Remote crop water requirement monitoring system based on multi-sensor

Wang Yongqian[1,2], Fan Lifeng[1,3], Huang Lan[1,3], Zhao Pengfei[1,2], Wang Ziyang[1,3], Wang Zhongyi[1,2,3]*

(1. *College of Information and Electrical Engineering, China Agricultural University, 100083 Beijing, China*;
2. *Modern Precision Agriculture System Integration Research Key Laboratory of Ministry of Education, 100083 Beijing, China*;
3. *Key Laboratory of Agricultural information acquisition technology (Beijing), Ministry of Agriculture, 100083 Beijing, China*)

Abstract: To estimate crop water requirement state accurately, a remote system was built. It makes irrigation decision based on various information when water deficit stress occurs. To meet demand of remote monitoring and automatic control, the system adopted master-slave structure, implemented remote view and control. It integrated crop physiological state and environmental sensors, such as plant electrical signal, stem-flow sensor, et al. In this work, configuration software was used to realize remote interaction between the master and slave. Preliminary results showed that the remote monitoring system is practicable and stable, and it allows us to investigate the relationship between the environmental factors and physiological parameters of crop in the greenhouse. The developed system will be a potential tool for evaluating crop water requirement state and precise irrigation.

Keywords: plant electrical signal, stem-flow sensor, configuration software, physiological state, remote monitoring system

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1 Introduction

Water stress limits the growth of crop in a short time or even irreversibly. So, estimating crop water requirement accurately and precisely is extremely important. Currently, in most crop cultivation process, crop water requirement state is just determined by the environmental or single physiological state information but rarely monitoring comprehensive physiological state, which is one-sided for decision-making and environmental control. Water stress results in a variety of changes in crops, ranging from altered physiological state to changes in growth rate and plant productivity (Shao et al., 2008; He et al., 2011; Escalona et al., 2015). Therefore, a system monitoring crop physiological states and environmental information simultaneously is significant (Fisher et al., 2010).

In addition to the environmental factors that can reflect crop water state, some previous studies have demonstrated that some physiological state information can be used to predict the crop water requirement state. Chlorophyll is one of the most important pigments related to photosynthesis, and its content determines the efficiency of photosynthesis. Chlorophyll content decreases under water stress and a recovery would be observed following rewatering for maize (Alberte et al., 1977; Efeoğlu et al., 2009; Akhkha et al., 2011). Stem flow of crops is related to soil water content, temperature and radiation, et al, making it to be a suitable and reliable indicator in detecting changes of water state (Ortuno et al., 2005; Conejero et al., 2007; Escalona et al., 2015). Since Tanner C. B. put forward that canopy temperature can be considered as an indicator of crop water deficit (Tanner, 1963), canopy temperature method has become an important means in the diagnosis of crop water

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* **Corresponding author: Wang Zhongyi,** Ph.D., Professor, Department Head of Electronic Engineering, China Agricultural University, Beijing 100083, China. Email: wzyhl@cau.edu.cn. Tel: +86-10-62737778

availability (Jackson et al., 1981; Fisher et al., 2010). Moreover, changes in stem diameter are frequently associated with plant water state (Katerji et al., 1994; Gallardo et al., 2006). Measuring the change in stem diameter of lemon trees, Ortuno et al. (2005) found that the water supply influenced the daily maximum trunk shrinkage directly. Yang et al. (2015) found that the stem base diameter of Populus euphratica seedlings decreased with the drought stress level rose. Furthermore, electrical excitability and signaling are frequently associated with rapid response to environmental stimuli. In our previous work, we have found that plant electrical signal is related to water stress (Wang et al., 2007; He et al., 2011). The characteristic of electrical potential during different light condition could be used as alternative tool to assess early plant stress (Fromm et al., 1998; Wang et al., 2007; Oyarce et al., 2010).

The main objective of this research is to discuss an automatic acquisition technique of crop water comprehensive information, develop sensors that can reflect crop growth and crop water information under water stress and build a remote monitoring system. On the basis of combining physiological state and environmental information, study data fusion technology and apply multifunction regulation devices, to achieve optimal system control and then water saving irrigation.

2 System design

2.1 System architecture design

Because there are many inconveniences during measurements in field, remote monitoring the water requirement of crop is extremely important. Remote crop water requirement monitoring system was designed for accurate monitoring of physiological state and environmental information in greenhouse, and it provided scientific basis for precise irrigation. The system adopted master-slave architecture divided into two parts: the server program and the acquisition-control system.

