Development of an Integrated Sensor and Instrumentation System for Measuring Crop Conditions

Y. Lan[1], H. Zhang[2], R. Lacey[2], W. C. Hoffmann[1], W. Wu[3]

[1]USDA-ARS, College Station, TX

[2]Department of Biological and Agricultural Engineering

Texas A&M University, College Station, TX

[3]College of Biological and Agricultural Engineering

Jilin University, P.R. China

ABSTRACT

Precision agriculture requires reliable technology to acquire accurate information on crop conditions. Based on this information, the amount of fertilizers and pesticides for the site-specific crop management can be optimized. A ground-based integrated sensor and instrumentation system was developed to measure real-time crop conditions including Normalized Difference Vegetation Index (NDVI), biomass, crop canopy structure, and crop height. Individual sensor components has been calibrated and tested under laboratory and field conditions prior to system integration. The integration system included crop height sensor, crop canopy analyzer for leaf area index, NDVI sensor, multispectral camera, and hyperspectroradiometer. The system was interfaced with a DGPS receiver to provide spatial coordinates for sensor readings. The results show that the integration sensor and instrumentation system supports multi-source information acquisition and management in the farming field.

Keywords: Ground-based integration system, multi-source information, remote sensing, GPS

1. INTRODUCTION

Accurate and reliable information technology is the basis of precision agriculture. Remote sensing has been widely used to obtain and map the temporal and spatial variability of crops in fields. Information on crop condition can be used to assess and monitor crop growth status, predict crop yield, or develop program for optimizing application of nitrogen fertilizer, fungicide, and growth regulator in precision agriculture.

Successful information acquisition relies on the ability of sensors and instrumentation in detecting these crop canopy variables, which are indicative of crop growth (Goel et al. 2003). The Normalized Difference Vegetative Index (NDVI) is a commonly used measurement of crop health in agricultural applications. NDVI is calculated as: NDVI= (NIR reflected – Red reflected) / (NIR reflected +Red reflected), where Red and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. Healthier crop canopy will absorb more red and reflect more near infrared light, and consequently has a higher NDVI value. Jones and Wechler (2007) has used a GreenSeeker sensor (NTech Industries, Inc.) to measure NDVI and there was strong correlation between NDVI and chlorophyll content per plant of spinach (R^2=0.91). NDVI was found to be closely correlated with the Leaf Area Index (Bechtel et al., 1997; Aparicio et al., 2002; Leon et al., 2003).

Leaf Area Index (LAI) is an important structural property of crop canopy. LAI is defined as the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows. LAI is used to predict the photosynthesis capacity of a crop and as a reference tool for crop growth. High correlations were found between reflectance factor and LAI and biomass by Ahlrichs et al. (1983). Many researchers also used spectral reflectance techniques for monitoring nitrogen and chlorophyll status in different crops (El-Shikha et al., 2007; Jones et al., 2007; Xue et al., 2004; Goel et al., 2003; Haboudane et al., 2002; Tumbo et al, 2002). Strong correlations between the spectral data from crops and various characteristics of crops have been elucidated in numerous studies (Yoder et al., 1995; Serrano et al, 2000; Thenkabil et al., 2000; Goel et al., 2003; Lee et al., 2004). Laudien et al. (2003) explained the contrast between healthy and diseased sugar beets by using a hyperspectral radiometer. Thenkabail et al. (2000) used a hand held spectral radiometer to obtain the correlation between spectral observations with crop parameters of cotton.

Darvishzadeh et al. (2008) examined the utility of hyperspectral remote sensing in predicting canopy characteristics by using a spectral radiometer. Among the various investigated models, they found that canopy chlorophyll content was estimated with the highest accuracy. Some studies used multispectral image sensor system to measure crop canopy characteristics. Jones et al. (2007) estimated biomass based on multispectral images taken by a Duncan Tech® MS3100 multispectral camera (Auburn, CA). Inoue et al. (2000) successfully estimated LAI and biomass for soybean and rice using a dirigible-mounted camera to collect spectral data. Ultrasonic sensing technology is good for non-destructive crop canopy characterization. Kataoka et al. (2002) in Japan has showed that ultrasonic sensors performed well for measuring the height of soybean and corn crops.

