Calibration Method of Capacitive Soil Moisture Sensor

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(Received 8 July 2020; revised 6 September 2020; accepted 7 September 2020)

Abstract: Soil properties and water content vary from place to place. The calibration method based on capacitive soil moisture and humidity sensor is carried out. The sensor readings are compared with the mass water content measured by the oven dried method, and the calibration formula of sensor reading and mass moisture content is established. Results show that the sensor reading has a good linear relationship with the mass water content measured by the oven dried method, and has high precision. It can calibrate the mass moisture content of the data obtained from the moisture migration test in the soil column.

Key words: capacitive soil moisture sensor; mass moisture content; calibration; laboratory tests

CLC number: U416.1 **Document code:** A **Article ID:** 1005-1120(2020)S-0109-06

0 Introduction

The drying method is a commonly used method for measuring soil moisture content, and can obtain relatively accurate test results, but this method is time consuming and laborious, and the obtained data has poor timeliness[1]. In recent years, with the rapid development of electronic information technology, soil moisture measurement methods are developing towards high precision, non-destructive, automation and so on. Time domain reflectometry and frequency domain measurements have appeared, which realize the automatic collection and transmission of soil moisture, and the timeliness of data has been significantly improved. With the gradual popularization of intelligent soil moisture measurement methods, how to improve the accuracy of soil moisture measurement has attracted the attention of many researchers. For example, Chen et al.[2] introduced the international main soil moisture measurement technology and analyzed its advantages in continuous dynamic measurement. Shi et al.[3] and Zhang et al.[4] introduced some new methods for measuring water content, analyzed and compared the principles, advantages and disadvantages of different methods. Wu et al.[5] used the time domain reflectometry (TDR) method to conduct indoor calibration test for soil sample volumetric moisture content. Zhou et al.[6] used frequency domain reflection (FDR) technology to determine the moisture content of loess roadbed.

In the work of measuring the soil moisture content, there are many kinds of soil moisture sensors available on the market, but no matter which sensor is selected, it needs to be calibrated to ensure the accuracy of the measurement results. That is to say, the drying method and the sensor method are used to measure and analyze the data. The calibration process includes determining soil dry bulk density, calibration data requirements, manual sampling and drying, and fitting calibration formulas. In this paper, according to the analog signal value of capacitive soil moisture sensor, the sensor readings are compared with the results of manual drying, and the calibration formula is fitted to improve the accuracy of the sensor.

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How to cite this article: XIAO Lei, JI Tianjian, ZHANG Qingsong. Calibration method of capacitive soil moisture sensor [J]. Transactions of Nanjing University of Aeronautics and Astronautics, 2020, 37(S): 109-114.

http://dx.doi.org/10.16356/j.1005-1120.2020.S.014

1 Capacitive Soil Moisture Sensor

1.1 Sensor introduction

The sensor used in the test is the DFRobot Arduino capacitive soil moisture sensor (Fig.1), operating voltage 3.3—5.5 V, output voltage 0—3.0 V, interface PH2.0-3P, size 98 mm×23 mm ($L \times W$).

Fig.1 DFRobot arduino capacitive soil moisture sensor

This sensor is different from other common resistive sensors. It uses the principle of capacitive sensing to determine the soil moisture. The schematic is shown in Fig.2. The circuit does not directly contact the moist soil under the protection of the insulating paint, which solves the problem that the resistive sensor is easily corroded. Its working life is longer. The sensor has built-in voltage regulator chip, supports 3.3—5.5 V wide voltage working environment, and can be directly used on platforms such as Arduino, ESP32, micro: bit, and control board. The standard DFRobot-Gravity interface can be directly connected to the Gravity IO extension board. Microcomputers such as raspberry pie need an ADC (analog signal to digital signal) module to work.

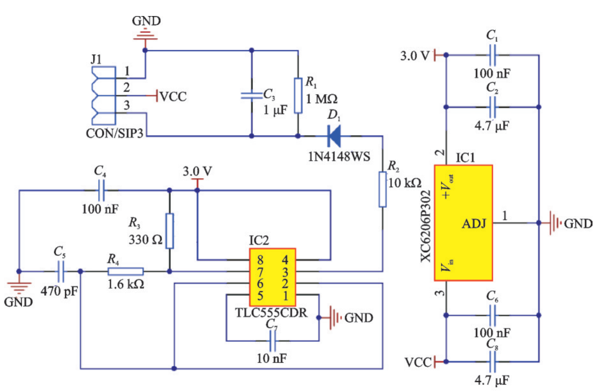


Fig.2 Schematic diagram of capacitive soil moisture sensor

1.2 Sensor calibration

A calibration process is required before the formal determination of soil moisture. Need to prepare a UNO control board, a soil moisture sensor, a PH2.0-3P wiring, software using the Arduino IDE, and connect the sensor and main control board according to Fig.3.