The acquisition-control system mainly included embedded integrated touch screen (running Monitor and Control Generated System (MCGS), which is a configuration software for rapid constructing monitoring and control system. Model: TPC7062Ti, Beijing Kunlundongtai automation software technology Corporation, China) and sensors. The embedded integrated touch screen has RS485 and Internet interfaces. The sensors included sensor for chlorophyll, stem-flow sensor, leaf temperature sensor, soil temperature and moisture sensor, stem diameter sensor, environmental temperature and moisture sensor, illumination sensor, radiation sensor and plant electrical signal sensor. Sensors could obtain crop physiological state and environmental information, and then the signals would be transmitted to the MCGS through acquisition modules. MCGS stored and managed the data, timely delivered it to the server program for deeper analysis. The embedded integrated touch screen with a network interface make users could browse sensor data, control buttons of irrigation switch, adjust pan-tilt direction of sensor for chlorophyll, and do control operations on the touch screen through the Internet. The acquisition-control system was equipped with an infrared network high-definition camera (DS-2DE7172-A, Hangzhou Hikvision Digital Technology Co., Ltd. China) which could be accessed through Internet, with horizontal direction 360° continuous rotation, vertical –15° to 90°. The camera real-timely monitored crop growth and the sensors in case they dropped from original position.

The server program running on a network server received data from the acquisition-control system. All the data would be uploaded to database and displayed on the program interface. The server program processed the data and then made irrigation judgement. Same to the acquisition-control system, users could control operations on server program, and the commands would be delivered to the acquisition-control system. After configuration, users could check data and do controls on the server program via Internet explorer anytime any place. Remote interaction was realized through Internet between the server program and the acquisition-control system. Architecture of remote monitoring system design is shown in Figure 1.

The system hardware consisted of power supply, signal module, an embedded integrated touch screen, sensors, and router. Power supply consisted of three switching power supply modules, respectively to provide

DC 24V (SA10024, Delixi Group Co., LTD. China), DC12V (SA5012, Delixi Group Co., LTD. China) and DC±12V (NET-50B, Taiwan Ming Wett Electric co., LTD. China) power supply for hardware equipment. Signal module contained acquisition module, output module, signal transducer module and terminal blocks. Modules connected sensors and touch screen. There were 4-20 mA acquisition module (EDA9017, Shandong Lichuang Science and Technology co., LTD. China) and 0-5 V acquisition module (C2000-A1-PAX0200-BX1, Shenzhen Zhonglian Chuangxin Autonomous System co., LTD. China), transmitting signal to the MCGS through RS485 interface. MCGS controlled the solenoid valve through output module. A signal transducer (MIK-502E-1-2-1-1-V2, Hangzhou Meacon Automation Technology Co., LTD. China) changed sensor's voltage output 0-20 mV to current signal 4-20 mA, and then signal would be transmitted to 4-20 mA acquisition module. The sensors are distinguished by address code in the RS485 protocol. All sensors' output and power were connected to terminal block. The hardware board was installed behind the embedded integrated touch screen.

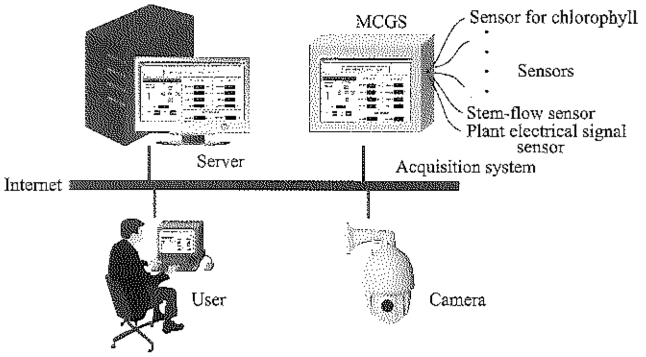


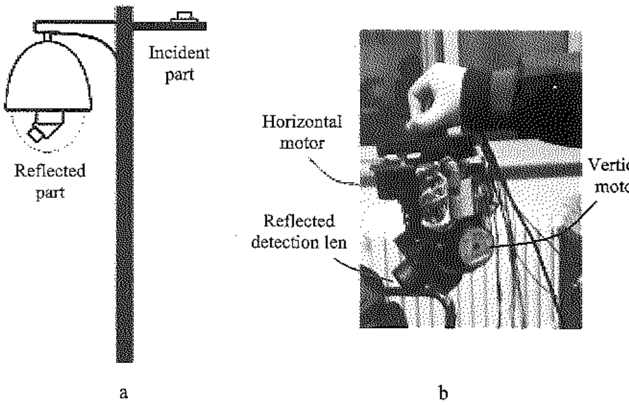
Figure 1 Architecture of the system

2.2 Sensors

2.2.1 Sensor for chlorophyll

The sensor for measuring chlorophyll of plant leaves in a region was designed based on visible-near infrared reflected spectroscopy using a nondestructive method with high accuracy and good repeatability. Researches make clear that the reflectivity of 700 nm light and crop leaf chlorophyll concentration have a significant correlation, which means the higher chlorophyll concentration, the lower reflectivity of 700 nm light. And chlorophyll concentration has no effect on the reflectivity of 840 nm light. In order to eliminate the background interference, we chose 700 nm as the measure wavelength and 840 nm as the reference wavelength. In our previous work, its feasibility and accuracy were verified (Tan et al., 2014).

