Development and application of crop monitoring system for detecting chlorophyll content of tomato seedlings

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Abstract: A crop monitoring system was developed to nondestructively monitor the crop growth status in the field. With a two channel multispectral camera with one lens, controlling platform, wireless remote control module and control software, the system was able to synchronously acquire visible image (red(R), green(G), blue(B): 400-700 nm) and near-infrared (NIR) image (760-1 000 nm). The tomato seedlings multi-spectral images collection experiment in the greenhouse was conducted by using the developed system from the seeding stage to fruiting stage. More than 240 couples of tomato seedlings pictures were acquired with the Soil and Plant Analyzer Development (SPAD) value measured at the same time. The obtained images were available to process, and some vegetation indexes, such as normalized difference vegetation index (NDVI), ratio vegetation index (RVI) and normalized difference green index (NDGI), were calculated. Considering the SPAD value and the correlation coefficient between SPAD and other parameters in different fertilization treatments, the multiple linear regressions (MLR) model for estimating tomato seedlings chlorophyll content was built based on the average gray value in red, green, blue and NIR, vegetable indexes, NDVI, RVI and NDGI in the 33.3% (N1), 66.6% (N2), and 100% (N3) nutrient levels during seeding stage and blossom and fruit stage. The R^2 of the model is 0.88. The results revealed that the developed crop monitoring system provided a feasible tool to detect the growth status of tomato. More filed experiments and multi-spectral image analysis will be investigated to evaluate the crop growth status in the near future.

Keywords: multi-spectral image, crop growth status, image acquisition, 2-CCD sensor, precision agriculture
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1 Introduction

Crop nutrient content is one of the important factors for measuring the crop growth status. Chlorophyll content is one of the most important parameters of crop nutrient content. Lack of chlorophyll could cause series changes of growth status, such as color, thickness, and morphological structure of leaf, and then result in the changes of spectral reflectance characteristics[1-3]. Hence, it is reasonable to research real-time chlorophyll monitoring and rapid diagnosis by spectral analysis technology which is to detect object based on its spectral reflectance characteristic.

Compared with experience guide and chemical analysis, the spectroscopy has the advantages of enormous information, fast diagnosis, saving time and labor. In recent years, with the development of spectral technology in agriculture, the spectral analysis was widely used for crop nutrition monitoring and research[4-6]. Zhang et al.[7] created a new red-edge reflectance spectra index (RERI) based on data in red/near-infrared (NIR)

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wavebands centre at 681.499 nm, 729.232 nm and 765.399 nm. The correlation between measured and predicted nitrogen concentrations suggested that RERI could sensitively measure the canopy leaf nitrogen content. Wang et al.[8] studied the interrelation between the different varieties of corn chlorophyll and normalized difference vegetation index (NDVI). The results showed that a positive correlation was observed between the chlorophyll content of corn and the NDVI values at different times. The values of correlation coefficient of different varieties were 0.865, 0.874, and 0.870 separately. Ni et al.[9] developed a four band multi-spectral optical filtering sensor embedded the relational model with Field Spec Pro FR 2500 spectrometer (average measurement errors are 5.6%, 4.6%, 1.4% and 4.5%, respectively). Those spectral devices developed based on previous research usually diagnose the growth status of the crop with single point measurement, it was low efficiency and had more and more difficult to meet the needs of rapid access to information in agriculture. Hence, the equipment to acquire field information quickly was needed.

Following the development of digital imagery technique, a lot of hyper-spectral and multi-spectral image monitoring sensors were widely applied in agronomic field, which provided the means of obtaining field information continuously with objective, prompt characteristics[10-12]. Sun et al.[13] used a multi-spectral CCD camera to detect the chlorophyll content in the field. In their study, there were three channels of green (G), red (R) and NIR; a new vegetation index, combination of normalized difference vegetation index (CNDVI), was developed and a positive correlation was observed between CNDVI and the chlorophyll content. The values of correlation coefficient were 0.63 and 0.60 under high and normal nitrogen treatment respectively. Wang et al.[14] built the correlation model between chlorophyll content measured by chemical method and the ration value NIR/G, the coefficient of correlation was 0.637. It provided a support for maize growth condition diagnosis based on the multi-spectral image.

