Ground-based Remote Sensing Technology for Precision Farming – Calibration of Image-based Data to Reflectance –

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Abstract: Assessing health condition of crop in the field is one of core operation in precision farming. A sensing system was proposed to remotely detect the crop health condition in terms of SPAD readings directly related to chlorophyll contents of crop using a multispectral camera equipped on ground-based platform. Since the image taken by a camera was sensitive to changes in ambient light intensity, it was needed to convert gray scale image data into reflectance, an index to indicate the reflection characteristics of target crop. A reference reflectance panel consisting of four pieces of sub-panels with different reflectance was developed for a dynamic calibration, by which a calibration equation was updated for every crop image captured by the camera. The system performance was evaluated in a field by investigating the relationship between corn canopy reflectance and SPAD values. The validation tests revealed that the corn canopy reflectance induced from Green band in the multispectral camera had the most significant correlation with SPAD values (r^2 = 0.75) and NIR band could be used to filter out unwanted non-crop features such as soil background and empty space in a crop canopy. This research confirmed that it was technically feasible to develop a ground-based remote sensing system for assessing crop health condition.

Keywords: Precision Farming, Ground-based Remote Sensing, Multispectral Image, Crop Canopy Reflectance, SPAD

Introduction

Precision farming has been a new concept of agricultural production system to optimize profitability and protect the environment by inputting agricultural materials according to within-field requirements. The realization of precision farming technology was difficult in the past, but it is getting real thesedays with the aid of low-cost powerful computers, real-time controllers, variable rate application hardware, accurate location systems and advanced sensor technology (Sudduth, 1999). Assessment of crop health is an essential element for the realization of precision farming. Chlorophyll content of a leaf, directly related to N-deficiency, has been an index indicating crop health condition. Compared with laboratory plant tissue analysis, the appearance of SPAD meter made *in situ* measurement of chlorophyll content possible, but tremendous field works were required to collect crop health data dense enough for precision farming. To overcome this limitation, rapid *in-situ* sensing systems have been developed for more efficient and practical use. Techniques using spectral reflectance of crop leaves became a promising approach to assess N-deficiency of corn (Bausch et al., 1990; Diker and Bausch, 1999; Schleicher et al., 2001; Tumbo et al., 2002; Souza et al., 2002) or soybean (Chappelle, 1992), and various types of spectral radiometers were used to acquire the spectral reflectance. While the spectral radiometer provided direct measurement of crop reflectance, it has some disadvantages such as small FOV (Field of View) and noise engagement from soil background or shadow. Alternative approaches to detect crop health condition were carried out using a multispectral image (Singh et al., 1996; Borhan et al., 2001; Kim et al., 2001). Unfortunately, these optical remotely sensed data are affected by sensor characteristics, illumination geometry and atmospheric conditions and, commonly expressed in arbitrary units such as digital number or gray scale (Smith and Milton, 1999). The values should be converted into physical units such as spectral reflectance in order to get lasting quantitative values (Teillet, 1986). One common method for calibrating optical sensed data such as satellite and aerial images was to compare the optical image with the reflectance of clear viewed objects like paved highway, water surface, or roof

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of building because the reflectance of these targets are relatively consistent. Smith and Milton (1999) suggested the empirical line method for the calibration, assuming that within the image there were one or more targets with different reflectance characteristics covering a wide range of reflectance values for the wavebands recorded, and concrete and tarmac surfaces and grass were used as targets for the calibration. For the aerial imagery, White et al. (2001) utilized 8-step gray scale radiometric targets (calibration tarps) placed adjacent to the field. Based on the spectral reflectance of the calibration tarps taken in the field at the same time of aerial imagery acquisition, the percent reflectance of imagery could be obtained using the empirical line calibration method.

Especially for small size farm in Korea and Japan, the above-mentioned technology with satellite or aerial images will not be appropriate in the aspects of efficiency and cost-effectiveness. A sensing system equipped on ground-based platforms may be more desirable. To be applicable, however, the ground-based sensing system should be real-time operated with geographical information of remotely sensed specific location. Although various calibration techniques have been tried, most of them were limited to a constant atmospheric condition such as clear sky.

