Identifying Leaf-Scale Wheat Aphids Using the Near-Ground Hyperspectral Pushbroom Imaging Spectrometer

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Abstract. This study is to identify leaf-scale wheat aphids using the near-ground hyperspectral Pushbroom Imaging Spectrometer (PIS). Firstly, the spectral characteristics between normal and aphid-infested wheat leaves were compared in spectral reflectance. Concerning the serious aphid damage level, it is obvious that its spectral curve is badly flattened such as green peak (centered around 550 nm), red valley (centered around 680 nm), due to the influence of aphid. Specifically, in the visible spectrum (500-701 nm), the maximum delta (the maximum value minus the minimum value) is 3.3 and it is 7.5 in the near-infrared spectrum (701-900 nm). Then, the spectral difference and change rate were further analyzed. It seems that both curves show the mirror symmetry and their maximum values are 55.8% and 17.4%, respectively. For the difference curve, the value is negative in the visible spectrum (400-700 nm), which shows that the reflectance of normal wheat leaf is less than that of the serious level. Conversely, it is greater in the near-infrared spectrum (700-900 nm). Finally, based on the high spatial resolution PIS image, ENvironment for Visualizing Images (ENVI-EX) was utilized to extract aphids and the overall accuracy reaches 97%. The result indicates that the PIS is sufficient to identify the wheat aphids and this study can lay a foundation for further applications in precision agriculture using such a hyperspectral imaging system.

Keywords: Hyperspectral remote sensing, leaf-scale, pushbroom imaging spectrometer (PIS), spectral characteristics, wheat aphids.

1 Introduction

Wheat (Triticum aestivum L.) is one of the most important cereal crops and it has been used as major consumable commodity by human beings in most areas of the

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world. However, global climate change has exerted a negative impact on wheat production [1]. As a result, the incidence of various kinds of stress is becoming more often, among which diseases and insects have strongly affected the wheat crop. As one of the most important insects in winter wheat, aphids (Rhopalosiphum padi L.) have caused significant losses in its quantity and quality [2]. In addition, insects and diseases in wheat can spread at a fast pace and serious hazards can be induced if they are not timely detected and prevented. Therefore, some effective measures must be taken to reduce production losses and ensure food safety. Nevertheless, on-farm pest management and crop protection strongly depend on diagnosis of disease or insect stresses in fields, while traditional field survey methods are labor-intensive and time-consuming, and they cannot yield full coverage [3]. Accordingly, it is of great importance to accurately monitor and evaluate the wheat aphids in a noninvasive and nondestructive way. On the other hand, it is also essential for ensuring that pesticide spraying can be limited and more time- and site-specifically [4].

With the fast development of advanced sensors and image processing techniques, quantitative remote sensing has facilitated extraordinary advances in monitoring and identifying wheat insects [5]. When it is infested, the reflectance spectra are obviously different between healthy and infested plant. To detect such a stress using the remote sensing, it is based on the assumption that insect stress interferes with photosynthesis or physical structure of plant. Furthermore, such destruction affects the absorption of light energy, and thus alters the reflectance spectra at different damage levels [6]. In previous studies, multi-spectral remotely sensed data were usually utilized to identify and monitor the crop stresses in several bands at a large scale in the visible and near-infrared regions [7-9]. However, the crude spectral resolution of the reflected and emitted energy from the earth is the primary limiting factor in differentiating subtle differences of plant stresses [10]. Consequently, hyperspectral remote sensing is currently being investigated by scientists with regard to the detection and identification of plant health/stress status [11]. Although airborne and spaceborne hyperspectral sensors can also acquire simultaneously imaging and spectrum in a single scanning process, lack of near-ground prior knowledge of stressed plants has greatly limited such data in the wide applications of precision agriculture. Conversely, near-ground hyperspectral imaging devices can derive the refined spectral characteristics of stressed plants in fields, which can lay the methodological foundation for those hyperspectral data at large spatial scales and further provide the ground truth data for accuracy validation.

