Study on Dynamic and Non-destructive Ultrasonic Echo Detection Method of Plant Stem Water Content

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Abstract. Stem water content is an important index of plant water balance. A new method based on changes in ultrasonic properties of stem was used to monitor stem water content in this paper, because the propagation of ultrasonic pulse echo signal and its attenuation characteristics in the material are closely related to the structure of the material. Ultrasound propagation echo signal was measured with an ultrasonic emission analysis system in the plant stem. The study showed that the increase of stem water content in the Populus simonii stem could cause the average amplitude, the root mean square (RMS) and the peak of value of the ultrasonic echo signal decreased obviously. The analysis of ultrasonic properties provides a new method for the detection of stem water content of trees and may be used to monitor plant water balance.

1 Introduction

The absorption, transporting and losing of water in plant are it's normal life activities to maintain the water balance[3]. Changes in the water content of the plant is often used as an indicator of water balance, which provides an important indicator for the diagnosis of plant physiological drought by directly measuring the moisture content of the stem plant [1],[4].

Currently direct detection method uses plant stem water content are: drying method, γ-ray method [7], nuclear magnetic resonance spectroscopy [5], Computer tomography [9], and dielectric constant resistance method[4]. However, taking the above detection means will cause varying degrees of damage to the plant. Nuclear magnetic resonance, computer tomography technology, drying method and γ-ray detection method, requiring stem samples truncated from trees, undermine the physiological activities of plants, which are unable to achieve on-line measurement. The resistance measurement has some limitations, because the absolute moisture content of living tissue with the resistance value is not a single-valued function [2]. Currently, time domain reflectometry (TDR) achieved quite good results for detection of water content in stems of standing trees [6],[8]. But this method still needs to insert probes into the plant stem to detect that causes some damage to the plant itself, affects plant physiological activity and finally generates detection errors of dynamical detection of water content in the stem.

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Since the propagation and attenuation of ultrasonic echo signal in the material are closely related to the composition and the structure of the material[1], this paper presents a dynamic non-destructive method of plant stem water content with ultrasonic echoes by analysing the average amplitude and other time features of the ultrasonic signal to detect water content of the plant stem dynamically.

2 Detection Principles

According to the ultrasonic propagation in elastic media, energy attenuation occurs that is the sound pressure amplitude exponentially decreases with the increasing ultrasonic propagation distance x, which can be stated by the expression of $p(x)= p_0^{-Ax}$, where p_0 is the initial pressure amplitude value, A is the attenuation coefficient [1]. Different elastic media holds different attenuation characteristics, such as the acoustic impedance of water at 20ºc is 1.48×MPa s-1, the air acoustic impedance is 0.0004 ×MPa s-1. Therefore, the impedance of elastic media will vary when the constituent of it changes.

The average water content of the plant stem will changes at different conditions. Generally, it is about 50% for plants. When the loss of water by transpiration is greater than the amount of absorption by the roots of plants, plant water content decreased, resulting in plant stems water content also decreased. Conversely, when the soil fills with moisture, roots absorbs sufficient moisture and the stems water content increase and transport to the other parts of the plant through the root pressure and transpiration. In words, plant stem water content changes can be reflected by the mean, RMS and peak-peak values of ultrasound.

3 Detection Plant stem water content by Ultrasonic Pulse Echoes

3.1 Equipment and materials

An ultrasound apparatus, ultrasonic pulse echo detection system for stem water content, is designed as shown in Figure 1. It consists of a transmitting and receiving ultrasonic probe (a non-metallic ultrasound 250KHz probe), a non-metallic ultrasonic pulse transmitting and receiving device (Shantou Ultrasonic CTS-8077PR), a Nextkit data acquisition module based on LabVIEW (Global China CNC Nextkit) and a PC machine.
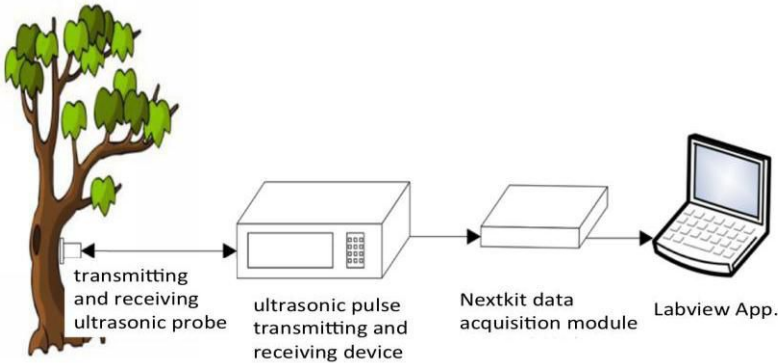

