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An Automatic Excitation Device for the Determination of Standing Tree Moisture Content by Lateral Impact Vibration Method

Zhipeng Zhang, Yuanhao Dang and Junguo Zhang
School of Technology, Beijing Forestry University, Beijing, 100083, China

Abstract: There exists a considerable amount of water in standing trees. The moisture content of standing trees is of great significance to the disciplines of plant physiology, the wood drying, plant irrigation, quality evaluation of trees and prevention of disease and pest. One of the methods for the determination of standing trees is lateral impact vibration. The moisture content can be determined by measuring the resonance frequency of standing trees. The traditional tool used to induce the vibration is the wood hammer. However, it relies on human and can't induce constant excitation. In view of the above limitations, an automatic excitation device is developed. The device consists of two parts, the mechanical structure and the control system. The mechanical structure includes the stepper motor, the mechanical arm and the base. The control system includes the MCU, the remote controller, the wireless receiver, the LCD and the stepper motor driver. The operation mode of the device can be set by the keys on the MCU or the remote controller. The device strikes the standing tree laterally and induces the vibration. It produces stable force, works automatically and promotes the efficiency remarkably in practical application.

Key words: Standing tree, moisture content, non-destructive measurement, automatic excitation device, lateral impact vibration method

INTRODUCTION

The moisture content of standing trees is of great significance to the disciplines of plant physiology, wood drying, plant irrigation, quality evaluation of trees and prevention of disease and pest. Constantz and Murphy (1990) described changes in moisture storage in trees concerned a variety of disciplines ranging from basic plant physiology to forestry and water-resources management. Menon *et al.* (1987) described the distribution and interactions of water in wood were of great importance in the commercial utilization of wood and studied the water distribution in wood during drying. Namken and Lemon (1960) described that the rapid rise in the use of supplemental irrigation to increase crop yields has stimulated the need for a better understanding of plant-water relations. Schulz and Bues (1987) proved that the moisture content of diseased spruce branches was lower than moisture content of healthy spruce branches.

There are many methods to determine the moisture content of standing trees. Kamaguchi *et al.* (2000) proposed a lateral impact vibration method to determine the heartwood moisture content of Sugi. It was found that the moisture content of the standing tree had a relationship with its resonance frequency. The excitation was induced by a wood hammer and the vibration was measured by an acceleration sensor at the opposite side.

However, the manual excitation method has some deficiencies. Wood hammer can't induce constant excitation. In addition, the result may depend on the person performing the wood hammer. What's more, it relies on human and decreases the efficiency. To compensate for the deficiencies, an automatic excitation device is developed. The device can be set to two operation modes, the single strike mode and the continuous strike mode. Additionally, the swing angle and speed of the device can be set by the keys on the MCU or the remote controller.

EXPERIMENTAL SCHEME OF THE LATERAL IMPACT VIBRATION METHOD

The lateral impact vibration method is a non-destructive determination for the moisture content of standing trees. Loos (1965) described that moisture content and density are constantly changing parameters in wood and wood products. Bergman *et al.* (2010) described that mechanical and physical behavior of wood is complex and is critically determined by the moisture content of wood. The moisture content has an influence

Corresponding Author: Junguo Zhang, Department of Automation, School of Technology, Beijing Forestry University, Beijing 100083, Peoples Republic of China

on the resonance frequency of wood. The resonance frequency of wood depends on its elastic modulus (Young's modulus) E and density ρ, as follows:

$$f \propto \sqrt{\frac{E}{\rho}} \quad (1)$$

If the moisture content increases, the resonance frequency decreases because Young's modulus decreases and the apparent density increases. Therefore, the resonance frequency depends on the moisture content of wood. Conversely, the moisture content can be determined by measuring the resonance frequencies of standing trees.

Taniwaki *et al*. (2007) adopted the vibrational technique to measure the moisture content of white oak and explored the feasibility of applying the method to the determination of the moisture content of standing trees. They found that the resonance frequency of the tree decreased as the moisture content increased and that the resonance frequency varied by approximately 600 Hz with a corresponding change in the moisture content by 60% d.b (Fig. 1).

To make up for the deficiencies of the traditional technique and improve the lateral impact vibration method, we set up a new experimental scheme. An automatic excitation device is used to induce the vibration of the standing tree. The signals from the Laser Doppler Vibrometer (LDV) are transformed to spectrum data by FFT and displayed on the user interface. The resonance frequency can be easily obtained from the spectrum data. Finally, the moisture content can be calculated according to the relationship between the resonance frequency and the moisture content. The schematic diagram of the automatic excitation device is shown in Fig. 2a. The schematic diagram of the data acquisition is shown in Fig. 2b. The experimental set-up for the promoted lateral impact vibration method is shown in Fig. 3.

