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Machine vision for crack inspection of biscuits featuring pyramid detection scheme

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ABSTRACT

One of the challenges associated with machine vision inspection of biscuits or baked products with non-uniform colour distributions and textured background is the detection of a small and minute crack. In this study, a pyramid automatic crack detection scheme was proposed. This requires an enhancement method to properly distinguish the crack and intact samples. Canny–Deriche filter was used to emphasis the crack and reduce the noise. In order to segment minute crack pattern with less noise, a unimodal thresholding technique was developed and tested. The detection was based on support vector machine (SVM) featuring Wilk's λ selection criteria. The accuracy of the system was compared with standard discriminant analysis. It was discovered that the pyramid SVM after Wilk's λ analysis was more precise in detection compared to other classifiers, resulting in the specificity and sensitivity of 98% and 96% respectively, and average correct classification of consistently more than 97%.

1. Introduction

Among the many tests that need to be carried out on most biscuit or baked products is the inspection of crack. It is for this reason that food processors have over the years devised various strategies in attempting to detect the appearance of small hairline cracks in biscuits and crackers. However, this is very challenging task due to biscuit images exhibiting various colours, texture, and background irregularities. In the last decade, several methods for automatic crack detection have been proposed. Some of the popular techniques include the morphological operation (Brosnan and Sun, 2004; Iyer and Sinha, 2005), the wavelet analysis (Han and Shi, 2007), the fractal analysis (Quevedo et al., 2008), the diffusion method (Tsai et al., 2010), and the edge detection scheme (Li et al., 2012). Hutchinson and Chen (2006) employed Canny filter and thresholding methods to detect cracks based on Bayesian decision theory in which simple images consisting of clearly observable cracks were considered. Meanwhile, a crack detection and inspection system based on SVM technique were proposed (Du and Sun, 2008; Han et al., 2010) and various schemes of Hough transform were investigated for line and ellipse detection (Hari et al., 2009; Chien et al., 2011). In another application, Tsai et al. (2010, 2012) proposed a scheme for micro-crack detection based on diffusion and Fourier based reconstruction techniques. Most recently, Li et al. (2012) proposed an advanced vision system for identifying micro-crack in eggshell. The method used Otsu thresholding (Otsu, 1979) to separate the image of egg from the background. Most of the above methods and techniques require an efficient image retrieval strategy to ensure accurate detection and reduce false negative. One of the most popular schemes is based on local approach such as the fixed partitioning method (Lu et al., 1994; Smith and Chang, 1996) and the sliding window scheme (Huang and Xu, 2006). The main advantage of these techniques is that they give additional information to the descriptor. However, these approaches are computationally inefficient and require every portion of the image to be examined, resulting in thousands of evaluations which need to be performed. A slightly better approach in capturing small but distinct spatial variation in the image is through the use of spatial pyramid scheme (Lazebnik et al., 2006). This method is frequently used to compute features at multiple resolution levels to increase the discriminative power of the descriptor. Multi-level image features normally produce different evidences of visual information. As a result, the performance is improved as reported in (Lazebnik et al., 2006; Bosch et al., 2007; Yan et al., 2011). In histogram-based feature extraction, spatial pyramid approach used the fixed partitioning scheme to combine several levels of histogram of orientation gradients (HOG) (Bosch et al., 2007). This method has been shown to improve recognition performance since it combines the global and the local features to describe an image. The features can be computed easily and the procedures preserve the spatial information by simply fusing local features at multiple levels; each level in the spatial pyramid presents different information

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and hence new features. Moreover, this method has the ability to characterise the entire image with a single vector, and hence, it is more sensitive to complex disturbances such as occlusion and small cracks. Also, this image partitioning scheme is expected to generate more useful and salient features, and consequently, classification methodologies can be implemented in a space with vastly reduced dimension and reasonable time.

Therefore, in this study, a spatial pyramid approach based on fixed partitioning scheme together with advanced image segmentation algorithm were further developed and tested for inspecting cracks in biscuits via machine vision learning. It will shown in this paper that the proposed methods and procedures are more efficient in detecting small as well as large cracks in heterogeneously coloured biscuit images.

