Integrated sensor system for monitoring rice growth conditions based on unmanned ground vehicle system

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Abstract: Ground-based platform systems provide a good tool for monitoring and managing crop conditions in precision agriculture applications and have been widely used for monitoring crop conditions. To develop an unmanned ground vehicle system (UGVS) based multi-sensors and test the feasibility of this system for monitoring rice conditions, an UGVS was developed to collect real-time rice condition information including NDVI values, reflectance measurements and crop canopy temperature in this study. Major components of the integrated system are GreenSeeker R100 system, hyper-spectroradiometer and infrared temperature sensor. The leaf area index (LAI) was measured by the CGMD302 Spectrometer. The Independent Samples T-Test method and the one way ANOVA method were used to determine the best spectral indices and analyze the relationship between the vegetation indices and rice LAI. It was found that the two best spectral indices for estimating LAI were NDVI (860 nm and 750 nm) with the correlation coefficient (R^2) at 0.745 and RVI (853 nm and 751 nm) with the R^2 at 0.724. The results show the UGVS can support multi-source information acquisition and is useful for crop management and precision agriculture applications.

Keywords: unmanned ground vehicle system (UGVS), multi-sensors, rice growth condition, spectral vegetation indices, leaf area index (LAI)

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1 Introduction

Monitoring crop conditions during the growing season and estimating potential crop yields are both important for the assessment of seasonal production[1]. Application of precision agriculture technology has become increasingly prevalent among farmers due to its capability of optimizing crop yields by facilitating sound crop status monitoring[2]. With the remarkable advances in Global Positioning System (GPS) receivers, microcomputers, and geographic information systems (GIS), remote sensing technology has the potential to transform the ways that growers manage their fields and implement precision farming techniques[3]. Remote sensing can be conducted through satellites, aircraft, low altitude and ground-based platforms. Having been used to monitor crop growth, crop stress, and predict crop yields[4,5], satellite and aerial remote sensing technologies have advanced rapidly in recent years and become effective tools for site-specific management in crop protection and production[6]. However, the images and information collected with satellite and aerial techniques during the growing season are usually with poor spatial resolutions and prolonged revisiting times[4,7]. Moreover, the manned airborne platform is limited by high operational complexity, costs and so on[8-10]. Unmanned aerial vehicles remote sensing technologies can acquire high resolution images in real-time with lower cost, improved safety, flexibility in mission planning, and

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simple operation[11]; but the high quality images are limited by poor flight stability[12]. Ground-based platforms, as good complements to satellite, aerial, and unmanned aerial vehicles remote sensing technologies for monitoring crop conditions, are typically used for ground truth study. With the help of ground-based remote sensors, such ground-based platforms can collect high resolution remote sensing information fast and accurately in real-time manner. So, ground-based remote sensing platform research and development plays as basis of remote sensing applications for crop monitoring and management, as well as a complement and verification for other remote sensing platforms.

Rice is a staple food crop of the world's population[13]. Acquisition of information on rice conditions is significant for estimating rice reproductive growth, enhancing nutrition and deceasing management and using efficiency, improving the yield of rice, and the protection of the ecological environment[14]. Remote sensing has great potential for such applications because it enables non-destructive, rapid, real-time, and accurate acquisition of information on rice plant conditions[15-16]. With the development of remote sensing technology, more and more remote sensors are used for rice monitoring[17]. Spectral techniques provide a good source of crop, soil, or ground cover information in agricultural research and applications[18]. Nowadays, real-time and accurate monitoring and diagnosing crop conditions has become the focus of remote sensing technology in agricultural applications[19-20]. Ground-based remote sensors have already been applied extensively in resent years. A hand-held Multi-Spectral Radiometer (MSR) was used to monitor rice plant conditions during the growing season through obtaining rice field reflectance parameters and estimating its aboveground biomass and LAI[21]. FieldSpec Pro FR2500 hyperspectral radiometer is manufactured by the U.S. Analytical Spectral Device (ASD) Company, and can be used to measure rice leaf and canopy spectral reflectance values. Researchers found that there is a significant relationship between the hyperspectral vegetation index (NDVI, RVI, DVI, and red edge parameters) and rice LAI, chlorophyll content, rice nitrogen content, which indicated that the hyperspectral remote sensors are good choices for monitoring rice growth status[22-25]. Chen et al. measured the rice canopy spectral reflectance during the stages of tillering and elongation with three different canopy spectral sensors (Fieldspec FR 2500, MSR-16 and GreenSeeker RT 100), and found some vegetation indices were closely related to rice growth indices and there were significant differences among the estimation models based on different canopy sensors[26].