By comparing with commonly used hyperspectral spectrometers such as the ASD (Analytical Spectral Devices, Boulder, CO, USA), near-ground hyperspectral imaging device can acquire simultaneously imaging and spectroscopy in a single system, which can be an effective tool in describing the variability between healthy and infected plants. In the last several years, more attention has only been paid to such an imaging device. Several studies have shown that the near-ground hyperspectral imaging systems can detect insect- and disease-infested plants in a non-invasive and non-destructive way [12-14]. However, corresponding applications and processing techniques have not yet been enough explored in detecting wheat insects or diseases [15-16]. Therefore, based on the Pushbroom Imaging Spectrometer (PIS), the primary objective of this study lies in characterizing the spectral characteristics of leaf-scale wheat aphids and identifying the aphids using the high spatial resolution image.

2 Materials and Method

2.1 Near-Ground Hyperspectral Imaging Device

The hyperspectral imaging device used in our study is the PIS, which was jointly developed by Beijing Research Center for Information Technology in Agriculture and University of Science and Technology of China. This system acquires images by linear array push-broom imaging and Fig. 1 is the demonstration of collecting hyperspectral imaging data. Table 1 shows some key specification parameters of the PIS. It is obvious that PIS is superior to the commonly used ASD field spectrometer in spectral resolution and sampling interval. Additionally, the PIS can also acquire spectro-images with a very high spatial and spectral resolution by which land features of interest can be identified.

Table 1. Some key specification parameters of the PIS imaging system

Sensor parameters	PIS
Spectrum range	400~1000 nm
Spectral resolution	2 nm
Sampling interval	0.7 nm
FOV	16°
Spatial resolution	5-10 mm
Pixel dimension	7.4 μm×7.4 μm
Image resolution	1400 (Spatial dimension) × 1024 (Spectral dimension)

2.2 Data Acquisition and Preprocessing

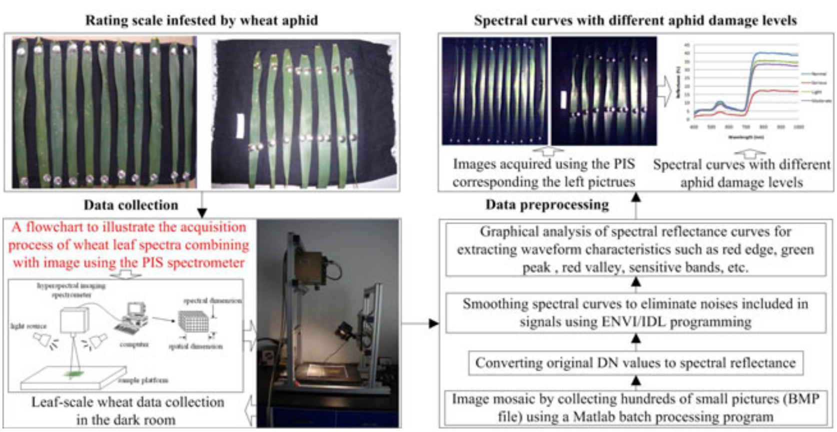


Fig. 1. A demonstration of acquiring the spectra combing with image of different aphid damage levels using the PIS

An experiment was carried out at the experimental farm of Beijing Academy of Agriculture and Forestry Sciences (39.93° N, 116.27° E) on 26 May 2010. At that time, it was just the grain-filling stage of winter wheat, which is the key yield-forming period and is also extremely sensitive to various kinds of biological disasters. In this study, wheat aphids were used as the study object. When aphid-infested symptoms of wheat leaves were evaluated, relative insect damage levels were assessed according to the aphid populations under the help of experienced pathologist.

Before using the device to measure wheat leaves, strict laboratory calibration must be firstly performed for ensuring a high radiometric accuracy. When collecting the reflectance spectra, the PIS lens was set at 80 cm over the wheat leaves and halogen lamp irradiation was fixed at a 45° angle. Then, the inverse 2nd leaves were picked up and immediately put onto the scanning platform, and the PIS moved evenly along the track and the image and spectra of wheat leaves on the black cloth were acquired (Fig. 1). Before and after collecting the leaf spectra, white reference panel was used to optimize the instrument. Finally, further processing were required to covert the original DN (Digital Number) values to reflectance by the empirical linear method (Eq. 1). Afterwards, a moving-average smoothing algorithm was utilized to exclude abnormal values and smooth the spectral curves in order to accurately derive the reflectance characteristics between healthy and aphid-infested wheat leaves.

$$\rho = a * DN + b \ . \tag{1}$$

Where ρ is the real reflectance, a and b are the coefficients. When putting the measured spectral value and corresponding DN into Eq. 1, a and b can be obtained by Least-Square Method (LSM), and then ρ can be obtained.