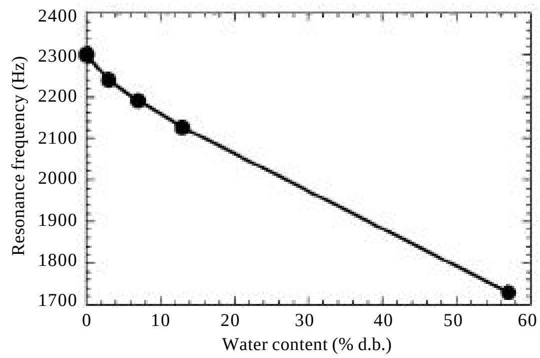

Fig. 1: Relationship between the resonance frequency and the moisture content

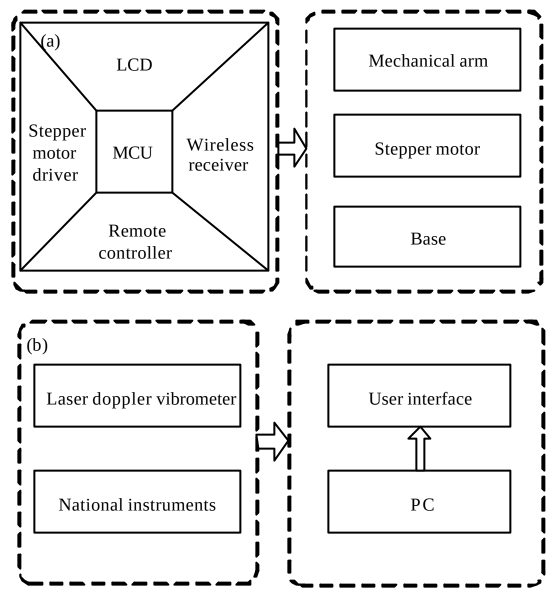

Fig. 2(a-b): (a) Schematic diagram of the automatic excitation device and (b) Schematic diagram of the data acquisition

DESIGN OF THE AUTOMATIC EXCITATION DEVICE

The automatic excitation device plays an important role in the promoted lateral impact vibration method. It can make up for the shortcomings of the manual excitation method and promote the efficiency dramatically in practical application. The device consists of two parts, the mechanical structure and the control system.

The mechanical structure (Fig. 4) includes the stepper motor, the mechanical arm and the base. We adopt 42BYG-25°C as the stepper motor. Its rotating speed and angle can be controlled easily and precisely. The mechanical arm and the base are both made of steel. The front of the arm is 10mm in diameter, while the rear of the arm is 6 mm. A hammer is installed at the front of the mechanical arm. The hammer comes in three different diameters, 6, 8 and 12 mm, applied to standing trees of different materials.

The control system (Fig. 5) of the device includes the MCU, the remote controller, the wireless receiver, the LCD and the stepper motor driver. The MCU is used to control the stepper motor, the LCD and the wireless receiver through the input-output port. The 12 V lithium battery is taken as the power supply of the stepper motor driver.

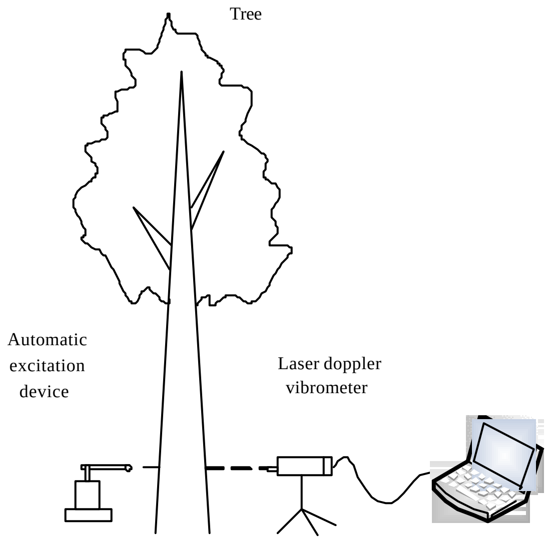

Fig. 3: Experimental set-up of the promoted lateral impact vibration method

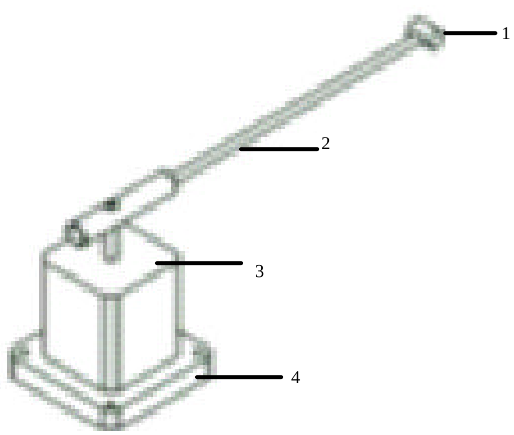

Fig. 4: Mechanical structure of the automatic excitation device, 1: Hammer, 2: mechanical arm, 3: Stepper motor, 4: Base

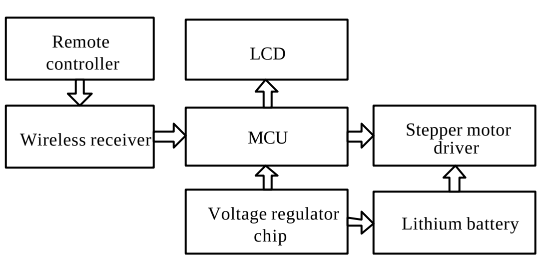

Fig. 5: Control system of the automatic excitation device

The voltage regulator chip is used to transfer the voltage from 12 to 5 v and powers the MCU. The stepper motor driver is used to set the output current, the segments and the attenuation mode. Four keys are designed on both the MCU and the remote controller, a key is used to set the angle of the swing, a key is used to set the motor speed, a key is used to set the operation mode, another key is used to start or stop the device. The LCD is used to display the working condition of the device, including the angle, the speed and the frequency of the swing. The remote controller and Wireless receiver are used to achieve the remote control.