The sensor had two parts, the detection module and the control module. Detection module included incident and reflected light detection parts. Incident light part contained an astigmatism piece, two optical filters, and two photoelectric sensors. Ensuring the incident light stable and maximum, we placed the incident detection part on the top of system horizontally. Reflected light part contained a quartz glass window, a dispersion prism, two optical filters, two photoelectric sensors. Reflected components were installed in the black opaque lens ensuring undisturbed, and the reflected part was installed on a rotating pan-tilt for the alterable measure scope. Control module installed inside of pan-tilt processed the data received from the detection module, then transmitted it to MCGS through RS485 protocol. The sensor for chlorophyll installation diagram is shown in Figure 2.



a. Installation diagram of sensor for chlorophyll, the control module was installed inside of pan-tilt above the reflected part b. The reflected part

Figure 2 Sensor for chlorophyll installation diagram

2.2.2 Stem-flow sensor

The stem-flow sensor was designed based on the theory of heat transfer and thermal balance (Kjelgaard et al., 1997). On the basis of this theory, we employed outside package design. And plastic insulation materials were adopted to reduce the external interference. There was a heating element and two sets of thermopile inside. Temperature measuring probe obtained the heat difference produced by the stem-flow movement. The transducer was used for signal excitation and preprocessing. More information about the sensor and calibration method could be found in our published paper (Liu et al., 2010). Its structure diagram is shown in Figure 3. As a result of the existence of stem flow, the heat generated by the heating element would be delivered to crop top direction, causing temperature difference between two thermopiles. The transducer connected MCGS and the sensor part. This sensor can be used to measure crop which has a small stem diameter of 1-2 cm.

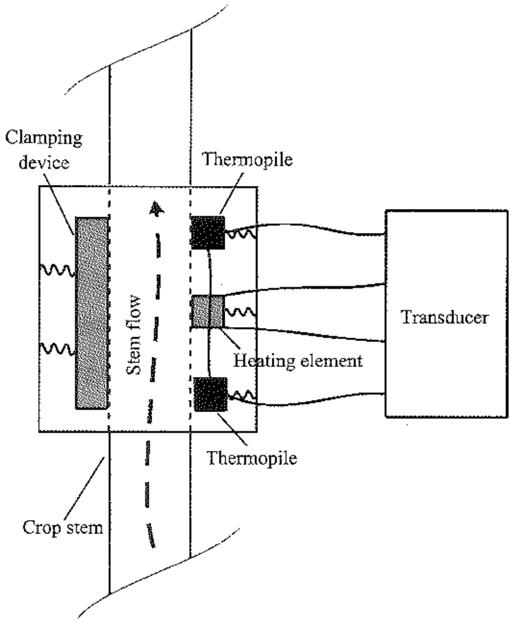


Figure 3 Structure diagram of the stem-flow sensor

2.2.3 Sensor for plant electrical signal

Stimuli give rise to extracellular signal transmission (chemical signal, electrical signal) in plant, and the occurrence and transmission of electrical signal may be the initial response (Huang et al., 2006). We adopted the sensor we used in our previous work for measuring the plant electrical signal, which consisted of two Pt electrodes and a transducer. Considering the environment and signal characteristic, two metal thread electrodes were applied as the measuring electrode. The electrodes were stabbed into the stem of crop. The transducer had high input impedance and low temperature drift (Wang et al., 2009). After the transducer's filter and amplification, the signal would be transmitted to the collecting module then to MCGS.

2.2.4 Other sensors

Monitoring system also integrated other physiological state sensors, leaf temperature sensor (provided by National Engineering Research Center for Information Technology in Agriculture, China), stem diameter sensor (Model: TWZ, accuracy of 0.05% of the full scale, range from 0 to 10 mm, Beijing Taize Science & Technology Development Co., LTD. China) and some other environmental sensors (air temperature and humidity compound sensor, model: DWS-T4,with accuracy of ±0.5°C and ±3% in relative humidity, range from –40°C to 80°C in temperature and 0% to 100% in relative humidity; soil temperature sensor, model: JWB/KP-A, with accuracy of ±0.5°C, range from –20°C to 80°C; soil moisture sensor, model: FDS100, with accuracy of ±2%, range from 0% to 100%; illumination sensor, DZD-T4, with accuracy of ±5% of the full scale, range from 0 to 200000 Lux; radiation sensor, HSTBQ-2, with accuracy of ±2%, measurement wavelength range from 300 to 3000 nm. All these sensors were provided by Beijing ColliHigh Sensing Technology Co., LTD. China). These sensors are supplied by DC 12 V or DC 24 V powers, and their outputs are 4-20 mA or 0-20 mV. They were connected to the signal module.

2.3 Software design

System software was written in MCGS script language. It consisted of embedded program and server program. Embedded program was written in MCGSE configuration environment, running in the embedded integrated touch screen. Server program was written in MCGS online configuration environment, running on server. The architecture of application software written in MCGS configuration soft is shown in Figure 4.

