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Design of capacitance measurement module for determining critical cold temperature of tea leaves

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ABSTRACT

Critical cold temperature is one of the most crucial control factors for crop frost protection. Tea leaf's capacitance has a significant response to cold injury and appears as a peak response to a typical low temperature which is the critical temperature. However, the testing system is complex and inconvenient. In view of these, a tea leaf's critical temperature detector based on capacitance measurement module was designed and developed to measure accurately and conveniently the capacitance. Software was also designed to measure parameters, record data, query data as well as data deletion module. The detector utilized the MSP430F149 MCU as the control core and ILI9320TFT as the display module, and its software was compiled by IAR5.3. Capacitance measurement module was the crucial part in the overall design which was based on the principle of oscillator. Based on hardware debugging and stability analysis of capacitance measurement module, it was found that the output voltage of the capacitance measurement circuit is stable with 0.36% average deviation. The relationship between capacitance and 1/Uc2 was found to be linear distribution with the determination coefficient above 0.99. The result indicated that the output voltage of capacitance measurement module well corresponded to the change in value of the capacitance. The measurement error of the circuit was also within the required range of 0 to 100 pF which meets the requirement of tea leaf's capacitance.

1. Introduction

Tea (*Camellia sinensis*) is a subtropical plant, which is planted on the hilly areas in the central and southern China and its optimum growth temperature is around 20 °C [1]. Freezing injuries happened in the early-spring caused huge damage on tea production and quality, and resulted in enormous economic losses to tea industry. In recent years, kinds of equipment and techniques which are based on airflow disturbance frost prevention have been developed and applied in tea fields and orchards such as anti-frost fans, large wind machines, helicopters and sprinklers [2–5]. The main control strategy of above equipment is to determine the time of plants suffers from critical freezing injury and the critical cold temperature is used as one of the most crucial parameters [6,7].

Plant electrical signal is a sensitive indicator for the early prediction and real-time evaluation on the physiological changes of the plant [8–13]. In the non-destructive determination of moisture content of maize leaves, Guo et al. [14] designed a moisture detector based on leaves' capacitance and tested it to develop a model on the relationship between capacitance and moisture content of maize leaves at the best pressure. The running test indicated that the absolute measurement error of the designed detector for moisture content of maize leaves was 1.2% to 1.7% on wet basis when the moisture content was between 55% and 80%, and the response time was within 3 s at oscillation frequency of 8 MHz. Similarly, Wei et al. [15] employed a pair of electrical-capacity-type electrode to test the effects of test voltage and frequency on physiological capacitances (C_p) and physiological resistances (R_p) of wheat seedling leaves with different water contents, and found that both C_p and R_p were significantly related to the leaf water content. The authors reported that C_p was a better indicator of leaf water content than R_p which could measure water content of wheat seedling leaf quickly and harmlessly. In another work, Bao and Shen [16] established an interesting the relationship between the plant water deficit and the electric property it found that the capacitance of leaves to have changed with the drought degree under the frequency of 100 Hz, providing a useful tool for efficient and precise assessment of plant water lack degree. Luan et al. [17] further investigated the changes in water parameters of wheat leaves by determining the total water content, the ratio of bound water/free water and the capacitance under different PEG stress period. Their study also showed a decreasing trend of the ratio of bound/free water to capacitance with

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increasing drought stress period indicating that physiological capacitance as a potential tool for characterizing the water dependent properties in wheat leaves. Other studies have also proposed new approaches to quantifying moisture properties and their relationship with electrical properties such impedance and capacitance for the leaves of tea and other crops [18,19].

Recent work by Lu [20] established a test system of tea leaf's electrical property to measure the typical temperature of the samples and measured relative electrical conductivity (*REC*) and cell damage rate of two varieties under different cold stress conditions, and found that the capacitance of tea leaves had obvious peak response to a typical temperature where the cells were undergoing serious cold stress and mostly of them had been destroyed, which showed that typical temperature could be used to evaluate the freezing tolerance of different varieties of the tea and indicate critical temperature.

Therefore, this study sought to the utilize capacitance as an essential indicator for nondestructive testing the physiological characteristic of tea plants. A new detector was designed to measure tea leaf's critical cold temperature based its capacitance peak response to a typical low temperatures and its stability verified using the capacitance measurement module.

2. Design principle of capacitance measurement module

Critical cold temperature is a crucial parameter for the control of frost protection equipment and this is clearly as shown in the test principle of the detector in Fig. 1. Capacitance and temperature of tea leaf were measured and the peak of capacitance identified to extract the effective peak. Critical cold temperature was indicated by the corresponding temperature where the effective peak capacitance was utilized. As a result, the critical cold temperature detector based the capacitance peak response to a typical low temperature mainly consisting of microprocessor, signal detecting circuit, power supply module, capacitance measurement module, temperature measurement module, keyboard and display module was built (Fig. 2). Capacitance and temperature measurement module is used to measure the capacitance of tea leaf and ambient temperature around the leaf. Microprocessor is the main part for the control detector and the keyboard is used to select different function, and for LCD display, it is used to display the output parameters and the state of detector. Power supply module is composed of power source, power source circuit and power conversion module, and which applies stability working voltage for microprocessor and functional circuits.