Meanwhile, many spectral imaging systems for crop detection were developed. Michio et al.[15] integrated a multi-spectral camera system. Two visible wavelengths and a NIR wave band could be measured simultaneously. The camera system included three same monochrome cameras, a cold mirror, a beam splitter, and three interchangeable lens filters. This camera system was complicated to operate with camera parallax and asynchronous triggering. The image registration algorithm for each channel would reduce the detection efficiency. Du et al.[16] developed a multispectral image acquisition system based on liquid crystal tunable filter (LCTF) with 16 wavelengths tuning in 400-720 nm wavelength range. The system would need to change the filter for many times, and as the characteristics of filter were different, the accuracy of image measurement would be affected. Thus, it is necessary to develop a feasible image acquisition system with simple operation used for multispectral image acquisition.

The purpose of this study, therefore, was to develop a crop monitoring system. The system was developed based on the multi-spectral imaging technology with the hardware device and software control system. The greenhouse experiment was conducted to collect the multi-spectral image of tomato leaves to measure the chlorophyll content of tomato seedlings. The image processing and analysis were conducted after acquisition. The results could reveal that the developed crop monitoring system would provide a feasible tool to detect the growth status of tomato in the greenhouse.

2 Materials and methods

2.1 System overview

The crop monitoring system consisted of hardware device and software control system. A two-channel multi-spectral camera was integrated as the main device. A controlling platform and wireless receive module was available. The software control system installed in the controlling platform was mainly used to control multi-spectral image acquisition equipment and process the crop images. The control part of software was developed with two basic capabilities including the equipment parameters setting and multi-spectral image acquisition modes selecting. The image processing module was composed of four parts: image preprocessing, image feature extraction, a variety of vegetation index calculation and image model analysis.

2.1.1 Hardware device

The hardware device consisted of three parts: a multi-spectral image sensor, controlling platform and wireless remote control module. The hardware structure of the system is shown in Figure 1.

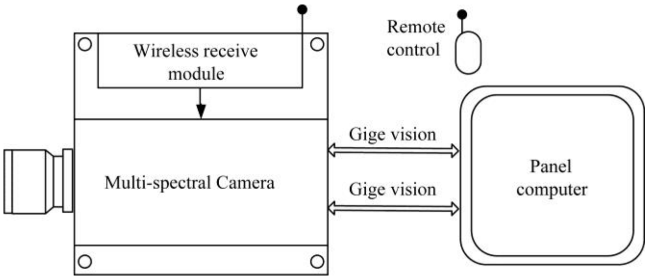


Figure 1 Structure of hardware equipment

A two-channel CCD camera with one lens was integrated as the core part of the multi-spectral image acquisition device. It was designed based on the principle of splitter prism with two reflecting mirrors. The reflected light of crop canopy was measured and split into two wavebands with 400-700 nm and 760-1 000 nm. The outputs of CCD camera were RGB (red, green, blue) and NIR images with center length at 470 nm, 550 nm, 620 nm and 800 nm, separately. Output images with GigE Vision standard were sent to the controlling platform. The highest output bandwidth was 960 Mbps and the CPU occupancy rate was less than 1%. The active pixels were 1 024(h), 768(v) per channel.

The controlling platform was combined with a panel computer and the installed control software. It was developed to control the multi-spectral image acquisition device. It was a Core Duo processor at 1.66 Hz and with 1 GB memory. 320 G SATA disk space was used to store collected multi-spectral images. 12 V DC power was required. An 8.4 inch LCD touch screen provided good interface. Two 1 000 Mbps Ethernet ports were offered.

Wireless remote control module contained a wireless receive module and RF remote control. It was used as an external trigger to control the multi-spectral camera. It worked when the edge of the trigger signal is received. The control distance was 100 m and the radio frequency was 433 MHz.

2.1.2 Software system

The software developing platform was Windows XP. It provided a friendly and stable place to launch software. The camera control software was developed based on JAI SDK, using Visual C++ 6.0. The developing environment of image processing was MATLAB (matrix laboratory). The MATLAB is a numerical computing environment with a strong image processing toolbox and can allow interfacing with programs written in other languages, including C, C++, and Java. The image processing was integrated to the camera control software via the interface technology between MATLAB and VC++[15].