3 Results and Discussion

3.1 Analysis of Spectral Characteristics of Leaf-Scale Wheat Aphids

On the high-resolution PIS image (Fig. 2(a)), two pixels including a healthy leaf point and an aphid-covered leaf point were selected. Fig. 2(b) is the comparative result of their spectral reflectance curves in the 500-900 nm spectral range. It is obvious that the spectral reflectance values are markedly different between normal and aphid leaves. Furthermore, between 500 nm and 701 nm, the reflectance of aphid leaf is larger than that of normal leaf, while it is smaller in the 701-900 nm spectral regions. In the visible spectrum (500-701 nm), the maximum delta (the maximum value minus the minimum value) is 3.3 and it is 7.5 in the near-infrared spectrum (701-900 nm). Concerning the locations of the minimum value, they are very similar between normal and aphid pixels, which are 664 nm and 661 nm, respectively. However, they are very different for the locations of maximum values which are 785 nm and 852 nm, respectively.

Comparing the spectral curves between normal and aphid-infested leaves, it can be found that both of them show the typical spectral characteristics of green vegetation: green peak centered around 550 nm, red valley centered 680 nm and high near-infrared reflectance centered around 780 nm, but they are different at specific spectral values for different damage levels. Furthermore, comparing the reflectance between the visible and near-infrared spectra, the spectral differences are more obvious in the near-infrared spectrum. Nevertheless, the spectral curve of aphid-affected leaf is badly flattened especially for the characteristic bands such as green peak, red valley owning to the influence of aphid.

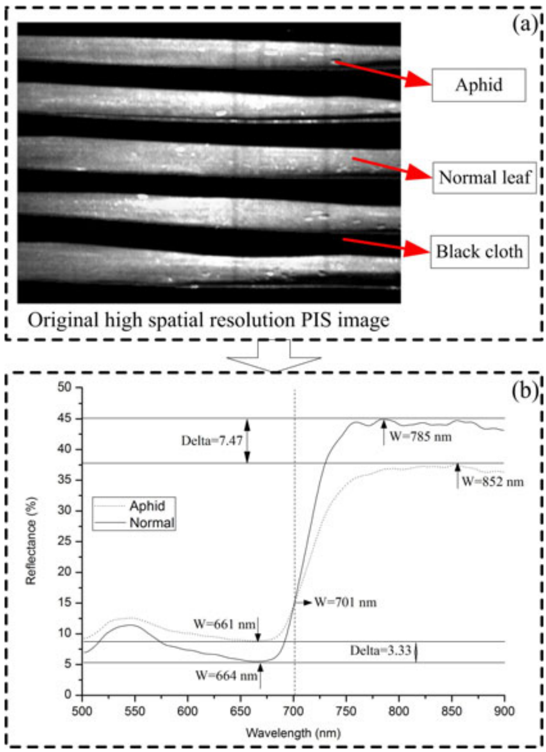
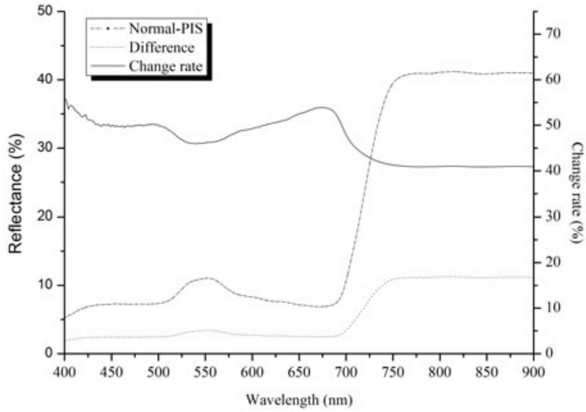


Fig. 2. The comparative of spectral curves (b) between normal and aphid-infested leaves on the PIS image (a)

Additionally, the analysis of spectral difference and change rate were also performed between normal and seriously aphid-affected leaves (Fig. 3). Due to the constraint of spectral range, the PIS can only obtain the spectral characteristics in the visible and partial near-infrared wavelength. In the 400-900 nm spectral regions, it can be found that they are very different in the spectral difference and change rate curves. It seems that they show the mirror symmetry and the maximum change rate and difference are 55.8% and 17.4%, respectively. As can be seen in the difference curve, the value is negative in the visible spectrum (400-700 nm), which shows that the reflectance of the normal wheat leaf is less than that of the serious level. Conversely, it is greater in the near-infrared spectrum. This phenomenon shows that the reflectance is determined by different factors in the visible and near-infrared spectral ranges. For the change rate curve, it fluctuates more severely in the visible spectrum than in the near-infrared spectrum, which shows that aphids exerted more evident impact in the visible spectrum.



