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Visible-near infrared spectrum-based classification of apple chilling injury on cloud computing platform

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ABSTRACT

This paper evaluates the feasibility of applying cloud computing technology for spectrum-based classification of apple chilling injury. The reflectance spectra of Fuji apples with four different levels of chilling injury (none, slight, medium, and severe) were collected. During data processing, the spectra at 400–1000 nm were selected, and first- and second-order-derivative spectral data sets were obtained through integral transformations. Five optimal wavebands were chosen as inputs for the classification models. A cloud computing framework based on Spark and the MLlib machine learning library was used to realize multivariate classification models based on an artificial neural network (ANN) and support vector machine (SVM). The ANN and SVM classification models were used for multivariate classification and analysis of the spectral data sets (raw, first derivative, second derivative) and corresponding optimal wavebands. Of the total data samples, 70% were used for training, while the remaining 30% were used for prediction. The experimental results showed that, by using the cloud computing platform, we could establish an efficient spectrum classification model of apple chilling injury; the ANN model had slightly higher accuracy than the SVM model (not including the second-derivative spectra), but the SVM model was more efficient. Moreover, the classification accuracy using full-waveband spectral data sets was higher than that of data sets using five optimal wavebands. Furthermore, the Spark framework and MLlib were used to implement binary classification models (decision tree and random forest), and these were compared with the multivariate classification model; the binary classification method had better performance in near-infrared spectrum-based classification of apple chilling injury. Finally, we extended the existing spectrum data set to verify the efficiency of the cloud computing platform and desktop PC for handling larger data sets. The results showed that the efficiency of the cloud computing platform was significantly improved by increasing the spectral data set capacity or number of working nodes. Owing to processor and memory limitations, the classification algorithm and model of abundant spectral data sets cannot complete all of the tasks on a desktop PC.

1. Introduction

The apple is one of the five ‘healthy’ fruits recommended by the Food and Agriculture Organization, and it is ranked first for recommendations. In the 2016–2017 production season, the total global apple yield is expected to be around 77.6 million tons, and the worldwide demand for fresh apples continues to grow (USDA, 2016). Planting and harvesting of apples are affected by many factors, including the growth season, harvest time, and storage conditions.

Around 40 main varieties of apples are planted around the world. Apple trees have stable growth cycles under normal climatic conditions, and apples of different varieties have different harvest times. Some late-maturing varieties are picked in late autumn or winter, and when the weather becomes extremely cold or the temperature declines sharply, apples can incur chilling injuries. During the storage and transportation of applies, the fruit may be stored in a low-temperature and oxygen-deficient environment, and the peel and pulp may become damaged due to the low temperature, low oxygen, and low concentration of carbon dioxide (Lumpkin et al., 2014).

Chilling injury can result in poor sales of apples (Watkins and Nock, 2004). It is difficult to detect and diagnose chilling injuries at an early stage, because as long as the apples remain in a low-temperature environment, they look normal on the outside; chilling injury symptoms only become apparent as the temperature rises (ElMasrya et al., 2009).

To date, many researchers have studied chilling injuries in apples. The research of Watkins and Liu (2010) showed a risk of fruit browning when stored at a temperature below 0 °C, and when apples were stored at a temperature above 3 °C, there is a risk of senescent breakdown. Val

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Fig. 1. Chilling injury categories.

et al. (2010) stored apple samples in a cold storage environment (0–4 °C) for 4 months, and used the low O_2 pre-treatment method to reduce the rate of stippen (14%). ElMasrya et al. (2009) used hyperspectral images and an artificial neural network (ANN) to build an analysis model of "Red Delicious" apple chilling injuries. Leisso et al. (2015) studied the influence of fruit peel damage to "Honeycrisp" apples, stored under low-temperature storage conditions, on oxidation resistance and lipid and phenolic metabolism.

Visible–near infrared (VNIR) spectrum technology has been used widely for quality inspection of apples and for natural disaster-related inspections. VNIR can be used to determine the harvest time in accordance with changes in apple pigment and internal components (Bertone et al., 2012), and to predict storage quality (Ignat et al., 2014). VNIR can also be used to analyze common types of damage to apples, such as chilling (ElMasrya et al., 2009), sunburn (Torres et al., 2016), and scratch injuries (Luo et al., 2012).