Many remote sensing technologies have been used to obtain information from different platforms, such as ground-based, airborne and space. For truth measurement, ease of availability and cost-effectiveness, ground-based methods are the most widely used and developed. Tumbo et al. (2002) constructed the on–the–go system for sensing chlorophyll status in corn. A tractor traveled at 0.6 km/h and equipped with a dual fiber–optic spectrometer, an analog–to–digital (A/D) converter, a fiber–optic sensing probe, a sensing probe holder, and a computer. The fiber–optic spectrometry was used to acquire spectral response patterns. A neural network model incorporated into the mobile system showed good correlation between predicted SPAD (Konica Minolta Sensing, Inc.) chlorophyll readings and actual chlorophyll readings (r^2 = 0.85, RMSE = 1.82 SPAD units). Scotford et al. (2004) in Europe used a tractor–mounted radiometer system in parallel with an ultrasonic sensor to obtain information about crop cover and the structure of the crop canopy. The radiometer system used two radiometers. One was mounted pointing upwards to measure incoming radiation while the other pointed downwards to measure the reflectance light from the crop canopy. The ultrasonic sensor was mounted one meter above the ground. The output signals from each sensor were transferred to a laptop computer for processing. Reyniers et al. (2006) compared an aerial image with an on the ground platform measuring device to predict yield of winter wheat. A multi-spectral radiometer was mounted on the end of the boom on a tractor. The software they developed for automatic data acquisition was programmed in Labview 6 (National Instruments, 2000) environment. NDVI of the ground system was better related to yield variables at harvest compared to NDVI of the aerial system.

The data acquisition methods and information resources used in previous studies were limited. Considering precision agriculture practice, it is essential to acquire multi-source information. The use of a number of sensing techniques working in combination could provide a better characterization of the crop canopy (Scotford et al., 2003). A method of Multi-sensor Data Fusion has been developed for high quality data analysis and processing in measurement and instrumentation (Huang et al., 2007). The objectives of the presented work are to develop a ground-based, multi-source information collecting system and test the feasibility of the system.

2. SYSTEM DESCRIPTION

2.1 Integration System

The ground-based multi-source information system consisted of NDVI sensor, crop canopy analyzer for Leaf Area Index, hyperspectroradiometer, multispectral camera, and crop height sensor (Figure 1). The system is interfaced with a DGPS (Differential Global Positioning System) receiver to provide spatial coordinates for sampling points from hyperspectroradiometer. The integrated system collected multi-sensor data and store the spatial information and crop property information in database. The different components and how they were integrated are described in the following sections.

