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SOIL PARAMETERS MONITORING SYSTEM

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***Abstract*—*Soil parameters monitoring is vital for different areas such as climatological and ecological studies, agriculture, etc. Large scale measurement systems are based on satellite technologies however their spatial and temporal resolutions still must be improved for real-time measurement tasks and control of local areas. Such systems also require in-situ measurements for calibration. It rises the need of local sensor networks development. The paper proposes a soil monitoring system which allows measuring temperature and humidity. Wireless communication between sensors and data collection unit allows to form sensor array at required area without additional cables. Usage of thermal noise method allows to perform measurement of both parameters with a single sensor which allows to avoid soil moisture content changes due to absence of local soil heating which could be caused by probing currents in other methods. Proposed method also allows to increase measurement accuracy.*

Index Terms—Soil moisture; soil temperature; thermal noise; monitoring.

I. INTRODUCTION

Soil parameters monitoring is vital for many areas such as agriculture, environmental studies, hydrology, etc. The most important among them [1] are soil moisture and soil temperature as they are influencing land–atmosphere interactions, impacting rainfall–runoff processes, regulating net ecosystem exchange, and constraining food security.

In agriculture knowing and controlling soil moisture slows to provide optimal irrigation and ensure sustained growth of vegetation.

Different methods of soil moisture monitoring are being developed by the scientists around the world to provide the accurate measurement data from the large areas.

II. PROBLEM STATEMENT

Large scale soil moisture monitoring systems are focused on remote-sensing methods using satellites [2]. Such systems provide data with spatial resolution from several meters to several hundreds kilometers [3] – [5] and temporal resolution from 2 to 60 days [6], [7]. It may be suitable for different ecological and climatological studies however agricultural applications require small resolutions and closer to real-time data update interval. It requires building the local sensor networks [8].

The available commercial sensors for soil monitoring use different methods to assess the water content of the soil [8]. The most relevant existing methods for obtaining moisture values from the soil [9] are the gravimetric method, tensiometric method, neutronic method, gamma-ray attenuation method, dielectric method, Wenner or resistive method, and light method infrared [10]. Generally, when low-cost sensors are used to measure soil moisture, conductivity-based sensors are based on the use of two electrodes [11]. These types of sensors have two fundamental disadvantages, lack of reliability, and durability. On the one hand, depending on the type of soil and its salt content, the conductivity measurement can vary even when the amount of water in the soil is maintained. On the other hand, the electrodes must be in contact with the ground, and consequently, they can suffer rapid deterioration. Inductive sensors are also employed to measure soil moisture. However, they do not integrate the system into a sensor node to be able to read the parameters.

It is necessary to create the sensing system that would allow to avoid accuracy degrading due to electrode deterioration and will remain relatively low-cost.

III. SENSING SYSTEM STRUCTURE

Proposed moisture monitoring system includes array of sensors and master unit that provides data collection and telemetry for user. It may also provide information about current soil moisture values for automatic irrigation systems. Simplified structure of proposed system is shown in Fig. 1.

System includes an array of moisture sensors 1 which communicate with master data collection unit

(MCDU) via wireless communication 2 that allows measurement data and sensor telemetry collection as well as remote adjustment of sensor operation parameters. Telemetry for consumers may be provided using wireless or wired internet connection 4.

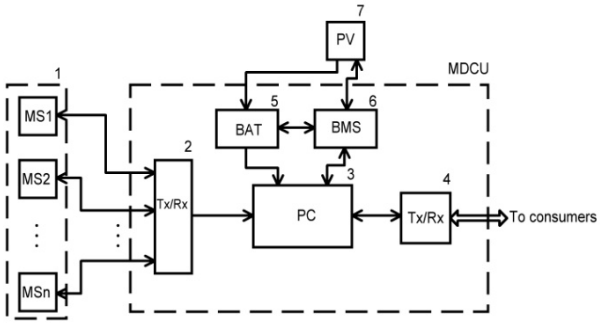

Fig. 1. Simplified structure of soil monitoring system

System also allows autonomous operation provided by battery 5 with dedicated battery management system 6 and solar charging system 7. All communication and data storage processes are carried out by the computer 3.

IV. SENSOR STRUCTURE

Structure of a singular moisture sensor unit is shown in Fig. 2.

