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LOW-COST WIRELESS SOIL MOISTURE MONITORING SYSTEM

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Abstract. *This paper presents the design and operation of a low-cost system for soil moisture monitoring. The presented system is developed with inexpensive off-the-shelf components and it is capable of measuring soil moisture tension up to 200 kPa. The system is modular and consists of a base unit connected to a PC via USB communication and a sensing node based on a Watermark 200SS soil moisture sensor. The system is designed for practical application in agriculture hence the maximal distance between base unit and sensing node in open space is up to 10 km. A proper virtual instrument made in LabVIEW is developed for data acquisition, visualization and data storage. Calibration procedure is presented along with the obtained test results.*

Key words: *Wireless system, soil moisture monitoring, Watermark 200SS, Virtual instrument, LabVIEW*

1. INTRODUCTION

Nowadays the intelligent farming plays an essential role in order to achieve a maximum crop yield and it is continuously improved and increasingly implemented [1, 2]. One of the major factors in farming is soil moisture i.e. the amount of water in the soil.

The soil acts as a sort of reservoir in which the water between two irrigation or rain intervals is retained. Since the water is essential for plant growth it is necessary to monitor soil moisture so the irrigation schedule can be properly arranged. Farmers need an easy and convenient ways to monitor soil moisture to improve their irrigation scheduling [3].

Measurement of soil moisture is typically expressed as a percentage of water in a specific amount of soil measured in %, or as the physical force actually holding water in the soil, measured in kPa of soil moisture tension [4]. Soil moisture tension is usually measured by electrical resistance sensors.

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The two most common types of electrical resistance sensors are *gypsum blocks* (with a life of as little as one year but at cost of only \$5 to \$15 a piece) and *granular matrix sensors* (lasting three to seven years or more and costing \$25 to \$35 each). Freezing can cause cracking and premature aging in gypsum blocks, but will generally not hurt granular matrix sensors.

The proposed system is based on a soil moisture sensor Watermark 200SS made by IRROMETER Company and shown in Fig. 1.

Fig. 1 Soil moisture sensor Watermark 200SS

This inexpensive sensor provides good performances and represents a good choice for cost effective system for soil moisture monitoring.

The Watermark 200SS is a granular matrix sensor, similar to gypsum block. It consists of two stainless steel electrodes embedded in a defined and consistent internal granular matrix material that acts like a soil in terms of water retention. This matrix is encased in a hydrophilic material that establishes good hydraulic conductivity with the surrounding soil and is held in place by a durable stainless steel perforated shell with plastic end caps [5]. Movement of water between the soil and the sensor results in changes in electrical resistance between the electrodes in the sensor in the way the resistance decreases when soil moisture increases [5].

Watermark 200SS sensors are manufactured to reasonably controlled specifications and don't require calibration for most commercial purposes. However, for research tasks calibration of each sensor is needed. The accuracy is about 10 kPa within a range of 50–150 kPa. Readings are highly repeatable over the time but exhibit hysteresis [4].

Wireless monitoring system allows greater mobility and it is capable of covering large land areas with sufficient number of sensing nodes without any wire issues. Furthermore, the wireless system can easily be upgraded to monitor other parameters relevant for farming such as those presented in paper [6].

In this paper implementation of the low-cost wireless system for soil moisture monitoring based on the sensor Watermark 200SS is presented. The proposed solution is capable of measuring soil moisture tension up to 200 kPa, and it is intended to be used in agriculture.

2. System Design

2.1. Hardware design

The proposed system is similar to one presented in paper [7]. It is designed for a remote use and it is PC based which means the real-time readings and data storage are performed by a custom made PC application i.e. virtual instrument.

The system is composed of two functional units: the sensing node and the base unit connected via RF communication. The functional block diagram of the proposed system is shown in Fig. 2.

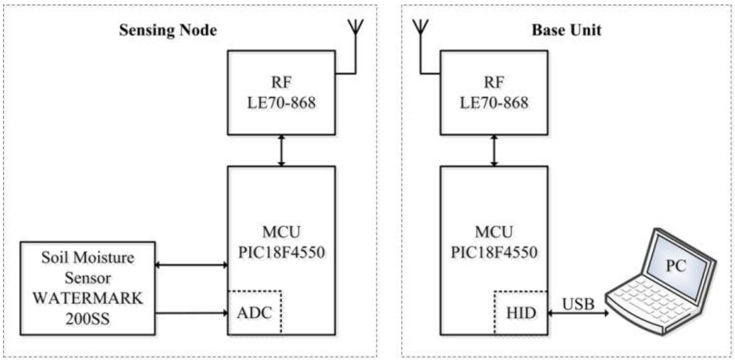

Fig. 2 Functional block diagram of the proposed system

Since the realized system is designed for practical applications in agriculture, the transmission range between the two units must be longer than a several tens of meters in order for larger agricultural fields to be adequately covered. For this reason, high power LE70-868 RF transceivers are utilized because they can support the range up to 10 km.