EXPERIMENTAL METHOD

An elm tree, growing in Beijing Forestry University, approximately 5 m in height and 0.2 m in diameter, was chosen as the experiment subject in autumn. The measurement position is at its breast height. The experimental set-up described in Fig. 3 was prepared firstly. Then the measurement pattern of the LDV was set to single-knock mode or continuous-knock mode. The device was fixed at the breast height of the standing tree. The angle setting key and speed setting key were used to set the swing angle and speed of the device. The operation mode of the device was set according to the measurement pattern of the LDV. The device was activated and the resonance frequency was obtained. Then, the position of the device was changed twice and another two measurements were done. The average value of three measurements was taken as the final result. Finally, the frequency was analyzed by the software and the moisture content of the standing tree was obtained.

The program flow of the device is shown in Fig. 6. The device can be operated in three steps. First, switch on the power and initialize the system. Second, set the operation mode. Use the angle setting key and speed setting key to set the swing angle and the swing speed. Then use the operation mode setting key to choose the single strike mode or the continuous strike mode. Third, use the start/stop key to start or stop the device. When the start/stop key is pressed, if the device is set to single strike mode, it swings once; if the device is set to continuous strike mode, the device swings until the start/stop key is pressed again.

RESULTS

The resonance frequency of the elm tree was obtained by the experimental method described above.

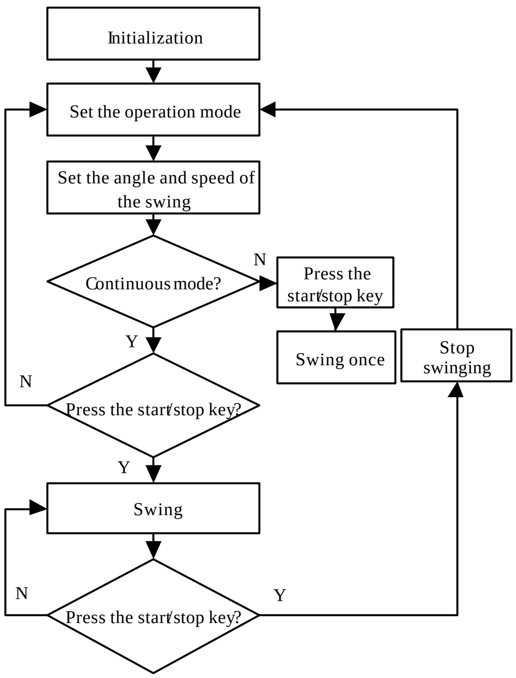

Fig. 6: Program flow of the device

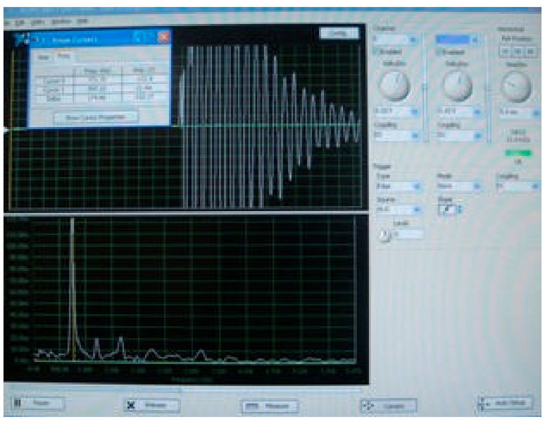

Fig. 7: User interface used to display the resonance frequency

The measurement pattern of the LDV was set to continuous-knock mode. The signals of the vibration were transformed to spectrum data by FFT and the resonance frequency was displayed on the user interface. The wave of resonance frequency has the peak amplitude, which is clear in Fig. 7. According to the relationship between the resonance frequency and the moisture content, the moisture content of the elm tree can be obtained.

CONCLUSION

The moisture content of standing trees is of great significance to the disciplines of plant physiology, the wood drying, plant irrigation, quality evaluation of trees and prevention of disease and pest. Lateral impact vibration, which is non-destructive, easy and fast, is a promising method. However, it's critical how to induce the vibration of the standing tree in this method. To compensate for the shortcomings of the traditional way of inducing the excitation, this study proposes an automatic excitation device. It has simple mechanical structure and well-designed control system. It can induce constant vibration automatically and improve the efficiency remarkably in practical application.

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