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Combined WiFi sensor for temperature and moisture of soil

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Abstract. *Physical parameters, such as temperature and moisture of soil, are important indicators in agriculture. The current study focuses on the development and assembly of an autonomous sensor for soil moisture and temperature through the use of a standard Arduino d1 mini module, equipped with a capacitive humidity sensor. The developed sensor configuration is distinguished with the possibility to transmit data via WiFi communication network and renewable energy system with photovoltaic power panel, which allows the results to be transmitted wirelessly and the sensor to operate autonomously powered by solar energy.*

Keywords: soil moisture sensor, capacitive sensor, soil moisture, arduino, PV panel

1 Introduction

Different approaches are applied when measuring soil moisture (Jensen and all, 1998) according to needs and features (Heim, 2002), such as: electromagnetic, tensiometric, gravimetric, nuclear, hygrometric, resistive, etc. (Fedro S. and all, 1994). Considered in the present study is a gravimetric method for calibrating an electromagnetic sensor with a capacitive type of sensor for soil moisture. Capacitive-type soil moisture sensors use the difference in dielectric constant between water and soil, so dry soils have a relative dielectric constant between 2-6 and water-rich soils have a value of approximately 80 (Martinez A. and all, 2002). Measuring water content in soils is essential in agriculture in view of the fact that water occupies up to 60% of the soil volume. Given the specific porosity of the soil, it is necessary to perform calibration of the sensor with respect to the local conditions in order to ensure accurate assessment of the parameter in interest. Thus, an Arduino-based sensor is developed for the measurement task under discussion. The analog signal from the chosen capacitive sensor in the form of output voltage values is calibrated considering the volume moisture content of the soil, corresponding to gravimetric methods (using the volume and weight of dry and moist soil). The purpose and task of this study is to implement a wireless sensor with the possibility for data remote monitoring, on one hand, and on the other, to ensure its autonomous operation by independent PV power supply sources.

2 Materials and methods

2.1 Parallel plate capacitor

It is well known that electrical capacity is defined by the amount of charge stored within the dielectric material when an electric potential is applied. The general capacitor configuration includes two metal plates in parallel separated by a dielectric.

Equation (1) shows the general relation between the parameters capacitance, charge and electric potential:

$$C = \frac{Q}{V} = \frac{\oint_s \epsilon E.ds}{\int E.dl} \tag{1}$$

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where - Q is the amount of charge and V is the potential difference between the two plates of the capacitor.

Q - The amount of charge is determined by the integral of the electric field E described over the entire conductive surface of the plates of the dielectric material with a relative dielectric constant ε_r. The line integral of the electric field is determined by the electric potential (V). The electric field is assumed to be constant at the surface of the dielectric in a parallel plate capacitor. This leads to:

$$C = \frac{\epsilon E A}{\delta E} = \frac{\epsilon A}{\delta} \quad (2)$$

where - A is the cross-sectional area of each plate; δ is the thickness of the dielectric; ϵ is the dielectric constant of the dielectric.

2.2 Plate capacitive sensor for measuring moisture of soil

Unlike the standard parallel plate capacitor the value recorded by the soil moisture sensor differs in consequence of its different structure. With the sensor, adopted is a scheme in which the conductive plates are placed in one plane, unlike the standard scheme where they are parallel. In this structure of serial plates (in the sensor), the soil acts as a dielectric substance.

In the capacitive soil moisture sensor, the capacitance depends on the geometry of the sensor wafers and the dielectric constant.:

$$C = \epsilon G \quad (3)$$

where - G is a function that is determined according to the geometric characteristics of the sensor. The capacitor voltage can be written as the ratio of the geometric characteristics of the plates (area A) to the input capacitance:

$$V = A/C \quad (4)$$

We can determine the dielectric constant from the following equation:

$$\epsilon = \frac{A}{GV} \quad (5)$$

The equation shows the relationship between the reciprocal of the sensor voltage V and the dielectric constant.

2.3 Volumetric water content

The volume of the soil water content θ_V is the ratio of the volume of the soil to the volume of water contained in it. It is defined by the formula (Jim B., 2001):

$$\theta_v = \frac{\frac{m_w}{\rho_w}}{\frac{m_s}{\rho_s}} \quad (6)$$

where - m_w - the mass of water; m_s - the mass of soil. m_s - is a parameter applicable only to dry soil. ρ_w - determines the density of water; ρ_s - is the density of dry soil.