2. Materials and methods

2.1. Machine vision system

The hardware for the machine vision system used in crack detection consisted of a HP Workstation XW4600 CPU 2.5 GHz, colour frame grabber board, an illumination system, cable, and a charge-coupled device camera. The frame grabber is a 32-bit Meteor II type manufactured by Matrox Electronic System Limited, Canada. A high quality 3-CCD Sony XC-003P camera is used as the image acquisition device, capable of capturing image at spatial resolution of 640×480 pixels. The camera came with standard C-mount type optical lens connected to a frame grabber via 2-m external BNC cable. The camera was mounted to a test station, which comprised of iron holder fixed at the height of 45.5 cm and at an angle of 90° mounted from horizontal arm. The test station was illuminated using a white, Stocker Yale (USA) ultra-high-frequency fluorescent ring light, model 13 plus high frequency steady light with a maximum oscillating frequency of 85 kHz. In this case, the calibration was performed using four colour samples manufactured by Labsphere Inc., USA. The samples are SCS-RD-010, SCS-GN-010, SCS-BL-010, and SCS-YW-010, corresponding to red, green, blue, and yellow colour standards respectively. The Labsphere colorimeter data which is traceable to international colour standard of CIELAB 1964 and illumination D65 was used as a reference. Calibration was performed by capturing each sample, adjusting and storing the appropriate RGB setting in the software so that the colour reading matched with the corresponding Labsphere colorimetric data. These RGB settings are used in capturing all colour images reported in this paper. The proposed crack detection system is divided into two main steps: pre-processing and post-processing. In summary, the pre-processing involved, image acquisition, enhancement, edge detection, and image segmentation. Meanwhile, the post-processing included pyramid representation, feature extraction based on the Hough space, dimensionality reduction, and SVM classification. Example of biscuit images with several types of cracks are shown in Fig. 1.

This figure highlights the presence of dotted structure and non-uniform colour distributions, reflecting some unique textural characteristics of this baked product. In this study, the image processing is performed using the Matrox Image Library (MIL 9.0), implemented using the Visual C++ programming language. Experiments are divided into two stages: training and inspection. For the sake of thoroughness, the accuracy of the system is compared with the conventional discriminant analysis (DA) method.

2.2. Crack feature

The key component of a robust crack detection system is feature selection. This feature should be able to describe the physical characteristics of cracks. Careful examination of image in Fig. 1 indicates that the majority of pixels belonging to cracks have three important properties: (i) the biscuit texture and cracks share similar gray scale values; (ii) the aggregation of pixels belonging to crack approximately forms a line or a unique pattern in the image; and (iii) the changes in the gray scale values from any side and direction of the crack are approximately symmetrical. Hence, to describe these physical characteristics, a new enhancement method and an improved feature extraction based on Hough space are investigated. Hough transform itself has many merits, such as invariance to image rotations and robustness to image translations. In addition, crack often appears in different sizes and lengths in the images. Therefore, crack features must be extracted at multiple resolutions to detect the minute details of an image.

2.3. Proposed enhancement and segmentation

Coloured image analysis is an important step for object recognition and machine learning. Several colour spaces have been developed for particular applications, and each of them has its own way for visualising the colours. In crack detection, the images are captured by the CCD camera and represented in the three-dimensional RGB colour space. This colour space is used in the analysis because it enhanced image segmentation and produced better results (Gonzalez and Woods, 2002). To amplify the crack and reduce the effect of colour heterogeneity, a new enhancement method for a non-uniform colour is proposed. In order to examine the relation between crack and the background, the colour image is decomposed into different colour planes. Fig. 2(a–c) shows images displayed on three colour planes.

It can be observed from this figure that the red plane produces image with a good contrast between crack and the background. On the other hand, the image in blue plane represents mostly the background features. This effect can also be seen in the RGB line profile shown in Fig. 2(d). Therefore, it is theoretically possible to enhance a crack by performing pixel-to-pixel subtraction of blue from red plane images. Mathematically,

$$I_s^+(p_i) = (I_r(p_i) - I_b(p_i))^+ \quad i = 1 \ldots N_T, \quad I_s^+(p_i) = \begin{cases} I_s(p_i) & \text{if } I_s(p_i) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where $I_r(p_i)$ and $I_b(p_i)$ are the intensity of pixel p_i in red and blue plane images respectively; i is the pixel index, and N_T is the total number of pixels. In this case, the images of biscuit reflect the colour range from brownish to reddish spectrum. Hence, the red plane reflects high intensity values compared to the blue and green planes as shown in Fig. 2(a–c). The subtracted image is then processed using Laplacian-based Canny–Deriche filter (Deriche, 1987, 1990). This filter was used to detect the edge by Laplacian-based method and performs smoothing operation to reduce noises and remove isolated ones. In this study, the smoothness parameter of the Canny–Deriche filter is fixed to the default value of 50% in all cases. The results are presented in Fig. 2(e) and (f). It can be observed from these figures that the presence of crack has been enhanced and the noise reduced after subtraction and filtering. Thereafter, the edge image is used as input to the proposed unimodal thresholding strategy (Nashat et al., 2012) for edge segmentation which is described in the following section briefly.

2.4. Unimodal thresholding

The basic requirement for efficient crack detection is that the crack must be accurately segmented, and the noise removed as much as possible from the scene. Successful implementation of image segmentation relies heavily on a threshold that gives the