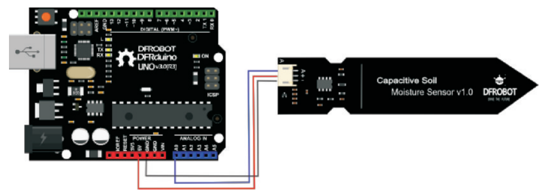


Fig.3 Wiring diagram

Calibration code:

```
void setup() {
Serial. begin (9600) ; // open serial port, set the baud rate to 9600 bps
}
void loop() {
Serial. println (analogRead (A0) ) ; //connect sensor and print the value to serial
delay(100);
}
```

Write the calibration code to the main control board. Open the serial port monitor and set the baud rate to 9 600 according to the program. The sensor is first placed in the air to read the analog value, which represents the reading when dry. Then take a glass of water, insert the sensor into the water to a certain depth (do mark it, this depth is the depth to be inserted into the soil), and record the analog value read at this time, representing 100% humidity. The output data is inversely proportional to the humidity and the output in water is minimal. The insertion depth is shown in Fig.4.

Since the sensor value is affected by the depth of the soil and the tightness of the soil, only the relative humidity of the soil can be detected. We divide the range of humidity into three equal parts, which means dry, wet and very humid. The sensor reads 535 in the air and 259 in the water. These two data constitute the humidity range. So it can be divided into (535, 443], (443, 351], (351, 259]. These

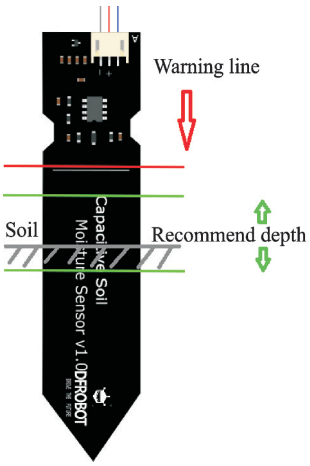


Fig.4 Illustration of sensor insertion depth

three intervals are dry, wet, and very humid, respectively.

2 Calibration Method

The test soil is taken from the borrowing site of a road project in Nanjing. According to the Highway Geotechnical Test Procedure (JTG E40—2007)[7], the dry density of the soil sample is 1.64 g/cm^3, and the initial moisture content is 10.2%. The soil sample is directly placed in an oven for drying for 12 h to prepare a sample with a water content of 0%. Take completely dry soil samples and add different water according to Eq.(1) to prepare samples with 5%, 10%, 15%, 20%, 25% and 30% moisture content, and prepare two samples for each moisture content. Spray water evenly on the soil layer with a spout, mix it evenly and put it into a plastic bag for sealing. After 12 h, the soil moisture distribution is uniform.

$$m_{\mathrm{w}}=\frac{m_{\mathrm{m}}}{1+w_0}(w-w_0) \tag{1}$$

where m_{w} is the amount of water required to prepare a soil sample at a certain moisture content; m_{m} the mass of the soil sample when the water content is w_0; w_0 the original mass moisture content of the soil sample and w prefabricated mass moisture content.

The prepared samples are respectively loaded into the container, and then inserted into the humidity sensor, reading every 10 m until the reading of the humidity sensor is constant. After recording the final data, the moisture content of soil samples in the container is measured by the drying method. Two samples of moisture content per group are used, and the results are averaged. The moisture content of soil quality obtained by the drying method and the values measured by the humidity sensor are fitted. Repeat the above steps and then conduct two groups of parallel experiments. The results are marked as Nos. 1, 2 and 3, respectively. To verify the correctness of the coefficient and the feasibility of this method, two soil samples are taken from the borrowing site to carry out two sets of tests, which are recorded as Group A and Group B, and the previous test steps are repeated. Therefore, the measured sensor readings can be converted into the mass moisture content by the fitting formula and compared with the mass moisture content obtained by the drying method, so as to verify the correctness of the coefficient.

3 Results and Analysis

The sensor reading is an analog signal value, which is a dimensionless quantity. Experimental results are shown in Table 1.

Table 1 Sensor reading and mass moisture content measured by drying method

No.1	Sensor reading					
	494	488	482	471	465	457
Mass moisture content/%	4.73	9.17	14.87	19.82	24.86	29.45
No.2	Sensor reading					
	495	487	482	471	466	457
Mass moisture content/%	4.65	9.33	14.56	19.41	24.32	29.12
No.3	Sensor reading					
	494	487	482	470	465	458
Mass moisture content/%	4.46	9.24	14.32	19.62	24.56	29.37

The mass moisture content and sensor readings are fitted as

$$y=Ax+B \tag{2}$$

where y is the soil moisture content measured by the drying method (%) and x the sensor reading. A and B are the regression coefficients.

