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A least-squares support vector machine (LS-SVM) based on fractal analysis and CIELab parameters for the detection of browning degree on mango (*Mangifera indica* L.)

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ABSTRACT

This paper introduces a least-squares support vector machine (LS-SVM) classifier to detect the degree of browning on mango fruits as a function of fractal dimension (FD) and $L^*a^*b^*$ values. Our results showed that the best classification accuracy of browning degree was up to 100% using the LS-SVM classifier based on FD and $L^*a^*b^*$ ($\gamma = 6.13$, $\sigma^2 = 9.36$). However, the correct classification rates of 85.19% and 88.89% were achieved for the LS-SVM models based on FD ($\gamma = 1.13$, $\sigma^2 = 5.52$) and based on $L^*a^*b^*$ ($\gamma = 6.68$, $\sigma^2 = 2.44$), respectively. Therefore, this study indicated the possibility of developing a potentially useful classification tool using the LS-SVM combined with FD and $L^*a^*b^*$ values for classifying the degree of browning on mango fruits during processing, storage and distribution.

1. Introduction

Mango (*Mangifera indica* L.) originated over 4000 years ago in Burma and India (Mitra and Baldwin, 1997), and now is grown in most tropical and subtropical regions of the world with a global production of more than 33 million tons (FAOSTAT, 2008) due to its bright color, characteristic taste and nutritional value. Although this fruit has heavy demand in world market, it deteriorates rapidly after harvest, especially pericarp browning, resulting in reduced market value. The fruit market requires their suppliers to distribute the fruits according to high standards of quality and visual appearance, thus fruit sorting is essential in postharvest handling. However, hand sorting of fruit is tedious and can cause eye fatigue. In addition, it is also subject to sorting errors because of different judgment by different persons. Thus, many technologies have been explored for automated grading of fruits, such as computer vision (Brosnan and Sun, 2004), infrared spectroscopy (Sun, 2008), acoustic method (Elbatawi, 2008), chlorophyll fluorescence (Zheng et al., 2010) and electronic nose (Li et al., 2010). For mango fruits, much research has focused on the analysis of nutrition component (Ribeiro et al., 2008), the use of postharvest treatments to extend shelf-life (Kim et al., 2009; Sivakumar et al., 2010), the determination of harvest maturity (Lebrun et al., 2008; Naglea et al., 2010; Wanitchang et al., 2011), and the evaluation of texture and firmness (Valente and Ferrandis, 2003; Valente et al., 2009). However, there are no data on automated sorting of mango fruit quality based on the degree of browning.

Therefore, we try to develop a new approach for the automatic sorting of browning degree on mango using LS-SVM as a function of fractal analysis and CIELab parameters. Fractal geometry is mathematical sets that process high degree of geometrical complexity and can model numerous natural phenomena. Contrary to classical geometry, it is not regular and may have an integer or non-integer dimension (Mandelbrot, 1983). Recently, fractal analysis has been successfully used in food research field such as food structure (Barrett and Peleg, 1995), food classification (Mendoza et al., 2009), food appearance characterization (Quevedo et al., 2002; Valous et al., 2009), fruit bruise detection (Lu et al., 2011; Zheng et al., 2011a) and food quality prediction (Kerdpiboon et al., 2006; Zheng et al., 2011b). Food color is the first quality parameter evaluated by consumers and is critical in the acceptance of the product. In addition, color measurement is an objective parameter for the evaluation of quality changes during food processing, storage, and distribution (Giese, 2000). Several models have been developed for the analysis of color, but the CIELab system is the one that nowadays presents a high acceptance since the color perception is uniform which means that the Euclidean distance between two colors corresponds approximately to the col-

Abbreviations: LS-SVM, least-squares support vector machine; FD, fractal dimension; BCD, box counting dimension; CD, correlation dimension; DD, dilation dimension.

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or difference perceived by the human eye (Hunt, 1991). The $L^*a^*b^*$ is an international standard for color measurement proposed by the Commission Internationale d'Eclairage (CIE) in 1976. L^* is the luminance component (from 0 to 100), and a^* (from green to red) and b^* (from blue to yellow) are the two chromatic components (from −120 to 120) (Papadakis et al., 2000).

The objectives of this research is to evaluate and compare the performance of LS-SVM classifier based on fractal analysis and $L^*a^*b^*$ for the detection of the degree of browning on mango fruits. The success of this study will provide a potential tool for automatically classifying the quality of not only mango fruits, but also any other fruits during processing, storage, and distribution.

