Spectral Detection of Wood Moisture Content at 1899.703 Nm

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Abstract. In order to realize real-time, rapid and continuous measurement of wood moisture content, this paper studies the real-time measurement of wood moisture content based on near-infrared spectroscopy. In the experiment, a distributed feedback (DFB) laser with a central wavelength of 1899.703 nm was used as the light source, and poplar moisture content was chosen as the measured parameter to build the software and hardware system of the near infrared moisture detector. Because wood is a strong scattering medium, the modified Langbo-Beer law is adopted. The experimental measurement and data fitting of the moisture content of poplar wood showed that the true value of the moisture content of wood and the output power value of the laser measurement of the moisture content of wood could be fitted as a linear relationship within a certain range, and the correlation coefficient was above 0.90. The change trend of the measured value of the moisture content of wood was consistent with the true value, and the absolute error of the two was less than 0.15%. The experimental results show that the wood moisture content can be measured by near infrared technology.

Keywords: Near Infrared Technology, Spectral Detection, Wood Moisture, Absorption Spectrum, DFB Laser.

1. Introduction
Wood moisture content is an important characteristic parameter of wood, which will lead to instability of wood size under certain circumstances. Therefore, the real-time non-destructive and accurate detection of wood moisture content plays an important role in promoting the production efficiency and technological upgrading of wood processing industry [1, 2].

The most traditional wood moisture content measurement method is drying method, namely the national standard "gbt1931-2009 wood moisture content measurement method" method [3]. This method is accurate, so it can be used as the calibration method in this paper. But because it can not meet the requirements of real-time, fast and continuous measurement [4], the electrical measurement method has become the main measurement method of moisture content. The shortcoming of the resistance method is that it is destructive to the wood under test [5]. But the data measured by capacitance method and electromagnetic wave method are not accurate, and there is a problem of low accuracy [6]. The research of wood moisture fast nondestructive testing method and the development of wood moisture tester are of practical significance and urgent needs of the market. Therefore, the near infrared spectroscopy method for wood moisture measurement is studied in this paper.
Near infrared (NIR) technology is a new detection technology with many advantages, such as short response time, high measurement accuracy and non-destructive testing\cite{7, 8}. Therefore, we apply it to the study of wood moisture detection. The so-called spectral characteristics, that is, the response characteristics of substances to different bands of spectrum, and the absorption and reflection of electromagnetic waves of different wavelengths by each substance are different. In recent years, monitoring water status based on spectral characteristics has become a research hotspot of plant parameter detection because of its non-destructive and rapidity. The system designed in this paper will be used for wood moisture detection.

2. Principle of Water Content Measurement by Near Infrared Absorption Spectroscopy

Near infrared (NIR) is an electromagnetic radiation wave between visible and mid-infrared light. The American Material Testing Association defines the NIR region as 780-2526 nm \cite{9}. In the near infrared region, the stretching and bending vibration of hydrogen and oxygen bonds in water and other molecules is the decisive factor for plants to absorb electromagnetic radiation. Near infrared (NIR) technology usually uses the frequency doubling and combining absorption of OH bonds in the near infrared region (800-2500 nm) to establish the correlation between absorption spectra and water content. There are five absorption bands in the water absorption spectrum. The central wavelengths are located near 760, 970, 1145, 1450 and 1940 nm respectively \cite{10}. Based on this, spectral information in this region has been widely used to analyze the water status of plants. Near-infrared light may be absorbed by most or almost no substances. Based on Lambert-Beer's law, that is, light is irradiated on a medium with a certain thickness of absorbable light. After passing through the medium, part of the light energy is absorbed by the medium, and the energy of transmitted light will be reduced. The higher the concentration of absorbing medium is, the thicker the medium is, the more obvious the attenuation of light intensity is \cite{11}. The higher the concentration of the measured material is, the weaker the reflected light is, that is, the more light is absorbed. However, because wood is a strong scattering medium, the classical Langbo-Beer law can not accurately describe the law of light transmission. We adopt the revised Langbo-Beer law: its relationship is as follows:

\[
\OD = \log \frac{I_0}{I_1} = s \times c \times r \times DPF + G
\]  

Among them, OD is the optical density, $I_0$ is the intensity of incident light, $I_1$ is the intensity of emitted light, $\varepsilon$ is the extinction coefficient, $c$ is the concentration of matter, $r$ is the distance between light source and detector, DPF is the optical path correction coefficient, $G$ is the attenuation caused by scattering. DPF values are correlated with scattering and absorption of tissues.