Fitting the relationship between sensor readings and mass water content is shown in Fig.5.

It can be seen from Fig.5 that the regression coefficients A and B are $-0.659\ 6$ and 331.09, respectively. It can be seen that the mass moisture content has a good linear correlation with the sensor reading, and the correlation of the fitting formula is more than 99%, indicating that the determination method is feasible. The correlation of the formula is very good.

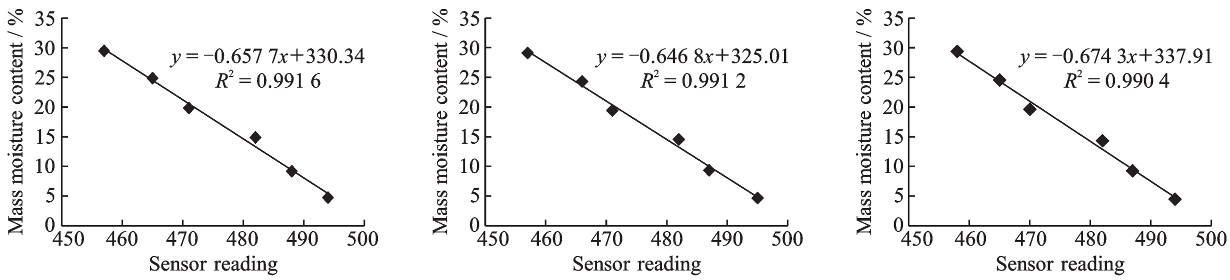


Fig.5 Relationship between sensor reading and mass moisture content

Regression coefficients A and B should be related to the dry density of soil. The moisture content of the same soil sample measured under the same sensor readings and different dry densities is different. To verify it, a soil sample with a sensor reading of 485 is taken. When the dry density is 1.64 g/cm^3, the measured mass water content is 10.36%. When the same soil dry density is 1.78 g/cm^3, the measured mass moisture content is 11.65%. Therefore, it is proved that under the same sensor reading, the greater the dry density of soil, the greater the measured mass moisture content.

To verify the accuracy of the relationship between the fitted sensor reading and the mass moisture content, the readings measured by the same roadbed soil are converted according to the fitting formula obtained above, and the results of the comparison with the Group A and Group B tests are shown in Table 2.

It can be seen from Table 2 that the range of the difference between the mass water content converted by the fitting formula and that of by the drying method is not more than 0.07%. It shows that the analog signal output by capacitive sensor can be converted into mass moisture content by the fitting formula with high accuracy.

Table 2 Comparison of mass water content obtained by two methods

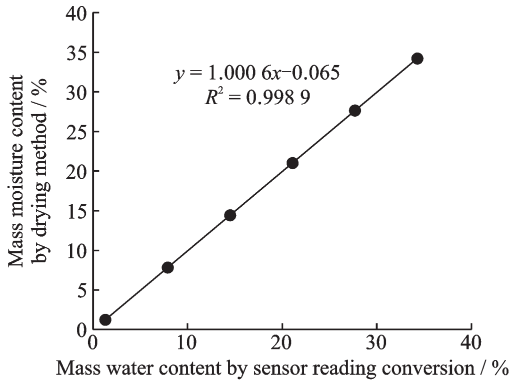
Group A	Sensor reading					
	500	490	480	470	460	450
Mass moisture content converted from formula / %	1.29	7.89	14.5	21.1	27.7	34.3
Mass moisture content measured by drying method / %	1.22	7.73	14.4	21	27.6	34.2
Group B	**Sensor reading**					
	495	485	475	465	455	445
Mass moisture content converted from formula / %	4.59	11.2	17.8	24.4	31	37.6
Mass moisture content measured by drying method / %	4.54	11.1	17.7	24.3	30.9	37.5

The mass water content converted by the fitting formula is compared with the result measured by the drying method, and the fitting is performed by

$$y = Cx + D \tag{3}$$

where y is the soil moisture content measured by the drying method (%) and x the mass moisture content of sensor reading conversion (%). C and D are the regression coefficients.