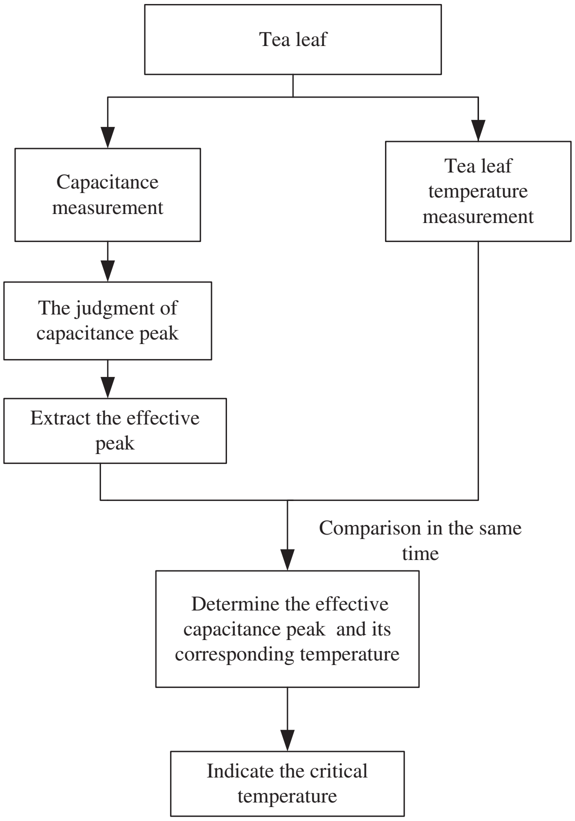

Fig. 1. Approach of the detector design.

The analog signals of capacitance and temperature are collected by capacitance and temperature measurement module. The signal detecting circuit changes analog signal into voltage signal, and then transferred to microprocessor for AD conversion and extracting the effective capacitance peak, and LCD display presents critical cold temperature.

2.1. Design of the detector's hardware

2.1.1. Design of capacitance measurement module

Capacitance measurement module is the crucial part in the overall design which used the method of oscillator type to measure the capacitance of tea leaf. The unknown capacitance C_x (tea leaf) and a size known inductance L_1 are connected in parallel to a voltage controlled oscillator chip which constitutes a LC oscillation circuit. The high frequency sinusoidal wave outputs from the voltage controlled oscillator carried on waveform transformation and frequency division by division circuit, and then transmitted by its frequency signal is converted to voltage signal through the voltage/frequency conversion circuit. Eventually, the MSP430F149 MCU acquires the output voltage signal for further data processing.

LC oscillation circuit uses MC1648 voltage controlled oscillator chip (Motorola, USA) as an oscillator which has a high purity of frequency spectrum and its working frequency is up to 225 MHz (Fig. 3), and its maximum current is 19 mA when the excitation voltage is 5 V [21]. The output signal from MC1648 is a kind of high frequency sine wave which is converted into square wave in order to achieve the input range of voltage/frequency (V/F) converting chip. As shown in Fig. 4, the design adopts two levels frequency division. This is due to the fact that the signal frequency is still above MHz after only one level which is hard for further processing. The first level uses MC12017 (Motorola, USA) which is a dual mode front divider with 63/64 frequency division and it has a good match with MC1648. The second one uses 74HC4040 which is a CMOS asynchronous counter with 12 bit high speed and it achieves 2^1 to 2^{12} times frequency division and converts the sine wave to a square wave. The frequency signal after two levels frequency division is low enough to be converted into DC voltage signal through the V/F convert circuit [22]. As shown in Fig. 5, the design adopts LM331 as voltage-frequency conversion chip which has highly cost effective and the design of peripheral circuit is simple and uses common capacitance and resistance (R_2 is 100 kΩ, R_4 is 5.1 kΩ, C_{11} is 0.01 uf and R_3 is 14 kΩ.

In measuring the capacitance in the circuit, the relationship between capacitance and frequency with an output from the MC1648 oscillation chip could be expressed as,

$$f = \frac{1}{2\pi\sqrt{L(C_1 + C_x)}} \tag{1}$$

where, C_1 is the inherent capacitance in the circuit, C_x is the capacitance to be measured, L_1 is a size known inductance. The F/V conversion equation of LM331 is $U_c = k_2 \cdot f$.where, K_2 is a constant. U_c and C_x can be rewritten as,

$$U_c = k_2 \cdot \frac{1}{2\pi\sqrt{L(C_1 + C_x)}} \tag{2}$$