By adding TCP/IP devices, the two MCGS programs established network connections. The interface windows of program were created in user window. All the variables were listed in real-time database window and strategies could be created in operation strategy window.

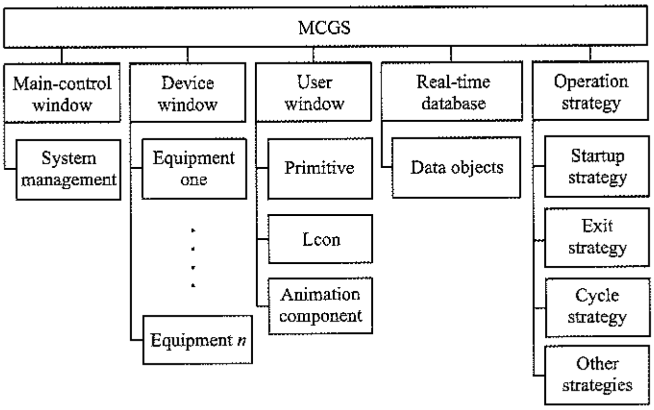


Figure 4 General software architecture of MCGS

2.3.1 Embedded program

Embedded program's functions are as follows: data preprocessing, data transmission to server program, real-time data storage, data copy, information display, irrigation solenoid valve control and control of pan-tilt direction of the sensor for chlorophyll. Embedded program interface is consisted six user windows: main window, system login, historical data, system setting, save setting, and data copy. The main window exhibits the sensors detail data, control buttons and system menu as the Figure 5 shows. Users can do some basic settings on system settings window, such as the time and IP. The setting of start and end time of data copy is in data copy window, and returns state parameter as hints. Data save interval setting is in save setting window.

Signal from collection modules is the standard 4-20 mA type. According to the relationship between signals collected and the actual value they presented, we set data processing function for each signal.

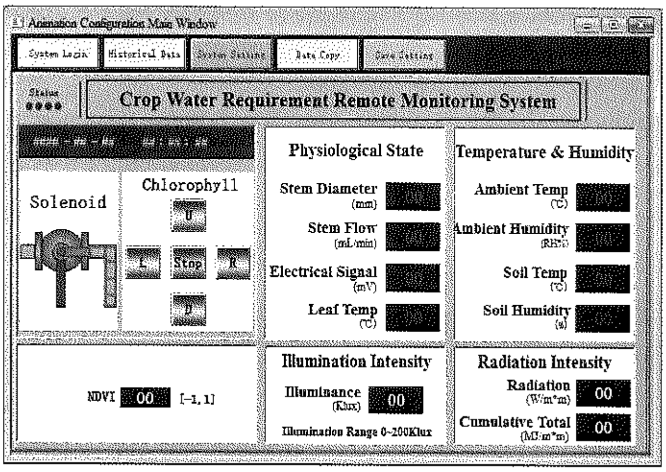


Figure 5 Embedded program running interface

2.3.2 Server program

Server program's functions are as follows: data process, sending data to database, data and control commands display and decision-making. There are two irrigation modes, manual mode and automatic mode. In the automatic mode, the program will perform irrigation operation based on the sensors data. Server program contains two user windows, the main window and calibration window. The main window exhibits the sensors detailed data and control buttons as is shown in Figure 6.