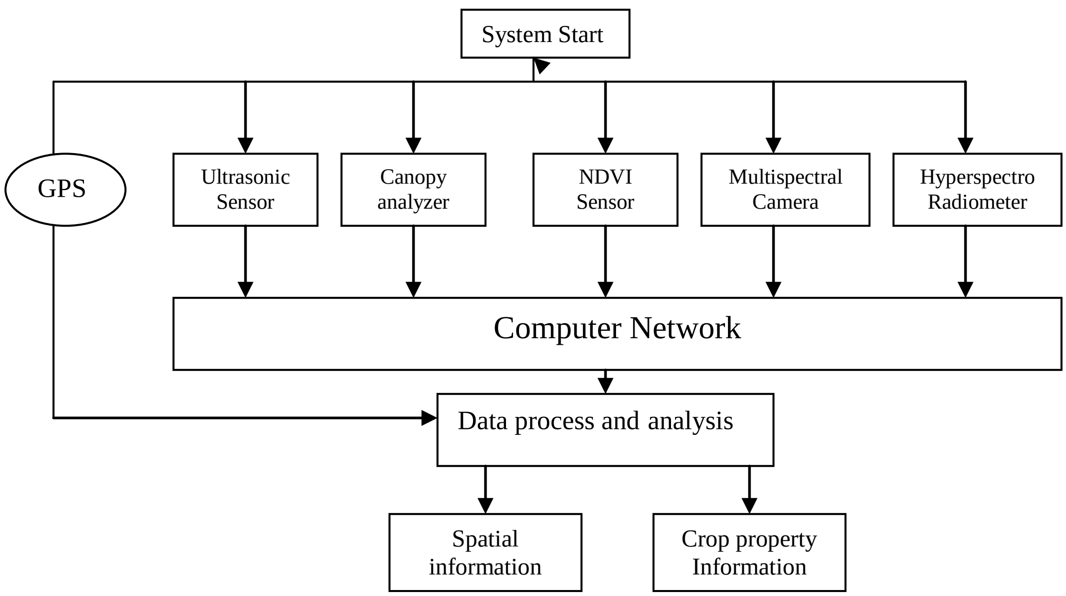


Figure 1. System diagram: ultrasoncic sensor, Canopy analyzer, NDVI sensor, Multispectral camera and Hyperspectroradiometer

2.2 NDVI Sensor

NDVI is an estimate of biomass and nitrogen content in many crops. The NDVI sensor used in the system was a GreenSeeker Hand Held Data collection and Mapping Unit (NTech Industries, Inc., Ukiah, Cal.) (Figure 2). It is an advanced tool in precision agriculture technology for providing useful data to monitor the growing status of crops

(Figure 2). The instrument has been used widely to look at nitrogen status in-season as discussed in the Introduction.

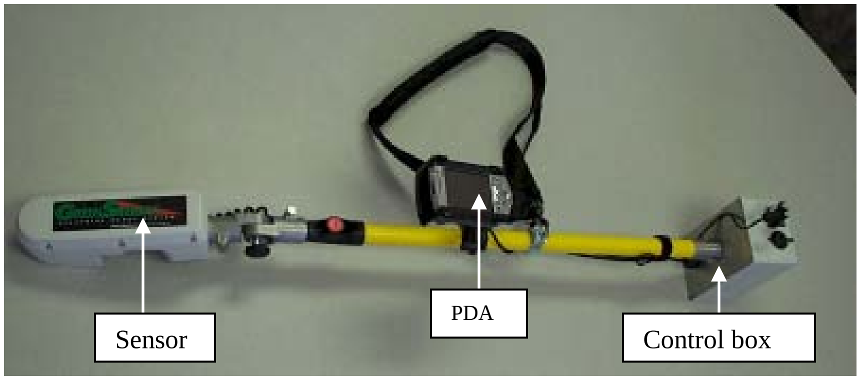


Figure 2. GreenSeeker

The GreenSeeker Sensor is adjustable in 15 degree increments and mounted on an adjusted-length pole to set the Sensor parallel to the target canopy. The Control Box supplies power to the Sensor and external connectors. The GreenSeeker is equipped with a Compaq iPAQ pocket PC and specific software for data collection. Reflectance data from the Sensor is captured and converted into a text file on the pocket PC.

The sensor is an active sensor, which uses light emitting diodes (LED) to generate its own red and near infrared (NIR) lights. As the sensor passes over the crop surface, it measures incident and reflected light from canopy and outputs both NDVI and Red to Near Infrared Ratios. The output rate is about 10 readings per second. The distance between the sensor and target should be 32 to 48 inches. The NDVI readings are not affected by height variance as long as the sensor height is maintained within this range.

2.3 LAI Canopy Analyzer

Leaf Area Index is commonly used for monitoring crop growth. Instead of the traditional, direct and labor-consuming method of physically measuring the plant with a ruler, an optical instrument, SunScan canopy analysis system (Delta-T Devices Ltd., UK) is used. The instrument is indirectly measuring leaf area index by measuring the ratio of transmitted radiation through canopy to incident radiation. The system is configured with SunScan probe and Data Collection Terminal (a Psion Workabout) (Figure 3).

Figure 3. SunScan Canopy Analyzer

The SunScan probe has an array of 64 PAR (Photosynthetically Active Radiation) sensors embedded in a 1m long probe, and may be connected via an RS-232 cable to the Data Collection Terminal or a PC. (The Data Collection Terminal is much more convenient to observe and store reading from the probe than portable PC for field work.) The portable and weatherproof instrument can be used in most light conditions. When a reading is taken, all sensors are scanned and the measurements transmitted to the Data Terminal. The average light level along the probe is calculated and canopy leaf area index is estimated. All of the individual sensor readings are available if required for detailed PAR mapping.

