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Detection of insect-damaged vegetable soybeans using hyperspectral transmittance image

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ABSTRACT

Insects in vegetable soybean products pose potential hazard to consumers, thus making the food industry liable for economic losses. The objective of the current study is to develop a hyperspectral imaging technique for detecting insect-damaged vegetable soybeans. Hyperspectral transmission images were acquired from normal and insect-damaged vegetable soybeans over the spectral region between 400 nm and 1000 nm for 100 vegetable soybean pods (225 beans). Four statistical image features (minimum, maximum, mean, and standard deviation) were extracted from the images for classification and given as input to a discriminant classifier. The support vector data description (SVDD) classifier achieved 100% calibration accuracy. SVDD achieved 97.3% and 87.5% accuracies for normal and insect-damaged samples, respectively, with a 95.6% overall classification accuracy, for the investigated independent test samples. Therefore, the hyperspectral transmittance technique can discriminate insect-damaged vegetable soybeans.

1. Introduction

Vegetable soybean, commonly known as green soybean, is favored by people from different countries because of its rich and unique nutritional value (Hou et al., 2011). However, a major moth of the Phaseolus lunatus, Etiella zinckenella Treitschke, usually damages soybean, as well as cowpeas, beans, lentils, peas, and other species of Fabaceae, especially those that creep into the pod on the larva stage. Furthermore, picking out insect-infested beans judging solely from the external appearance of the pod is very difficult. Etiella zinckenella Treitschke in bean crops brings potential hazard to the consumer and reduces the economic benefits of vegetable soybeans. Hence, an effective detection technique is needed to ensure that final soybean products are not infected with insects.

A number of techniques have been studied to detect internal pests in crops including proportion method (Milner, 1958), sound method (Hagstrum et al., 1990), conductivity technology (Pearson and Brabec, 2002), X-ray technology (Melvin et al., 2003), near-infrared spectroscopy technology (Ridgway and Chambers, 1998). However, these technologies have complex or destructive shortcomings. In addition, detecting dead and larva insects is difficult. Moreover, the detection environment contributes to unsatisfactory results. Machine vision technology has been widely applied for the detection of external pests in agricultural products, achieving good results. However, penetrating the insides of the pods using machine vision technology with a visible light source is difficult. Therefore, it is not suitable for the detection of internal pests, such as Etiella zinckenella Treitschke, in soybean pods.

As a novel, non-destructive technology, hyperspectral imaging covers both visible and near-infrared wavelength information coupled with image information. These features can provide more detection information, including internal structure characteristics, morphology information, and chemical composition, compared with a single machine vision technology or spectroscopy analysis technology. Hyperspectral imaging technology has been studied in agricultural fields, including the detection of the internal quality of fruits (Lu and Peng, 2006; Huang and Lu, 2010; Naganathan et al., 2008), identification of the internal damage of pickling cucumbers (Ariana and Lu, 2008), and the acquisition of crop growth information (Ruiz-Altisent et al., 2010; Ramalingam et al., 2005). Recently, there are some reports for insect detection using the hyperspectral imaging technology. Xing et al. (2008) used the hyperspectral transmittance and reflectance images to detect internal insect infestation in tart cherry. Singh et al. (2009) identified insect-damaged wheat kernels using the near-infrared hyperspectral imaging technology. Singh et al. (2010) adopted short-wave near-infrared hyperspectral and digital color images to detect the insect-damaged wheat kernels. Wang et al. (2011) detected external insect infestations in jujube fruit using hyperspectral reflectance imaging. Hence, it is a promising technology for detecting insects inside vegetable soybean pods.

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The overall objective of this work in the current research was to use a hyperspectral transmittance imaging technique for detecting insect-damaged vegetable soybean in the vegetable soybeans.

2. Materials and methods

2.1. Vegetable soybean samples

One hundred vegetable soybean samples harvested from the garden of Haitong Food Company in Cixi, Zhejiang Province during the 2011 harvest season were used in the experiment. The samples were kept in the freezer (−20 °C) after preprocessing, prior to the experiment. These vegetable soybean samples were kept at room temperature (∼24 °C) for about four hours before the experiment was started.

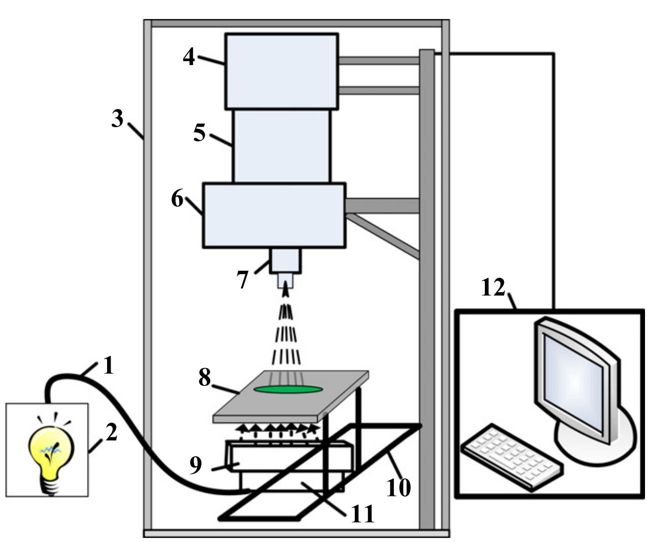
Unfortunately, there were only a few occurrences of insect-damaged vegetable soybeans. Consequently, vegetable soybean samples with insects were difficult to obtain. Only eight insect-damaged vegetable soybeans were obtained (i.e., the beans either had an insect inside it without a hole on the surface, a small hole on the surface, or an insect excrement inside or in a small hole on the surface). The rest of the samples were all in good condition.