Figure 1. Ultrasonic Pulse Echo Detection System for Plant Stem Water Content

One 15-year-old Poplar leaflet (Populus simonii Carr) at the Southwest of Forestry University in Kunming, China was used as the test materials. The diameter at the breast height (1m from the ground level) is 12.7cm. The test data are 4th, 5th and 7th of June in 2015. Before 4th of June, Kunming lasted for 20 days without rainfall. From 5th to 7th of June, Kunming last continuous rainfall. The test temperature is 20℃.

3.2 Data Acquisition

The detection system uses ultrasonic echo technique to detect water content in plant stem. Firstly, the ultrasonic pulse transmitting device generate 1KHz narrow pulses with 1000ns pulse width, which makes the 250kHz ultrasonic probe to generate ultrasonic waves; and then, the probe is placed at the plant stem with a sufficient amount of coupling agent which make ensure that the probe can fully be coupled with the plant stem; after that, the ultrasonic waves spread in the plant stem in the axial direction. The absorption of the ultrasonic energy by the plant stem leads to reduction of ultrasonic energy. Therefore, when the ingredient of the plant stem changes to intent to absorb more energy, the energy attenuation of ultrasounds increases gradually. Finally, the ultrasonic echo signals are received via a receiving probe, which will be stored and displayed on a PC via the data acquisition card on Nextkit and LabVIEW platform with 1MHz sampling rate and 1000 points sampling depth.

3.3 Data Pre-processing

The ultrasonic echo data are pre-processed before analysing on Matlab. For each ultrasonic record is about 5s ~ 10s filled with a lot of noise. In order to reduce the detection error caused by disturbance, the formula (1) is adopted to select effective ultrasonic echo pulses when the EH of an ultrasonic echo pulse is bigger than settled EH_S.

$$EH > EH_S \tag{1}$$

The EH considers 2 important factor: energy(ENE) and high-order difference (HOD) that presents the high frequency feature in time domain. EH_S is the threshold of EH. It presents as following steps:

Step1. Compute energy (ENE) and the absolute sum of order-n difference (HOD).

Step2. Select a weighting factor w within [0, 1] to compute a new curve $EH = w*ENE + (1-w)*HOD$.

Step3. Find a ratio to compute the threshold of EH to determine the effective. The threshold is equal to:

$$EH_s = EH_{min} + (EH_{max} - EH_{min})*r$$

Step4. Select the effective ultrasonic data using the formula(1).

The above method involves three parameters to be determined: n, w, r. In this paper, the values of these parameters are n = 4, w = 0.76, and r = 0.012. However, these values vary with data sets. It is always advisable to have these values tuned by using the target data set for a more robust result.

4 Results

The ultrasonic data of 3 days about 10s are pre-processed using the above method to get the effective data as shown in Figure2. Each test effective data are average to one ultrasonic echo pulse as shown in Figure3 for further analysis. This paper analyses the mean, variance, RMS and the peak to peak values of the one ultrasonic echo pulse as stated in Table 1.
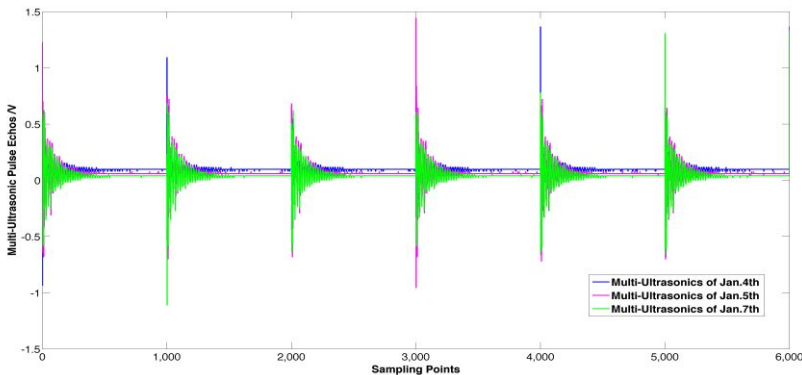