The software of the crop monitoring system consisted of camera control and the image processing. The camera control has two basic capabilities including the device parameters setting and the acquisition mode selection. The parameter setting function included the exposure time, gain and white balance adjustment. The acquisition mode selection included three modes to obtain multi-spectral images: the manual mode, the automatic timing mode and external trigger mode. The multi-spectral image could be stored as TIF, BMP and JPG format. The Image process function included four parts: image preprocess, image feature extraction, a variety of vegetation index calculation and image model analysis. The software structure of the system is shown in Figure 2.

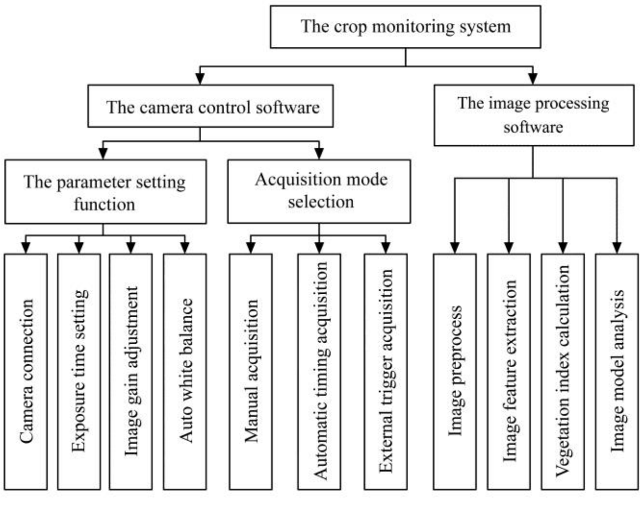


Figure 2 Structure of the software control system

The parameter setting function was used to control the multi-spectral camera acquiring high quality visible and

NIR images. Camera connection was prepared for image acquisition. To find and open camera correctly was the premise to do the next. The function J_Factory_Open and J_Camera_Close were called to open and close camera, start and stop image acquisition. Exposure time can range from 1/30 s to 1/10 000 s, the image gain can be adjusted between -3 dB to +21 dB. Adjusting exposure time and aperture was to obtain high-quality multi-spectral images. By setting camera registers, named ExposureTimeRaw, GainAuto, and BalanceWhiteAuto, and calling functions J_Camera_SetValueInt64, based on GigE Vision protocol, the software could achieve the corresponding parameters adjustment.

The acquisition mode selection module was used to choose the suitable mode to collect the images. The manual acquisition mode was the basic mode to obtain images. It was conducted by users themselves with the advantage of flexibility. Users can manually adjust the exposure time, gain and white balance based on their need. In the automatic timing acquisition mode, the acquisition interval time could be set from one to 30 seconds. In the process of automatic acquisition, the gain of images could be automatically adjusted according to environmental light changing. The external trigger mode was used to long-distance control. In this mode, wireless receive module received trigger edge signal to control the multispectral images capture and save images to the default path.

The image preprocessing for the crop canopy image included histograms, image smoothing, and image segmentation. The gray level histograms of the images in the R, G, B and NIR band were drawn. After adaptive filtering, the HSI (Horizontal, Situation, Indicator) color mode was used to separate crop leaves from background. The average gray values of the R, G, B, and NIR waveband extracted as the image features were based on the images after the former step. NDVI, RVI and other plant vegetation index were calculated. Two chlorophyll monitoring models were embedded, based on the calculated average gray value and the vegetation index value, to predict the chlorophyll content of the crop canopy.