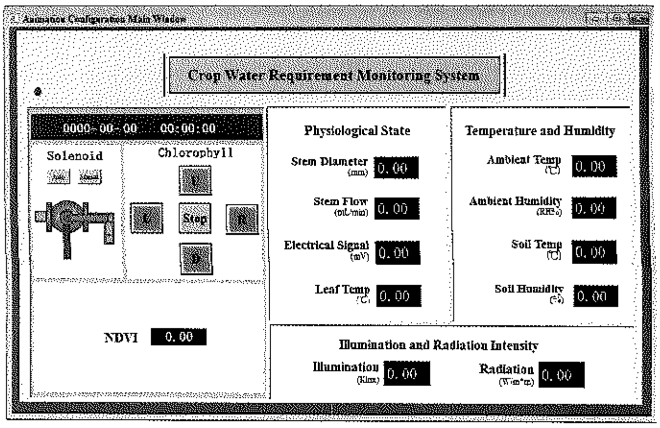


Figure 6 Server program design interface

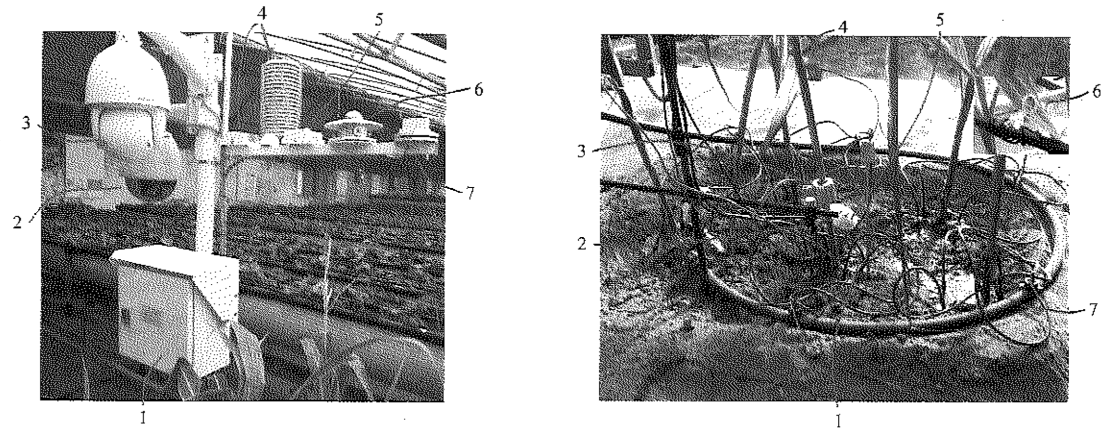
3 System application

The system was tested with maize (*Zea mays* L.) to verify the feasibility and stability in the greenhouse of China Agriculture University Zhuozhou test site in Hebei province, China. Environmental temperature sensor and leaf temperature sensor were calibrated by precision thermistor. Illumination meter was calibrated by GM technology JTG01 hand-held illumination meter. Users could modify the calibration parameters in the calibration window.

The MCGS acquired data of each sensor regularly, then real-timely displayed and storage. Besides, the server program could also real-timely display, storage data, and upload the data to database. According to the fusion data, system judged whether the crop was currently in the state of water shortage or not. If it was in water shortage, the irrigation operation would be made. The system installation is shown in Figure 7.

System continuously operated months normally without faults. The interface of infrared network high-definition camera is shown in Figure 8, and we can see the chlorophyll sensor. The server program running interface is shown in Figure 9.

The results reveal that: (1) Using MCGS achieved a good automatic remote monitoring system. It is simplicity, good visibility, strong maintainability, stable performance. (2) Acquisition of accurate information about the physiological state of the crop and environmental information was realized. All the sensors operated normally.



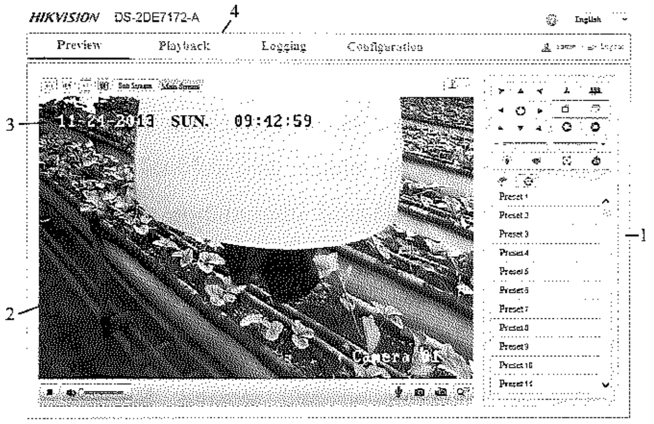
1. The acquisition-control system box 2. Reflected light part of sensor for chlorophyll 3. Camera 4. Air temperature and moisture sensor 5. Illumination sensor 6. Radiation sensor 7. Incident part of sensor for chlorophyll

a. Part one of system installation

1. Soil moisture sensor 2. Stem diameter sensor 3. Stem-flow sensor 4. Electrical signal sensor 5. Soil temperature sensor 6. Leaf temperature sensor 7. Drip irrigation equipment

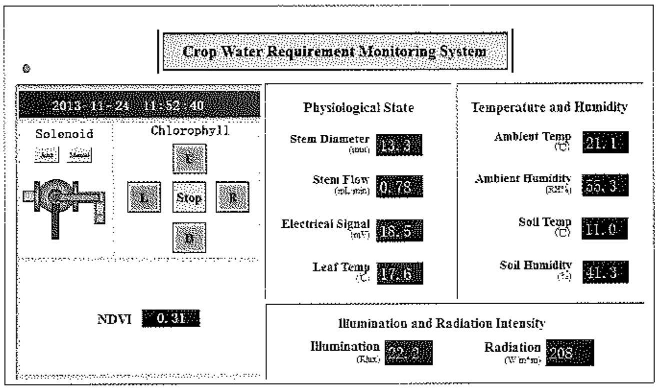
b. Part two of system installation

Figure 7 System installation



1. Camera direction control and zooming control panel 2. Video display area 3. Current time 4. Camera production model and configuration menu

Figure 8 Camera monitoring the sensor for chlorophyll



Crop Water Requirement Monitoring System

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Physiological State

Stem Diameter (mm) 13.3

Stem Flow (mL/min) 0.78

Electrical Signal (mV) 16.5

Leaf Temp (℃) 17.6

Temperature and Humidity

Ambient Temp (℃) 21.1

Ambient Humidity (RH%) 55.3

Soil Temp (℃) 11.0

Soil Humidity (%) 41.3

NDVI 0.31

Illumination and Radiation Intensity

Illumination (Klux) 22.2

Radiation (W/m²) 208

Figure 9 Server program design interface

4 Results and discussion

Plenty of data were obtained in months' operation. Data of sensors in four days is shown in Figures 10-14.

