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IFAC-PapersOnLine 49-16 (2016) 194–198

Method of Measuring the Spectral Reflectance of Crop Canopy Based on Three-Dimensional Structural Analysis

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Abstract: Before measuring the spectral reflectance of a crop canopy, it is necessary to determine the distance from spectrometer to canopy or measure the distance in combination with field calibration after fixing the distance from canopy to spectrometer. However, the actual distance from canopy to spectrometer is hard to obtain as a canopy's reflecting surface is not a planar surface, increasing the difficulty of collecting data in agricultural fields and measurement errors. This paper describes a method of automatically measuring the distance from spectrometer to canopy using a binocular vision system. This method involved the use of binocular vision to obtain the three-dimensional (3D) point cloud data of crop canopy as well as a statistical analysis and weighting of the data obtained to automatically detect the distance from spectrometer to canopy. Reduced measurement errors compared to manual distance measurement and simplified reflectance measurement process can be achieved using this method. In this study, a set of miniature binocular cameras and an independently designed spectrometer were assembled and used to conduct a field measurement of the reflectance of wheat canopy. In the measurement experiment, the distance from spectrometer to canopy top was between 60 and 100 cm. The 3D point cloud density of the wheat canopy in the vertical direction followed a normal distribution; the values of canopy reflectance calculated by weighting the 3D point cloud data were stable, with a maximum relative deviation of 5.92%, an average relative deviation of 3.91%, and a relative standard deviation of 3.39%. The experimental results suggested that the proposed method enables automatic and stable determination of the distance from the spectrometer to canopy and avoids the need to consider the distance from canopy to spectrometer during reflectance measurement. Therefore, this simplified method can facilitate field measurement of spectral reflectance using a hand-held or rack-mounted spectrometer.

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Keywords: Crop canopy, Spectral reflectance, Distance Measurement, Binocular vision, Precision agriculture

1. INTRODUCTION

Acquisition of information about crop growth from the diffuse reflectance spectra of crop canopies is currently an important direction of research in the field of agricultural information. Scholars have done extensive, in-depth research on the relationship between diffuse reflectance spectra and related crop growth information (Daniel and John, 2002; Zhang et al., 2006). Nitrogen is an important factor affecting crop growth, and proper and timely nitrogen fertilizer management is an effective measure to improve crop yield and quality. Therefore, proper fertilization based on real-time information about crops' nutritional state plays a critical role in agricultural production (Bodo and Urs, 2008; Tianet al., 2005; Yoder and Pettigrewcrosby,1995). Driven by the rapid development of remote sensing techniques, a lot of studies have been conducted recently to discover the relationship between reflectance spectra of crop canopies and agronomic parameters of crops under different environmental conditions by means of plant spectrum analysis (Chen et al., 2012; Broge and Mortensen, 2002). Crop canopy spectrometer is an important means of practical application of this relationship. Related commercial products have emerged in some developed countries and the mainstream products commonly use active light sources (Erdle et al., 2011; Solari et al., 2008; Kipp et al., 2014). However, spectrometers of this type existing in China are normally imported at high prices, limiting extensive application of these instruments.

Spectral reflectance of canopy is an essential parameter considered in the creation of spectral index (Ding et al., 2013). In current common methods of measuring reflectance, canopy top is normally considered the reflecting surface of a crop canopy. However, this practice is unscientific because the reflection from crop canopy occurs, in fact, from a three-dimensional space rather than from the canopy top. Moreover, the distance from canopy to spectrometer is usually manually fixed at a certain value due to the lack of an effective method for determining the distance from canopy to the measuring equipment. This approach is inconvenient, inaccurate and inapplicable to real-time measurement in the field.