2.2 Collection of multi-spectral images of greenhouse tomato seedlings

The developed crop monitoring system was applied to collect the multi-spectral images of tomato canopy in the greenhouse in June and July, 2012. Forty-eight seedlings, chosen at random, were averagely transplanted into four soilless mix (turf : vermiculite = 1:0, 0.2:0.8, 0.5:0.5, 0:1) in wooden flats, and placed in a fiberglass production greenhouse. On 20 days after the transplantation, seedlings were assigned to one of four fertilization treatments: 0% (N0), 33.3% (N1), 66.6% (N2), and 100% (N3), with 12 seedlings in each treatment. The multi-spectral image acquisition device was installed above the tomato canopy about 2 m in height. The visible and NIR images were shot vertically. The device was controlled by the camera control software with parameter adjusting and image saving with manual acquisition mode. Simultaneously, the chlorophyll content of tomato leaves was measured three times at each sample point by SPAD-502. The averages of measured values were as the tomato seedlings leaves chlorophyll content standard values.

During the seeding stage, blossom and fruit stage and fruiting stage of tomatoes, the multi-spectral images of tomato seedlings were collected using the crop monitoring system. In order to eliminate the effect of nature light condition change to quality of images, the visible and NIR images of tomato canopy were collected from 10:00 to 12:00 in a sunny day. Every moment exposure time and aperture were adjusted according to light intensity. More than 240 couples of pictures were acquired with the same camera parameters and meanwhile their chlorophyll contents were measured by SPAD during the experiment.

Figure 3a showed crop monitoring system in the greenhouse during the collection experiment. The 2-CCD multi-spectral camera and the panel computer were connected by two Gigabit Ethernet cables, and the 12 mm lens was vertical fixed to the ground with vertical distance of 130 cm and angular field of 26.2°. Figure 3b showed the SPAD which was used to measure the tomato leaves during the seeding stage.

a. Crop monitoring system in the greenhouse

b. SPAD-502

Figure 3 Crop monitoring system

3 Results and discussion

3.1 Image processing

Using the image preprocessing module as mentioned above, the acquired seedling multi-spectral images were processed. The RGB and NIR images were processed by median filtering algorithm to eliminate the noise, and then HSI color model was used to segment the image of tomato canopy from background. The average gray value of tomato canopy at four channels (R, G, B, NIR) were achieved by image processing, and could be used to calculate different vegetation indexes based on their definitions embedded in the image processing software, which could be used to measure chlorophyll status of tomato seedlings. The flow chat of image processing is shown in Figure 4.

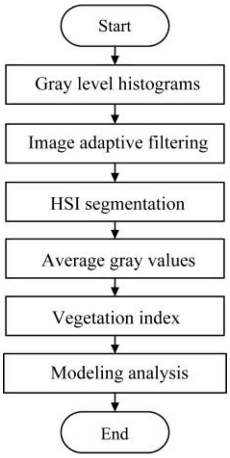
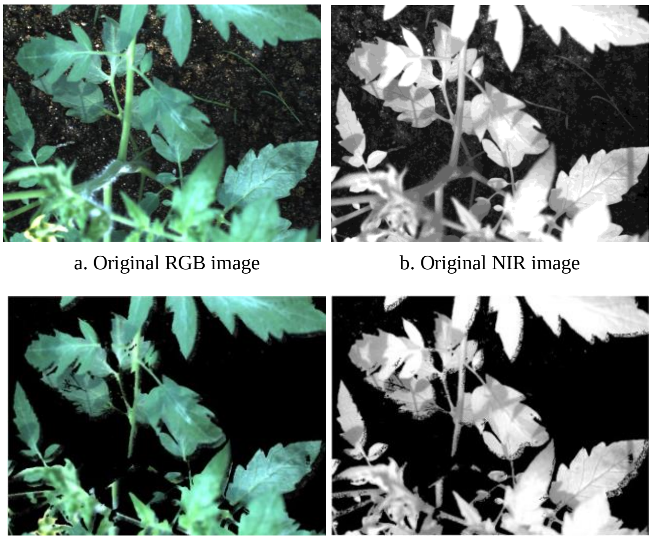


Figure 4 Flow chat of image processing

Figures 5a and 5b are the collected RBG and NIR images during seeding stage and the input of the image processing. After the preprocessing, the tomato canopy part of images was extracted from the soil background with the angle of intensity factor, π/4 and 7π/6, as threshold values of the green parts. Figures 5c and 5d showed the output RGB and NIR images of the HSI segmentation. The results showed that most of the green canopy was selected, and only one stem of tomato was missing because the reflective light of stem affected the extraction.