The data in Figure 10 shows the changes of air and leaf sensors in greenhouse. Because of transpiration cooling the leaves, the leaf temperature is lower than air temperature under sufficient water condition. However, when the crop is in water deficit state, transpiration becomes limited which will result in increase of the leaf temperature, even may be higher than air temperature (González-Dugo et al., 2006). After the straw-curtain of the greenhouse is rolled up and ventilation, the air relative humidity begins to decline and reaches its minimum in high noon. In the afternoon, after covering the straw-curtain, the humidity rises. The humidity maintains a high level in the night and reaches its maximum early in the morning. Based on the leaf temperature, judgement can be made whether the crop is in lack of water. And air temperature and humidity as reference show the external environmental conditions.

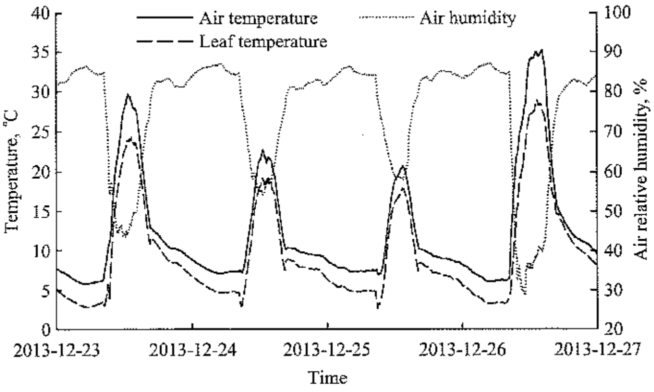

Figure 10 Data of air and leaf sensors

The data of soil moisture and temperature in Figure 11 shows the changes of four days in greenhouse. The soil moisture is the most intuitive factor reflecting if the crop is in water deficit environment. The trend of soil moisture decreases daily overall, and there are small fluctuations in a day and night. Water migration in soil can accompany with the processes of evaporation, dynamic distribution within the soil and water uptake by roots (Klute, 1973). Soil water moisture exhibits a marked diurnal variation, which occurs in our data shown in Figure12 (Jackson, 1973; Idso et al., 1975). The reason of this is soil water moisture is correlated with soil temperature, atmospheric factors and other movements caused by plants (Jackson, 1973; Idso et al., 1975; Hui-Xing et al., 2007). Meanwhile, soil temperature has a huge effect on crop growth. Higher and lower temperature than certain value will result in biomass decrease (Delucia et al., 1992). The soil temperature sensor goes deep into the underground 30 centimeters and the probe is near the root zone of maize. Because of the soil heat storage capacity, the soil temperature daily changes lags behind the air temperature and manifests periodicity. Relative to air temperature, the soil temperature variation is smaller and slower. And the deeper the sensor goes, the smaller the fluctuation range (Jackson, 1973; Idso et al., 1975). Soil temperature is correlated with soil moisture and a variety of meteorological parameters (season change, radiation intensity, soil texture et al.). Water has a higher specific heat capacity than soil. With the soil moisture decreases, the heat storage capacity of soil weakens, so does the amplitude of fluctuation of soil temperature (Hui et al., 2017).

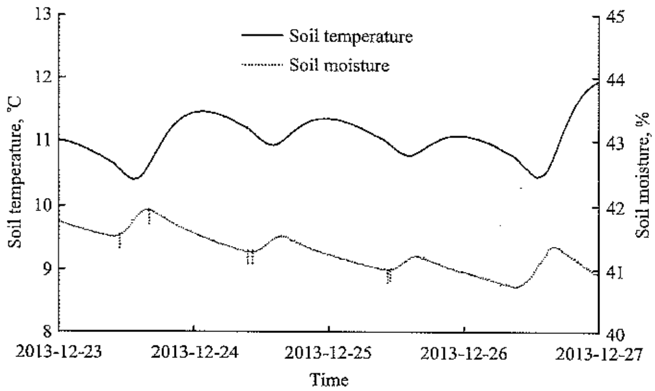

Figure 11 Data of soil sensors

The diurnal fluctuations of radiation and illumination intensity are shown in Figure 12. The tendency of radiation and illumination intensity has high correlation, which precisely illustrates the weather condition of the greenhouse site. The intensity of radiation directly effects many physiological activities such as photosynthesis and transpiration and ambient factors. The necessity of monitoring radiation and illumination intensity is to provide explanation of some data of sensors when the crop is in adequate water state.