The sensing node is responsible for soil moisture measurement and it transmits the results of measurements to the base unit. Photo of this node is shown in Fig. 3.

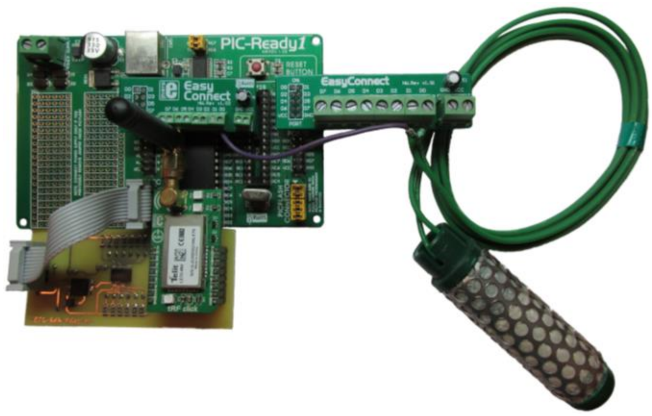

Fig. 3 Photo of the sensing node

The heart of the sensing node is the Microchip PIC18F4550 microcontroller to which the soil moisture sensor and RF transceiver are connected. The Watermark 200SS is connected to the MCU's 10-bit built-in analog to digital converter (ADC) which measures the output voltage of the Watermark 200SS sensor upon which the acquired results are sent to the base unit via the LE70-868 RF transceiver.

The electrical resistance of the Watermark 200SS is converted to the voltage with the help of interface circuitry. To properly read a Watermark 200SS sensor, it is necessary to apply an AC current source in order not to polarize the sensor with a prolonged DC current, which consequently impacts sensor measurements and degrade the sensor over the time. The applied AC current source is driven by a pulse wave excited from the MCU (see Fig. 4) by alternately setting digital pins RB0 and RB1 to high (5V) and low (0V) logic level. Initially digital pin RB0 is set high and RB1 low so the current can flow in one direction and the output voltage is measured. The voltage polarity is then switched by setting pin RB0 low and pin RB1 high so the current can flow in the opposite direction and output voltage is again measured.

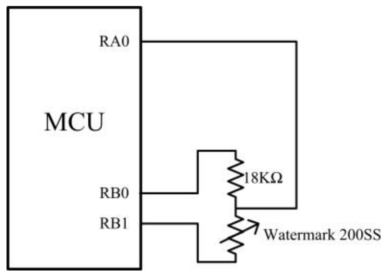

Fig. 4 Applied AC current source

The output voltage of the sensor Watermark 200SS, voltage between the 18 kΩ resistor and the sensor Watermark 200SS is measured with the ADC. The sensor resistance is calculated using the voltage-divider equation:

$$V = \frac{R_{Watermark}}{R_{Watermark} + 18000} \times 5 \tag{1}$$

where V is output voltage of the Watermark 200SS measured by the ADC and $R_{Watermark}$ is resistance of the Watermark 200SS.

The base unit receives the measurement results transmitted from the sensing node and forwards them to a central PC using USB communication. The photo of this unit is shown in Fig. 5.

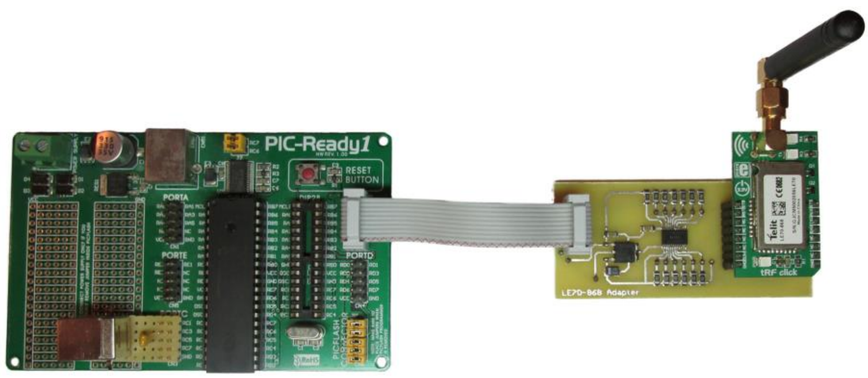

Fig. 5 Photo of the base unit

2.2. Software

A suitable virtual instrument for real-time readouts and visualization of the results is developed in LabVIEW. Accordingly, this virtual instrument handles data acquisition, processing, visualization and storage of the measurement results. Additionally, the results can be saved in form of an Excel file format for further processing and analysis. The communication between the PC and realized system is achieved via USB port using MCU's built in HID protocol. Print screen of the virtual instrument is shown in Fig. 6.