Ground-based platform systems have been widely used for monitoring crop growth status. Tumbo et al. developed the on-the-go system for sensing chlorophyll status in corn. The system included 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[27]. Scotford et al. used a tractor–mounted radiometer system in parallel with an ultrasonic sensor mounted one meter above the ground to obtain information about crop cover and the structure of the crop canopy. The radiometer system used two radiometers: one was mounted upwards to measure incoming radiation while the other mounted downwards to measure the crop canopy reflectance light[28]. Reyniers et al.[29] conducted a ground-based optical measurement platform consisted of a 12 m wide adjustable sprayer boom. A Cropscan MSR16R was mounted on one end of the boom to obtain wheat canopy information. The ground-based system provided a better estimation of wheat growth status and was better related to dry matter content, and the average error percentage was lower for the platform than for Ikonos[29].

Considering precision agriculture practice, it is essential to acquire multi-source information simultaneously. The use of a number of sensing techniques working in combination could provide a better characterization of the crop canopy. Also, there are few studies about monitoring crop conditions using UGVS, especially for rice monitoring. The objective of this study was to develop a UGVS and test the feasibility of this system for monitoring rice conditions. It will provide a good tool for monitoring and managing crop conditions in precision agriculture applications.

2 Materials and methods

The multi-sensors, which included a GreenSeeker R100 system, a FieldSpec® Handheld portable spectroradiometer, and an infrared temperature sensor, are mounted on an UGV. Each of these instruments is described in detail in the following sections. The system is designed to quickly measure real-time crop conditions including NDVI, spectral reflectance, and canopy temperature in rice growth season simultaneously.

2.1 Experiment design

The experimental field for this study is located at the Texas A&M University Agricultural Research and Extension Center in Beaumont, TX, USA (30.06 N, 94.29 W). There are eight blocks used for measuring in the whole rice field and each block is controlled in different disease treat. The rice variety is Presidio. The dimension of each zone is 1.2 m by 5.5 m to fit the UGV driving. Rice canopy information was collected by the UGVS around noon time on cloud-free sunny days in rice early maturity stage. At the same time, the LAI is collected by the CGMD 302 Spectrometer in the rice field.

2.2 UGVS

The UGV is a light-weight and height/width-adjustable platform with the capabilities of auto-control, four-wheel drive, wireless data communication, and 3D rotary connector rotation (Figure 1). The width can be adapted to the planting ridge spacing from 1 m to 2.2 m, and the height of equipment install platform is adjustable from 0.5 m to 2 m. The travel speed is set to 3 km/h to ensure stability of data measurement. The load capacity is more than 100 kg. The front frame and the rear frame are connected by the 3D rotating connector. The 3D rotate coupler is the main part of the platform to fulfill the turn and adjust the front frame and the rear frame when the four wheels in the uneven ground. The video image obtained by a network camera locating in front of the platform can be sent to the control computer, and the operator could control its moving status by computer control software (Figure 2). It also can be set to the automatic control mode. The embedded image processing software will determine the crop and soil edge, and adjust the moving direction dynamically. The third controlling mode is the GPS control mode, before experiment, the GPS position information for the desired track needs to be input into the control system. After the start button was pushed, it would move according to the preset GPS information. The position control accuracy depended on which kind of GPS receiver was used. If the Centerpoint RTK was used, the position accuracy would be less than one inch.

