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RESEARCH ARTICLE

Development of a Vehicle-Mounted Crop Detection System

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Abstract

In order to monitor plant chlorophyll content in real-time, a new vehicle-mounted detection system was developed to measure crop canopy spectral characteristics. It was designed to work as a wireless sensor network with one control unit and one measuring unit. The control unit included a personal digital assistant (PDA) device with a ZigBee wireless network coordinator. As the coordinator of the whole wireless network, the control unit was used to receive, display and store all the data sent from sensor nodes. The measuring unit consisted of several optical sensor nodes. All the sensor nodes were mounted on an on-board mechanical structure so that the measuring unit could collect the canopy spectral data while moving. Each sensor node contained four optical channels to measure the light radiation at the wavebands of 550, 650, 766, and 850 nm. The calibration tests verified a good performance in terms of the wireless transmission ability and the sensor measurement precision. Both stationary and moving field experiments were also conducted in a winter wheat experimental field. There was a high correlation between chlorophyll content and vegetation index, and several estimation models of the chlorophyll content were established. The highest R^2 of the estimation models was 0.718. The results showed that the vehicle-mounted crop detection system has potential for field application.

Key words: optical sensor, vegetation index, chlorophyll content, ZigBee, wireless sensor network (WSN)

INTRODUCTION

As an important part of precision agriculture, precision nitrogen management could have great economic and ecological benefits. Uniform fertilization is the conventional fertilizing method and may have a lower nitrogen use efficiency (NUE) because of the spatial variability of soil fertility. As the core of precision agriculture management, variable rate fertilization (VRF) can fundamentally solve this problem. This kind of management requires real-time detailed information on crop nitrogen content. However, at present the most common way to get the nitrogen content is by chemical analysis method in a lab, which is expensive, complicated and time-consuming.

On the other hand, spectral analysis has been widely applied in evaluation of crop nutrient status. Previous research revealed that nitrogen had a great effect on the chlorophyll content of the crop leaves, and could further cause a change of the spectral reflectance of the crop canopy (Filella *et al*. 1995). When the nitrogen content was deficient, the chlorophyll level in those plants decreased accordingly causing a decrease in spectral reflectance in the near infrared (NIR) and an increase in the visible waveband (Li *et al*. 2006). This characteristic made it possible to use spectroscopy to estimate nitrogen content. Since the 1970s, many related studies have been conducted. Walburg *et al*. (1982) reported that it was

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possible to estimate the nitrogen content in corn plants in terms of reflectance spectra from crop canopy. Xue *et al*. (2004) reported that a ratio index of reflectance in the NIR band to the green band (R810/R560) was capable of representing the nitrogen status of rice plants. Bell *et al*. (2004) measured the energy reflected from a turf grass canopy in the range 350-1 100 nm and found that there was an acceptable correlation between normalized difference vegetation index (NDVI) and chlorophyll content, and concluded that the NDVI could be used to estimate the chlorophyll content of turf grass. With the advantages of being non-destructive, simple and low-cost, spectral analysis devices have become more popular. Researchers have invented many kinds of crop detector based on the principles mentioned above. Sui *et al*. (2005) developed a device for detecting nitrogen status in cotton plants by measuring the spectral reflectance of the cotton canopy at four wavebands (blue, green, red, and NIR). Zhang *et al*. (2006) developed a handheld spectral instrument to diagnose the growth status of the crop in a greenhouse using optical fibers. Xu *et al*. (2008) developed an optical sensor after analyzing the optical characteristics of canopy spectral reflectance and the optical principle of non-destructive nitrogen monitoring. Some laboratory or handheld spectrometers with high accuracy have also been commercialized but most are expensive, fragile and difficult to use for on-the-go measurement.

Hence, it is necessary to develop a new vehicle-mounted detection system for easily monitoring crop canopy spectral characteristics. ZigBee, as a newly developed wireless communication technology, can organize a wireless sensor network (WSN) to make the system more flexible. Compared to Bluetooth or Wi-Fi, ZigBee has advantages such as an easier-to-use protocol, lower power consumption, higher reliability and lower costs which have made it more popular for agricultural use (Esfahani *et al*. 2008). Morais *et al*. (2008a, b) developed a wireless communication system based on ZigBee technology to support powdery mildew prediction in a vineyard. They chose a JN5121 ZigBee module to set up the network, and used solar panels as the power supply. Ruiz-Garcia *et al*. (2008) used wireless nodes for monitoring storage and transport of fruits. Liu *et al*. (2008) developed a farmland monitoring system for soil moisture and temperature based on ZigBee wireless sensor network. Park *et al*. (2011) used a ZigBee-based WSN connected with air temperature and air humidity sensors to monitor the leaf growing environment. Deng (2010) also built a ZigBee WSN system to collect the soil moisture, environment temperature and humidity information in field. In this paper, a system is described to work as a ZigBee wireless sensor network with one control unit and one measuring unit. All the units were installed on an on-board mechanical structure so that the detection system could measure crop spectral characteristics on-the-go and in real time.

RESULTS AND DISCUSSION

Test of the wireless performance

The wireless performance was tested at a winter wheat experimental field located in Changping District, Beijing. There were no obstacles between sensors and controller in the open wheat field. The link quality index (LQI) is an index related to the packet loss rate. The test of LQI was executed in the Shangzhuang Experimental Farm of China Agricultural University. Both sensor node and personal digital assistant (PDA) were placed in the 1 m of height and the test distances between the sensor nod and the PDA were set as 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, and 140 m, respectively. The experiments were repeated 100 times and then the LQI values were calculated. The results were shown in Fig. 1 and Table 1. It was observed that the communication of WSN was reliable when the distance was less than 100 m since LQI was greater than 40. It was confirmed that the wireless network could achieve the best communication quality when the antenna was placed vertically and meet the requirements of agricultural application.

Calibration of the optical performance

As described above, photodiodes were used as transducers. The output of each photodiode was current since it had proportional relation with the intensity of the light. And then the current was converted into voltage by a series of I/U converting circuit, conditioning circuit, amplifying circuit to become voltage at the range of 0-5 V