Fig.6 shows that the C values of fitting parameters are very close to 1. It shows that the mass moisture content of the capacitive soil moisture sensor reading conversion has a good correspondence with the results obtained by the drying method, verifying



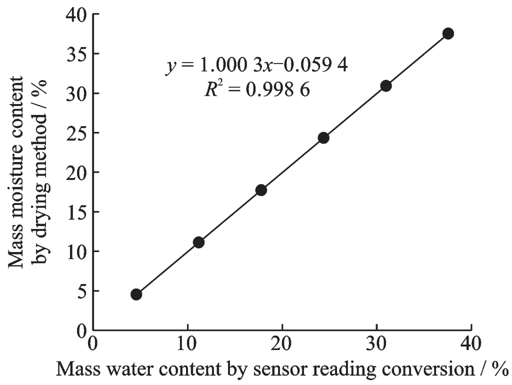


Fig.6 Comparison of mass water content obtained by two methods

the rationality of the method.

According to the regression coefficients A and B after fitting, the soil column moisture migration test under the dry-wet cycle condition is calibrated. The position of the sensor in the soil column is shown in Fig.7, in which GS-X is the sensor number.

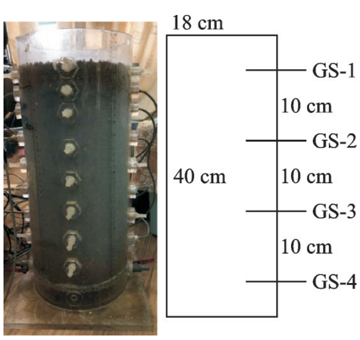


Fig.7 Sensor placement position in the soil column

Take the monitoring values of each numbered sensor at several different times to calibrate the mass moisture content. The calibration results are shown in Table 3.

Table 3 Sensor monitoring data and mass moisture content

Number	Data type	Time 6:00	9:00	12:00	15:00	18:00
GS-1	Sensor reading	440	448	454	461	470
	Mass moisture content/%	40.9	35.6	31.6	27	21.1
GS-2	Sensor reading	438	446	451	458	464
	Mass moisture content/%	42.2	36.9	33.6	29	25
GS-3	Sensor reading	436	442	448	454	462
	Mass moisture content/%	43.5	39.6	35.6	31.6	26.4
GS-4	Sensor reading	434	439	444	450	458
	Mass moisture content/%	44.8	41.5	38.2	34.3	29

From Table 3 and Fig.8, it can be seen that the readings of the sensor can only reflect the trend of humidity change, but not the specific value of water content. Calibrating sensor readings as mass moisture content can more directly reflect the specific values of water content in the soil column and the trend of humidity change.

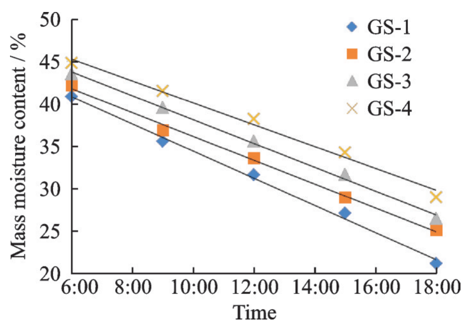


Fig.8 Calibration results of mass moisture content

4 Conclusions and Prospect

(1) Through indoor experiments, the analog signal value measured by capacitive soil moisture sensor is fitted with the mass moisture content measured by drying method, and the fitting curve and regression coefficient are obtained. According to the fitting curve and regression coefficient, the sensor readings can be quickly converted into the mass moisture content.

(2) In the test, the mass moisture content converted by the fitting formula is compared with the mass water content measured by the drying method, and the maximum error is not more than 0.07%, which has high precision.

(3) The reading of the sensor can only reflect the trend of humidity change, but cannot reflect the specific value of water content. Calibrating the sensor readings to the mass moisture content can more directly reflect the specific values of moisture content in the soil column and the trend of humidity changes.

(4) In the calibration process, the influence of compaction degree is not considered. Therefore, the moisture content calibration for subgrade soil may cause large errors, which requires further research in the future.

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Author contributions Prof. **JI Tianjian** designed the study, revised and modified the manuscript. Mr. **XIAO Lei** conducted the experiment and wrote the manuscript. Mr. **ZHANG Qingsong** was responsible for the installation and debugging of the sensor. All authors commented on the manuscript draft and approved the submission.

Competing interests The authors declare no competing interests.

(Production Editor: WANG Jing)

电容式土壤水分湿度传感器标定方法的研究

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摘要:由于各地土壤性状各不相同,含水率也不尽相同。开展基于电容式土壤水分湿度传感器的标定方法的研究,将传感器读数与烘干法测得的质量含水率进行对比分析,建立了传感器读数和质量含水率的标定公式。研究结果表明:传感器读数与烘干法测得的质量含水率具有很好的线性关系,具有很高的精度,可以对土柱中水分迁移试验所得的数据进行质量含水率标定。

关键词:电容式土壤水分湿度传感器;质量含水率;标定;室内试验