2.2. Hyperspectral transmittance image acquisition

An in-house developed line-scan hyperspectral transmittance imaging system was used to acquire hyperspectral transmittance images from vegetable soybean pods (Fig. 1). The hyperspectral transmittance image system mainly consisted of a hyperspectral imaging unit, a transmittance light source structure, and a sample handling platform. The hyperspectral imaging unit was made up of a back-illuminated 1392 × 1024-pixel CCD (charge-coupled device) camera (pixelfly QE IC*285AL, Cooke, USA), an imaging spectrograph (1003A – 10140 Hyperspc™ VNIR C-Series, Headwall Photonics Inc., USA) with 20 µm slit covering an effective range of 400 nm to 1000 nm connected with a zoom lens (10004A-21226 Lens, F/1.4 FL23 mm, Standard Barrel, C-Mount., USA), and a computer for controlling the camera and acquiring the images. The transmittance light source structure was composed of a 150-W DC light source (halogen lamp, 3250 K, Techniquip, USA) and a single optic fiber coupled with a 3″ lightline (9135-HT) and a 3″ diffuser to evenly deliver 90 mm × 20 mm light to the sample. The sample handling unit consisted of a horizontal motorized stage; a bracket fixing; and a two-millimeter thick, 100 mm × 100 mm, 92% transmission sodalime glass (ROCOES Electro-Optics CO., Ltd. Taiwan). Each test vegetable soybean pod was placed onto the glass; the sample was oriented such that its stem-calyx axis was kept parallel to the scanning line of the hyperspectral imaging unit. A 30 mm scan length of longitudinal and a 60 µm horizontal step size parameters were preset to acquire the whole undistorted image of one soybean sample. The horizontal motorized stage automatically moved the sample to the pre-determined initial position. The transmitted light illuminated the sample under the glass vertically. The horizontal stage then started to move horizontally, as synchronized with the acquisition of the camera of hyperspectral transmittance images from the sample.

A total of 500 scans covering 30 mm distance were acquired for each test sample at an exposure time of 180 ms for each hyperspectral image. The imaging spectrograph has a 1.29 nm/pixel spectral resolution and a 0.15 mm/pixel spatial resolution. Hyperspectral imaging system has a 0.64 nm/pixel spectral resolution covering the spectral region of 400 nm to 1000 nm using a 1392-pixel camera. The resulting hyperspectral transmittance images had 6.4 nm-spectral resolution per pixel and 94 wavelengths after 10 spectral binning operations. Thus, a special block of 1392 × 500 × 94 transmittance image was created; that is, one represented a 2-D image with *x* axis and *y* axis coordinate information and the other represented the spectral information. Hyperspectral transmittance images of the glass and the darkness were also acquired for every 10 samples. These images were used as references to calculate the relative transmittance images of the samples.

Hand-peeling tests were performed after the acquisition of hyperspectral transmittance images to detect whether insects were in the samples.



1. Optic fiber 2. Light controller 3. Black box 4. CCD controller

5. CCD camera 6. Hyperspectral imaging spectrograph 7. Zoom lens 8. Sodalime glass

9. Diffuser 10. Electric moving platform 11. 3” lightline 12. Computer

Fig. 1. Schematic of the hyperspectral transmittance imaging system.

2.3. Data analysis

Hyperspectral transmittance images contained both spectral information and image information for each vegetable soybean. The relative transmission images were obtained by the following equation:

$$T_R = \frac{T_A - T_D}{T_G - T_D} \tag{1}$$

where T_R is the relative transmission; T_A and T_G are the absolute transmission of a vegetable soybean sample and the sodalime glass, respectively; and T_D is the dark signal for the CCD detector. All further analyses were carried out on the relative transmission images.

Hyperspectral transmission images provide a huge amount of data for whole soybean pods. Among of this huge data, bean information of the pod are valid and important for the detection of insect-damaged soybean. Thus, a selected rectangular region of interest (ROI) (called sub-image) was obtained from each relative hyperspectral transmission image in the position of every bean to guarantee the integrity of each bean. A 3 × 3 median filter was applied to the sub-images to reduce the noise. A total of four statistical sub-image features, namely maximum, minimum, mean, and standard deviation were extracted used the software of ENVI V.4.3 (Research System, Inc., USA), and given as input to the discriminated classifier.