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Automatic threshold method and optimal wavelength selection for insect-damaged vegetable soybean detection using hyperspectral images

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ABSTRACT

Insects in vegetable soybean undermine the quality and safety of soybean products. Thus, a non-destructive technique of detecting insect-damaged vegetable soybean must be developed. An efficient detection method based on a hyperspectral image was proposed by selecting the region of interest (ROI) through automatic threshold segmentation and optimal wavelength selection using the fuzzy-rough set model. For the 362 samples of beans, three image features (i.e., entropy, energy, and mean) of the ROI were extracted as classification features, whose spectral region covered 400–1000 nm and contained 94 wavelengths. Three or less optimal wavelengths were then selected using a fuzzy-rough set model based on the thermal charge algorithm (FRSTCA). Support vector data description (SVDD) was used to develop classification models for the insect-damaged soybean. For the prediction samples of the beans, the classification results indicated that the normal samples were 100.0% correctly classified using the automatic extracting ROI method based on automatic threshold segmentation. The classification accuracy for the insect-damaged samples was 91.7%, and a 98.8% overall classification accuracy was achieved with the FRSTCA selecting two wavelengths.

1. Introduction

The vegetable soybean known as green soybean is delicious in taste and nutritious (Hou et al., 2011) to be welcomed by people. In the process of growth, the vegetable soybean would be affected by insects, and the insect-damage (e.g., pod borer) of soybean is difficult to control. However, with the spread of organic practice and concern of environmental protection, fewer chemical pesticides are used, which increases the insects found potential in vegetables and fruits. Insects in vegetable soybean products cause potential harm to consumers, so countries around the world proposed strict requirements against the number of quarantine insects for imported legumes. For example, America import and export trade standards require the number of pod borer not more than 1 for each 26 pounds, and the length of pod borer is less than 0.7 cm in legume agricultural products. The stringent requirements for the occurrence of insects in vegetable soybean impose great pressure on soybean industry and impede the export of vegetable soybean. The main insects to soybean include pod borer, whitefly, aphids, black cutworm, cutworm and other 13 kinds of insects (Liu et al., 2011), among which pod borer is a worldwide pest to vegetable soybean. The life cycle of pod borer consists of egg, larva, and moth. The larva of pod borer is a serious damage source to the vegetable soybean because the larva is born into the pod, and feeds on the bean, which results in shriveled pod, empty pod and also damage the petiole and stem (Okeyoowuor et al., 1991). Although the internally damaged soybeans cannot be easily distinguished from the normal ones by their external appearances, identifying them during processing is indeed beneficial to both consumers and industries. Excluding these damaged soybeans can diminish the possibility of having infested soybeans in the final products, which is forbidden by food safety regulations. An efficient detection method is needed to detect insects in the vegetable soybean considering the quality and safety of soybean products.

A number of techniques have been studied to detect internal pests in agricultural products, such as the sound method (Hagstrum et al., 1990), the Microwave radar method (Mankin, 2004), conductivity technology (Pearson and Brabec, 2002), near-infrared spectroscopy technology (Dowell et al., 2002, 2010), X-ray technology (Melvin et al., 2003), and machine vision technology (Zayas and Flinn, 1998). However, these methods are

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either destructive or complex and have difficulty in detecting larva or dead insects. Compared with the methods above, the hyperspectral imaging technique provides a noninvasive and accurate food and agricultural product inspection system because it gives more information about the sample to be detected. Such information includes the internal structure characteristics, chemical composition, the morphology information. The applications of hyperspectral imaging technology in fruit and agricultural products detection include the following: the measurement of the optical properties of fruits and vegetables (Qin and Lu, 2008), the classification of internally damaged fruits or vegetables (Nakariyakul and Casasent, 2011; Lü and Tang, 2012; Lorente et al., 2012), the detection of the internal quality of fruits (Huang and Lu, 2010), and insect detection (Singh et al., 2009; Bhuvaneswari et al., 2011; Zhao et al., 2012). From the work of Huang et al. (2013) who adopted hyperspectral transmittance images to detect insect damage in vegetable soybeans, hyperspectral imaging technology was concluded to be feasible for detecting insects inside vegetable soybean.

Given that the insect feeds on the bean, the position of the bean should be considered in the region of interest (ROI) to study the change of the chemical composition, the organization structure of the soybean, and detect the insect. When detecting insects in vegetable soybean, the typical approach for selecting a ROI of vegetable soybeans relies on a manual method that controls selection in software (Huang et al., 2013). However, the manual method in selecting this ROI requires a large amount of time and a complex format conversion, speed and the human disturbance factors could undermine the efficiency and accuracy of this method. Besides, Huang et al. (2013) used the full wavelengths to develop a classification model for the insect-damaged soybean detection, which it is not suitable for a real-time assessment because of the time-consuming computation in the image processing. As a follow-up study, the automatic threshold segmentation based on the iteration method and an optimal wavelength selection method were investigated to provide a new approach for the real-time and online detection of hyperspectral images.

