Development of a wireless communication system for monitoring crop condition with leaf wetness sensor

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Abstract: Wireless sensor networks play an essential role in smart agriculture, especially on the future farms without farmers. This paper presents a new wireless communication system (WCS) for crop leaf wetness monitoring using a nRF905 wireless transmit module together with a STM32 controller, a data acquisition board and developed software. The further developed nRF905 wireless module was used to transmit crop canopy leaf wetness data collected by LWS (Leaf Wetness Sensor) in the field to the monitoring central station. A simple graphical user interface has been developed and implemented to display crop canopy moisture by LWS. The WCS was tested and validated in LabVIEW2013. The 3-day time series model of wetness was built based on the data collected by the monitoring system. In this paper, the structure of this system was introduced, and the system performance evaluation in field was described. The results show that the wireless system has promise to have a higher accuracy for crop canopy leaf wetness monitoring and application which will improve the efficiency of smart agriculture application.

Keywords: wireless communication system, nRF905, leaf wetness sensor, crop condition, canopy moisture, smart agriculture
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1 Introduction

Sensor plays a central role in smart agriculture in achieving valuable information for crop monitoring, yield prediction, plant disease detection, and weather forecasts[1]. A leaf wetness sensor (LWS) measures the change in the electrical impedance of a wire grid on the artificial leaf, and yields an output signal that changes with the sensor's surface wetness[2]. In particular, the time of free water remaining on the surface of plant tissues, named leaf wetness duration (LWD), is one of the most important driving variables for forecasting plant disease epidemics because of its considerable impact on the process[3]. The dry/wet thresholds to determine LWD from output signal are mostly empirical, so that currently LWS are intended to be connected to external devices such as data loggers for further data processing to determine LWD[4]. The nRF905 module has been widely employed as LWS owing to providing a fully integrated frequency synthesizer, receiver chain with demodulator, a power amplifier, a crystal oscillator and a modulator[5]. LabVIEW is a graphical programming language which is exploited by the United States NI Company (National Instrument Company, Austin, USA, 78759). The language of LabVIEW is developed on the basic of the Graphics Language. It also has software development function covering the virtual instrument which can be employed to deal with time-varying signals[6].

However, wire transmission has many shortcomings: (1) The wired systems are lack of easy installation and extension ability and increased maintenance costs; (2) When machine bracket moves, signal transmission should be checking for its stability. (3) Sensor with contacting method will cause larger errors during long-distance transmission; and (4) Increasing long-term driving and safety barrier causes high cost. WSN was widely adopted in smart agriculture and numerous other application domains since it provided real-time crucial data from the monitored environment[7,8]. Compared to transmit the data by the wired systems, wireless data transmission can effectively avoid the above shortcomings. Then wireless data transmission technology will inevitably become key technology research and innovation of the project.

In this paper, we have proposed a reliable, economic and energy efficient leaf wetness wireless monitoring system which can measure the moisture of leaf and transmit the collected data to a personal computer (PC) equipped a program compiled by LabVIEW. The PC display interface in the monitoring system will show the LWS output voltage in real-time, water mass and wetness on the plant canopy which are very essential to precisely diagnosis the crop growth status and the crop diseases. This system can be applied to a smart sensor array for a high population of nodes within a field because of the relatively low power and cost of the nodes, closely examine the relationship between humidity of plant leaves and crop growth status and especially crop disease. Also, the system can be utilized to prevent the crop disease by monitoring the environment of crop canopy.

2 Materials and Methods

2.1 System overall structure design

The system is composed of three parts: field parameter data monitor terminal equipment, monitoring center station, and canopy moisture center station. Field parameter data monitor terminal equipment consists of STM controller, leaf wetness sensor signal acquisition, wireless communication mode and other function

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extended for the purpose of power supply, leaf wetness sensor signal collection and RF transmitting. Monitoring center station consists of STM controller and wireless communication mode to achieve RF receiving and communication module. Canopy moisture monitoring center station consists of monitoring system to achieve data analyzes and processes receiving data and upload to computer. The system structure diagram is shown in Figure 1. The smart sensor board acquired Decagon moisture sensor (Pullman, USA, 99163, Decagon Devices) values and wirelessly transmitted those values to a RF receiver. We chose Decagon sensors for this system because of their low cost, depend- ability, ease-of-use, and because they are commonly used by the agricultural community for measuring leaf wetness[9,10].