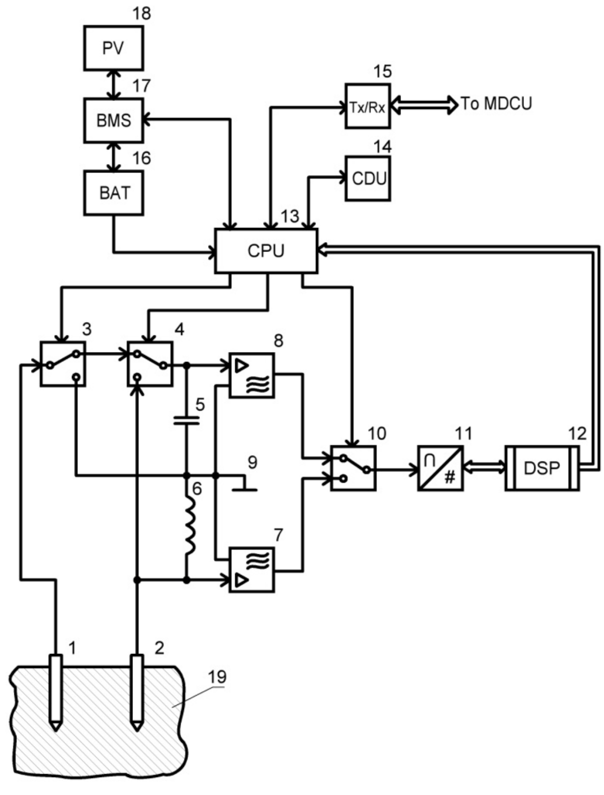

Fig. 2. Block diagram of soil moisture sensor

Each sensor consists of electrodes 1 and 2, controlled switches 3, 4 and 10, resonant circuit, formed of capacitor 5 and inductance coil 6, pair of bandpass amplifiers 7 and 8, common ground 9, analog to digital converted (ADC) 11, digital signal processor (DSP) 12, microprocessor (CPU) 13, control display unit (CDU) 14, communication module 15, battery 16, battery management system 17 (BMS), photovoltaic system 18. Position 19 represents the controlled soil.

Electrodes 1 and 2 are placed into the soil. Input of automatic switch 3 is connected to the electrode 1. First of it's outputs is connected to the input of automatic switch 4, another output is is connected to the point between the capacitor 5 and inductance coil 6 of the resonant circuit. The second input of the automatic switch 4 is connected to the electrode 2, inductance coil 6 and the high potential input of the bandpass amplifier 7. Output of the automatic switch 4 is connected to the capacitor 5 and the high potential input of the bandpass amplifier 8. Low potential inputs of bandpass amplifiers 7 and 8 are connected to the common ground 9. Outputs of the amplifiers 7 and 8 are connected to the inputs of automatic switch 10 output of which is connected to the input of DSP 12 by means of ADC 11. The output of DSP 12 is connected to the input of CPU 13. Logic outputs of CPU are connected to the with controlling inputs of automatic switches 3, 4 and 10. It is also connected to the CDU 14, communication device 15 and BMS 17. The BMS is connected to the battery 16 and PV system 18.

V. SYSTEM PRINCIPLE OF OPERATION

Sensor operation is based on measuring of natural thermal noise that is present in the wet soil due to thermal fluctuations of electric charge carriers (electrons and ions).

The sensor operates in a following way.

Thermal noise signals, generated in the wet soil, are perceived by the electrodes 1 and 2. Noise signals are passed through the automatic switches 3 and 4 and are received by the resonant circuit formed of capacitor 5 and an inductance coil 6. This resonant circuit can be reconfigured from serial to parallel by means of switches 3 and 4. Reconfiguration is carried out according to program uploaded to the CPU 13.

At first switches are set in the way to configure the resonant circuit as serial (as shown in Fig. 2).

Resonant frequency of the circuit is defined by the parameters of it`s elements:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}, \tag{1}$$

where C is the capacity of capacitor 5; L is inductance of coil 6.

At the resonant frequency f_0 reactive resistances of both capacitor and inductance coil are equal. This means short circuit mode of the generating medium. In this case thermal noise current is determined only by the active resistance of the generating medium (soil).

According to the Nyquist`s formula mean square value of short circuit current is determined by the temperature and resistance of the medium:

$$I_n = \sqrt{\frac{4kT_x \Delta f}{R_x}}, \quad (2)$$

where k is Bolzmann constant; T_x is the controlled medium temperature; Δf is the bandwidth of thermal noise selected by the resonant circuit; R_x is the resistance of the soil between the electrodes.

Voltages created by the noise current (2) on the capacitor and inductance coil are amplified by the bandpass amplifiers 7 and 8 and by means of automatic switch 10 are serially converted into digital codes by means of ADC 11. Amplified signals are the mixture of useful thermal noise voltages and amplifiers own noises. Amplified mixture of noise signals is converted into digital form by ADC and passed to the input of DSP 12 where input signals multiply and being processed according to correlation algorithm.

Such processing allows to remove an uncorrelated own noise of bandpass amplifiers because informative thermal noise voltages are mutually correlated as they originate from a single source. The result of such processing is a digital code:

$$N_1 = \frac{K_1 K_2 \frac{L}{C} I_n^2}{q}, \quad (3)$$

where K_1 and K_2 are amplification coefficients of bandpass amplifiers 7 and 8; q is the lower order unit of ADC 11. Digital code (3) is stored in the CPU 13 memory.