2.4 Spectroradiometer

Spectral reflectance in the visible and near infrared region has been recognized as a popular method to estimate crop properties. Spectroradiometers are used to quickly measure light energy over a range of wavelength and to identify crop stress. Crop conditions can be closely monitored by using reflectance spectral imagery. FieldSpec® Handheld, an ideal portable field hyperspectral radiometer (FieldSpec®, Analytical Spectral Devices, Inc., Boulder, CO) (Figure 4), was used in the system.

Figure 4. FieldSpec

The hyperspectroradiometer arrives pre-calibrated and ready to use. It is capable of measuring radiance from 325nm to 1075nm wavelengths with a sampling interval of 1.6nm. The field of view of the instrument is about 25º. The reflectance of light on the canopy is collected by an optic sensor and data is sent to a laptop via a RS232 to USB cable. Instantaneous graphs are displayed. To decrease the signal to noise ratio and increase the overall accuracy, integration time needs to be changed as light conditions change, while the dark current scan is automatically taken when every reflectance scan is taken. In addition, before taking the reflectance data, it should be calibrated by taking a white reference from a white reference panel.

2.5 Multispectral Camera

The multispectral camera we used is a single sensor agriculture digital camera (ADC) (TETRACAM, Inc.) (Figure 5). The simple and low-cost

Figure 5. Multispectral ADC Camera

ADC camera has a resolution of 2048×1536 pixels per frame and able to measure visible light wavelengths longer than 520nm and near-infrared wavelengths up to 920nm reflectance of plant canopies. The camera is equipped with a 4.5 to 10mm CS mount varifocus lens. Focusing can be carried out automatically or manually. The camera incorporates a removable Compact Flash card which stores up to 80 images. The images, stored in Tetracam DCM loseless format, can be downloaded later to a computer. DCM files are grayscale images displaying “raw” pixel values. PixelWrench2, a powerful image editing program working with ADC camera, provides full access and control of the camera. It also has a several specific multispectral function of image management, such as calculation of Vegetation Index and canopy/background segmentation.

Tetracam SensorLink is another simple application interface to the camera. SensorLink enables capture of GPS data from a receiver connected to the computer's serial port. The data is compared to a set of waypoints and direction to waypoint information is displayed. When the waypoint is acquired, the camera is triggered and the GPS data is written into the image file header.

2.6 Ultrasonic Sensor

Ultrasonic sensors are inexpensive and very accurate for detecting objects. Ultrasonic sensors generate high frequency sound waves. When the waves strike and bounce off an object, the sensors will receive and evaluate the echo. Sensors then determine its distance from the object based on the time interval between sending the signal and receiving the echo.

A commercial ultrasonic sensor (Honeywell, type 943-F4V-2D-002-180E) (Figure 6) was used. It is operating with an oscillating frequency of 180KHZ and a sensing range of 200-2000mm. The sensor is fitted with operating temperature from -15 to 70^{o}C.

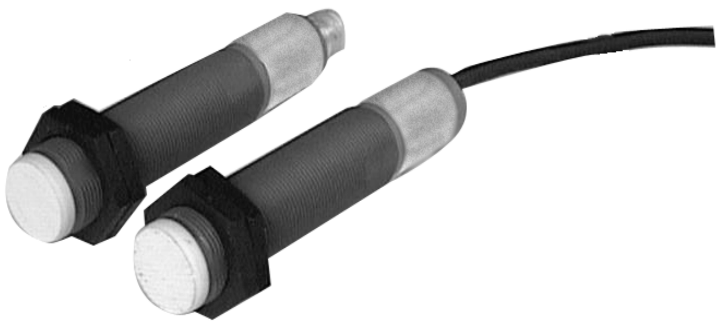


Figure 6. Ultrasonic sensor (Honeywell, type 943-F4V-2D-002-180E)

2.7 GPS

With GPS unit, the integrated system can obtain both the time and position information at the sampling spots. ESRI (Environmental Systems Research Institute) has provided ArcPad to work with mobile GPS and field mapping application. The Thales MobileMapper CE (Thales Navigation, Santa Clara, CA) is a cost effective handheld GPS/GIS receiver for high-accuracy mobile mapping. It features an open platform design with embedded Microsoft® Windows® CE, Bluetooth wireless technology, and many other mobile applications. MobileMapper CE is simple, rugged and affordable.