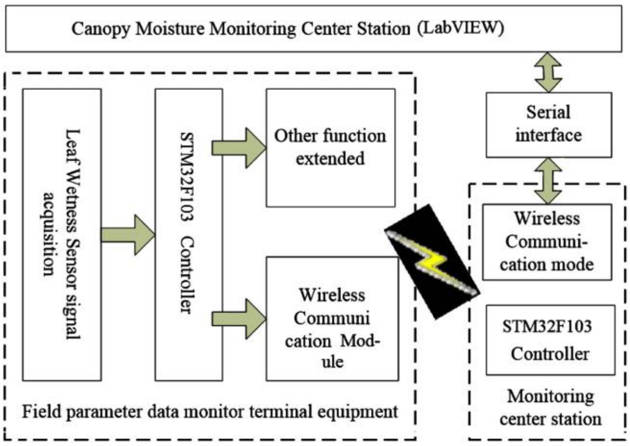

Figure 1 Distribute network structure

2.2 The Design of Hardware

2.2.1 Wireless communication module

The wireless communication module is composed of nRF905wireless transceiver chip produced by NORDIC company (NORDIC Semiconductor, Trondheim, Norway, 7003) and its peripheral circuits[11-13]. The nRF905chip is a single chip radio transceiver for the 433/868/915MHz ISM band, consists of a fully integrated frequency synthesizer, receiver chain with demodulator, a power amplifier, a crystal oscillator, and a modulator[14-16]. The SPI transmission interface is used to connect to the microcontroller through four pins, CSN, SCK, MISO and MOSI (Table 1). The operating voltage range is 1.9-3.6 v, and 3.3 v is used in this paper. Its data frame can contain up to 32 bytes of user data. According to the size of user data, the time required to complete a frame of data communication is about 1.3-6.4 ms. The nRF905 micro power transmission module can directly connect to computer, SCM, and other UART component by standard RS-232, 485, and UART/TTL electric level interface style. Considering the real-time requirements of motion control for data processing, the 32-bit microcontroller STM32F103 is selected as the processing core with the highest clock frequency of 72 MHz.

NRF905 has two kinds of work mode and saving energy mode, which are Shock-Burst^{TM} receiving mode, Shock-Burst^{TM} transmitting mode, shutdown mode, and idle mode, respectively. The nRF905 chip will enter receiving mode when control chip setting high electric level of PWR_UP, TRX_CE, and low electric level of TX_EN. Work mode is decided by TRX_CE, TX_EN and PWR_UP different electric levels of combination. Where, 0 and 1 express low electric level and high electric level respectively, X expresses 0 or 1 random state. The control chip sets nRF905 chip inter register, read, write data and address must be under standby or shutdown mode through SPI bus. NRF905 mode setting of TRX_CE, TX_EN AND PWR_UP is shown as Table 2. It uses advanced RISC architecture with built-in rich peripherals and large capacity FLASH storage space. The highest working frequency is 72 MHz, which can meet the requirement of real-time data processing for making a quick response[17].

Table1 nRF905 pin functions

Pin	Name	Pin function	Description
0	VCC	Power	Power supply (+3V DC)
1	TRX_CE	Digital input	Enables chip for receive and transmit
2	TX_EN	Digital input	TX_EN="1"TX mode, TX_EN="0"RX mode
3	PWR_UP	Digital input	Power up chip
4	AM	Digital output	Address Match
5	CD	Digital output	Carrier Detect
6	MISO	SPI - interface	SPI output
7	SCK	SPI - Clock	SPI clock
8	MOSI	SPI - interface	SPI input
9	CSN	SPI - enable	SPI enable, active low