The switching frequency of automatic switch 10 is set 5–10 times lower than resonant frequency.

Next CPU 13 sets switches 3 and 4 into lower position (Fig. 3) and transforms resonant circuit into parallel.

Parallel resonant circuit has greater electrical resistance than controlled medium and thermal noise source begins to operate in the idle mode. Mean square value of noise voltage reaches the idle mode value:

$$U_n = \sqrt{4kT_x \Delta f R_x}. \quad (4)$$

Noise voltage (4) is amplified by the bandpass amplifiers and after the similar processing is being stored in the CPU in the form of a digital code:

$$N_2 = \frac{K_1 K_2 U_n^2}{q}. \quad (5)$$

At the next step CPU performs operation of mutual division of N_1 and N_2 codes as a result of which we obtain N_3 code:

$$N_3 = \sqrt{\frac{L}{C}} R_x, \quad (6)$$

that is independent from the temperature of controlled medium.

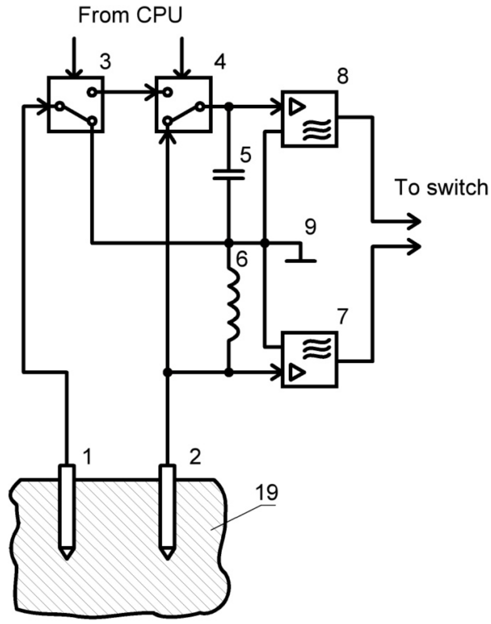

Fig. 3. Resonant circuit reconfiguration

Measured resistance R_x is connected with soil moisture W by the logarithmic dependency which must be preloaded into the CPU memory as the calibration curve. Calculated value of soil moisture is displayed on CDU 14 and transmitted to the MDCU for registration and further use.

The next step includes the multiplication of N_1 and N_2 codes and results in N_4 code that is proportional to the soil temperature:

$$N_4 = \frac{4kK_1 K_2 \Delta f T_x}{q}. \quad (6)$$

Equation (6) shows that T_x value is independent from resistance of soil. Calculated value of temperature is also displayed on CDU screen and transmitted to MDCU for storage and further processing.

Stored data can be used for visualization of soil moisture and temperature levels across the controlled area.

System can also provide data output for external systems such as automatic irrigation systems that removes the need in additional sensors.

VI. Conclusion

Proposed soil monitoring system allows to measure two parameters at the same time using a single information source that is the thermal noise of controlled medium.

It provides independent measurement of soil moisture and temperature. Only two electrodes are used to obtain the information from the medium. Changing of electrodes immersion depth allows to obtain information of soil moisture and temperature at different depth.

The absence of probing electrical current trough the controlled medium excludes the inevitable local temperature increases and resultant changes of soil moisture.

Wireless communication between sensors and master data collection unit allows to use huge number of sensors distributed across the area.

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М. П. Василенко. Система моніторингу параметрів ґрунту

Моніторинг параметрів ґрунту надзвичайно важливий для різних сфер, таких як кліматологічні та екологічні дослідження, сільське господарство тощо. Великомасштабні вимірювальні системи базуються на супутникових технологіях, однак їх просторову та часову роздільну здатність все ще потрібно покращувати для завдань вимірювання в реальному часі та контролю невеликих територій. Такі системи також вимагають вимірювань на місці для калібрування. Це підвищує необхідність розвитку локальних сенсорних мереж. У статті запропоновано систему моніторингу параметрів ґрунтів, яка дозволяє вимірювати температуру та вологість. Бездротовий зв’язок між датчиками та блоком збору даних дозволяє сформувати масив датчиків у потрібній зоні без додаткових кабелів. Використання термошумового методу дозволяє проводити вимірювання обох параметрів одним датчиком, що дозволяє уникнути зміни вологості ґрунту через відсутність локального нагріву, який може бути викликаний зондувальними струмами в інших методах. Запропонований спосіб також дозволяє підвищити точність вимірювань.
Ключові слова: вологість ґрунту; температура ґрунту; тепловий шум; моніторинг.

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