a. Original RGB image b. Original NIR image

c. RGB segment action d. NIR segment action

Figure 5 Tomato multi-spectral images after image processing

The processed image results revealed that this method successfully selected the tomato seedling leaves from bare soil and shaded background. The algorithm embedded was available to improve the speed of processing. Spectral reflectance of tomato canopy at four channels (R, G, B, NIR) were achieved by image processing, and could be used to calculate different vegetation indexes based on their definitions embedded in the image process software, which could be used to measure chlorophyll status of tomato seedlings. The vegetation indexes are: NDVI = (R_NIR−R_Red)/(R_NIR+R_Red); RVI = R_NIR/R_Red; NDGI = (R_Green−R_Red)/(R_Green+R_Red). R_Red, R_Green and R_NIR were the reflectance of leaf at R, G and NIR wave bands.

3.2 Correlation analysis

Figure 6 shows the histogram of SPAD value of tomato seedlings at different stages under different nutrient levels. After the analysis of multispectral images and obtained SPAD values in different tomato growing stages, the results (Figure 6) revealed that the measured SPAD chlorophyll content showed the following characteristics: The SPAD values of seedling and blossom and fruit stage were closed. The measured SPAD values of fruiting stage were significantly lower than those of the first two periods.

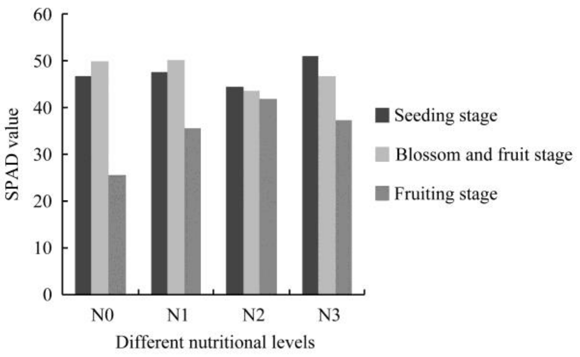


Figure 6 Histogram of SPAD values at different stages under different nutrient levels

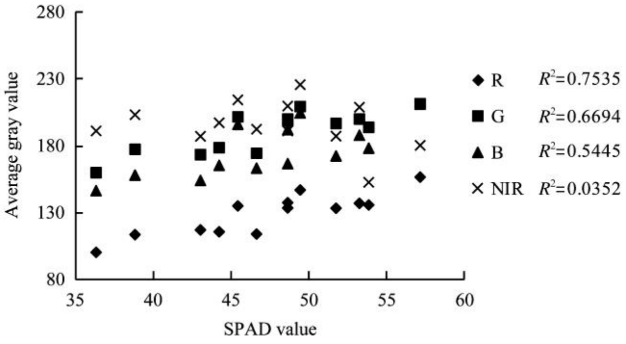
Since the tomato fruits were abundantly supplied and the leaves were lack of the nutrient during the fruiting stage and the acquisition experiments were conducted in late stage. Fewer plants survived in group N0 because of the lack of nutrient, and also lack of experimental data.

Given the results mentioned above, the multi-spectral images in the N1, N2 and N3 nutrient levels during seeding, blossom and fruit stages were chosen to research tomato seedlings chlorophyll content diagnosis, and then NDVI, RVI and NDGI were calculated based on the embedded definitions and used to establish correlation with tomatoes chlorophyll content.

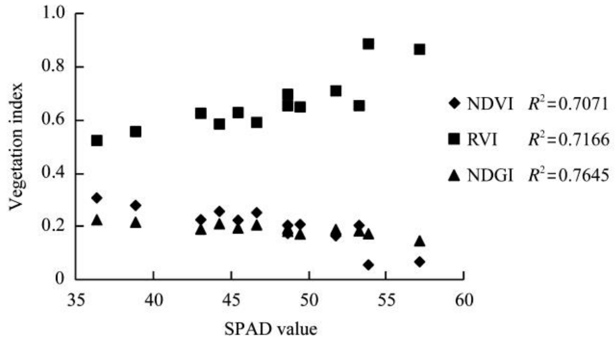
Table 1 Correlation coefficients between SPAD values and other parameters in different fertilization treatments