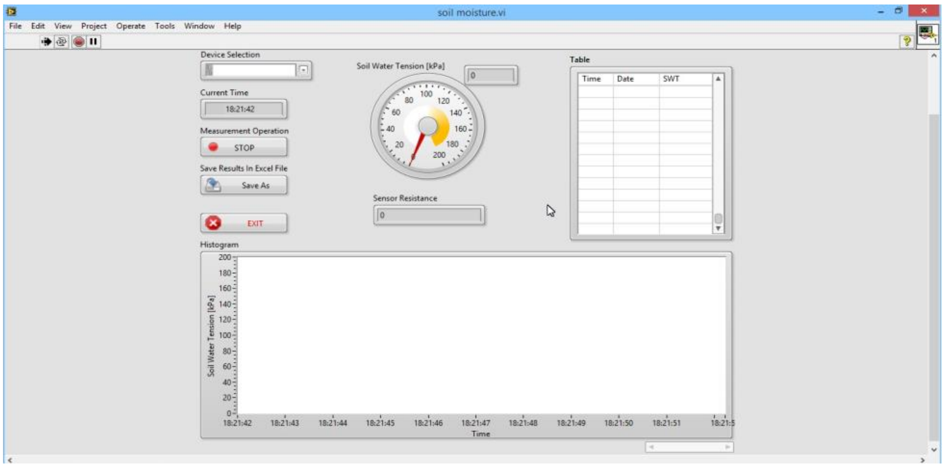

Fig. 6 Print screen of the virtual instrument

Real-time measurements of soil moisture tension are displayed on the round gauge and numeric indicator. To make data analysis a little bit easier the readings can optionally be displayed in the table along with a time of measurement and in the chart diagram in form of a real-time histogram, as it can be seen in Fig. 6.

3. Calibration and Results

To convert the sensor resistance to soil moisture tension in kPa a calibration equation is required. For this reason few calibration points at the temperature of 24°C given by the manufacturer and shown in Table 1 [8, 9] are used in calibration procedure.

Table 1 Calibration points

SWP [kPa]	Resistance [Ω]
0	550
9	1000
10	1100
15	2000
35	6000
55	9200
75	12200
100	15575
200	28075

Based on the calibration points given in table 1, a transfer function of Watermark 200SS can easily be drawn as shown in Fig. 7.

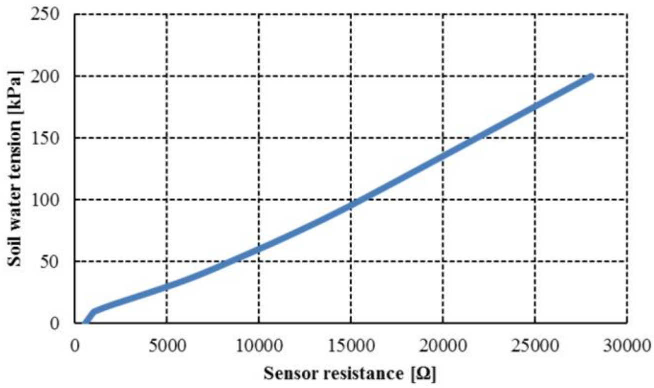

Fig. 7 Transfer function of the Watermark 200SS

Over the past years several calibration equations for the Watermark 200SS sensor have been proposed, such as those presented in papers [9-13]. The equation proposed in the paper [10] is highly recommended in literature and, therefore, is chosen for calibration of the realized system. This equation is:

$$SWT = \frac{4.093 + 3.213 \times R}{1 - 0.009733 \times R - 0.01205 \times T} \tag{2}$$

where *SWT* is soil water tension (kPa), *R* is sensor resistance (kΩ), and *T* is soil temperature (°C).

Based on equation 2, chart diagram illustrated in Fig. 8 can be drawn at the constant temperature of 24°C.