The following is a description of the overall approach of insect-damaged vegetable soybean detection: (a) vegetable soybean hyperspectral images within the spectral range of 400–1000 nm are acquired. (b) Automatic threshold segmentation based on the iteration method for image segmentation is adopted to extract the ROI of the soybean. (c) The fuzzy-rough set model based on the thermal charge algorithm (FRSTCA) is applied to select the optimal wavelengths. (d) SVDD is used to develop the classification model for insect-damaged vegetable soybean detection.

2. Materials and methods

2.1. Vegetable soybean samples

In this experiment, vegetable soybean samples were acquired from the garden of Haitong Food Company in Cixi, Zhejiang Province in 2013. They were then sorted, washed, blanched. Before each experiment, these samples were kept at room temperature (~24 °C) for approximately four hours to ensure that the samples were completely thawed. Each sample was assigned with a number. A normal sample is defined as intact on the surface, without insects in the internal area, have intact beans, and set to level 1. Samples representing two quality grades are shown in Fig. 1. An insect-damaged sample is defined as having no poles outside, but with insects in the internal area, or internal contain insects' excrement, and set to level-1. The levels of 1 and -1 were used as labels in classifications.

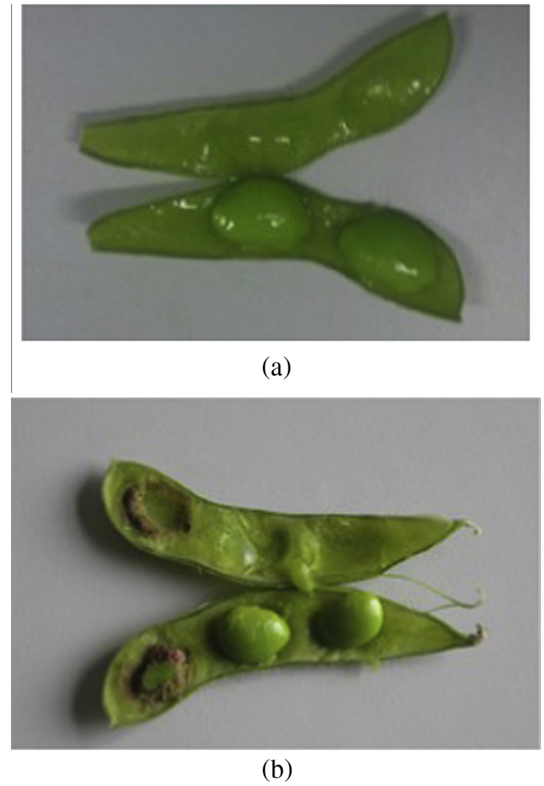

Fig. 1. Vegetable soybean beans representing two quality grades: (a) normal and (b) insect-damaged.

2.2. Hyperspectral transmittance image acquisition

A hyperspectral transmittance imaging system is schematically shown in Fig. 2. An in-house, line-scan hyperspectral imaging system was used to acquire hyperspectral transmittance images from vegetable soybean pods. This system consisted of a hyperspectral imaging unit, a sample handling unit, and a DC-regulated light source. The hyperspectral imaging unit was made up of a

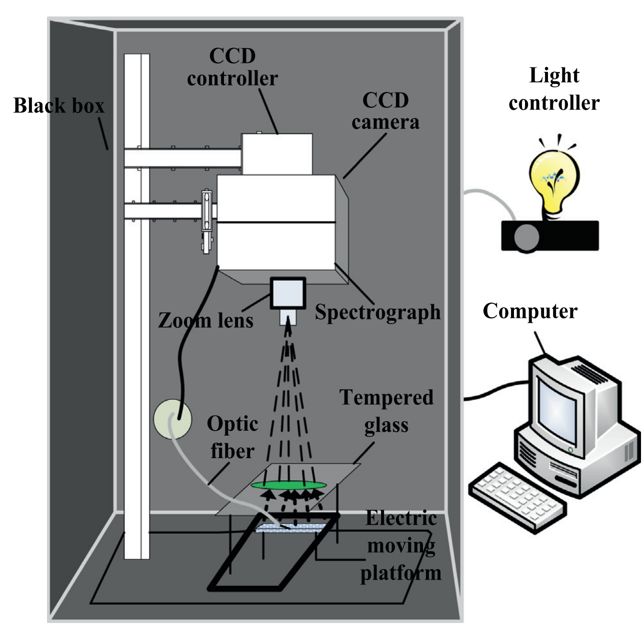

Fig. 2. Schematic of the hyperspectral transmittance imaging system.