Design and Implementation of IoT Based Soil Moisture Data Logger for Irrigation and Research Applications

Mr. Abin Satheesan¹, Dr. Sanjoy Deb², Mrs. Shri Tharanyaa J. P³

¹Assistant Professor, Bannari Amman Institute of Technology, Department of Electronics and Communication Engineering, Sathyamangalam, Tamilnadu, India.
²Associate Professor, Bannari Amman Institute of Technology, Department of Electronics and Communication Engineering, Sathyamangalam, Tamilnadu, India.
³Assistant Professor - II, Bannari Amman Institute of Technology, Department of Electronics and Communication Engineering, Sathyamangalam, Tamilnadu, India.
abin@bitsathy.ac.in, tharanyaa@bitsathy.ac.in, sanjoydeb@bitsathy.ac.in

Abstract. A fundamental way to schedule irrigation is possible through the continuous monitoring and management of soil moisture. Soil moisture is directly related to soil water content and this water content will affect the quantity of nutrients available to plants and soil aeration status. Proper irrigation can be done with the help of the accurate measurement of soil moisture. This proposed system is capable to collect the soil moisture content using watermark 200SS sensor and will be recorded in the permanent storage medium and will be accessible through wireless media. The soil moisture value is calculated in Centibar (cb) or Pascal ( SI unit ) based on the resistance value of soil moisture sensor and temperature sensor. This cost-effective system will be useful for irrigation, automatic plant watering, and get the details of the soil moisture. The system has been tested in different environmental conditions and verified the values. The system is completely powered by solar energy and consuming very less amount of processing power to run.

Keywords: Soil moisture, soil water tension, centibar, irrigation, granular mixture, tensiometers, GUI.

1. Introduction

The precise irrigation can be done by either based on the crop evaporation, transpiration, and measure the plant water stress [1]. Soil water tension measurement is a mechanism that is used in this system to do proper irrigation or other soil analysis. So the irrigation is strictly based on the content of water in the soil. Watermark 200SS is the sensor being used here. This is a granular mixer material (GMS) based sensor. The gypsum technology has problems of inherent but in GMS sensor it is reduced [2]. The material does not dissolve in the soil [2] and the sensor is enclosed by stainless steel cover. The soil moisture is calculated by the value of resistance from the sensor and the temperature of the soil. Resistance value is directly related to the soil moisture.
The sensors are installed under the soil at different depths to calculate the most accurate value of soil moisture. The sensors are paired and the combination consists of one watermark sensor and one temperature sensor. The first pair will be installed at a depth of 1 foot (30 cm / 12 inch) from the earth’s surface and the second one will be at a depth of 3-3.5 feet. After the installation process and powering the circuit the system will start to measure the values from the soil moisture sensor and temperature sensor simultaneously. Once the measurement is over the algorithm will calculate, the value of soil moisture based on the temperature and will be recorded in the permanent storage memory for future use.

2.Materials and Methods

There are many soil moisture calibration and loggers are available in the market. However, they are not providing much flexibility in data processing and access. The watermark 200 SS sensor has evaluated for the soil matric potential (SMP) [8] with a drip-irrigated vegetable crop and verified. Here the measuring equipment was a watermark sensor and Tensiometers.

The block diagram (Fig 1) of the system is given below. The system consists of a high-performance microcontroller (32 bit ARM), watermark (Irrometer 200SS) temperature sensor, Real-time clock and SD card. Two pairs of soil moisture sensors and temperature sensors are sensing the soil moisture as well as temperature to obtain the most reliable and accurate data. The system automatically measures the soil moisture and soil temperature from the two different depths. This measurement is more appropriate for the deep-rooted plants and narrow rooted plants. According to the values from the sensor pairs, an irrigation mechanism can be carried out. Once the sensor’s values are captured, the measured value will be undergone for the soil moisture calculation. Clinton Shock’s equation is used to calculate the soil moisture in centibar or kilopascal (kPa) [5]. The system automatically cross-checks the calculated value with standard soil moisture value and intimated through the wireless transmission medium. The system is enabled to access the complete information and critical stage warning. This low power wireless transmission provides more flexibility to access the data from remote and hill areas.

![Figure 1: System development](image)

2.1 Soil moisture measurement

The relation between the resistance of the sensor and soil water potential is provided in the equation (1).

\[ R = 0.5 - [0.1275 \times S - (1.38 - 0.018 \times T)] \] (1)
where R is the resistance (kΩ), S is the soil water potential (kPa) and T is the soil temperature in degree Celsius [2].

The response time of the sensor is moderate and the data coming from the sensor is more accurate and reliable while comparing with other soil moisture sensors. In addition to the watermark sensor, a soil temperature sensor is also playing a vital role in the real-time calculation of soil water tension. Once the calculation of soil water tension is completed by a set of mathematical formulas then the system will be ready to store the data in a permanent memory like SD (Secured digital Card) card for long time use. This data will be saved with proper date and time to avoid the complexity in future analysis.

Irrometer Watermark 200SS is a resistive type sensor that capable to provide the measure of water tension in the soil in terms of resistance. The manufacturer has provided the range of resistance values corresponding to the water tension in the soil. We have observed the resistance up to 20 kΩ from the field.