Figure 7. MobileMapper CE

3. RESULTS AND DISCUSSION

3.1 Integration System

Two field experiments were conducted in the USDA-ARS Field 14 in College Station, Texas on May 28 and July 22, 2008. They were cloud free sunny days and around noon time. Greenseeker sensor, FieldSpec hyper spectral radiometer, SunScan canopy analyzer, multispectral camera and the ultrasonic sensor were mounted on the tractor in both tests (Figure 8).

May July

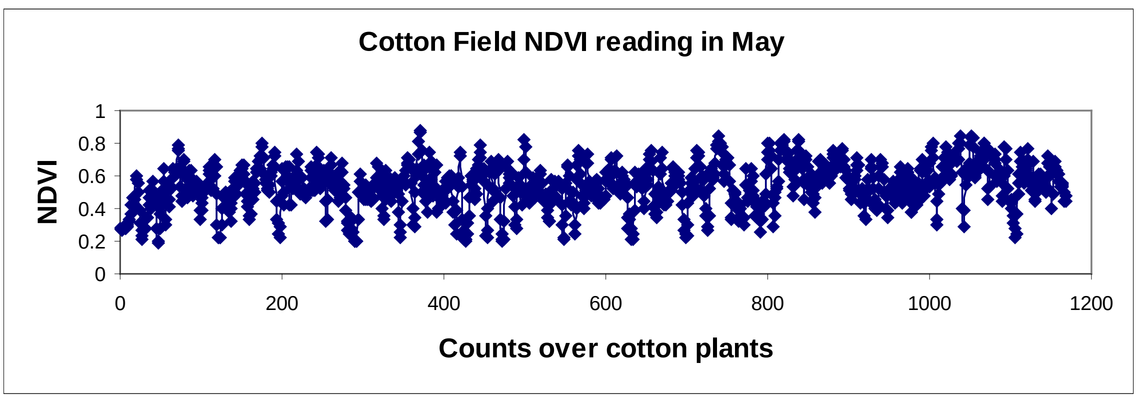
Figure 8. The integration system in operation

In May, the Greenseeker sensor was mounted on the top of the row about 32 inches height. The NDVI readings were stored in the PDA and transferred to PC later. FieldSpec was mounted about one meter above the crop canopy with the optical sensor facing the crop. The readings were taken within the field-of-view. The integration time was 217 ms. The time interval to save a spectrum was one second. FieldSpec was connected to laptop

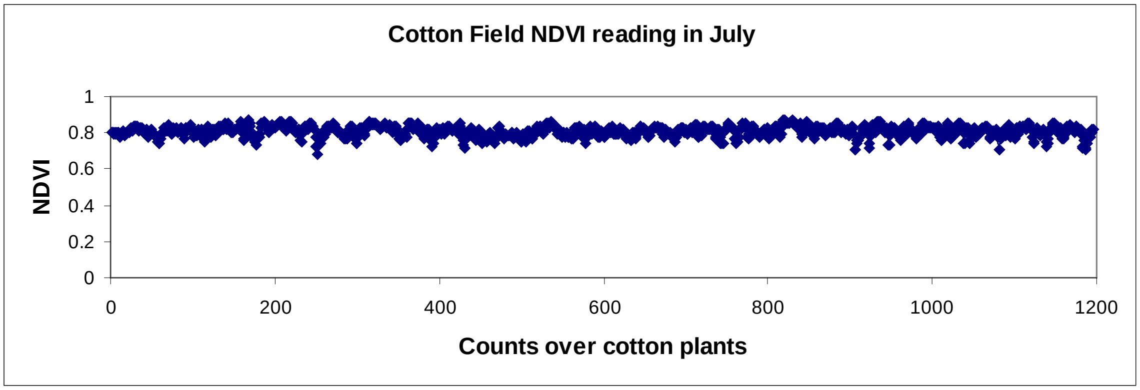
No.1 via serial RS232 to USB cable. The Sunscan canopy analyzer was mounted about 20 cm above the crop surface. It was also connected with laptop No.1 via a serial port. The LAI data was automatically stored into the laptop. The sampling interval was one second. The ultrasonic sensor was positioned just on the top of the row 4. The software for automatic data acquisition from the ultrasonic sensor was programmed using Labview 8.5 (National Instruments, 2007) in laptop No.2. During the test in July, the position of each sensor and instrument was adjusted according to the height of plants. Greenseeker sensor and Fieldspec were mounted in the same row.