3. System Design

3.1. System Structure Design of Water Detection by Near Infrared Spectroscopy

Near Infrared Wood Moisture Detector is an integrated and hybrid optical system. In terms of structure design, it is compact and simple, with the premise of ensuring the high accuracy of optical instrument, and with the comprehensive factors of convenience and reliability of instrument adjustment, the overall structure design of near infrared water detection is completed as shown in Figure 1. The device consists of three parts: laser source, photoelectric detection and data processing.
Figure 1. Near infrared moisture measuring instrument system

The computer transmits the relevant control parameters and commands to the control chip through RS232 serial port. The control chip transmits the current control parameters to the laser driver through a function generator. At the same time, the temperature control parameters are sent to the laser driver. The function generator superimposes a high frequency sinusoidal modulation signal on the low frequency scanning current signal of the laser to realize wavelength modulation. Laser driver controls the DFB laser to emit near infrared laser, and irradiates the wood to be measured after collimating and focusing; the wood to be measured is reflected to the detector, and the photoelectric detector converts the light signal into the current signal, and the preamplifier amplifies the current signal and converts it into the voltage signal into the control chip for measuring signal; the control chip detects harmonics according to the measured signal and lifts it. Taking the second harmonic component as the signal value, the signal value is proportional to the light intensity, and the moisture content of the wood can be obtained by formula (1).

3.2. Selection of Absorption Lines for Hydrogen Peroxide

In order to select suitable water absorption lines between 3500 and 7000 cm\(^{-1}\), the anti-interference spectra of NH\(_3\), H\(_2\)O, CO\(_2\), CO, N\(_2\)O and CH\(_4\) gases were compared. The absorption spectra of NH\(_3\), H\(_2\), CO\(_2\), CO, N\(_2\)O and CH\(_4\) gases were consulted in HITRAN database as shown in Figure 2. The interference of five other gases except hydrogen peroxide should be avoided when the central wavelength of near infrared water measurement is chosen. Fig. 2 shows that there are no absorption peaks of other five gases in the range of 5250 cm\(^{-1}\) to 5500 cm\(^{-1}\). Therefore, the appropriate central wavelength can be selected in this range.
In order to select the central wavelength and eliminate the error caused by the absorption of near infrared light by other substances during irradiation, we need to examine the interference of other gases at the frequency of 5263.98 cm\(^{-1}\) (1899.703 nm). Since the concentration of CO\(_2\) in the air is about 400 ppm, which is much higher than that of other interfering gases, we take the absorption frequency of CO\(_2\) as an example. Figure 3 and Figure 4 show the absorption frequencies of H\(_2\)O and CO\(_2\) around 5263.98 cm\(^{-1}\) (1899.703 nm), respectively. From the two wavelength spectrum lines, we can see that the absorption intensity of H\(_2\)O at 5264 cm\(^{-1}\) (1899.703 nm) is 2.5e-20, the corresponding absorption intensity of the two adjacent H\(_2\)O absorption lines is 5265.835 cm\(^{-1}\) (1899.034 nm), the corresponding absorption intensity of H\(_2\)O is 2.85e-22, the corresponding absorption intensity of 5261.5 cm\(^{-1}\) (1900.599 nm) is 9e-21, and the left adjacent lines are 9e-21. The interval was 0.896 nm and the right adjacent line was 0.669 nm.

Two adjacent CO\(_2\) absorption lines at 5264 cm\(^{-1}\) (1899.703 nm) were 5263.907 cm\(^{-1}\) (1899.729 nm) with corresponding absorption intensity of 3.5e-27 and 5264.094 cm\(^{-1}\) (1899.662 nm) with corresponding absorption intensity of 3.7e-27.

Compared with the absorption intensity of hydrogen peroxide, there is a difference of 5 to 6 calorimeters, which meets the modulation requirements. Therefore, we can determine the wavelength of 5264 cm\(^{-1}\) (1899.703 nm) laser for wood moisture detection by near infrared spectroscopy.

**Figure 2.** Absorption spectra of NH3, H2O, CO2, CO, N2O, CH4

**Figure 3.** Absorption spectra of H2O in 5263.98cm\(^{-1}\)
4. DFB Laser Source
Halogen lamps, tunable distributed feedback lasers (DFB) and External Cavity Diode Lasers (ECDL) are commonly used in domestic light sources. The design uses distributed feedback lasers encapsulated in industrial butterfly as light sources.