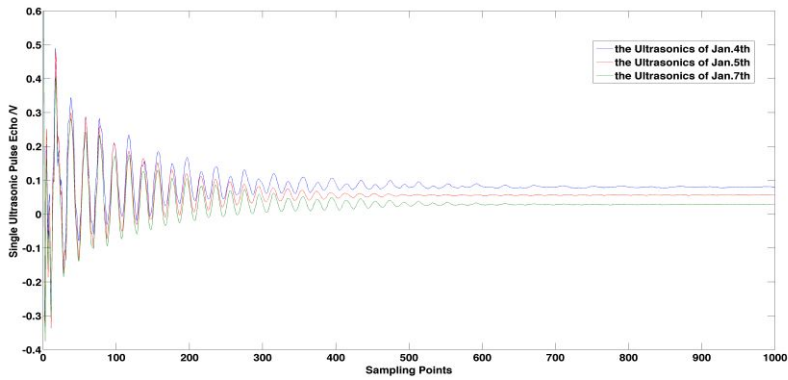**Figure 2.** Multi-Ultrasonic Pulse Echoes in the Stem of Populus simonii

Figure 3. Single Ultrasonic Pulse Echo in the Stem of Populus simonii

Table 1. the Analysis of Ultrasonic Pulse Echo in the stem of Populus simonii

Test Date	June 4	June 5	June 7
Mean	0.0731	0.0595	0.0326
Variance	0.0041	0.0034	0.0032
RMS	10.6957	6.9415	4.2962
Peak to Peak	0.8959	0.8127	0.7058

4.1 the Analysis of Ultrasonic Pulse Echo Envelope and Plant Stem Water Content

Figure 3 shows that the envelopes of ultrasonic echo signal in plant stem attenuate exponentially, the expression of $p(x) = p_0^{-Ax}$. The attenuating exponent is closely related to the water content in the plant stem. The exponent A1 of June 4 is the maximum in those of all the 3 days for without rainfall, which followed by A2 of June 5 for starting to rain, the minimum is A3 for lasting continuous 3-day rainfall, namely A1> A2> A3. The results indicate that the smaller the exponent is, the more the water content of same stem plant is.

4.2 the Analysis of Ultrasonic Pulse Echo Means and plant stem water content

The means in Table 1 shows that on June 4 ,rain-free, the mean of the ultrasonic is maximum, which indicates that the ultrasonic signal propagation in plant stem met the smallest impedance, leading the minimum energy attenuation; on June 5 ,rain for 1 day, the mean significantly reduced down to 0.0269v; on June 7 ,rain for 3 days, the mean continues to decline, but the decline was significantly better than June 5, 0.0136v to that of on June 5. The above data show that the changes of the water content in plant stem can be reflected by the mean of ultrasonic pulse echo signals. When the plant stems water increases, the energy absorption of ultrasonic pulse echo by the stem gets more, so that the ultrasonic echo attenuation increases, eventually leading to the reduction of the mean ultrasonic pulse echo signal.

4.3 the Analysis of Other Properties of Ultrasonic Pulse Echo and Plant Stem Water Content

The RMS, variance and amplitude from peak to peak of the first wave may reflect the propagation of ultrasonic energy. The greater of these parameters are, the smaller the impendence of the ultrasonic is. According to Table 1, on June 4 rain-free the RMS, the variance and the value of peak to peak, which presents the ability to radiate the ultrasonic energy, are the maximum in the 3 test days, indicating that

on June4 the stem has the maximum ultrasonic energy, hindered minimum attenuation with the greatest outward radiation energy capacity. After one day raining the significant decreasing of RMS and variance manifests the reducing of the ultrasonic energy and the ability to radiate energy also declined. After 3 days raining, the 3 parameters   continuously decline but not so sharply as they dose in the first two test days.

5 Discussion

A plant stems ultrasonic echo detection system, a no-destructive dynamic detection, was designed for detecting the changes of water content in living plant stems as a new and effective means. In this paper, the stems of plants of ultrasonic pulse echo signal only from the time domain analyses the energy mean, variance, peak to peak and RMS future timely frequency from the frequency domain to the angle of the echo signal as a basis for further analysis of the signal characteristics relationship between moisture changes. However, due to the ultrasonic echo signal attenuation is very strong in plant stem body, the first echo signal in the test data is not obvious. Therefore, the ultrasonic probe depth analysis is not discussed here.

6 Acknowledgement

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