Cloud computing has an important role in the development of modern agriculture, where it has been a driving factor of progress in the field of precision agriculture (Nguyen et al., 2017). With the wide range of information collected in the agricultural field, and increases in the overall volume of data, high-performance computation based on cloud computing can be used in agriculture and other data-intensive disciplines to collect, save, analyze, mine, and make predictions based on big data information. High-performance computation may also allow for faster and more accurate agricultural management, which could improve decision-making quality, reduce information asymmetry, and increase profits (Woodard, 2016; Lokers et al., 2016). At present, researchers are applying cloud computing technology to the field of precision agriculture, such as for greenhouse environment monitoring and decision-making, intelligent agricultural environment management, and crop performance analysis and recommendations (Vatari et al., 2016; Radu et al., 2016; Jayaraman et al., 2016).

This study was performed to evaluate the application of VNIR spectroscopy and cloud computing to classify apple chilling injury. This study had the following research objectives: (1) classification of the chilling injury of Fuji apple under low-temperature storage conditions; (2) determination of the optimal waveband for apple chilling injury detection; (3) use of cloud computing technology to develop and verify the spectrum classification model for apple chilling injury; and (4) performance analysis of a cloud computing platform. The results of this study should be useful for agricultural product detection and contribute to the agricultural application of cloud computing technology.

2. Materials and methods

2.1. Apple samples

In total, 240 Fuji apples were purchased from a local retailer; these apples were fresh, with no apparent mechanical damage, plant disease, or insect pests. Experiments were conducted at Jiangsu Academy of Agricultural Sciences. First, all apples were stored at 20 °C for 24 h. Then, the apples were divided into two groups: one group consisted of 140 apples that were stored at 0 °C with a relative humidity of 80–90% for 11 weeks, while the other 100 apples were stored at −1 °C with a relative humidity of 80–90% for 14 weeks. Before spectral measurements, all 240 apples were stored at 20 °C for 24 h to observe any symptoms of chilling injury. Then, we collected the external reflectance spectra of all of the apple samples. Classification was conducted in accordance with the degree of damage to the apple surface.

2.2. External visible–near infrared reflectance spectroscopy measurements

The ASD FieldSpec HandHeld[2] portable spectrometer was used to collect external reflectance spectra of the sample apples. The spectra were collected over the wavelength range of 325–1075 nm; the spectral resolution was less than 3 nm and the integral time was 8.5 ms. A circular, white reference plate with a size of 3.6 cm^2 was used for spectral equilibration and calibration. For each apple sample, the reflectance spectrum samples of chilling injured area was scanned twice, and the mean value was calculated. Fig. 1 shows the external condition of apples with different degrees of chilling injury.

2.3. Grading of apple chilling injury

All apples kept under two different storage conditions were used for the classification of apple chilling injury. The apples suffered more severe chilling injury at lower temperature with a longer storage time. During low-temperature storage of fruit, the classification of chilling injury can be performed according to the texture, browning, dryness, and smell of the fruit (Cai et al., 2010; Sun et al., 2017). For example, the harvest time, size, and maturity of an apple all affect the likelihood of chilling injury. Under similar storage conditions, not all apples will present with the same degree of chilling injury at low temperatures; that is, the development of injury varies among individual apples. Thus, in accordance with the texture, taste, and smell of an apple, chilling injury can be classified into four levels: 0 = none, 1 = slight, 2 = medium, and 3 = severe.

In accordance with the classification principles described in Table 1, manual observation and screening of the 240 sample apples were

Table 1
Sensory evaluation of degree of apple chilling injury.

Level	Texture	Taste	Smell	Classification
Level 0	Lustrous and smooth	Crisp and sweet	Obvious fragrance	None
Level 1	Slight wrinkling	Slight rottenness, still edible	Slight fragrance	Slight
Level 2	Partial softening	Partial rottenness, still edible	Slight rotten smell	Medium
Level 3	Soft and not crisp	Soft, not edible	Obvious rotten smell	Severe