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Prediction of banana quality indices from color features using support vector regression

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ABSTRACT

Banana undergoes significant quality indices and color transformations during shelf-life process, which in turn affect important chemical and physical characteristics for the organoleptic quality of banana. A computer vision system was implemented in order to evaluate color of banana in RGB, $L^*a^*b^*$ and HSV color spaces, and changes in color features of banana during shelf-life were employed for the quantitative prediction of quality indices. The radial basis function (RBF) was applied as the kernel function of support vector regression (SVR) and the color features, in different color spaces, were selected as the inputs of the model, being determined total soluble solids, pH, titratable acidity and firmness as the output. Experimental results provided an improvement in predictive accuracy as compared with those obtained by using artificial neural network (ANN).

1. Introduction

Banana is one of the most popular fruits in the world and a main one in international trade [1]. In 2011, bananas (*Musa* spp.) were grown in 10.6 million ha with an average fruit yield of 13.6 t ha^{-1} [2], being Cavendish the most widely banana cultivar. Suitable temperature, humidity, time and air flow are all needed for ripening of bananas and by using controlled ethylene gas, the ripening treatment of banana could be artificially made [3]. During banana ripening period, the peel color changes, the flavor evolves and the pulp softens. Banana peel color changes from green to yellow, with brown spots appearing on the yellow color at the end of shelf-life; being the synthesis of few pigments the reason of this change in peel color [4]. So, on-line quality control of banana during ripening treatment is quite important to keep a firm pulp texture, good color and flavor and also to prevent from bruise [5]. This makes monitoring of quality parameters in the orchard, package and delivery points necessary in producing acceptable bananas for the customer [3].

Most of the fruit quality measurement methods are destructive such as pulp to peel ratio determination and fruit firmness, which are mainly based on rheological properties [6]. Also, these methods do not sufficiently monitor the quality of banana fruits during ripening period [5], being employed just a small set of samples as representative of the whole because of difficulties of destructively analyzing every unit of fruit [3].

The development of instrumental non-destructive techniques could be highly appropriate to increase the number of fruit pieces which can be analyzed, to repeat several times the analysis on the same sample at a given time or during its physiological evolution, and to access to real-time information [7].

Several soft and non-destructive techniques that can be applied for quality measurement include proton transfer reaction mass spectrometry (PTR-MS) [8], ultrasound [9], magnetic resonance imaging (MRI) [10], time-resolved reflectance spectroscopy [11], X-ray and computed tomography (CT) [12], laser-induced fluorescence spectroscopy (LIFS) [13], Fourier transform infrared (FTIR) [14], sonic technique [15], near infrared spectroscopy (NIRS) [16], sound velocity [17], optical chlorophyll sensing system [18], capacitance technique [5] and electronic nose systems [19]. Nevertheless, most of the aforementioned analytical techniques are far from reaching a practical application and, sometimes, are time-consuming, expensive, difficult to be implemented and require to be made by trained personnel [7].

Near-infrared (NIR) spectroscopy has been used to correlate firmness and soluble solid content (SSC) in Cavendish bananas at different stages of ripeness [3,20]. On the other hand, Baiano et al. [7] proposed the use of hyperspectral imaging technique for prediction of some physico-chemical parameters of table grapes. Concerning banana shelf life, studies made by Wang et al. [21], Bora et al. [22] and Mendoza et al. [23] evaluated the ripening stage of bananas from their color but without making any

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quantitative study about their quality indices. However there is no precedent, in our own knowledge, about the use of external color of bananas to evaluate their quality.

At first instance, fruits quality is evaluated by looking at their color, gloss, size and, secondly, by texture, total soluble solids (TSS) content and acidity. These parameters may provide important information to the consumer in the choice of food supply. A special emphasis should be placed on quality attribution in trading. The ripening indices traditionally used to evaluate changes in skin color, softening, titratable acidity, soluble solids concentration and volatile compounds [7,24]. On the other hand, the application of sensors; such as optical, chemical, and tactile ones, provides a high correlation with the human senses. Different techniques have been reported to determine various quality parameters of fruits. However, there is currently no single or combination of techniques and computational methods available to quantify the overall quality of foods [25].

Color can be correlated with other quality attributes such as sensory, nutritional and visual or non-visual defects and helps to control them directly [25,26]. Color is considered a basic physical property of agro-food products. In fact, color plays an important role in the evaluation of external quality in food industries and food engineering research [7,27]. The role of color is important to evaluate food quality, but the use of color parameters to predict specific quality indices of foods has been less explored and represents an opportunity among researchers.