Table 2 nRF905 operational mode

PWR_UP	TRX_CE	TX_EN	Operating Mode
0	X	X	Power down and SPI-programming
1	0	X	Standby and SPI-programming
1	1	0	Radio Enable-Shock Burst RX
1	1	1	Radio Enable-Shock BurstTX

2.2.2 Sensor signal acquisition

A LWS (Decagon Devices, Pullman, USA, 99163) was taken to measure the dielectric constant of the top of the leaf for the purpose of wetness signal acquisition. It has a very low power requirement and high resolution which can meet the requirements of measure the tiny change in the electrical impedance of a wire grid on the leaf for a long period of time[18]. An mV signal proportional to the dielectric of the measurement zone outputted by the sensors can be collected to determine the relationship between the wetness state of the sensor, and the wetness state of various agricultural or natural plant canopies[19-21]. The parameters of LWS were shown in Table 3, and the sketch was shown in Figure 2.

Table 3 The parameters of LWS

Parameters	Value
Measurement Time	10 ms
Power	2.5-5 V DC
Output	320-1000 mV
Operating Environment	–20 to 60℃
Probe Dimensions	11.2×5.8×0.075 cm
Cable Length	5 m standard
Connector Type	3.5 mm plug

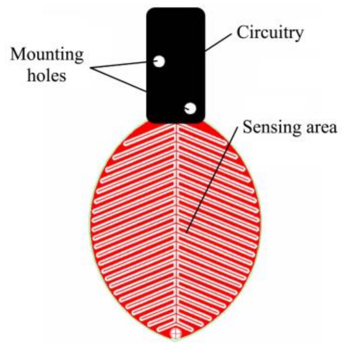

Figure 2 Leaf Wetness Sensor

Interface circuits for capacitive sensors are available wherein the sensor is directly connected to control chip that converts capacitance to a digital value without any previous signal conditioning stage, which makes those circuits simple, compact, and low cost.

2.2.3 Wireless Mode Hardware Design

The control of the sensors uses the 32-bit microcontroller STM32F103 (ST Microelectronics, Geneva, Switzerland, 1211) main control chip is selected as the processing core with the highest clock frequency of 72 MHz. The peripheral circuit and data acquisition box are shown in Figure 3 and Figure 4.