2. Materials and methods

2.1. Food material

Mango fruits (*M. indica* L. cv. 'sannianmang') were obtained from a local market in Jinghua (Zhejiang, China). In this study, a total of 90 fruits with different degrees of browning were selected, and browning of the fruit surface was evaluated by four referees according to a visual color scale of A–C, where A = fresh without any browning, B = moderate browning, and C = severe browning. These referees have long engaged in the classification of fruit quality. This index was employed as a reference for the browning state of mango fruits and was compared to the information obtained from the method used in this study.

2.2. Image acquisition and processing

Fig. 1 shows the basic procedures for image feature extraction and classifier development. Firstly, mango fruits were photographed using a Canon EOS 50 D camera with a Canon EF-S 18–55 mm f/3.5–5.6 IS lens at 50 mm. The lighting for images is entirely from natural light on a sunny morning in the spring. All image acquisitions were carried out at least in triplicate. Secondly, the image was subtracted background using the algorithm by Sternberg (1983). Thirdly, the feature parameter, including $L^*a^*b^*$ values and fractal dimension (FD), was extracted from the image. Finally, the relationship between image parameters and three grading levels (A, B and C) was established by least-squares support vector machine (LS-SVM) classifiers.

2.3. Measurement of color

The average $L^*a^*b^*$ values from the image were obtained using the Histogram Window of Adobe Photoshop CS5 (Adobe Systems, San Jose, CA) as described by Yam and Papadakis (2004). The parameters L, a and b in the Histogram Window are not standard color values, which can be converted to L^*, a^* and b^* values using the formulas:

$$L^* = \frac{L}{225} \times 100 \quad (1)$$

$$a^* = \frac{240a}{255} - 120 \quad (2)$$

$$b^* = \frac{240b}{255} - 120 \quad (3)$$

2.4. Calculation of FD

The FD is a useful method to quantify the complexity of an image and constitutes a geometrical description of an image (Moalla et al., 2006). The basic procedures for the calculation of FD were carried out as follows:

Step 1: Image acquisition and processing.

Step 2: The three-dimensional (3D) graph of the intensities of pixels of the mango fruit surface was studied with ImageJ plug-in Interactive 3D Surface Plot v2.32.

Step 3: The 3D surface image was converted to the binary image.

Step 4: Three methods were used for FD calculation from the binary image in this study: the box counting method, the correlation method and the dilation method. FD calculations were performed using Fractalyse analysis software (www.fractalyse.org, downloaded January 2010).

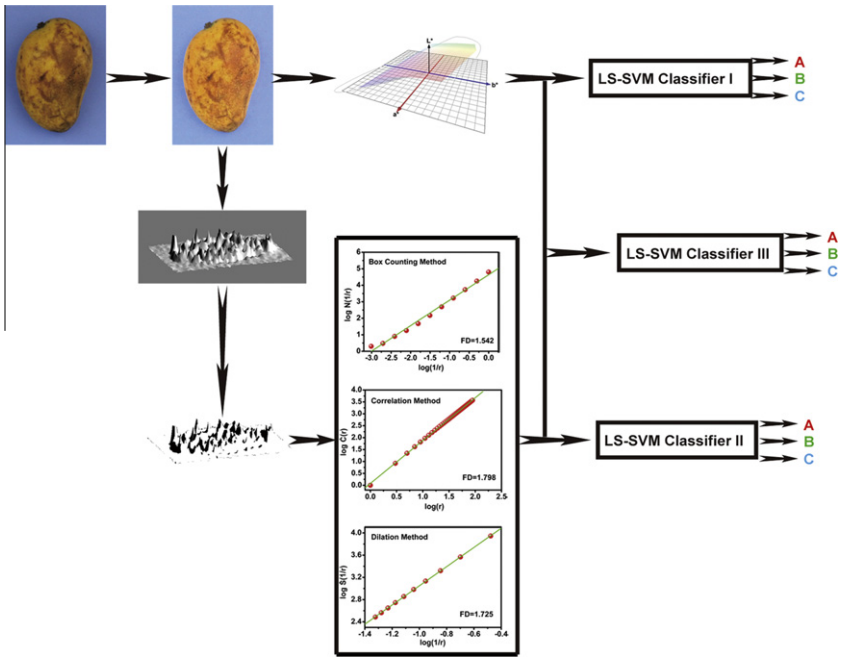

Fig. 1. Graphical representation of image feature extraction and classifier development.