It was, therefore, needed to develop a calibration technique on the ground-based optical sensor independent of the ambient illumination and / or solar zenith angle. A reference reflectance panel with four levels of different reflectance was proposed in this research to convert the gray scale of crop image to the value of reflectance. The particular calibration equation dependent on the ambient illumination could be established on every image with known reflectance values and their average pixel values for the four separate portions in the panel image. However, the reflectance of a target could be changed due to geometry of sensor location and sun view angle. According to Bausch et al. (1990), the reflectance from corn leaves increased as the view zenith angle of a sensor increased. They mentioned that the sensor seemed to get more specular reflection portion as the view zenith angle increased. However, the reflectance was comparatively constant at a nadir shot (view zenith angle of 0°) regardless of different view azimuth angles. Thus, it was proposed that the camera and reference reflectance panel were desirable to be installed in a nadir direction.

This research aims to investigate the feasibility of image-based sensing technology for the precision farming newly proposed calibration technology. The specific procedures included : 1) to construct a ground-based remote sensing system with a radiometric calibration function, 2) to evaluate the system performance using SPAD values of corn leaves.

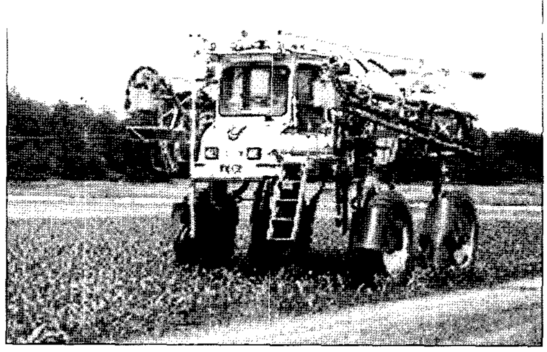


Fig. 1 Ground-based platform for remote sensing.

Materials and Methods

Platform and Sensor

A Patriot XL sprayer (Tyler industries, Inc., Benson, MN, USA), as shown in Figure 1, was modified and used as the mobile platform for this research. This platform has a high clearance (1.8 m) to travel in the cornfield during the growing season, and has 25 liquid fertilizer application nozzles on a 23 m (nozzle spacing 76 cm) boom.

A multi-spectral CCD camera (MS2100, Duncan Tech, San Diego, CA, USA) was used to estimate the chlorophyll contents of corn leaves, which indicating how well the crop is growing. This camera has 3 CCDs for Green, Red, NIR, whose center wavelengths are 550 nm, 650 nm, and 800 nm, respectively. The focal length of lens is a 25 mm to secure 14.6° of FOV with a resolution of 640×480. A digital frame grabber (IMAQ PCI-1424, National Instrument, Austin, TX, USA) was used to capture the multispectral crop images.

To reduce the effect of specular reflection and sun azimuth angle as much as possible, the camera was installed 3.4 m above the surface in a nadir direction (Slater et al., 1987; Bausch et al., 1990), which can cover an area of 2.7 m×2.0 m (4 rows of corn).

Reference Reflectance Panel

To apply the empirical line method (Smith and Milton, 1999), four reflectance panels were made of hard board and mixture of non-glossy flat paints to obtain different levels of reflectance. The reflectance of these panels were measured by a spectroradiometer (Handheld Pro, ASD, Boulder, CO, USA) under cloudy, partially cloudy, and sunny conditions to investigate the consistency of reflectance because it could not be a Lambertian reflector. Table 1 shows the average reflectance of the panels, based on 15 measurements performed under various weather conditions. It was found that the measured reflectance was often different at different spectral bands, even under exactly the same ambient light condition. The measured reflectance was 43%, 26%, 12%, and 7% at Green band, 42%, 24%, 11%, and 7% at Red band, 38%, 22%, 10%, and 7% at NIR band for four reflectance panels, respectively. These standard reference values were used to calibrate the corn reflectance. A frame containing 4 pieces of reflection panel was hung perpendicular to the camera view window, 1.0 m below the camera shown in Figure 2 so that the panel image was always included when crop image was captured in the field.