Halogen lamp uses filters to obtain a certain frequency light source, which can not guarantee the stability of the light source near the water absorption peak. The DFB laser has Bragg Grating built-in, which has very good monochromism (spectral purity). Its linewidth can be less than 1MHz and has a very high side mode rejection ratio (SMSR). At present, it can reach up to 40-50dB. Because of the limitation of modulation principle, the modulation speed of external cavity semiconductor lasers is not high enough to meet the requirement of fast measurement. The output energy of DFB varies smoothly with wavelength, and its frequency response characteristics are high, so it can be used in high frequency band. Therefore, compared with halogen lamp and ECDL, DFB laser is more suitable for the source of near infrared moisture meter.

Tunable DFB lasers are generally tuned by temperature and current. The tuning speed of DFB lasers is very slow, but the tuning range can reach 5nm. Therefore, it can be used to roughly select the position of the hydrogen peroxide spectrum, but not to scan the spectrum quickly. The typical value of current tuning is 2.0µm. The tuning range is narrow, but the speed is relatively fast. Therefore, the method of coordinating temperature and current is adopted in the measurement. Firstly, the output wavelength of the laser is located at the center of the absorption spectrum through temperature tuning, and then the spectrum is scanned by current tuning.

In order to verify the performance parameters of distributed feedback (DFB) lasers, the performance parameters of DFB lasers are tested by a comprehensive tester of semiconductor laser parameters as shown in Table 1.

| parameters (Units)   | symbol | minimum | typical | maximum |
|---------------------|--------|---------|---------|---------|
| central wavelength (nm) | λ      | 1780    | 1860    | 1990    |
| working voltage (V)  | V      | 3       | -       | 5       |
| threshold current (mA) | I      | -       | 12      | -       |
| output power (mW)    | P_0    | 1.5     | -       | 4.0     |

5. Tests and Results
Cut the disc with thickness of about 30mm downward at 1.3m of the trunk, along the north and South radius directions, and cut a poplar specimen with length, thickness and width of 20mm*20mm*20mm at the sapwood position. According to the schematic diagram of the experimental device in Fig. 1, the experimental system is built and tested. The experimental data are fitted as shown in Fig. 5. In the figure, the abscissa is the true value of wood moisture content, and the ordinate is the power value mW. Table 2 gives the experimental results, fitting results and their errors.
Figure 5. Fitting diagram of wood moisture content

Table 2. Experimental data test results

| true value of water content (%) | output power value (W) | rate of water content (%) | error (%) |
|---------------------------------|------------------------|---------------------------|-----------|
| 27.38                           | 0.681                  | 27.26                     | -0.12     |
| 27.26                           | 0.687                  | 27.18                     | -0.08     |
| 26.99                           | 0.693                  | 27.09                     | 0.10      |
| 26.85                           | 0.701                  | 26.98                     | 0.13      |
| 26.89                           | 0.715                  | 26.79                     | -0.10     |
| 26.53                           | 0.725                  | 26.66                     | 0.13      |
| 26.46                           | 0.733                  | 26.55                     | 0.09      |
| 26.48                           | 0.741                  | 26.44                     | -0.04     |
| 26.39                           | 0.749                  | 26.33                     | -0.06     |
| 26.23                           | 0.759                  | 26.19                     | -0.04     |
| 26.19                           | 0.762                  | 25.08                     | -0.10     |
| 25.9                            | 0.771                  | 25.94                     | 0.04      |
| 25.81                           | 0.789                  | 25.67                     | -0.13     |
| 25.5                            | 0.789                  | 25.6                      | 0.10      |
| 25.39                           | 0.801                  | 25.49                     | 0.10      |

From the trend of data change in Fig.5, it can be seen that the standard moisture content and power value show a significant monotonic correlation trend, and can be approximated to a linear relationship within a certain range. The fitting formula is $W = -15.06P + 37.557$, and the correlation coefficient is $R = 0.9647$. However, the samples collected in the experiment are relatively few, and the range of wood moisture content is limited. There may be errors when moisture content is not in the range of wood moisture detection. In order to expand the detection range, we can try to model in different moisture content range. To measure the moisture content of different kinds of wood, the corresponding prediction model should be established.

6. Conclusion

In this paper, water content of poplar wood is used as the measured parameter to detect water content based on spectral technology. The laser light source selected in the experiment is introduced, and the development of the system is completed. The experimental results show that the true value of water content can be fitted to the output power value in a certain range as a linear relationship. The correlation coefficient is above 0.90. The trend of the change of the measured value of water content is consistent with the true value of water content. The absolute error of the two values is less than 0.15%. The feasibility of the technology of measuring wood moisture content based on near infrared spectroscopy is preliminarily proved. However, due to the complexity of wood materials and the errors
in experimental operation, the experimental results will be affected, and the quantitative relationship needs to be further studied in the future.

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