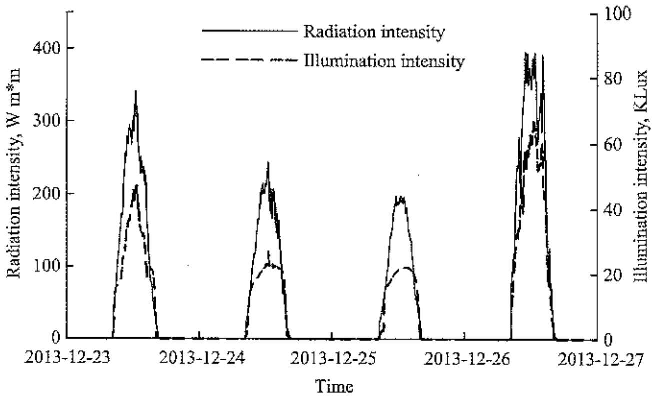

Figure 12 Data of radiation sensor and illumination sensor

The diurnal fluctuations of stem flow are shown in Figure 13. The stem flow is represented in percentage value of maximum diameter shrinkage of four days. Amplitude of stem flow is related to solar radiation, air temperature and soil moisture. (Li et al., 2011). So, the stem flow can reflect crop physiological state information and soil water dynamics. The stem flow data manifests daily periodicity because of existence of transpiration and reaches maximum at noon. As solar radiation intensity in winter is smaller than in summer, the figure just shows the stem flow status of sunny days in winter. And the difference of four day's stem flow simultaneously indicates the difference in radiation intensity. Plants are in water deficit state or sick state, when the stem flow is significantly lower than normal level in sunny days (Gavloski et al., 1992; Ortuño et al., 2006).

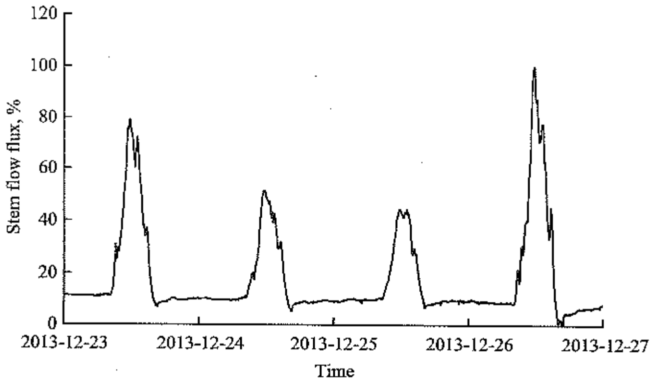

Figure 13 Data of stem flow

Our previously work has elucidated that low environmental temperature induces an obvious change in electrical signals in the cucumber plants and electrical signal can be induced in the leaf tissue by the change in light/dark (Wang et al., 2007). The results reveal the electrical signal decreases from dark to light, and then increases when back to dark. It also can be seen in the Figure 15, when the sun rises, simultaneously causing greenhouse temperature increase, the electrical signal rises and followed by decreases until sunset. The electrical signal plays a role as a switching signal, as we know that electrical signal is always involved in changes of stomatal conductance and CO_2 uptake (Gil et al., 2008; Fromm et al., 2013; Gil et al., 2014). There are fluctuations in day time, which may be effected by the instantaneous change of the ambient factors. Maybe under subsequent lightless conditions at night and lower temperature condition than daytime, the electrical signal starts to rise again (Wang et al., 2009). As we can see in Figure15, with the decrease of the soil moisture, the minimum value of electrical potential per day decreases, which is consistent with published result indicating EP as a good physiological trait is related to soil moisture (Gil et al., 2014). As shown in Figure 14, daily periodic regularity in electrical signal data is evident.

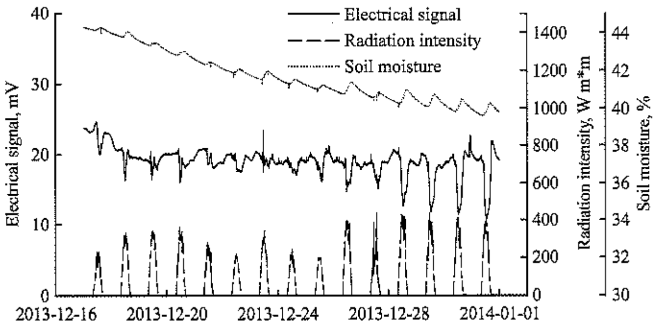

Figure 14 Data of electrical signal sensors and others

Electrical potential (EP) stimulated by external stimuli are various. And previous works indicate that EP behavior depends on plant species and anatomical differences in conductive pathway (Gurovich et al., 2009). Variations in light condition, e.g. dark/ light or light/ dark, will induce EP in plants (Fromm et al., 1998; Gil et al., 2008; Gurovich et al., 2009; Król et al., 2010; Gil et al., 2014), and the EP often manifests a daily rhythm. The explanations of initiation by light-on are divided into many theories. One is that light-induced chloroplast surface charges have an effect on plasma membrane. Another suggests there is a short and transient plasma membrane depolarization induced by light-on and then following a long-running hyperpolarization, which is associated with photosynthesis. As for dark condition, Chloroplastic Ca^{2+} release is possible to change membrane potential (Król et al., 2010). Moreover, the different EP fluctuations in day and-night may be associated with the different stem flow velocities (Gibert et al., 2006).