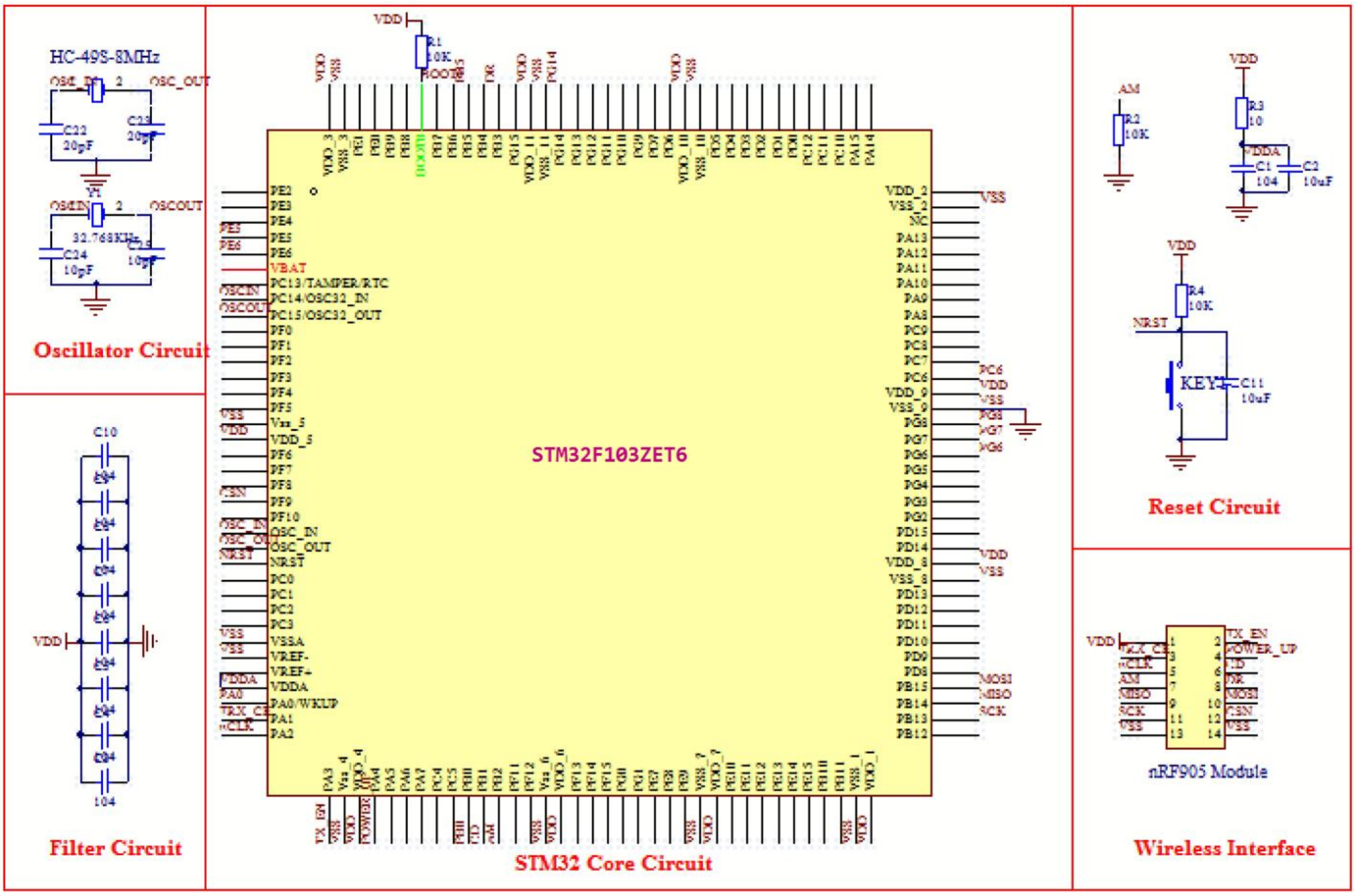

Figure 3 Wireless transceiver circuit

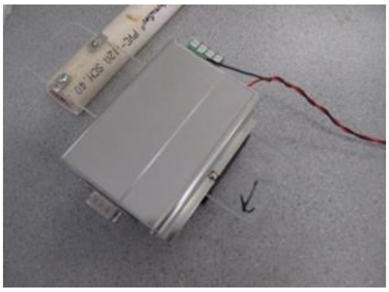

Figure 4 Data acquisition box

2.3 Software design

LabVIEW is a software environment for data acquisition and control which has evolved from a program that could send, receive, and integrate data to and from laboratory instruments equipped with a general-purpose interface bus (GPIB)[22]. It was the first software program to include graphical, and iconic programming techniques, which makes the form of programming more transparent, and the sequence of processing more visible to the user. Applications developed on one of these platforms can run on another platform with no or only minor modifications. The program consists of start button, channel choose, waveform chart, VISA communication module, and measurement module. The front panel of real-time canopy moisture monitor system was shown in Figure 5.

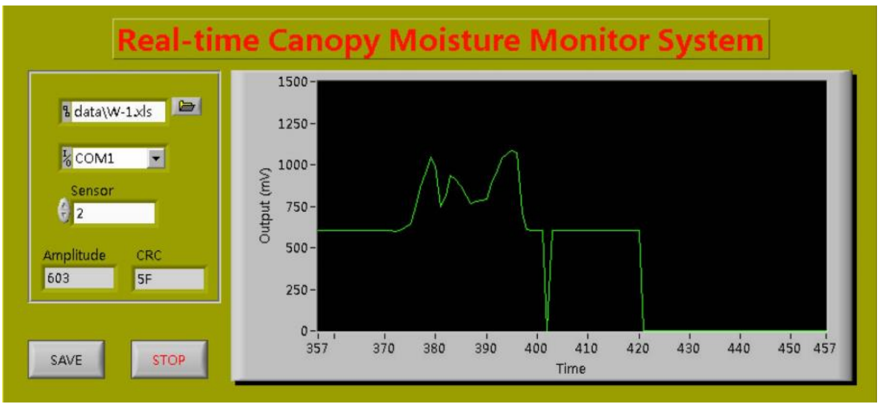

Figure 5 Measuring and analysis system front panel

2.4 Field testing of the smart sensor

Outdoor environment was used to simulate realistic application conditions for testing and demonstration of the smart sensor system. To evaluate the performance of the smart sensor, both device and LWD sensors were installed at the top of maize canopy. The LWD sensors were installed at 45° inside the maize canopy at height of 40 cm (Figure 6). With the performance tested, the system can measure accurately wetness information.