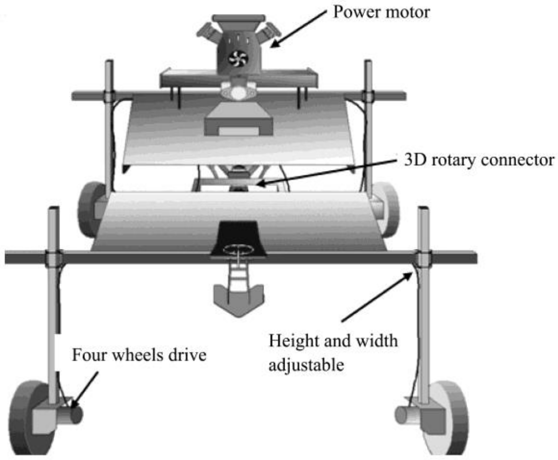

Figure 1 UGV platform

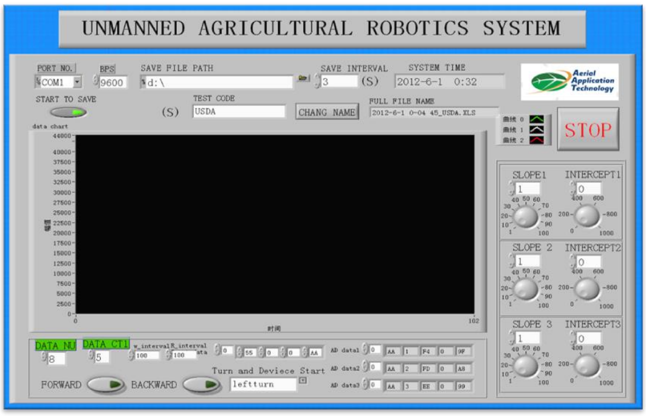

Figure 2 Computer control software

The GreenSeeker R100 system (① in Figure 3) was mounted on the front of the platform to collect the NDVI values. The NDVI readings were stored internally and transferred to the computer. The FieldSpec Handheld (② in Figure 3) was mounted on the back of the platform with the optical sensor facing the rice in the same line with the Greenseeker sensor and the spectral reflectance values were taken every second. The infrared temperature sensor (③ in Figure 3) was mounted close to the Greenseeker sensor for monitoring the rice canopy temperature. The infrared temperature sensor was connected to the laptop via serial RS232 to USB cable for controlling and collecting the readings. All of these sensors are mounted about 0.5 m above the rice canopy.

Figure 3 UGVS platform equipped with sensors working in paddy field

2.3 GreenSeeker R100 system

The GreenSeeker R100 system (NTech Industries, Inc., Ukiah, Cal.) is an advanced tool and has been used widely in precision agriculture technology to provide useful data to monitor the growing status of crops. The instrument is adjustable in 15 degree increments and mounted on a length adjustable pole to set the sensor parallel to the target canopy. The control box supplies power to the sensor and external connectors. The GreenSeeker sensor is equipped with a Compaq iPAQ pocket PC and specific software for data collection. Reflectance data 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 the red and near infrared (NIR) lights. As the sensor passes over the crop surface, it measures the incident, reflects light from canopy and outputs both NDVI and Red to Near Infrared Ratios. The output rate is about 10 readings per second[30].

2.4 FieldSpec® Handheld

FieldSpec® Handheld spectroradiometer, a highly portable field spectroradiometer (FieldSpec®, Analytical Spectral Devices, Inc. Boulder, CO), is suitable for estimating crop properties[31]. The instrument can detect reflected light from canopy ranging from 325 nm to 1 075 nm wavelengths with a sampling interval of 1.4 nm of the spectrum[18]. Sunny days must be chosen for the field tests and all data shall be collected around solar noon time. The instrument optimization and white reference measurements need to be performed prior to taking measurements[32]. The 25° field-of-view (FOV) mode of the sensor is chosen in this study.