SPAD Meter for Ground Truth Data

A SPAD meter (Minolta SPAD 502, Plainfield, IL, USA) measures the amount of light absorbed by the green pigments, mainly chlorophyll, in corn leaves. Since the amount of chlorophyll is closely related to the N content of a leaf, the SPAD meter can provide information similar to that provided by the conventional leaf sampling and laboratory determination of N content of leaf. Therefore, SPAD meter readings are used as a ground truth data of the nitrogen status of crops in corn leaves.

Within each image FOV, six SPAD readings were taken from the youngest fully expanded leaf, and the average of these six readings was used as the corresponding SPAD value for the image.

Preparation of Target Crop

To obtain sufficient variations in crop nitrogen deficiency, different amounts of base nitrogen were applied to the testing field in the Agricultural Engineering Research Farm of the University of Illinois at Urbana-Champaign, IL, USA. Seven treatment levels of liquid N-fertilizer with four duplicates were planned for the test. Each plot size was 18.3 m long and 6.1 m wide (equal to 8 crop rows) with enough buffer space, and total of 28 plots were arranged by the randomized block design to reduce the effect of intrinsic soil fertility. The nitrogen was applied as side dress when the corn was 15 to 25 cm tall at V6 stage, where the treatment levels were as follows : 1=0 kg/ha, 2 =33.6 kg/ha, 3=67.3 kg/ha, 4=100.9 kg/ha, 5=134.5 kg/ha, 6=168.1 kg/ha, and 7=201.8 kg/ha.

Table 1 Reflectance of reference panel in percentage at each channel wavelength of the spectroradiometer

Panel	Waveband		
	Green	Red	NIR
P1	43	42	38
P2	26	24	22
P3	12	11	10
P4	7	7	7

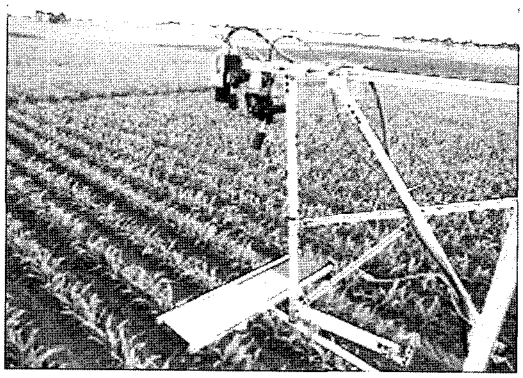


Fig. 2 Installation of camera and reference reflectance panels on the platform.

Image Acquisition

Six sets of multispectral images of the corn were acquired from the V6 stage (39th day after emergence) to the R2 stage (110th day after emergence). V6 stage is known to be the time the crop root system is well distributed in the soil and the plant start to absorb large amount of nutrients. Among these data sets, three were collected on sunny days and the other three were collected on cloudy days. The images were acquired from the center of each test plot.

Image Processing for Data Conversion

The original image taken in the field included many type of noises such as large portion of soil background in an early stage of corn growth and shadow in between corn leaves or leaf's shadow on corn leaves over the growth stage. To eliminate such a noise, the collected crop images were pre-processed to segment corn leaves from the soil background or shadow. According to typical reflection characteristics of corn leaves on soil surface, as shown in Figure 3, the reflection of corn leaves was much stronger than that of soil surface. Therefore, the image of NIR frame was used to separate soil background from corn leaves in terms of an appropriate threshold reflectance. Binary image of separated corn leaves was later used as a mask image for the segmentation in the necessary image processing from other CCD frames. After eliminating noises, the average gray value in the portion of corn leaves was converted into the reflectance using a calibration equation.