If the voltage function from (4) is replaced in equation (6), then the dielectric constant of the soil sample is specified as:

$$\theta_v = \rho \frac{\epsilon - \epsilon_s}{\epsilon_w - \epsilon_s} = \frac{\frac{B}{V} - \epsilon_s}{\epsilon_w - \epsilon_s} \quad (7)$$

where ϵ - the dielectric content of soil (DCS); ϵ_s – DCS of dry soil; ϵ_w – DCS of wet soil, V - is voltage, B - size of the slab. Returning to the equation above, the relationship between stress and bulk water content will be assumed to have a linear relationship, giving us:

$$\theta_v = a/V + b \quad (8)$$

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Referring to (Hrisko, J., 2020), the operational principle of the electromagnetic soil moisture sensor (capacitive type) is formulated as the voltage altered in dependence with the volumetric water content (Hrisko, J., 2020); (Ivanov I., 2022).

2.4 The experimental set consists of the following components:

1. Microcontroller - D1 Mini Pro 16M Node MCU Based ESP8266 CP2104 WIFI.
2. Capacitive Soil Moisture Sensor V 1.2.
3. Battery - BS186Q 18650 3100mah 3.7V 40A
4. Holder (battery) Case For 18650
5. Charging adapter TP4056
6. RGB LED WS2812
7. DC Jack
8. PV panel - 6V, 4.5W, 520mAh

2.5 Wiring diagram of the sensor

The wiring of the modules of measuring system is shown in Figure 1.

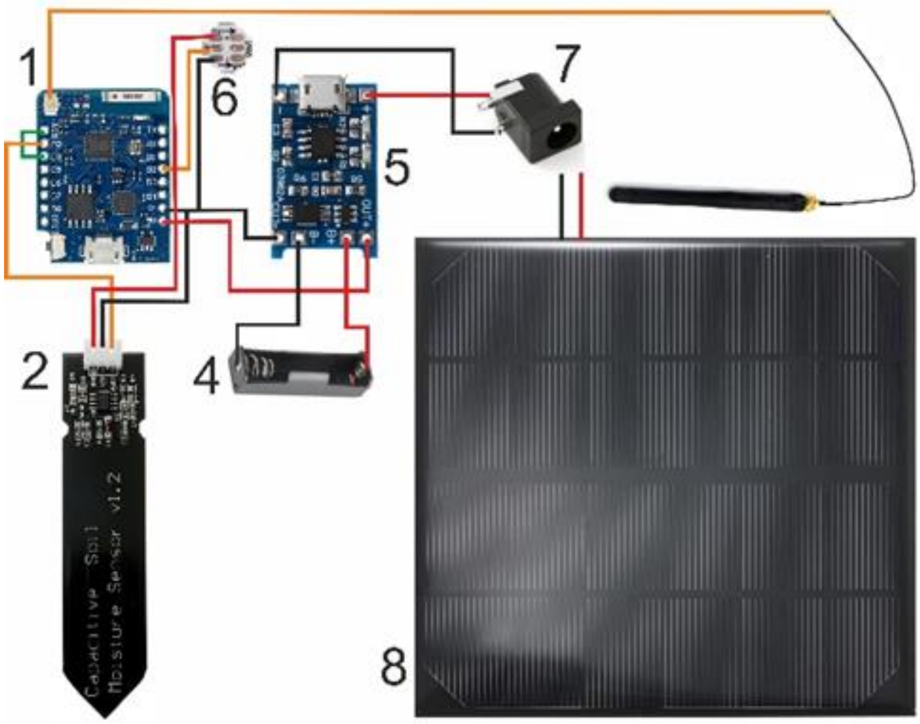

Fig. 1. Wiring of the measuring system components.

2.6 Sensor housing modeling

Modeling can be performed with CAD software in order to configure precisely the main parts of the device (Bankova A., 2020); (Bankova A. And all, 2016).

A more effective graphical model of the sensor housing was created via a 3D printer with the aim of improving its design. The 3D MAX software was used to reproduce the geometry of the housing provisioning proper details, suitable for printing on a 3D printer. Subject to the dimensions of the real components of the sensor their adequate placement within the solid case was ensured. The position of the solar panel and the antenna for the WiFi details are shown in Fig. 2.a.