Difference=f_{Normal}-$f_{Serious}$; Chang rate=Difference/f_{Normal}; f is the spectral reflectance.

Fig. 3. Analysis of spectral difference and change rate between healthy and seriously aphid-affected wheat leaves

The phenomenon for the change trend of spectral curves is that aphids cover the top of wheat leaf and they destroy the cell structure and change the chlorophyll content. In the visible spectral range, the reflectance of wheat leaf is mainly determined by various pigments, among which, chlorophyll is a leading one. When aphids break the wheat leaf, chlorophyll content will accordingly decrease which result in an increase of reflectance owning to the decreasing ability of chlorophyll absorption. Additionally, the secretions of aphids adhere to the leaf top can absorb some dust and other materials and increase the reflectance to a certain degree. Conversely, the reflectance depends on the cell structure in the near-infrared spectrum. Aphids destroy the cell structure of wheat leaf, so the reflectance of aphid-infected leaf decreases compared with the normal leaf.

3.2 Identifying Aphids Using the PIS Image

Based on the high spatial resolution PIS image, aphids were identified. Due to the only leaf-scale analysis in this study, it is easy to separate aphids from leaf background. Here, the ENVI-EX (ENvironment for Visualizing Images, Research Systems, Inc.) feature extraction module was used owning to the obvious aphid texture and single background. As shown in Fig. 4(a), there are five necessary steps to complete the object-oriented classification including choosing the scale parameter, merging the object primitives, refining the objects using a threshold value for just one band of the image and it is an optional step, extraction of the attributes, and object-oriented classification based on rules or examples. As can be seen on the aphid identified image (Fig. 4(b)), it is obvious that most aphids were extracted from normal wheat leaves. To evaluate the classification accuracy, 30 aphid pixels were randomly selected in the ENVI environment, and then they were found on the classification map using the link displays tool o ENVI. The comparative result showed that 29 points were correctly identified and the overall accuracy reached 97%.

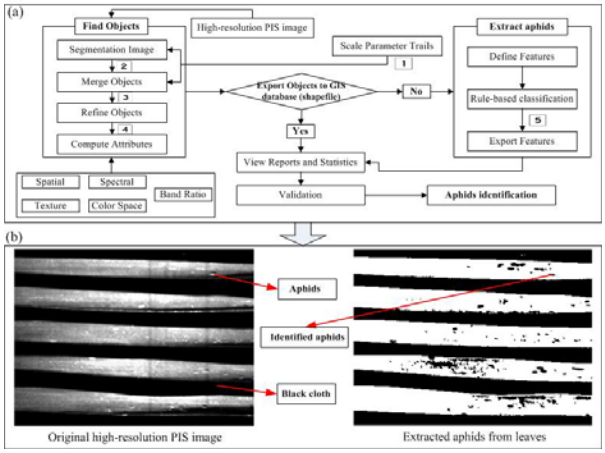


Fig. 4. The technical flowchart for identifying leaf-scale aphids using the ENVI-EX object-oriented classification module (a) and (b) is the high-resolution image acquired by the PIS spectrometer and the identification result

4 Conclusion

In our study, near-ground hyperspectral imaging data (PIS) were used to identify leaf-scale wheat aphids. By analyzing the spectral characteristics between normal and aphid-affected wheat leaf and classifying aphids using the PIS image, it has been proved to be an effective tool for identifying aphids using such a hyperspectral imaging system. According to the above analysis, we drew several conclusions: (1) the PIS can combine imaging with spectrum in a single system compared with commonly used non-imaging ASD spectrometer; (2) the PIS can collect the pixel-to-pixel spectrum, so it can obtain the pure spectral information on the basis of identification of targets of interest; (3) when the PIS is used in the canopy-scale wheat aphids, it will be more accurate to identify the targets of interest by using simultaneously spectral and spatial information of the PIS; (4) owning to very high spatial resolution of the PIS image, it will be very suitable for identifying the targets of interest using the object-oriented classification method.

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