Figure 4 shows a typical CIR (Color infrared) image for the early corn in the field. The gray value, the intensity of reflectance on an object by the incident light, of the image is dependent on the incident light at the time of image taken. The gray value of the calibration panel portion (lower portion in the image) would be also affected by the incident light at the same rate of amount. Based on this principle the calibration equation could be constructed using a least-square linear regression of the known reflectance value and the average gray value of corresponding reflection panel. Then the reflectance of corn leaves portion in the image could be calculated. Figure 5 shows a typical calibration equation, where the coefficient of determination was greater than 99%.

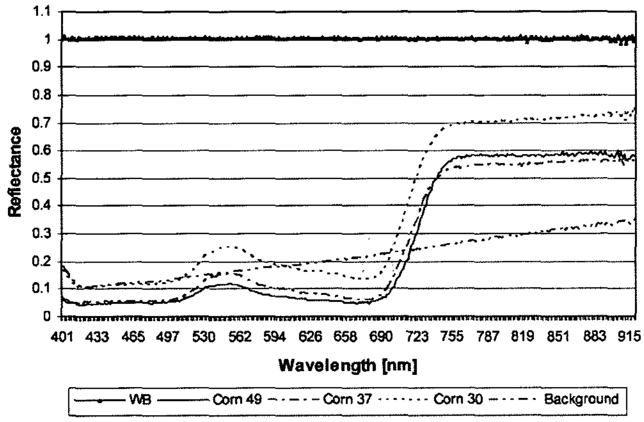


Fig. 3 Typical reflection characteristics of corn leaves on soil surface for three corns with different health conditions.

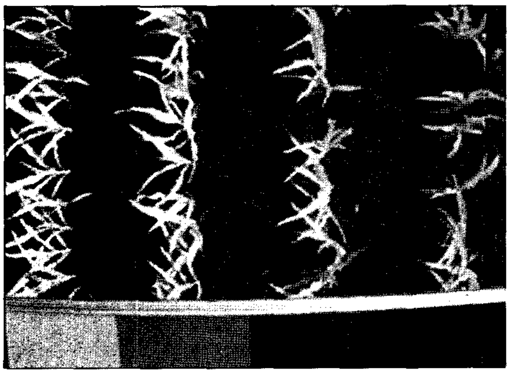


Fig. 4 Typical CIR image of corn in early growth stage.

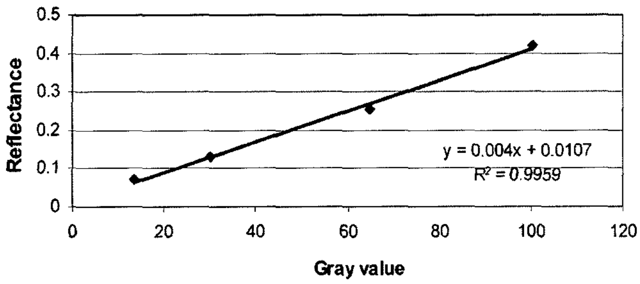


Fig. 5 Typical calibration equation on Green frame.

Selection of Corn Leaves Reflectance-related Variable

The preliminary investigation of spectral reflectance characteristics on 3 corn leaves with different health conditions (average SPAD values of those corn leaves were 49, 37 and 30 for excellent, fair and poor health conditions, respectively), as shown in Figure 3, assured that the information from Green band would be good to recognize the relative chlorophyll contents in corn leaves. Because significant and consistent difference among three corns leaves appeared around Green band while the measure of reflectance in fair and excellent corns were reversed at 800 nm band. It was obvious that the reflectance of corn leaves would be inversely proportional to SPAD value as ground truth data. This was also supported by the research results from Blackmer et al. (1994) and McMurtrey et al. (1994).

Evaluation of System Performance

The feasibility of using reflectance panels to obtain the corn reflectance was investigated during day time whether the consistency is maintained over the change of solar zenith angle. Then, the reflectance of living plant was investigated in the same manner. Finally, the relationships between SPAD reading and corn leaves reflectance on numerous levels of nitrogen-deficient corns in the field.

