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An all-optical miniature soil moisture content sensor

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1. Introduction

Based on the photothermal conversion effect of doped fiber and the principle of Fiber Bragg Grating (FBG) temperature measurement, an all-fiber miniature soil moisture content sensor is developed. The 1480 nm pump laser is used to heat the cobalt-doped fiber embedded in the soil, and the temperature change is measured by the Bragg grating engraved on the cobalt-doped fiber. The in-situ measurement of soil moisture content is realized according to the linear relationship between temperature characteristic value and moisture content in the heating process. In order to verify the feasibility of this method and the accuracy of the sensor, a soil moisture content test platform is built and experiments are carried out. The experiments show that there is a linear relationship between the characteristic value of temperature and soil moisture content; The soil moisture content measured by the all fiber micro soil moisture content sensor is in good agreement with the drying method, and the maximum error is -1.41%, which is obviously better than the conductivity method. This new type of soil moisture content measurement method has the characteristics of miniaturization and low power consumption.

2. Measuring principle

The measuring principle of the all-fiber miniature soil moisture content sensor is: soil thermal conductivity changes with different moisture content, the higher the moisture content, the stronger its thermal conductivity. Place a miniature optical fiber sensor probe with self-heating and temperature measurement functions in the soil to be tested, heat the optical fiber probe and measure its temperature change, use the relationship between the temperature characteristic value during the heating process and the soil moisture content to determine the soil moisture content. Assuming that the soil sample to be tested is homogeneous, the heat transfer inside the soil can be regarded as a one-dimensional problem. Through derivation, it can be concluded that the calibration relationship between temperature characteristic value and soil moisture content is as follows:

$$w = k_1 \Delta T_t + b_1$$

In the formula: k_1 is the water temperature conversion coefficient; b_1 is the water temperature correction factor. It can be seen that there is a linear relationship between temperature characteristic value and soil moisture content, which can be used for quantitative determination of soil moisture content.

3. System structure

The all-fiber soil moisture content sensing system (as shown in Fig 1) includes pump light source, sensing probe, Wavelength Division Multiplexing, fiber grating demodulation module, data processing module, etc.

