Plant Leaf Water Detection Instrument Based on Near Infrared Spectroscopy

Jiannan Jia and Haiyan Ji*

Key Laboratory of Modern Precision Agriculture System Integration Research,
Ministry of Education, China Agricultural University, Beijing, China 100083
`instru@cau.edu.cn`

Abstract. In the near infrared spectral region, a reflection plant water detection instrument was designed by using microcontroller STC12C5A60S2. The instrument consisted of signal acquisition system, microcontroller system, software system and calibration model. The signal acquisition system was composed of three LED of different wavelength and a light-to-frequency converter. Three LED of different wavelength were lighted by turns for avoiding interaction. Light-to-frequency converter was used as the receiving tube, thus simplifying the circuit structure greatly. This paper described the instrument's hardware design, software design, modeling of Forsythia leaf water content and forecasting. Predicted results were consistent with the true values of water, and the correlation coefficient between them was about 0.820. Advantages of this instrument were small, simple structure, low power consumption and so on. The experimental results showed that the instrument could detect plant water content rapidly on fieldwork.

Keywords: reflection measurement, water detection, leaves, portable instrument.

1 Introduction

Water is a major component of crop. Water deficit directly affect the plant's physiological and biochemical processes and morphology, thus affecting plant growth, yield and quality [1]. Getting plant water status rapidly is very important for agriculture, horticulture, forest water management and potential fire assessment [2].

Water absorption spectrum has five absorption bands, their central wavelength are located in near 760nm, 970nm, 1145nm, 1450nm and 1940nm. Based on this, the spectral information of this region has been widely used to analyze the water status in plants [3-6].

Several researchers have described relationships between leaf water content and infrared (700-2500nm) reflectance. Tucker [7] considered simulated leaf reflectance along with atmospheric transmission properties, and determined the spectral region between 1550 nm and 1750 nm was best suited for remotely measuring leaf water content. Carter et al [8] found that visible wavelengths (551nm) correlated best with the total water potential of loblolly pine needles. Hunt et al [9] and Hunt and Rock [10] described a liquid water content index that was used to estimate leaf relative water contents. Penuelas et al found that the water index WI ($WI=R_{900}/R_{970}$) or minimum of

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* Corresponding author.

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first derivative in the near infrared band can clearly indicate the change of water status [11]. The subsequent study of Penuelas and Inoue also showed that the ratio $WI/NDVI$ ($WI=R_{900}/R_{970}$, $NDVI=(R_{900}-R_{680})/(R_{900}+R_{680})$) not only could be used to predict the moisture content of leaves but also could be used to predict the water content of plant or canopy, and significantly improved the prediction accuracy [12,13]. By using derivative spectrum, Yan Shen established the water content model of monocots and dicots, it provided new ideas of remote sensing classification for identifying monocots and dicots [14]. By using principal component regression, Hanping Mao established the moisture content model of grape leaves based on spectral reflectance characteristics, and found that grape leaves dry-basis moisture content was significantly correlated with derivative spectra of 703nm [15]. By using spectral stepwise regression analysis and constructed spectral index method, Yong Yang analyzed the relationship between citrus leaf spectral reflectance and moisture content, and established the moisture content model of citrus leaves based on spectral reflectance [16]. These findings show that diagnosing plant water status by using spectral reflectance is feasible.

Near infrared water detection instrument generally has two measurement methods [17-19]: transmission method and reflection method. Reflection method, namely, determine the water content of samples by detecting the reflected light intensity from the sample surface. Near infrared water detection instrument designed by Xiaoying Lin [20], measured water by reflection method and used three beams of 1700nm, 1940nm and 2100nm. The instrument consisted of electronic circuit and complex optical probe, therefore its size was relatively large. The instrument in this paper is a battery-powered handheld device, so its Light source used LED. The system selected 970nm as measuring wavelength. In the band from 900nm to 680nm, the absorption of water is less and the curve of absorption tends to flat. Therefore, the system selected 900nm and 680nm as reference wavelength.

2 Instrument Design and Modeling

2.1 System Components

According to the logic function, the hardware circuit of this instrument was divided into several sub-modules. Modules could be divided into: microprocessor, light source, detector, LCD display unit, keyboard control unit and storage unit. System diagram of hardware is shown in Fig.1.

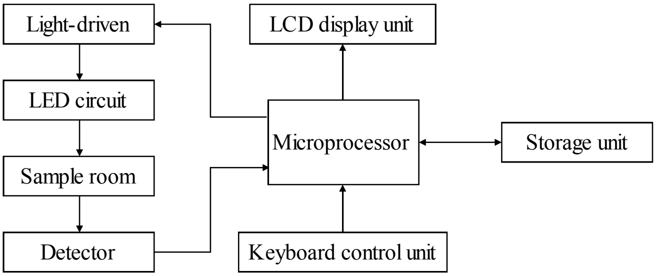

Fig. 1. System diagram of hardware

Microprocessor. The microcontroller used in this design was STC12C5A60S2. STC12C5A60S2 is an enhanced microcontroller of 8051 series, and its operating speed is faster. Its operating voltage is 5.5V to 3.3V. It has three kinds of operating mode, thus its CPU could be placed in power-saving mode firstly, then, waking up CPU by interruption to reducing power consumption as much as possible. It has the EEPROM function. And, it is very easy to develop, can download user program directly via the serial port.

