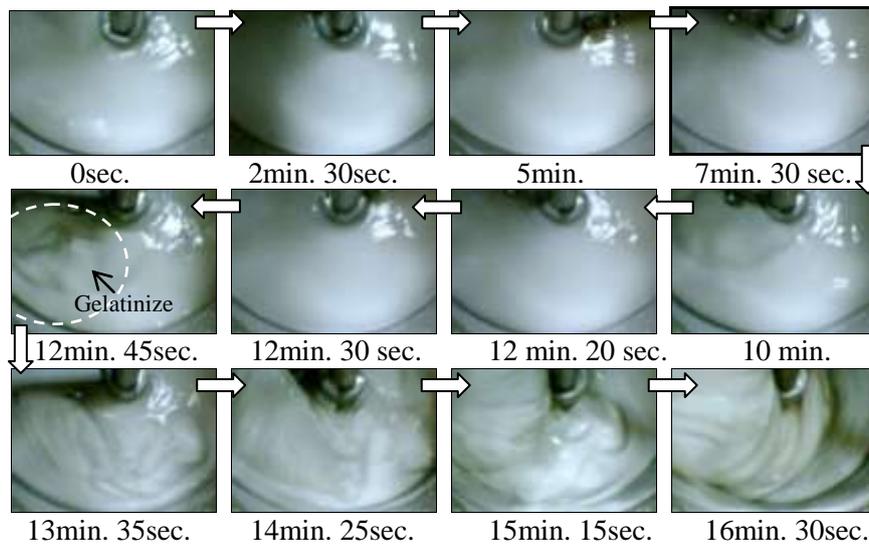
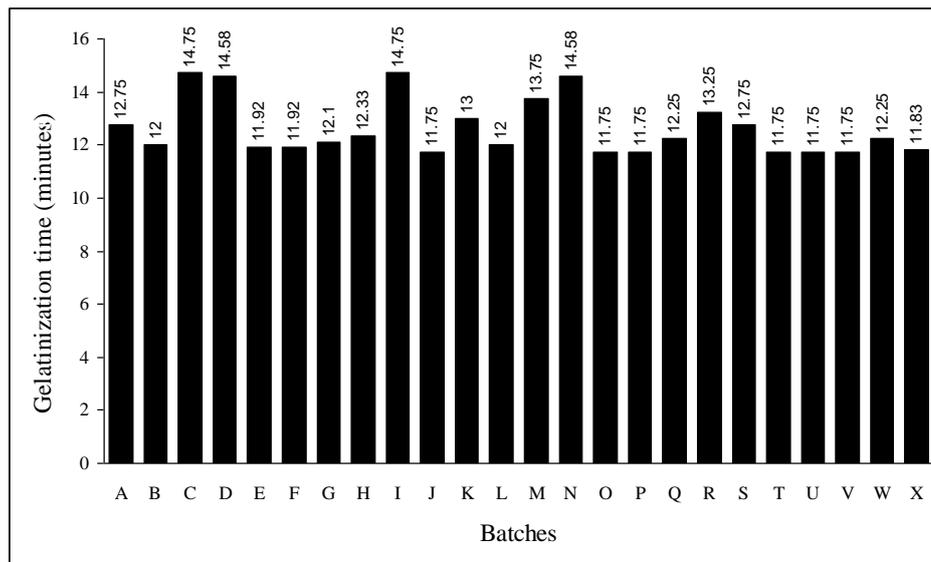**Figure 11**   Images of the GRFS gelatinization for the batch A.

Figure 12   Gelatinization time for 24 batches of the GRFS gelatinization.

4   Conclusions

The goal of this study was to detect and recognize the gelatinization phase of the GRFS using computer vision system. It was proven that it can be done efficiently and should be adopted in relevant food industries. The use of

computer vision system in food processing helps eliminate the subjectivity of visual inspections through human experience and increase accuracy and consistency in quality control and monitoring. Additionally, it allows fast identification and measurement of selected objects, high versatility for classification into categories and multiple options for analysis of the texture of the food surfaces. It is anticipated that a real time inspection of food could be implemented at reasonable costs.

Acknowledgement

Nomenclature

G	: grey level image
RGB	: Red, Green and Blue
I	: RGB image
σ	: the standard deviation of the distribution, i.e. Gaussian curve
$G1$	: grey level image pixel value
$G2$	: brighten image pixel value
a	: 170 (constant value : higher value will gives more brighten image)
u, R	: row pixel value of the grey-level image
v, C	: column pixel value of the grey-level image
F	: Discrete Fourier Transform
x	: ranges from 0 to R-1
y	: ranges from 0 to R-1
$x(k)$	: the signal state vector
A	: the state transition matrix
Q_w, Q_r	: covariance
$w(k)$	: the system noise with covariance Q_r
M	: the observation matrix $= \begin{bmatrix} 0 & 1 \end{bmatrix}$
$r(k)$	: the sensor noise with covariance Q_r
T_s	: the sampling time
$r_{(k)}$	: measurement noise
α	: constant with value close or equal to 1
w_k	: a white noise

References

[1]   Briones, V. & Aguilera, J.M., *Food quality evaluation using computer vision*, http://www.foodsciencecentral.com/fsc/ixid14224, (2006).

[2]   Cheng, J.D. & Da, W.S., *Recent developments in the applications of image processing techniques for food quality evaluation*, Trends in Food Science & Technology **15**, pp. 230-249, 2004.

[3]   Wikipedia, http://en.wikipedia.org/wiki/Dodol.

[4]   Kharis, Z., Normah, A. & Ajimilah, N.H., *Quality evaluation of 'dodol' developed using enzymatically modified starch*, Proceeding 13th National Biotechnology Seminar-Towards Commercialization of Malaysian Biotechnology, Bayview Hotel, Penang, Malaysia, 2001.

[5]   Brosnan, T. & Sun, D.W., *Improving quality inspection of food products by computer vision-a review*, Journal of Food Engineering, **61**, pp. 3-16, 2004.

[6]   Sun, D.W., *Computer vision - an objective, rapid and non-contact quality evaluation tool for the food industry*, Journal of Food Engineering, **61**, pp. 1–2, (2004)

[7]   Krutz, G. W., Gibson, H. G., Cassens, D. L. & Zhang, M., *Color vision in forest and wood engineering*, Landwards, **55**, pp. 2–9, 2000.

[8]   Du, C.J. & Sun, D.W., Recent developments in the applications of image processing techniques for food quality evaluation. Trends in Food Science and Technology, **15**, pp. 230-249, 2004.

[9]   Gunasekaran, S., *Computer vision technology for food quality assurance*, Trends in Food Science and Technology, **7**(8), pp. 245–256, 1996.

[10]   Shirai, Y., *Three dimensional computer vision*, Berlin: Springer-Verlag, 1987.

[11]   Kalman, R.E., *A New Approach to Linear Filtering and Prediction Problems*, Transaction of the ASME-Journal of Basic Engineering, pp. 35-45, 1960.

[12]   Gelb, A., *Applied Optimal Estimation*, MIT Press, 1982.

[13]   Crisafulli, S. & Medhurst, T.P., *Robust online digital differentiation with an application to underground coal mining*, IFAC 12th Triennial World Congress, Sydney, Australia, pp. 631-634, 1993.