R^2		R	G	B	NIR	NDVI	RVI	NGVI
SPAD	N1	0.3809	0.4164	0.4553	0.3671	0.2704	0.2772	0.3358
	N2	0.7535	0.6696	0.5445	0.0352	0.7071	0.7166	0.7645
	N3	0.5947	0.4832	0.3575	0.3301	0.2195	0.2186	0.4591

According to Table 2, correlation coefficient of R, G, B, NDVI, RVI and NDGI in the nutrition level N1, N3 were lower than in N2. The correlation coefficient of NDGI vegetation index is higher than the other two, because the crop chlorophyll content reflected in green characteristic of NDGI. Figure 7a shows the correlation between average gray value in each channel and the SPAD value in the nutrition level N2; Figure 7b shows the correlation between vegetation index and the SPAD value in the nutrition level N2. From Figure 7, under the level N2, the R^2 of the average gray value of G, R were 0.6696 and 0.7535, they were higher than the R^2 of B and NIR. The correlations of vegetation indexes were 0.7166, 0.7071, and 0.7654 of RVI, NDVI and NDGI. Hence, the correlations above were available to build the multiple linear regressions (MLR).



a. Correlation between average gray value in each channel and the SPAD value in the nutrition level N2



b. Correlation between vegetation index and the SPAD value in the nutrition level N2

Figure 7 Correlation between calculated parameters and the SPAD values in the nutrition level N2

3.3 Modeling analysis

According to the analysis above, tomato seedlings chlorophyll content diagnosis MLR model was built based on SPAD value, R, G, B, NDVI, RVI and NDGI in the N1, N2 and N3 nutrient levels during seeding stage and blossom and fruit stage. The coefficients of regression equation were calculated.

The regression equation is:

$$y=536.683+3.236R-2.801G+0.228B+0.349NIR-1231.58NDVI-679.098RVI+1149.266NDGI \quad (1)$$

where, y is the predicted SPAD value of MLR model.

The predicted SPAD value of MLR model and measured SPAD value were shown in Figure 8, R^2 of the model is 0.88, and passed the F testing and T testing.

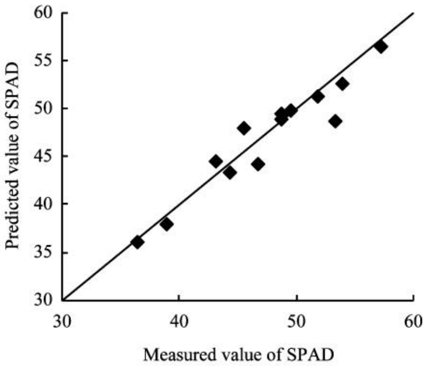


Figure 8 Relationship between predicted and measured SPAD values

The image processing software could achieve the basic image preprocessing and parameter calculation. The results calculated by the image processing software could be used to analyse and predict the chlorophyll of tomato seedlings. It is necessary to conduct more field experiments under the field condition to further evaluate the performance of the system and to extend its applications.

4 Conclusions

1) This study shows that a crop monitoring system was developed based on the multi-spectral image acquisition device to monitor the crop growth status nondestructively. Camera control module and image processing function were combined into a crop monitoring system. When the system was connected, the camera control software could work following camera linking, image acquiring, image displaying and saving, parameters adjusting and acquisition mode selecting. The image process function was embedded with image preprocessing, feature extracting, vegetation index calculating and model analyzing.

2) The greenhouse experiment was conducted to measure the chlorophyll content of the tomato seedlings. More than 240 couples of clear pictures were acquired with the software controlling, and some vegetation indexes, such as NDVI, RVI and NGVI, were calculated. The MLR model for estimating tomato seedlings chlorophyll content was built based on the calculated parameters. The R^2 of the model is 0.88. The result expounded that embedded software system could be used for monitoring tomato seedlings nutrition content monitoring, and would provide some guidance to cultivation management in the future. More filed experiments of multi-spectral image analysis and research will be investigated to evaluate the crop growth status in the near future.

Acknowledgments

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