Signal Acquisition Module. The Signal acquisition module of this hardware system included light source, sample room and detector. The incident light shined on the sample in the sample room, then, the detector detected the light intensity of reflected light. The detected results would be sent to microcontroller.

Light source consisted of three LED, and their central wavelengths located in 650nm, 880nm and 940nm. Each LED had adjustable constant current circuit to ensure the stability of light sources. Three monochromatic lights of different wavelengths under the control of the microprocessor shined leaves by turns, and the reflected light was received by detector. Whole device was located in a black-box to avoid the interference from outside light, and improve the measurement accuracy.

The system selected TSL230 as the detector. The TSL230 programmable light-to-frequency converters combine a configurable silicon photodiode and a current-to-frequency converter on single monolithic CMOS integrated circuits. The output can be either a pulse train or a square wave (50% duty cycle) with frequency directly proportional to light intensity. The sensitivity of the devices is selectable in three ranges, providing two decades of adjustment. The full-scale output frequency can be scaled by one of four preset values. All inputs and the output are TTL compatible, allowing direct two-way communication with a microcontroller for programming and output interface.

Interface Module. The system selected 1602 character LCD for displaying. Its displaying capacity is 16 × 2 characters. The system included six buttons, they were measuring the incident light intensity count, measuring the reflected light intensity count, showing water index and leaf water content, previous record, next record, deleting record. LCD and the six buttons achieved information input, output and display.

2.2 Software Design and Modeling

After hardware design work was completed, realization of the system function had to rely on software. Software achieved the function driving of each module, the data collection, calculation and display.

Software Design. Software source code was written with C language. Software system consisted of main program, data collection program, data storage program, LCD display program and button interrupt program. After initialization was completed, the program waited for button operation. System diagram of software is shown in Fig.2.

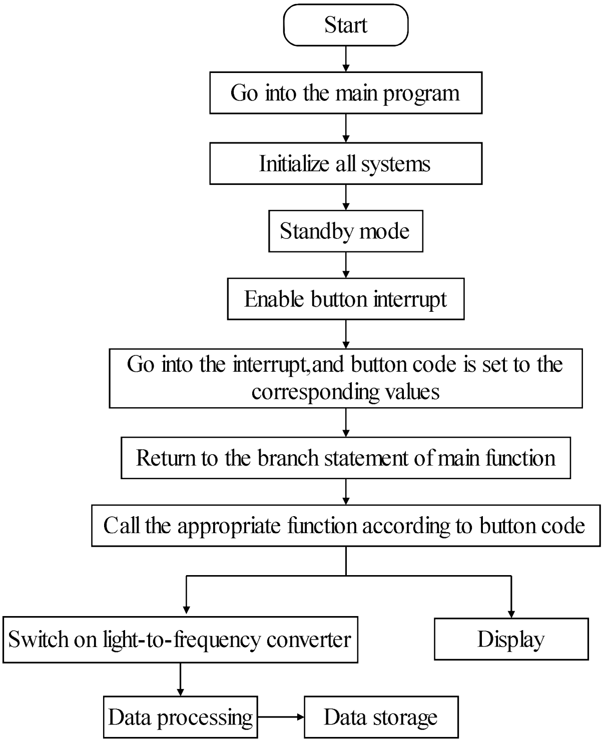

Fig. 2. System diagram of software

Modeling. The instrument measured some samples whose water content had been known. Three LED lights were lit by control of program, at the same time, switching on Light-to-frequency converter. Light-to-frequency converter would send pulse to the microcontroller. This frequency of pulse was gotten from incident light intensity I_0 and reflected light intensity I. Then, the time counter of microcontroller would record the corresponding frequency count value n_0 and n within a certain time. Therefore, light intensity and the count value are directly proportional. By the formula (1) to (3), we could calculate reflectivity R_{680}, R_{900} and R_{970}, and stored them in memory. The water index WI and $NDVI$ could be calculated by the formula (4) and (5). Then, we could build a mathematical model between the water index and water content by the formula (6) or (7), and downloaded it to the instrument. When measuring the same type of leaves again, as long as getting the reflectivity under three different wavelengths monochromatic light, the instrument can predict and display the water content.

$$R=I/I_0=f/f_0 \tag{1}$$

$$f \propto n \tag{2}$$

$$R=n/n_0 \tag{3}$$

$$WI=R_{900}/R_{970} \tag{4}$$

$$NDVI = (R_{900} - R_{680}) \, / \, (R_{900} + R_{680}) \tag{5}$$

$$PWC = k \times WI + b \tag{6}$$

$$PWC = k \, (WI/NDVI) + b \tag{7}$$

Where *PWC* is plant water content, *k* and *b* are coefficients.