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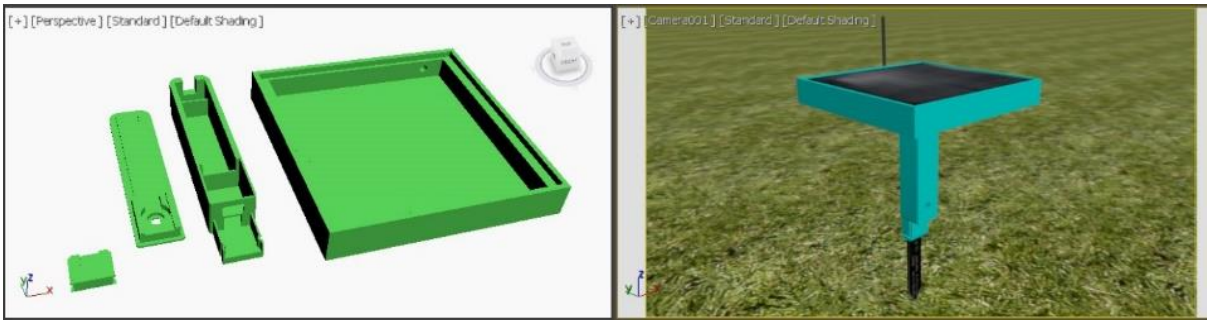


a) b)

Fig. 2. Housing components and sensor visualization: a) design elements, b) overall appearance.

The following settings are recommended for printing on a 3D printer:

• 0.2 mm layer height
• 20% filling

3 Results and discussion

3.1 Captions/numbering

The capacitive soil sensor uses 3.3V supply voltage and the AREF pin must also be connected to 3.3V to provide the best resolution for ADC module around 3.3V, instead of 5.0V. When the sensor is in the atmosphere (not in soil), its effective voltage should be approximately 3.15V, and when placed in moist soil (when measuring), its value varies between 1.9V - 3.0V.

3.2 Temperature sensor

An ESP32 DHT11 module is added to measure the temperature (Fig. 3).

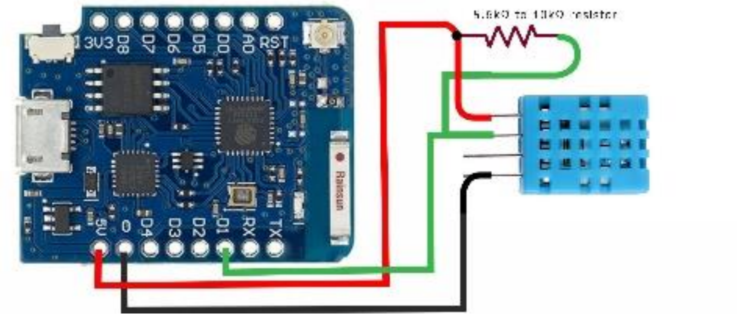


Fig. 3. DHT11 wiring diagram.

The module can measure air temperature and relative humidity.

Fig. 4. Display with sensor values.

3.3 Calibration of a soil moisture sensor

The volumetric water content of the test sample is the ratio of the volume of water in it to the total volume of the soil. When water is added to the test soil, the mass of the sample always changes, but the volume remains constant.

In determining the volumetric water content, each term in the equation affects the outcome of the experimental process. The difference between the mass of dry soil and the mass of wet soil gives the mass of water in the sample. This refers to Eq. (6).

The equation shows the relationship of the individual components included in the function of the volumetric water content of the soil:

$$\theta_v = \frac{\frac{(m_{wet} - m_s)}{\rho_w}}{\frac{m_s}{\rho_s}} = \left(\frac{m_{wet} - m_s}{m_s}\right)\frac{\rho_s}{\rho_w} \tag{9}$$

where: m_{wet} - the measured mass of the soil sample; m_s - the measured mass of dry soil; ρ_s - bulk density of the soil; ρ_w - density of water (Ivanov I., 2015).