2.5 Infrared temperature sensor

The infrared temperature sensor (Apogee Instruments, Inc) measures surface temperature of crop canopies accurately with non-contact, and automatically stores data. This sensor carries an impressive uncertainty of 0.2℃ at 95% confidence to ensure accurate measurements. It has a large range of calibrated target temperature from -30℃ to 65℃. The 22° field-of-view (FOV) mode of the sensor is chosen in the study.

2.6 CGMD302 spectrometer

The CGMD 302 Spectrometer is used for obtaining real-time non-destructive and accurate spectral reflectance and crop growth indicators of rice crop canopy, and is composed with the upstream optical sensor for receiving the solar spectrum, the downstream optical sensor for receiving crop canopy reflectance spectra, and the collector for processing the spectrum information and extracting crop growth index. With an angular field-of-view of 30°, it scans a range of ground area from 0.23 m^2 to 0.38 m^2. For monitoring the rice canopy, the downstream optical sensor has to be adjusted at the height of about 0.6 - 0.7 m above the rice canopy, the support rod has to be adjusted to an appropriate angle to make sure that the sensor maintains vertical to the crop canopy.

3 Results

3.1 NDVI measurement

The Normalized Difference Vegetative Index (NDVI) which was measured by the GreenSeeker R100 system was a commonly used measurement of crop health in agricultural applications[34]. NDVI is found to be closely correlated with the LAI[35-37]. The wavelength bands selected the visible (red, 660 nm) and infra-red (NIR, 770 nm) and the NDVI value was calculated. The one way ANOVA method was used to build the relationship between NDVI from the GreenSeeker sensor and rice LAI. The variation and correlation model were demonstrated in Figure 4. When the NDVI value increased, the rice LAI value increased. The correlation coefficient (R^2) was 0.728 and a significant positive correlation relationship was verified. This result shows that the relationship trend between NDVI and LAI agrees with results from other researchers, and the automatic measurement based UGVS is more reliable than manual measurement.

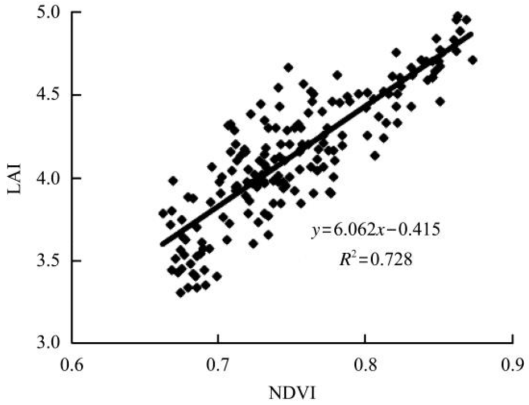

Figure 4 Relationship between NDVI (770 nm, 656 nm) and rice LAI

3.2 Relationship between spectral vegetation indices and LAI

Rice LAI is closely related to several hyper-spectral vegetation indices such as NDVI, RVI, and DVI, and the good combination band range of these three vegetation indices distributed in 750-860 nm and 730-770 nm were in significant correlation with LAI[33]. In this study, when the NDVI, RVI and DVI values increase, the rice LAI value increases, which shows a significant positive correlation between the three vegetation indices and the rice LAI. The Independent Samples T-Test method and the one way ANOVA method are used to determine the best spectral indices and analyze the relationship between the vegetation indices and rice LAI. It was found the two best spectral indices for estimating LAI were NDVI (860 nm, 750 nm) with R^2 at 0.745 and RVI (853 nm, 751 nm) with R^2 at 0.724. The R^2 of DVI (850 nm, 760 nm) was 0.697. The results are shown in Figure 5.