Figure 6 A Smart Sensor node with LWS installed in the USDA College station a few days after planting of corn

3 Results and analysis

A time series (3 days) of leaf wetness measured by the LWS at 0.4 m above the ground was shown in Figure 7 and the result of wetness in time series (3 days) was shown in Table 4.

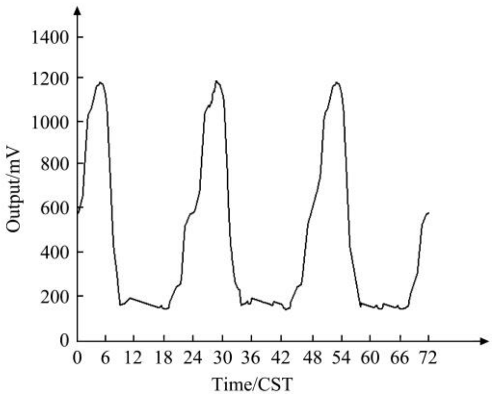

Figure 7 Three days leaf wetness measurements by LWS inside a maize canopy

Table 4 The result of wetness in time series (3 days)

Day	Level of wetness	Time (CST)	Output/mV
1	High	04:43	1251
	Moderate	08:56	843
	Low	18:24	420
2	High	04:47	1256
	Moderate	07:28	836
	Low	18:12	416
3	High	05:02	1253
	Moderate	08:31	846
	Low	07:13	420

Note: CST: Central Standard Time (USA).

The picture shows how the sensors react to dew formation. The curves drew by data collected showed the process of dew formation and evaporating and there is a strong consistency between three days. The maximum output is 1253 mV which represents the wetness was 76.24% and the minimum output is 416 mV which represents the wetness was 17.28%. The wetness was mainly affected by two factors. One is dew caused by fog lowering, and the other is sun light. For the first day, dew was presented from approximately 12:00 to 05:00 CST and started to evaporate at 05:00 CST due to the rise of sun. The wetness was nearly stabilized after 09:10 due to the disappear of dew until 19:30. IBM SPSS Statistics 24 (International Business Machines Corporation, Armonk, New York, USA) was taken to achieve regression analysis for the purpose of acquiring the law of output with time variation. The model (shown in Table 5) established to describe the varying law was $y = 0.002x^3 - 0.280x^2 + 3.513x + 1053.35$. In the model, x is time (CST) and y is output (mV).

Table 5 The result of wetness in 1 day from 00:00 to 24:00 CST

Freedom	b1	b2	b3	c	significance	F	R^2
3	0.002	–0.280	3.513	1053.35	0.000	136.097	0.745

4 Conclusions

The WCS described here offers real potential for reliably monitoring leaf wetness status in crops. The results showed that the WCS has a promise as a higher precision technique for crop monitoring application, which will provide technical support for future smart agriculture, especially in smart agriculture areas. According to the field results, the following conclusions can be obtained: 1) The system was able to successfully monitor leaf wetness within the canopy with few technical difficulties. Equipment modifications resulting from encountered problems resulted in a more robust system that can be installed in the field alone. 2) The measuring system, combining LWS and virtual instrument through the development of Lab VIEW, measures leaf wetness with the function of wireless transmission. It has the characteristics of small, flexible, and convenient. 3) The system combined a STM32F103 controller and a nRF905 short distance wireless communication module could also be applied to a smart sensor array for a high population of nodes within a field because of the relatively low power and cost of the nodes, this will provide a dynamic system capable of addressing varying leaf wetness in fields.

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