Soil mass is the parameter that changes after each moisture change. To conduct the experiment, the soil must initially be completely dry. The density of water is assumed to be 997 kg/m^3. At the beginning of the experiment, it is assumed that the bulk density of the soil is equal to the mass of the dry soil (under real conditions, the water content in the soil cannot be zero).

Different types of soil samples show different deviations in calibration parameters. Due to the peculiarities (of the texture) in the reading of the bulk density with the gravimetric method in different types of soil, the value can vary from 0.05-2.0 g/cm^3. An error of 5% to over 200% can occur with these features. To avoid measurement errors, the bulk density of the specific soil type should be tested and calibrated each time the capacitive sensor is moved to a different soil type.

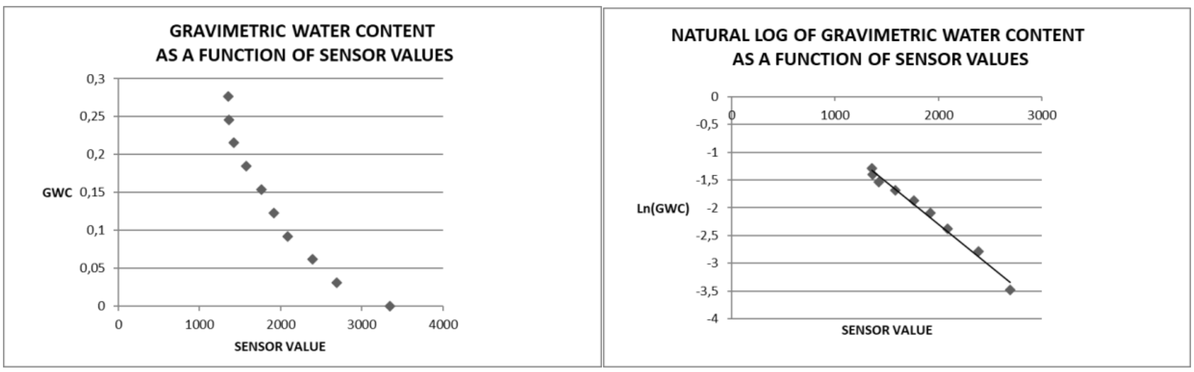
3.4 Gravimetric water content – calibration procedure

Calculation of gravimetric soil water content at calibration is based on the equation below:

$$\theta_V = m_{wet} / m_S \tag{10}$$

where m_{wet} - mass of water in the soil sample; m_s - mass of dry soil in the sample.

The weight of the dry soil is firstly measured in a container, and then the sensor is placed in the soil to obtain a test reading of the sensor. The water mass is assumed zero at this stage, as well as the sensor readings. Subsequently, the sensor is removed and a 10 ml of water is added, well mixed with the soil. The relevant record of the water mass equals 10 at this stage and the corresponding sensor read is registered. The process continues until the addition of water no longer affects the sensor readings. The result of the calibration process is shown in Fig. 5a. The next Fig. 5b shows the readings of the ratio mass of dry soil/water as a function of the output voltage of the sensor.



a) b)

Fig. 5. Experimental results.

The device is designed to be powered by a rechargeable Li-Ion battery type 14650, 7/5 AA, 3.7 V, 1000 mAh. Depending on the capacity of the battery the "deep sleep" mode is capable of extending its duration approximately up to 2-3 weeks. The battery can be charged via a standard 5V USB adapter

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connected to the micro-USB connector of the charging controller. In this particular case, a solar panel charging was used, ensuring a couple of advantages – design flexibility, independent operation and less maintenance services. In a test, the battery without the solar panel lasted for 5 days without being completely discharged. This time is more than enough due to the fact that the battery is designed to provide power during the dark hours of the day.

The distance from the test field to the building in a straight line is 15 meters. The transmission distance at 2.4GHz is up to 20 meters. This guarantees trouble-free operation and the created sensor is a reliable alternative to professional weather stations.

4 Conclusion

The intelligent soil moisture sensor is a reliable solution for determining the exact moisture of the soil. It is designed to detect the underlying trends in soil moisture change and applied on farms it is a cheaper alternative to professional meteorological stations. Experiments show that it is possible to shade the feeding solar panel depending on the sensor design. To avoid that, it is necessary to increase the mounting height of the solar panel. The sensor is to be developed with the addition of other sensors, as well as a Micro SD Card Module for data recording.

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