Results and Discussion

Variation in Reflectance with Various Ambient Illumination Conditions

To evaluate the consistency of the reflectance panels during the day, the spectral reflectance of prepared panels were taken every 20 min between 09:40 to 17:00 by the spectroradiometer, which was installed in a nadir direction. Only the data of interested waveband were analyzed. Figure 6 shows the variation of their reflectance at different times of the day. Although the reflectance values of panel were expected not to be changed with the solar zenith angle, some variations were observed. Around solar noon

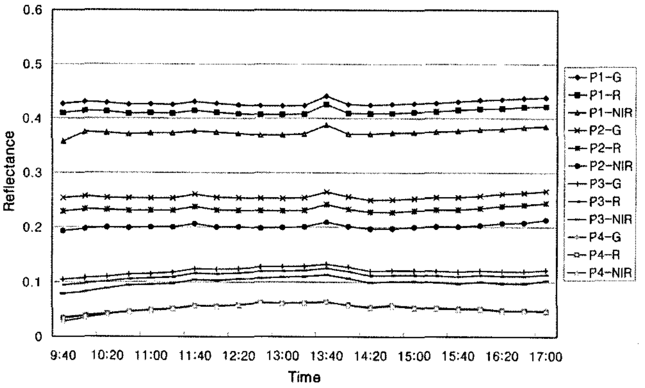
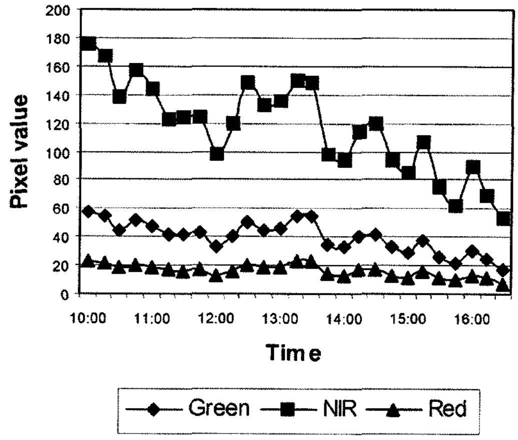


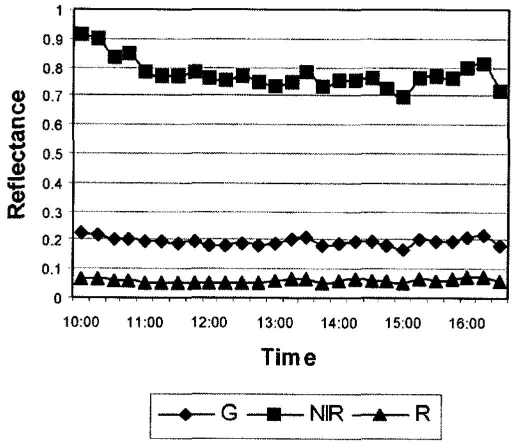
Fig. 6 Variation of reflectance of reference panels with solar zenith angles.

Table 2 Coefficient of variance for reflection of panels, in percentage

Panel	Waveband		
	Green	Red	NIR
P1	1.18	1.26	1.63
P2	1.69	1.93	2.31
P3	5.76	6.56	8.24
P4	13.95	14.66	16.86



(a) before calibration



(b) after calibration

Fig. 7 Variations of gray scale and calibrated reflectance of corn leaves with time.

the reflectance tended to be increased for all panels. The reflectance was low at low solar zenith angles in the morning and late afternoon, especially for panels P 3 and P 4. Since the reflection of prepared panel could not be perfectly Lamertian, the specular reflection must have been occurred during the measurement. The CV values for Green, Red and NIR bands on four panels are presented in Table 2. Compared to Green band, the variation of reflectance was greater in NIR band for all panels. In addition, the panel P 4 showed the largest variation in CV for all wavebands tested.

The performance of reflectance panels for the image calibration was evaluated with corn leaves. The corn images were taken every 15 min from 10:00 to 16:30, with partially cloudy condition in the morning, and sunny and fair conditions in the afternoon. Figure 7 shows the variation of gray scale value and reflectance of corn leaves measured in the Green, Red and NIR bands using the camera and reflectance panels at different times of day. The gray scale value was much more sensitive to the change in lighting condition than the reflectance in all three wavebands. For example, the gray scale varied from 180 to 60 in NIR frame, from 60 to less than 20 in Green frame, and from 20 to less than 10 in Red frame. The corresponding coefficients of variance were 27.25%, 25.12%, and 27.77% for Green, Red, and NIR frames, respectively.