3.2 NDVI

NDVI mappings from Greenseeker in both tests are shown in Figure 9. The Greenseeker is designed to be 32 to 48 inches above the target. The width of sensor measurement is a constant 24 inches. The width doesn't change with the height from the sensor to the target. The average width of cotton plants was less than 10 inches in May. The Greenseeker sensor not only scanned cotton plants but also soil around the plants. Therefore, the NDVI values were very low. The average width of cotton plants grew to about 20 inches in July. Consequently, the variance of NDVI readings in July was much smaller than the one in May.



May

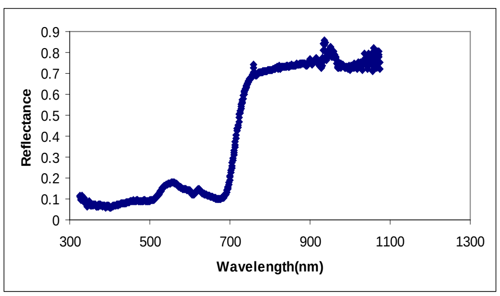


July

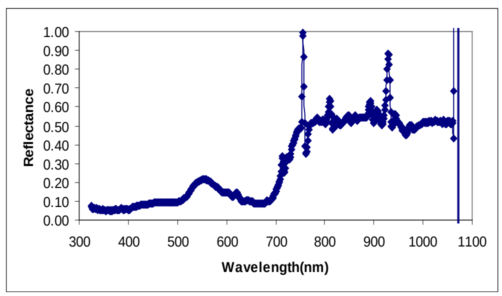
Figure 9. NDVI mapping in cotton field in May and July, 2008

3.3 Reflectance Measurements

Reflectance data were processed by ViewSpec^{TM} Pro4.05 comes with FieldSpec. Reflectance measurements were averaged to one curve for cotton and soybean fields (Figure 10).



Cotton



Soybean

Figure 10. Reflectance curves of cotton and soybean fields

The reflectance curves of both cotton and soybean are characterized by low reflectance in the blue (450nm-495nm) and red region (620nm-750nm) of the spectrum. The peaks in green (495nm-570nm) and high reflectance in the near infrared (above 800nm) region of the spectrum also appeared, although there were much more noise in the near infrared region of soybean curve than the one of cotton.

3.4 NDVI Values Comparison

The Greenseeker sensor and Fieldspec were mounted in the same row and took measurements in the same time and condition. The NDVI can be calculated from the reflectance data. Since the system was driven through the cotton field three times, the NDVI values taken by Greenseeker and FieldSpec were compared (Figure 11). In the third run, the NDVI value taken by Greenseeker was 0.7807, while the NDVI value from FieldSpec was 0.7804. The result indicated that reliable information could be acquired from these mounted instruments.

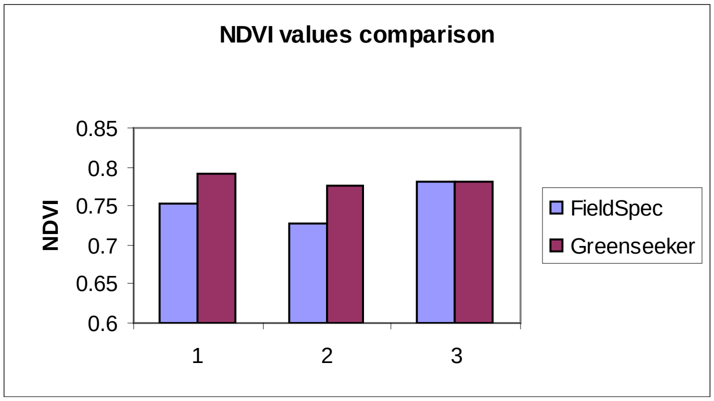
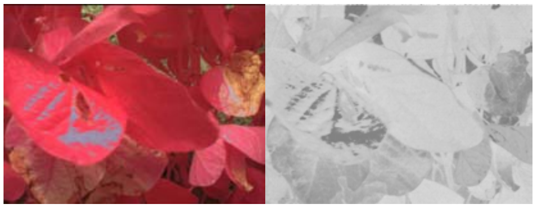