3 Results and Discussion

37 Forsythia leaves were collected for the experiment. First, by using the instrument, water index *WI* and *NDVI* were measured. And then, water standard content of these leaves was measured through drying method. The true values of water content (water standard content/fresh leaf weight×100%) were calculated. Two prediction models between water index and the real values of water content were built by using least square method according to the formula (6) and (7). By comparing two prediction models, we could find that the prediction model built by formula (6) was better. Scatter plot of *WI* and true values is shown in Fig.3. Figure 3 shows, plant water content *PWC*=88.3957×*WI*-11.3608. This formula could be downloaded to the instrument. After measuring the *WI*, the instrument can obtain water predictive values directly through this formula. Scatter plot of predicted values and true values is shown in Fig.4. It can be seen from Figure 4, predicted values are consistent with true values, and their correlation coefficient is 0.820. Among the 37 samples, the maximum of 37 relative errors is 4.66 percent, predictive value of this sample is 67.36 percent, and actual value is 70.65 percent.

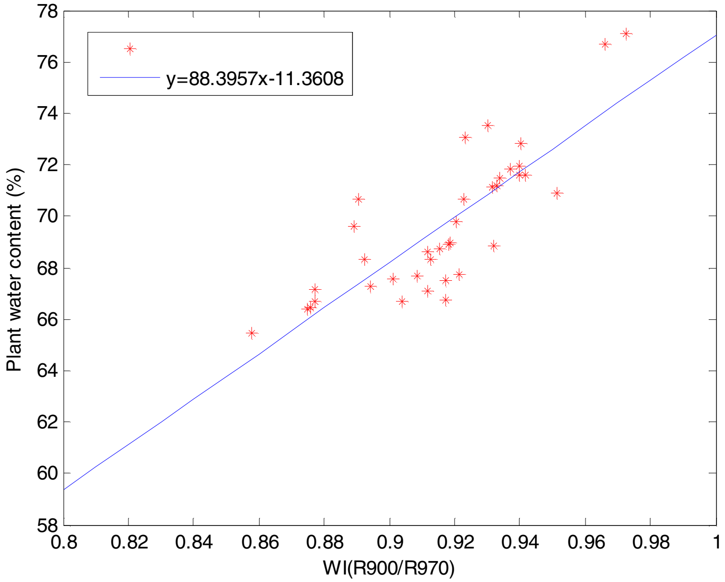

Fig. 3. Scatter plot of WI and true values

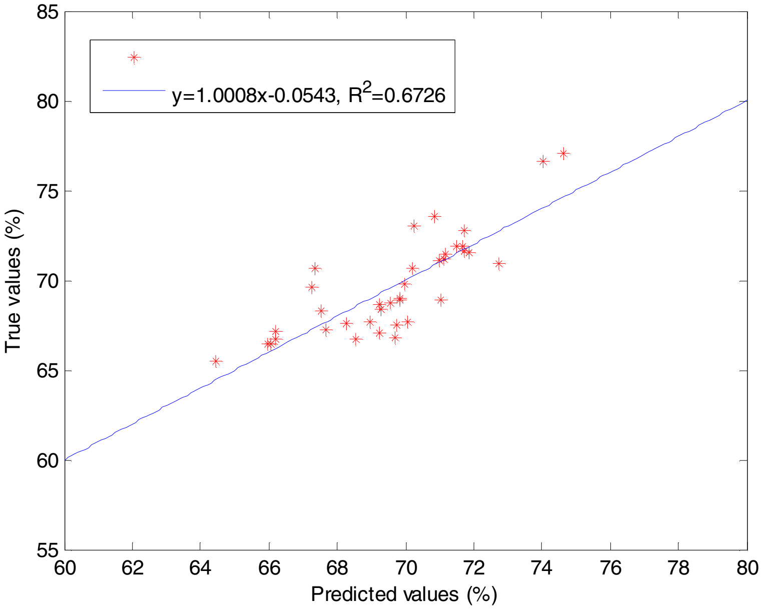

Fig. 4. Scatter plot of predicted values and true values

There were not filters in the sample room. Therefore, the collected light intensity signal was not a single wavelength, but light intensity count values in a bandwidth. Because the angle between LED and light-to-frequency converter could not be corrected accurately, so the size of leaves had some influence on the measurement result. These would affect the measurement result. In the experiment, because the range of water content was limited, so result would have a big error if it was used to forecast some water content outside this range. In order to expand the measuring range, segmentation modeling in different ranges of water content could be built. When Measuring leaves of different plants, different forecasting models need to be built.

4 Conclusions

In the near infrared spectral region, a water detection instrument based on the sensitive spectrum of water absorption was designed. Using near infrared light 650nm, 880nm and 940nm, microcontroller STC12C5A60S2 and a new type of light-to-frequency converter TSL230, initial design of the reflection plant water detection instrument and debugging were completed. Modeling and forecasting in water content of the experimental samples were finished, and got some satisfactory results. To different plant species, different forecasting models can be built to achieve the rapid measurement of leaf water. In the hardware design and software code writing process, features such as low power consumption and anti-interference were fully took into account. The instrument has good stability and good reproducibility, simple operation, small size, low cost, and it is easy to implement the commercialization. But, in order to using the instrument in the real life, filters need to be used, the angle between LED and light-to-frequency converter need to be corrected accurately.

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