Soil water tension has a close relation with soil temperature and it will affect the soil water content. In the watermark 200SS model, the water potential is expressed as (2) [1],

\[
S = \frac{-(4.093 + 3.213 R)}{1 - 0.009733 R - 0.01205 T}
\]

(2)

The system block diagram is shown in the Fig.1. The central part is an 8-bit microcontroller which is capable to handle watermark sensor and temperature sensor[6]. In addition to that RTC and SD, card units need protocols like FC and SPI to communicate with the microcontroller. The watermark sensor interfacing diagram is given in Fig.2. Here the network is arranged like a potential divider bias with supply is applied as a 50ms pulse. The sensor is excited by a dc pulse of pulse width 50 ms and the sensor will provide the resistance value after 100 μs[7]. After 50 ms the pulse will be at 0 for remaining 30 seconds for removing the charges from the sensor. Fully wet sensor measures 550Ω. In a complete wet condition of the watermark, the sensor offers 550 Ω and in the heavy dry condition, it will be more than 10 kΩ.

**Figure 2.** Connection of watermark 200SS sensor with ARM microcontroller Minimum Voltage across Watermark Sensor

\[
V_{min} = \frac{5 \times 550}{2400} = 1.14V \quad \text{and}
\]

maximum voltage \( V_{max} = \frac{5 \times 8000}{9400} = 4.25V \) or approximately 5 V.
If the watermark resistance increases beyond 8KΩ the voltage coming across the sensor will be nearly 5V [9]. The diffusion of water molecules into the sensor makes resistance variation inside the sensor. The granular matrix will get wet and resistance decreases [4]. Water content in the soil will directly affect the resistance of the sensor and this resistance represents the approximate value of soil water tension at the moment.

As the atmospheric temperature increases the evaporation rate drastically increases consequently the soil becomes dry during these climatic conditions [10]. Clinton Shock has developed an equation to calculate the water tension in soil and this equation have a close relationship with the soil temperature and soil moisture content. This atmospheric temperature directly affects the soil temperature; as a result, the soil water evaporation happens. If there have a sudden change in the climate the soil temperature and soil water tension will vary in an unpredictable manner. To get an accurate value about the soil water content the analysis must include all the important factors of soil water content in the calculation.

2.2 Temperature sensor

Here DS18B20 digital thermometer was used to measure the soil temperature. The sensor integration is shown in the Fig 3. This sensor provided 9 bit to 12-bit data for each degree in temperature (°C). A one-wire bus protocol is used for accessing the data from the device and one processor is enough to control many DS18B20 sensors simultaneously through a single wire. The sensor is covered by a steel frame and water-resistant material so that it is completely protected from water and moisture forever. The bits of the data coming out of the sensor depend on the temperature value. The sensor will measure the temperature from -55 °C to +125 °C.

![Figure 3. Installation of temperature sensor with ARM controller](image)

2.3 Wireless network design and architecture

The system consumes very low power in data processing and wireless transmission. A customized mobile application is used for accessing the data from the system. The complete circuit was enclosed in a plastic casing and it is protected by a metal box from water and mist. The solar panel is mounted on the top of the metal box and this panel is providing the power to the battery for charging. To ensure the connection with the system through the mobile phone it is necessary to provide an antenna from the system and this link will be established when the mobile unit comes inside the range of the network. Now the application provides the values of the soil moisture, soil temperature, resistance of the watermark sensor, and an alert to the threshold condition of soil health. The mobile phone is communicating with the system through wireless media using the MQTT protocol. Fig 4 depicts the working of data transfer via IoT devices using MQTT protocol.
2.4 System integration

A complete working system needs proper integration and packing. According to its operating conditions and environment, the system should be kept in a proper protecting shield. This proposed system is designed for external purposes and it will be available in the outside environment throughout its lifetime. Here the controller board and peripheral circuits are covered by a fiber box and the battery with charge controller is kept inside the steel frame. Fig. 5 shows the system integration and its connection. The solar panel is mounted on the top of the box so that it can be exposed to sunlight easily without extra solar panel stand. The thick steel frame will protect the circuits and battery from water and atmospheric moisture during the varying weather conditions. The involvement of the IoT unit will be helped the researchers to access the data from the systems without open the boxes.

3. Result validation

System performance can be evaluated from the output of the system. Here the soil moisture values are recorded in the SD card according to the date and time. Fig. 6 represents the relation between resistance and soil moisture. The resistance of the soil changes according to the water content in the soil. As the temperature increases the evaporation rate will be increased. According to these properties, we need complete details about the resistance of the sensor and temperature of the soil to calculate the soil moisture content. Fig. 7 represents the relation between temperature and soil moisture. Using Clinton Shock’s equation we can calculate the value of soil moisture manually. The system is also provided the same value without any deviation. This analysis is done by the observed values from the soil using the prototype system at different time intervals. The system has wireless connectivity and the data inside the system can
be accessed through a mobile phone. Fig. 8 represents the wireless data accessing through the phone. This application can be used as a wireless GUI for the data logger unit.

According to the variation of sensor resistance and temperature the soil moisture value will change. Soil moisture value is strictly bounded by these two factors. The graphs illustrate the variation of soil moisture versus temperature and resistance and the equation (3) shows the relation of temperature and resistance with the soil moisture.

\[
Cb \text{ ( centi-bar ) } = 20.00 \times (( \frac{Sensor \ Resistance}{1000.00} ) \times (1.00 + 0.018 \times (Temperature-24.00)) - 0.55)
\]  (3)

This equation is valid up to resistance 8000 ohm.

**Figure 6.** Variation of Resistance according to temperature

**Figure 7.** Variation of temperature according to soil moisture (cb)
4. Conclusion

This system is developed for soil moisture calculation and assessment for research purposes. In addition to that, it can be used for landslide detection based on the soil moisture value. This can be used as the future work of the system. The system has been undergone many trial conditions to ensure the value of the soil moisture and validated. The wireless connectivity of the system made it more flexible to access the data using a mobile phone. The secure digital card in the system will record the soil moisture in a regular interval and it will be available at any time. So the data reliability and retention capacity of the system is most high.

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