As a result of sudden drops in temperature, membrane depolarization is evoked and assimilate transport in plants will be strongly reduced even be interrupted (Fromm et al., 2013). In excitable cells of maize, the depolarization will lead to an action potential (Fromm et al., 1994; Król et al., 2010). Similarly, Plieth's result implied that active Ca-channels involved EPs by cold stimuli then resulting in calcium increases (Król et al., 2010). Besides these explanations, H+-ATPase is inhibited to trigger plasma membrane depolarization. The previous work suggested that ambient environmental factors control the whole plant metabolism shaping ATP (Adenosine Triphosphate) availability with action potential generation (Król et al., 2010).

EP may be the primary one in a cascade of physiological response to changes of soil water content (Fromm et al., 1998). With the decrease of soil water content, the concentration of abscisic acid increases in roots, and hormone will be synthesized, simultaneously the EP decreases (Fromm et al., 1998; Gil et al., 2008). After watering, there was an abrupt increase to the original level in EP (Fromm et al., 1998; Sukhov, 2016). The soil and root water content state directly affects stomatal conductance which was associated with EP. Moreover, drought stress can bring about an increase in the apoplastic pH of the leaf causing rapid stomatal closure (Gil et al., 2008).

As light acts like the trigger in electrical potential generating and changes in soil water content may causes EP variation. Correlation analysis was used to analyze the relationship of electrical signal, radiation intensity and soil moisture. We select the data from 17th December 2013 to 31th December 2013. We take EPmin, Rmax and Soilave respectively for minimum EP in a day, maximum radiation intensity in a day, the average of the whole day data. We found that the Pearson correlation coefficient of EPmin vs Rmax or Soilave respectively are –0.737 and 0.788. The result indicates radiation intensity and soil water content plays an important role in EP's generating and amplitude. To identify whether the soil water content can be inferred from EP, linear-regression analysis was used. The coefficient of determination R^2 of Soilave vs EPmin is 0.622. The result shows it is very important in evaluating crop water requirement state and precise irrigation.

Interestingly, these previous papers have reported that plant electrical signals responding to external stimuli often originate at the roots and travel through the vascular system to the leaves, or vice versa (Król et al., 2010; Gil et al., 2014). These signals are responsible for rapid transmission of information within plant body in order to enable a response of distant organs to abiotic stress (Fromm et al., 2013). Previous works have revealed that stomata should be able to receive information on the soil water status independently from the leaf water potential (Fromm et al., 1998; Gil et al., 2008; Fromm et al., 2013). The rapid response in the leaves as a result of soil water changes suggests that hydraulic or electrical signals involve communication from the root to the leaves (Gil et al., 2008). The EP induced by re-irrigation of drought-stressed in maize and cold systemly propagates via the phloem from roots to leaves to regulate photosynthesis (Fromm et al., 2013).

Furthermore, water stress leads to the loss of chlorophyll. Randall et al. had proved that the majority of chlorophyll lost from maize leaves is lost from the mesophyll cells (Alberte et al., 1977). Randall also explains the reason for this phenomenon is that mesophyll cells get less water resource than bundle sheath cells, for bundle sheath cells is closer to the vascular supply of water, which leads to a greater loss of chlorophyll. Alternatively, it is because they contain more of the light-harvesting chlorophyll a/b-protein which is more susceptible under water stress conditions. Thus, by monitoring leaf chlorophyll content allow us to estimate water requirement of plant. The data of sensor for chlorophyll goes wrong, and will be analyzed after correction.

In addition, for higher plants, stem diameter normally indicates diurnal fluctuations with maximum values before sunrise and minimum values in the afternoon. Plant stem decrease by day is because the stem phloem water drained by transpiration stream, and expansion by night is due to re-hydration of stem phloem and plant growth (Kozlowski, 1972). So, the change of stem diameter lags behind stem flow's change. The stem diameter can reflect soil water content and radiation intensity which can directly affect the stem flow. The data of stem diameter goes wrong as the stem is extremely vulnerable to ambient factors effecting position of stem, and the data will be analyzed after correction.

5 Conclusions

This paper shows that a system based on multi-sensor and physiological state of crop for remote water requirement monitoring system is built and have been tested in greenhouse. Unlike the experiments based on single physiological state, we integrated physiological state sensors, which was important for comprehensive judgement of crop water requirement state. More detailed data, further and deeper data analysis is needed to better understand the law of crop water requirement for guiding the agricultural irrigation. Test results show that the remote monitoring system is practicable and stable, and is a potential tool for evaluating crop water requirement state and precise irrigation.

Acknowledgments

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