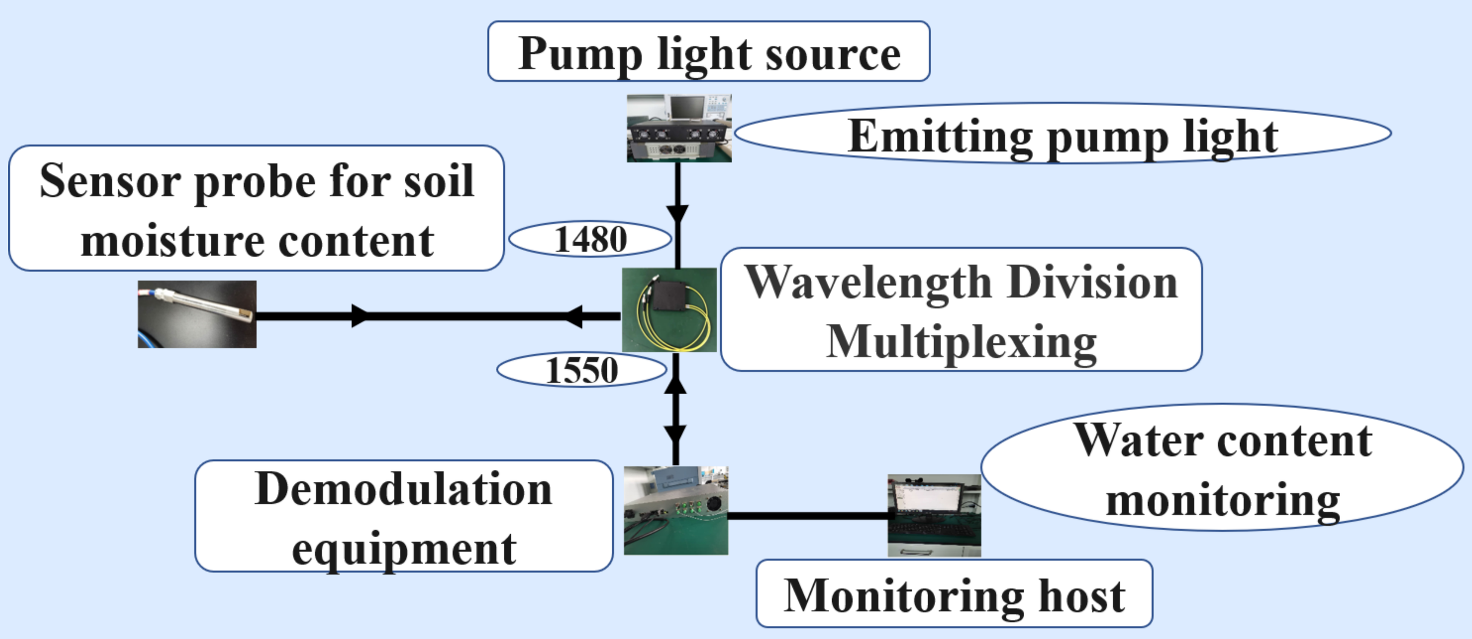

Figure 1.Sensing system structure diagram

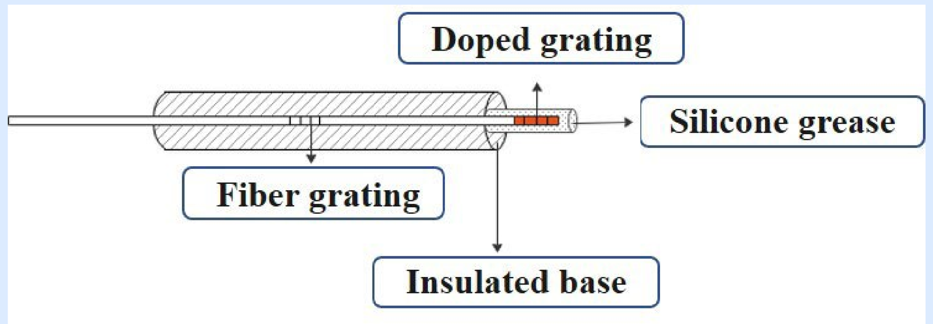

Figure 2. Probe structure of all-optical fiber soil moisture sensor

4. Verification of the relationship between temperature characteristic value and soil moisture content

Choose 3-9min, 3-16min, 3-23min, 3-30min, 10-16min, 20-26min time period, get the fitting curve of soil moisture content and corresponding temperature characteristic value, as shown in Fig 3. It can be seen that the soil moisture content has a linear relationship with the temperature characteristic value in each time period, and the temperature characteristic value decreases as the soil moisture content increases.

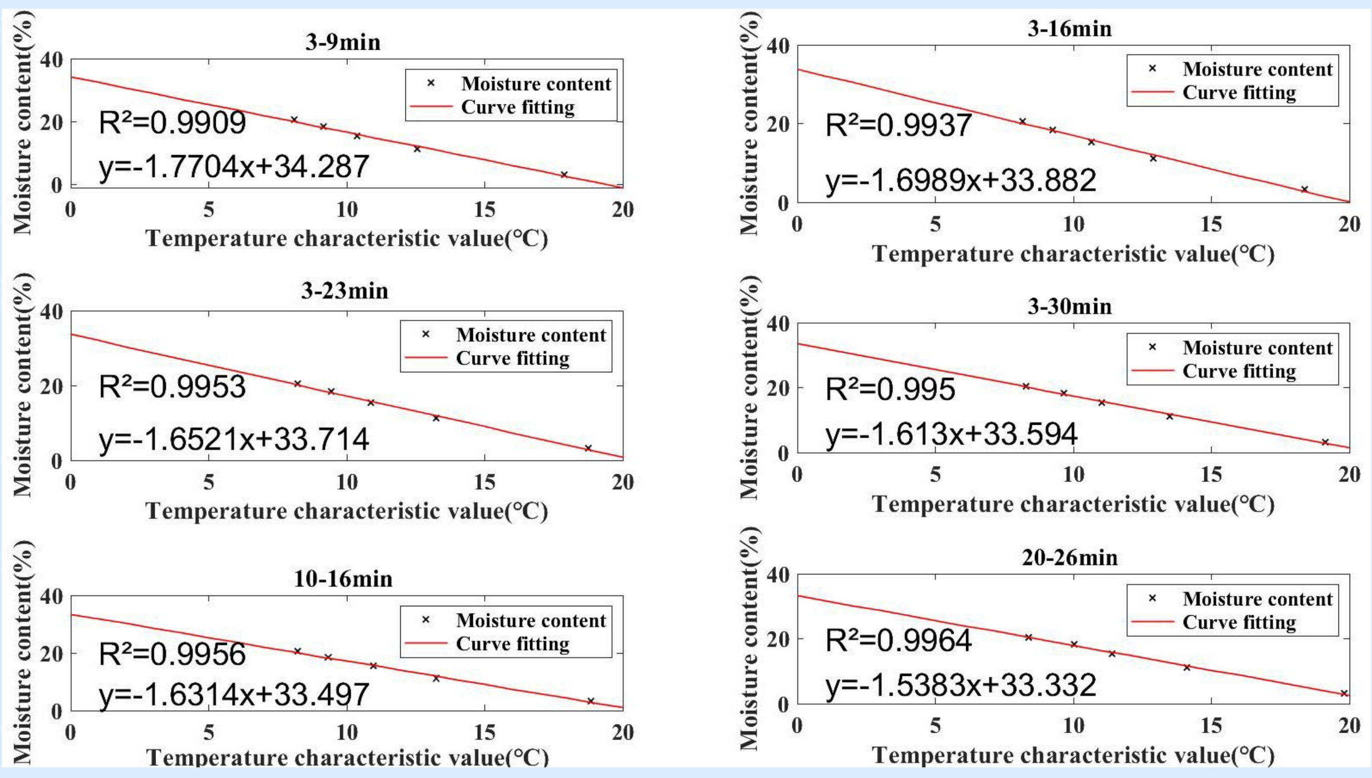

Figure 3. Temperature characteristic value fitting curve

5. Error analysis

Five groups of soils with different moisture content are selected, and the measurement results of the drying method are used as the benchmark, and the electronic soil moisture sensor is used as a comparison, and the soil moisture content measurement comparison experiment is carried out. The measurement results are shown in Table 1. The measurement results show that the maximum measurement error of the optical fiber sensor is -1.41%, and the maximum measurement error of the electronic soil moisture sensor based on the conductivity method is 2.90%. It can be seen that compared with the soil moisture sensor based on the electrical conductivity method, the all-optical micro soil moisture content sensor has a smaller measurement error, which can meet the measurement requirements of water content in practical applications such as geotechnical engineering model tests and agricultural precision irrigation.

Table 1.Error of different moisture content measurement methods

Drying method	Fiber Method		Electronic Method	
	Measurements	Error	Measurements	Error
3.1%	4.26%	1.16%	5.3%	2.20%
6.5%	6.99%	0.49%	8.9%	2.40%
14.4%	12.99%	-1.41%	15.6%	1.20%
15.6%	15.4%	-0.20%	18.3%	2.70%
17.5%	18.28%	0.78%	20.4%	2.90%

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