After the gray scales being converted into reflectance using the linear regression based dynamic calibration model, the levels of variance were noticeably reduced as shown in Figure 7(b). As comparison, the coefficients of variance for reflectance were 6.93%, 9.14%, and 6.41% for Green, Red, and NIR frames, respectively. These analyses showed that the dynamic calibration method using reflectance panels could effectively reduce variation in the leaf reflection caused by both the ambient illumination condition and solar zenith angle.

Correlation Between SPAD Value and Reflectance

Figure 8 shows the correlation between SPAD readings and the reflectance of corn leaves from Green band based on the whole canopy. There was an inverse relationship

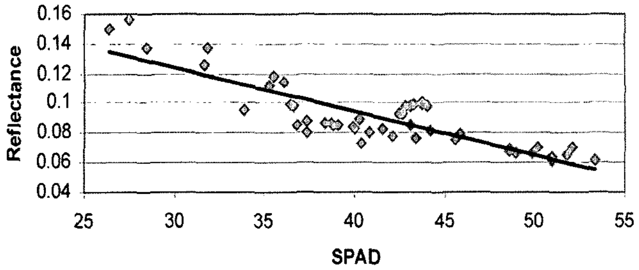


Fig. 8 Relationship between SPAD and reflectance obtained from Green channel.

Fig. 9 Typical corn leaves image at middle growth stage.

between SPAD values and the corn leaf reflectance detected in the Green channel. The result of least square linear regression indicates that the leaf reflectance has strong correlation with the SPAD value (r^2=0.75). Therefore, it could be used to assess the measure of health condition of corn leaves as the SPAD reading was used by the agronomist. Same analyses were conducted on the corn leaves reflectance in the Red and NIR bands, resulting in lower r^2 values, 0.62 and 0.02 for Red and NIR bands, respectively.

Effect of Leaf Shadow in the Image

Figure 9 shows a typical corn leaves image taken at sunny condition in the middle growing stage. Although the soil surface could not be seen in the image, the empty space between planted corns was expressed as a dark black. Furthermore, some light dark appeared on the surface of corn leaves due to the shadow caused by adjacent corn leaves. To evaluate the effect of shadow on the capability of determining crop health, the reflectance of corn leaves was calculated in three ways based on the whole area, the bright area, and the shadow area in the image of corn leaves. Table 3 lists the results of analyses on 3 data sets at sunny weather condition. Only Green band showed fairly consistent coefficients of determination of reflectance with

Table 3 ifference in coefficient of determination, r^2 by selection of image-processed area

Waveband	Area of interest to be analyzed		
	Whole	bright side	shadow side
Green	0.74(-)	0.71(-)	0.70(-)
Red	0.17(-)	0.28(-)	0.77(-)
NIR	0.45	0.08(-)	0.10

- indicates inverse proportional

SPAD reading among all image processing methods including the whole leaves segment, the bright area and the shadow area of the leaf.

Conclusions

A remote sensing system using a multispectral camera on the ground-based platform was feasible for detecting the health condition of crop by measuring the corn canopy reflectance. The reflectance panels proposed in this research turned out to be an effective tool to convert the gray scale data from the camera to the canopy reflectance data compensating for the image gray-scale variation caused by changes in cloud effect and solar zenith angle. An image processing algorithm was developed to segment out the unwanted soil background or empty space between crops from corn leaves image by the mask image prepared in NIR frame of multispectral camera.

The validation tests revealed that the correlation coefficient between corn leaves reflectance and SPAD reading, r^2 were 0.75, 0.62, and 0.02 for Green, Red, and NIR frames, respectively. It could be, therefore, concluded that Green band was most useful to assess the crop health condition in the field while NIR band could be used for the image segmentation purpose.

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