Figure 11. Comparison of NDVI values taken by FieldSpec and Greenseeker

3.5 Multispectral Images

Figure 12 (a) shows the image was taken by ADC camera when the tractor was driving through the soybean field. In PixelWrentch2 (TETRACAM, Inc.), the original image (a) was processed to NDVI image (b).



a b

Figure 12. Multispectral images of soybean plants

3.6 Crop Height Measurements

The speed of the tractor was 1MPH, so the ultrasonic sensor was passed over crop plant at 0.45m/sec. The sampling frequency of the height measurements was 10Hz. The distance between sampling points was 4.5cm. Figure 13 shows an example of the raw data of the ultrasonic sensor measurements in the cotton field in May, 2008.

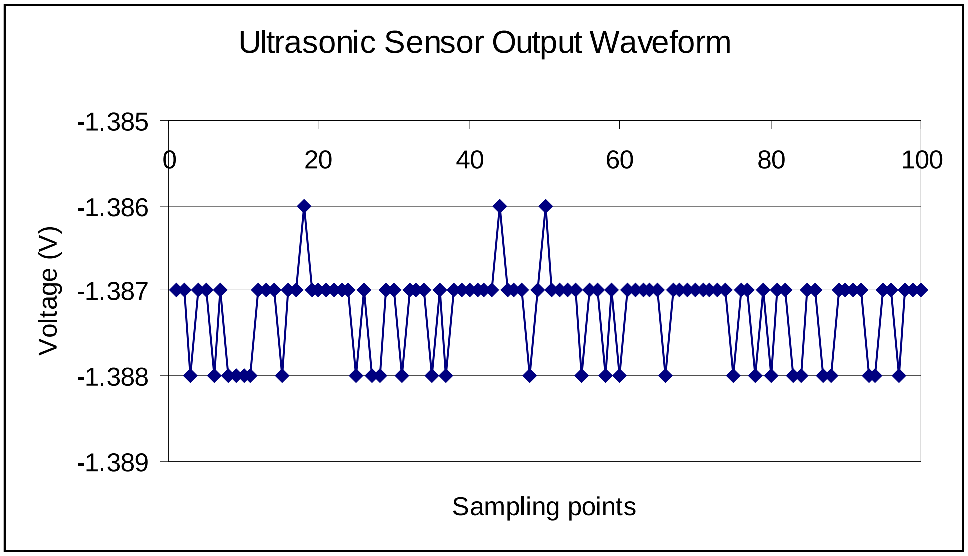


Figure 13. An example of raw measurements by ultrasonic sensor

The ultrasonic signal needs to be filtered by using a low pass filter to minimize the effect of noise and processed with Matlab (Version 7.6, from Mathworks, Natick, MA). Time period of each detected peak can be converted into the distance between sensor and the object, such as soil and canopy surface. Whether the speed of sensor passing over the plants and the sampling frequency are appropriate for characterizing the height of plants needs to be investigated.

3.7 Leaf Area Index Measurements

LAI readings were taken every second by SunScan Canopy Analyzer while the tractor was moving through the soybean and cotton fields. The average LAI measurements were 1.19 for soybean field and 1.37 for cotton field in May 2008.

4. CONCLUSIONS

The reliable and accurate information on field crop, such as NDVI values, reflectance measurements and multispectral images has been acquired by the integration system. The crop heights data and LAI data need to be further processed and analyzed. This preliminary study indicates that the potential of the integration sensor and instrument system to realize multi-source information acquisition and management in the field. It was a part of basic work in the development of the system. We have proposed a serial of solutions according to each problem we had met. In the future study, we will emphasize on improving the performance of the multispectral camera, eliminating or reducing the noise signal on the reflectance measurement and providing spatial coordinates for measurements form other instruments in the system.

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