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Pixel based bruise region extraction of apple using Vis-NIR hyperspectral imaging

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ABSTRACT

Bruises on apples will directly influence its preservation and marketing for they can cause the internal decomposition and flaws of the appearance of apples. Therefore, an effective pixel based bruise region extraction method was proposed in this study to obtain the complete bruise region. Hyperspectral images of 60 apples were obtained via the hyperspectral imaging (HSI) system at 0, 12 and 18 h after the damage experiment. Principal Component Analysis (PCA) was used to compression data size and eliminating redundant data of hyperspectral image cubes. After the selection of the region of interest (ROI) by certain rules, different pixel based apple bruise extraction models were built and compared. The result shows that Random Forest (RF) model have a high and stable classification accuracy, which turns out that RF algorithm is more suitable for classifying bruises on apples than others. The average accuracy of bruise extraction models reached 99.9%. Compared with the most used image processing method in recent literature for extracting bruises of apples, the bruising region predicted by RF model was more consistent with the true bruise region. Additionally, two characteristic wavebands around 675 nm and 960 nm related to the bruise region were singled out for reducing the dimensionality of data by analyzing the feature importance scores of the built RF model. The overall results indicated that the proposed method has a great potential to detect complete bruise region on apples based on hyperspectral imaging for improving the efficiency of apple grading and sorting.

1. Introduction

Apples as one of the most popular fruit in the world are prone to mechanical bruise due to the impact, squeeze and abrasion during picking and transportation. The bruise can not only influence the apple's taste and causes its nutrient loss, but also accelerate its decay velocity and reduce the economic value of the apple (Xing et al., 2007). Hence, bruise on apples is a critical factor in the assessment and grading of apple quality, which can directly influence its preservation and marketing (Li et al., 2016). There are still considerable factories using manual fruit grading method to detect bruises and classify fruits (Baranowski et al., 2012). However, manual fruit grading is a tedious, inefficient work, and the sort result is also less than satisfactory (Pu et al., 2015). For enhancing the efficiency and the accuracy of bruise detection, researchers have explored various green methods to detect the bruise region or the existence of bruise on apples. A setup for bruise detection and grading was developed based on machine vision with the correlation between predicted and measured bruised areas ranging from 0. 63 to 0.84 (Rehkugler and Throop, 1986); Jackson and Harker (2000) detected bruises on apple by measuring the electrical impedance of apple, which achieved the value of R^2 up to 0.71; An X-ray radiographic imaging technique for detecting internal defects in apples was investigated by Schatzki et al. (1997). Unfortunately, the detection accuracy of this technology was lower than 50%, which cannot be used to replace manpower. All methods mentioned above can detect the bruise to varying degrees, which provided various ways for detecting and classifying bruises on apple automatically.

With the development of the HSI technique, more and more studies have been reported on using HSI for the quality and safety inspection of food products (Lorente et al., 2012; López-Maestresalas et al., 2016; Ariana et al., 2006). HSI data is a 3-dimensional cube which contains both spatial (2-dimensional) and spectral (1-dimensional) information of an object. Every pixel in spatial dimension corresponds to a spectrum, meanwhile, all data under a wavelength in spectral dimension can compose an image(Ferrari et al., 2015). HSI technique is frequently used for detecting apple quality for its merits of nondestructive and chemical-free determination. Lu (2003) analyzed hyperspectral images whose wavelength ranged from 900 nm to 1700 nm for predicting the

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time after bruising (1-47d) on two cultivars of apples ('Red Delicious' and 'Golden Delicious') via principal component and minimum noise fraction transforms. The correct detection rate of this approach was from 62% to 88% for red delicious apples and was from 59% to 94% for golden delicious apples. Xing et al. (2005) obtained hyperspectral images of 'Golden Delicious' apples with the spectral region from 400 nm to 1000 nm. For reducing the dimension of HSI data, Principal Component Analysis (PCA) was applied to characteristic waveband selection. A classification algorithm for detecting bruises on apples based on moments thresholding was developed subsequently, and its accuracy reached 86%. In addition, partial least squares method and stepwise discrimination analysis had been studied by ElMasry et al. (2008) for selecting three effective wavelengths (750, 820, 960 nm). Afterwards, the bruised region was obtained by adaptive thresholding method with the averaged image of characteristic images. What's more, Baranowski et al. (2013) detected the bruised region by image thresholding method and the averaged image of images at wavelengths from 680 nm to 960 nm. Various pretreatment methods and classification methods were used and compared for selecting the most accurate model. The research showed that the prediction accuracy was higher than 90% when the best model was built with the combination of second derivative pretreatment method and the linear logistic regression neural networks method. The Bruise susceptibility of apple was studied by Zhu et al. using hyperspectral scattering image ranging from 500 to 1000 nm (Zhu et al., 2016). To get bruised regions, image segmentation method was implemented through Adobe Photoshop CS (San Jose, CA). Keresztes et al. (2017) detected stem, glossy, sound and bruised regions on apples via partial least squares-discriminant analysis (PLS-DA) algorithm. An average bruise detection accuracy reached 94.4% after the post-processing of the predicted binary images.