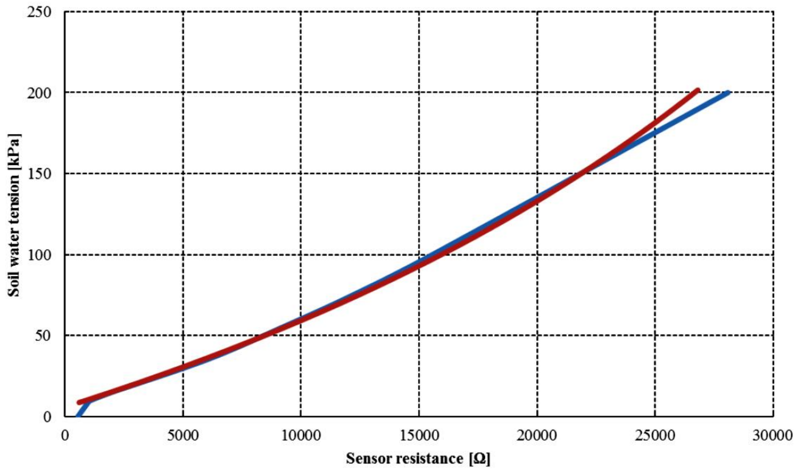

Fig. 8 Calibration curve vs. transfer function

In Fig. 8, red curve represents the results obtained by the realized system and blue curve is transfer function of the Watermark 200SS shown in Fig. 7. Equation 2 provides the best results i.e. the least error compared to the transfer function of the Watermark 200SS in the range between 10 and 75 kPa [10], as can be seen in Fig. 8. This is because the range from 10 to 75 kPa is in fact the most important for agriculture, since irrigation schemes typically maintain tension in this range.

While the temperature compensation factor is included in the calibration equation 2, the soil temperature was not measured but instead, a constant temperature of 24°C was used in calibration process.

The proposed system had undergone thorough test procedure in laboratory during which the soil was sampled in the large flowerpot at about 20 cm dept. The results obtained during the short test on a previously watered soil that was drying for several hours and sampled on every 500 ms are shown in Fig. 9.

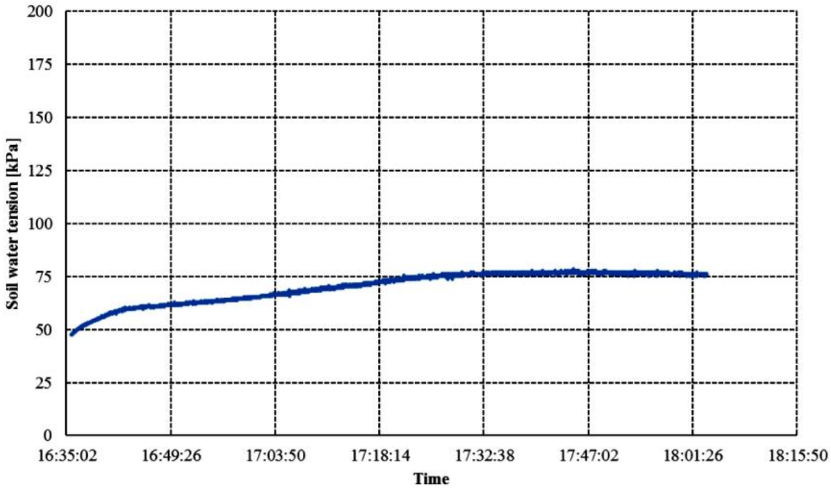

Fig. 9 Test results

4. Conclusion and Outlook

This paper presents the implementation of the low-cost wireless system for soil moisture monitoring based on the sensor Watermark 200SS. The requirements were that the system should be modular and flexible in terms of use and be fairly inexpensive. The proposed solution is capable of measuring soil moisture tension up to 200 kPa, and it is intended to be used in agriculture.

The developed system has several advantages among which are flexibility, small size, real-time communication, cost-effectiveness and easy to use functionality. It represents a good and inexpensive alternative to more expensive similar instruments currently available, especially when it is necessary to monitor soil moisture on several locations or cut down the costs.

The developed system provides a good data transfer trough wireless communication and it can easily serve as a basis for efficient irrigation scheduling system with minor modifications.

Future work will include several activities. The first is to evaluate measurements of the realized system using a proper reference instrument. The second is for the sensing node to be autonomous in terms of the power supply by using solar panel and battery. The third is to implement a temperature sensor so the temperature compensation factor is included.

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JEFTINI BEŽIČNI SISTEM ZA MONITORING VLAŽNOSTI ZEMLJIŠTA

U ovom radu prikazani su dizajn i način rada jeftinog sistema za praćenje intenziteta vlažnosti zemljišta. Prezentovani sistem je realizovan pomoću jeftinih i komercijalno dostupnih komponenti i može da meri vlažnost zemljišta do 200 kPa. Sistem je modularan i sastoji se od bazne stanice povezane na PC pomoću USB-a i autonomnog senzorskog čvora baziranog na senzoru vlažnosti zemljišta Watermark 200SS. Pošto je sistem realizovan za praktičnu primenu u poljoprivredi, maksimalna udaljenost na otvorenom prostoru između modula je 10 km. Odgovarajući virtuelni instrument razvijen u programu LabVIEW je namenjen za akviziciju podataka, njihov prikaz i memorisanje.

Ključne reči: *bežični sistem, monitoring vlažnosti zemljišta, Watermark 200SS, virtuelni instrument, LabVIEW.*