Commonly used methods of distance measurement, such as ultrasonic, infrared, and laser range finding, hardly apply to non-planar objects like crop canopies, because the results

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.036

usually exhibit apparent randomness. Binocular stereo vision, a 3D reconstruction method, has many uses in agriculture in China and other countries (Rovira-Mas et al., 2006; Kise et al., 2005; Francisco, 2003). In this study, the spatial distribution of a canopy was measured using the binocular vision technique and the distance from spectrometer to canopy was quickly derived from the distribution using a statistical method, thus avoiding the need to consider the distance from canopy to spectrometer during field measurement. This provides a new approach to dynamic measurement of canopy reflectance.

2. MATERIALS and METHODS

2.1 Binocular cameras

Each miniature camera used in the experiment has overall dimensions of 36.5 mm * 36.5 mm * 10.5 mm, 300,000 pixels and an image sensor with a minimum illuminance of 1.0 Lux. The NTSC/PAL video signals from the cameras were first decoded by video decoding chips and then processed by a DM642 hardware platform with a DSP/BIOS real-time operating system for image acquisition and analysis. The optical axes of the binocular cameras were in parallel and 800 mm apart.

2.2 Equipment for measuring canopy reflectance

A canopy reflectance measuring system based on active light sources independently developed by the author was used to measure the reflectance spectrum of crop canopy in the experiment. This system can emit two simultaneous bands of active light and the bands can be altered by changing the LED light source. The spectrometer allows users to pre-store a fitted equation describing the relationship between the spectral response of standard white plate and the distance from canopy to spectrometer so that the canopy reflectance can be derived from the distance from canopy to spectrometer and the spectral responses of the detected bands. Fig. 1 shows the field test using this stereovision.

2.3 Principle and Method of Measurement

A crop canopy is not a planar surface and the light received by the measuring system is reflected from leaves at different heights within the canopy. The intensity of reflected light is associated with the areas of reflecting surfaces and light path lengths. Therefore, the areas of reflecting surfaces and the distances from the reflecting surfaces to the measuring system should be considered when measuring canopy reflectance. The measurement method is based on the following principle: the distance from canopy to spectrometer can be determined by weighting the depth information of matching points in the canopy obtained by the binocular vision, and then the canopy reflectance can be measured based on the pre-stored reflection information of the standard white plate. There is no need for the users to consider the distance from canopy to spectrometer in practical application of this measuring system.

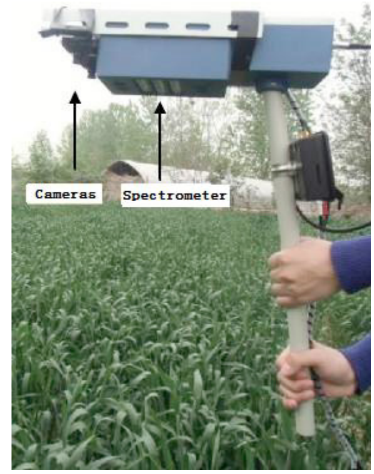

Fig.1 Experimental system consisting of binocular vision and spectrometer

2.4 Method of canopy reflectance measurement

The measurement method involved the following steps:

(1) First, the images taken from the left and right cameras were rectified and matching operations were performed on the rectified imaged using a matching algorithm to obtain the binocular disparities of the matching points;

(2) Depth information of effective matching points was extracted according to the internal and external parameters of the stereovision;

(3) The distance from canopy to spectrometer, denoted H, was calculated by weighting the extracted depth data. The weighting algorithm was determined based on the point cloud distribution of the canopy;

(4) The white plate response L_w at the distance H can be calculated using the calibration curve of the standard white plate: $L_w = f(H)$,

where f(H) is the equation representing the relationship between the spectral response of standard white plate and the distance from canopy to spectrometer;

(5) Canopy reflectance can be expressed as

$$R_{\lambda} = L_c / L_w \quad (1)$$

where

R_{λ} is spectral reflectance of active light whose central wavelength is λ (%);

L_c is the spectral response from the canopy (V) ; and

L_w is the spectral response from the standard white plate (V)

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