Industrial food product quality was monitored and controlled by an on-line imaging system [25, 28]. However, there are only few studies available on modeling kinetics of green–yellow transformations in fruits and vegetables. Engineers need quantitative models to develop and improve processes [29]. Therefore, current investigation was conducted to study changes in color features of banana during shelf-life and to evaluate the use of image analysis technique as a rapid and nondestructive alternative for the accurate prediction of quality indices.

On the other hand, the scientific literature shows the valuable application of artificial intelligence in food research field [30–34] and radial basis function-based support vector regression has been employed to process color data of bananas at different shelf-life stages.

2. Materials and methods

2.1. Experimental material

Banana fruits (Cavendish variety) imported from the Philippines were used in this research. The banana fruits were stored at 14 °C during transportation. Then, the fruits were stored in an airtight warehouse. Bananas' ripening was completed in 4 days. In the first day, fruits were stored at 20 °C, and in the second day, ethylene gas was injected. In the third day, ethylene was removed and temperature decreased to 18 °C and finally temperature was decreased so that it achieved 11 °C in the fourth day. The control of temperature, humidity and ethylene gas concentration in the ripening room are very important. Bananas were kept in the warehouse at the humidity level of 85–88% for 4 days, as this time period needed for completing the ripening treatment of fruits. At this site, ripeness is currently assessed visually by comparing the peel color of banana with standardized color charts describing various stages of ripening.

Fruit development can generally be divided into three major steps: growth, ripening, and senescence. The period of growth generally involves cell division and enlargement, which accounts for the increasing size of the fruit. During ripening fruit become soft textured, and accumulate soluble sugars, pigments and volatile aroma. Senescence is the period when chemical synthesizing pathways give way to destruction processes, leading to aging and death of tissue. Additionally, it has been identified seven stages in the ripening period of bananas which change the color from green to yellow and brown [35].

Before entering the warehouse, bananas are in the first ripening stage and after leaving the warehouse, they are in the fifth ripening stage. For performing the experiments, 15 bananas of the same size, weight and ripening stage, were daily transferred from the warehouse to the laboratory for image analysis. The bananas were picked from the same position of each branch. Then tests were done on the samples till the fifth ripening stage. Moreover, all the measurements were performed in the day of transferring from the warehouse. For experiments conducted during the senescence period, banana samples were selected after the end of fifth ripening stage and were studied during additional 4 days until mealiness completion. This period represents the time interval between delivering bananas from the warehouse and reach to distribution centers and as long as are usable by the consumer. In general, after completing the ripening period in five stages, senescence period starts and this period takes four days. All this process is represented shelf-life period of banana samples.

2.2. Machine vision system

A machine vision system was designed that includes two main parts. An image acquisition system to take images from banana samples at any stage of shelf-life. The second part was an image analysis algorithm written in MATLAB v8.1 (The Mathworks, Natick, MA, USA) software for automatically emphasizing the fruit surface in the images as the region of interest and extract average color features from the skin of the banana fruits.

2.2.1. Image acquisition

The setup used to take the images from bananas consisted of four main compartments for: (1) lighting and imaging system, (2) computer case, (3) monitor and user interfaces and (4) accessories.

The D65 standard light source, which is commonly used in food image processing studies, was employed in this research to provide reproducible, uniform-steady lighting conditions [36]. A box made of wood with the interior walls painted in mat black was used as the illumination chamber. Two fluorescent lamps (Natural Daylight, 230 V/12 W) with a color reproduction index up to 95% and color temperature of 6500 K were placed on left and right sides of the box. PVC sheets were located in front of the lamps to avoid direct lighting and shading. The banana samples were mounted on top of a black tray with very low reflectivity to be adequately discriminable from the background. High quality images from samples were taken by a Power shot color camera (Canon EOS kiss ×4 digital color camera, Japan, 18MP) with remote capturing capability mounted at a vertical distance of 25 cm above the samples.

Camera and fluorescent lamps were turned on 1 h before image recording to achieve a stable lightening [37]. All of the images were taken under totally stabilized camera characteristics according to Table 1 variables. The images were transferred automatically to the computer and loaded into image processing toolbox of MATLAB software for further operations.

2.2.2. Color feature extraction

The flowchart of image analysis algorithm is illustrated in Fig. 1. Image enhancement processes including common median filtering was the first operation performed on the loaded RGB images to suppress noises.

Loaded images were segmented, which is one of the most