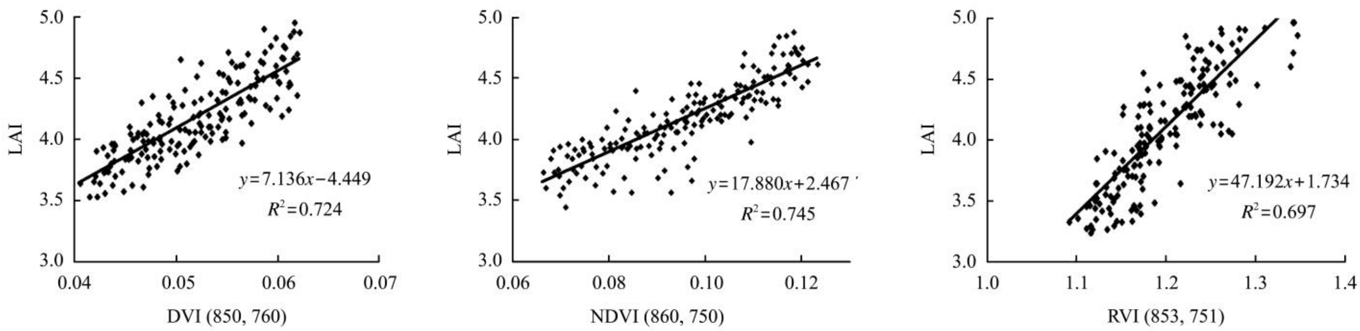

Figure 5 Relationship between DVI (850, 760), NDVI (860, 750), RVI (853, 751) and rice LAI

3.3 Canopy temperature

Crop canopy temperature, which was also the main means of monitoring crop water content, was measured by the infrared temperature sensor based UGVS. A variation of rice canopy temperatures in eight blocks is shown in Figure 6. The rice canopy temperatures are significantly different in different disease treatment blocks. The maximum value of canopy temperature is 39.0℃, while the minimum value is 37.9℃. There is a positive correlation between the crop canopy temperatures with disease degree, the higher the rice disease degree, the higher the canopy temperature. This result may be due to the negative correlation between the rice disease degree and the low moisture content in rice mature period.

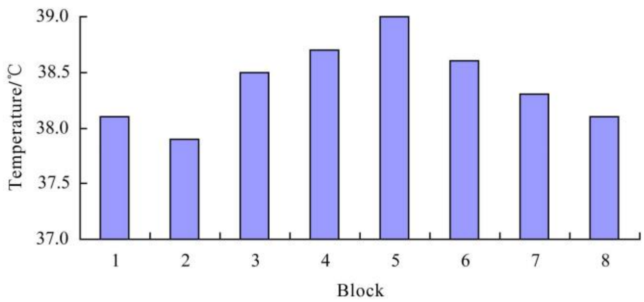

Figure 6 Variation of rice canopy temperature in eight blocks

4 Discussion

A UGVS was developed to monitor crop conditions for precision agriculture applications. The reliable and accurate information on rice field, such as NDVI values, reflectance measurements, and crop canopy temperature was acquired fast, automatically, non-destructively and simultaneously by the UGVS and used to monitor crop conditions. This preliminary study indicates the potential of the developed UGV-based multi-sensors system in realizing multi-source information acquisition and management in the field. According to the needs of users, other sensors for monitoring field crop information can be easily integrated to this UGV-based multi-sensors system for precision agriculture applications.

5 Conclusions

NDVI, spectral reflectance, and canopy temperature in rice growth season have been acquired by the UGVS simultaneously. The Independent Samples T-Test method and the one way ANOVA method are used to determine the best spectral indices and analyze the relationship between the vegetation indices and rice LAI. There are high correlation coefficients among DVI, NDVI, RVI and LAI, but the two best spectral indices for estimating LAI were NDVI (860 nm, 750 nm) and RVI (853 nm, 751 nm). In addiction, the higher the rice disease degree is, the higher the canopy temperature is. This preliminary work indicates that the UGVS can support multi-source information acquisition and is useful for crop management and precision agriculture applications. Future studies should focus on improving the performance of the UGV system, which may include improving steering flexibility, adding a suspension system, and ensuring attitude stability of mounted instruments.

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