Image processing method such as thresholding and feature vectors extracting method is one of the most popular methods of most of the existing studies to obtain bruises on apples (Xing et al., 2007; Tian et al., 2014). Nevertheless, considering the influence of the individual diversity and the variety of environment, the use of image processing methods is limited in some circumstances. For instance, bruised region is easily mis-segmented when the surface of apple exists mixed colors or the bruise has a complex shape and a tiny region (Keresztes et al., 2016). Beyond that, it is hard to evaluate the accuracy of the bruise detection with image processing methods since the difficulty in counting the correct selected bruise pixels. From the application point of view, the accurate prediction of bruised regions can be used for estimating the area of the bruise, which is a critical index to grade different levels of apple quality. Hence, an accurate and stable method capable of segmenting bruise on apples is needed.

The overall goal of this research was to find a non-destructive, fast and stable method which can accurately predict the bruised regions on apples. The specific targets were to:

(1) Develop a pixel based bruise extraction model in view of spectral classification for overcoming drawbacks of the traditional bruise segmentation method (image processing method).
(2) Evaluate the accuracy of the bruise extraction method proposed in this study.
(3) Determine several optimal wavebands instead of full bands for reducing dimensions of large-scale HSI image data.

2. Material and method

2.1. Sample preparation

60 fresh apples with a diameter of 7–8 cm, of Fuji variety, were manually selected and purchased in Harbin, Heilongjiang Province, China in September 2016. For obtaining a better apple samples, apples without obvious bruises and different surface colors were given higher priority during visual inspection. After being shipped to the laboratory, apples were numbered and stored at the room temperature of 18 °C and relative humidity of 75% until the experiment was conducted.

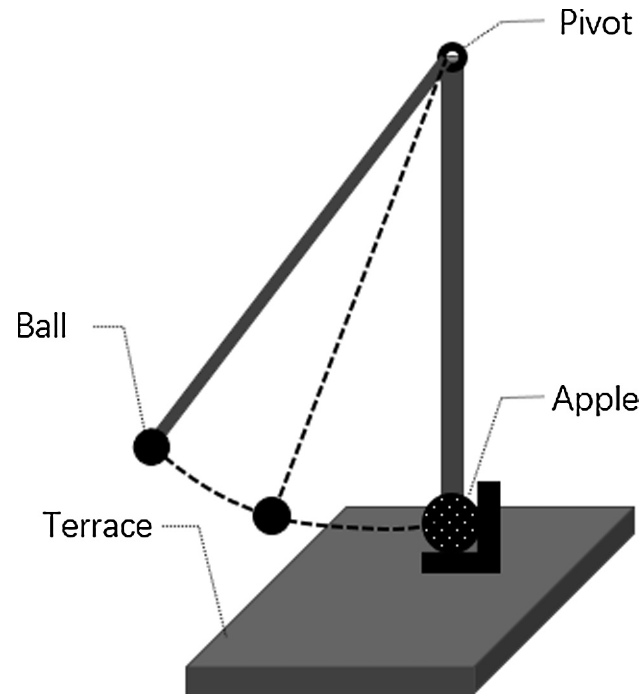

Fig. 1. Apple damage equipment.

2.2. Bruising experiment

Fig. 1 illustrates the design of the equipment for bruising apples. An evenly distributed steel rod is 80 cm in length and 230 g in weight, which connects a pivot to a steel ball whose diameter is 1.6 cm and weight is about 22 g. For controlling the variability during the experiment, the steel rod was set at a fixed angle (57 degrees measured by goniometer) to vertical. Tested apples were fixed at the bottom of the equipment while the steel rod and ball fall onto the apple's equator after toggling the switch, and bruised region with a diameter of approximately 1.4 cm would be caused. Since the angle between the rod and perpendicular line and the height from the ball to the ground was fixed, the force acting on the surface of apple was almost equivalent at each collision, hence, the consistent data was generated in the end.

Apples in this experiment were hit sequentially in ascending order by the sample number. The hyperspectral image was obtained immediately after the collision via the HSI acquisition system. Since the bruise might occur at any time in course of harvest, transportation and storage, hyperspectral images at 12 and 18 h after bruising were also collected for simulating apples bruised at the different time. There were 180 raw hyperspectral images acquired at last.

2.3. Acquisition of hyperspectral images

HSI system which is used to obtain the hyperspectral images consists of: (1) A hyperspectral camera (SOC710, Surface Optics Corp., San Diego, CA, USA); (2) Illumination unit contains four 75 W angle-adjustable tungsten halogen lamps (PHILIPS, USA) around the box; (3) Computer with data acquisition software HyperScanner2.0. As represented in Fig. 2, the hyperspectral images acquisition system keeps the inner environment consistent in each shooting for reducing the interference from outside. The spectrograph covers the spectral range between 400 and 1000 nm (include the visible and near infrared ranges) with a resolution of 4.68 nm, 128 bands. There are 520 × 696 pixels in one band, and the scanning velocity is 30 lines per second. The