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A HUMIDITY SENSOR BASED ON SOIL THERMAL CONDUCTIVITY

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Abstract: Measuring soil moisture is one of the most important activities in multiple domains of agricultural activities and industries. This procedure helps farmers to improve their automation systems for watering more efficiently. In the other sense of meaning, soil moisture sensors are devices providing the amount of water retrieved in a volume of soil. This paper presents a prototype of moisture sensor that can measure the quantity of water in greenhouses but useful in different fields of agriculture. The sensor is able to measure the humidity of soil and transmit it to a central processing unit for further reactions. The sensor is based on dsPic30f3012 controller system and can be controlled remotely via a RS485 interface, allowing complex configurations of data acquisition and control. Despite of the imperfections of soil, containing a lot of impurities, using this sensor and the precision improvement techniques implemented, the soil humidity can be successfully evaluated.

Keywords: *sensor, soil moisture, humidity, greenhouse*

I. INTRODUCTION

In our days technology reaches a new level of improvement. Agriculture is one of the largest areas are dependent by evolution of technology. One of the biggest problems in greenhouses is to measure the quantity of water from soil, to provide the temperature of soil and the amount of water consumed in process of irrigation. In these days the world is facing a water crisis which is hampering the normal evolution of crops.

In the context of water management for irrigation, measuring and monitoring soil water status is an essential component of best management practices to improve the sustainability of agriculture.

Water content in the soil can be directly determined using the difference in weight before and after drying a soil sample. This direct technique is usually referred to as the thermo-gravimetric method (or simply gravimetric) when expressing water content as weight of water over weight of dry soil, GWC (i.e., the ratio of the mass of water present in a sample to the mass of the soil sample after it has been oven-dried (100-110 °C) to a constant weight). On the other hand, the thermo-volumetric method (or simply volumetric) gives the water content as volume of water in a volume of undisturbed soil VWC (i.e., volume of water related to the volume of an oven-dried undisturbed sample). Although these direct methods are accurate and inexpensive, they are destructive, slow (2 days minimum), time-consuming and do not allow for making repetitions in the same location. Alternatively, many indirect methods are available for monitoring soil water content. These methods estimate soil moisture by a calibrated relationship with some other measurable variable. The suitability of each method depends on several issues like cost, accuracy, response time, installation, management and durability.
Depending on the quantity measured, indirect techniques are first classified into volumetric and tensiometric methods (Figure 1). While the former gives volumetric soil moisture, the latter yields soil suction or water potential (i.e., tension exerted by capillarity). Both quantities are related through the soil water characteristic curve specific to a given soil. [1]

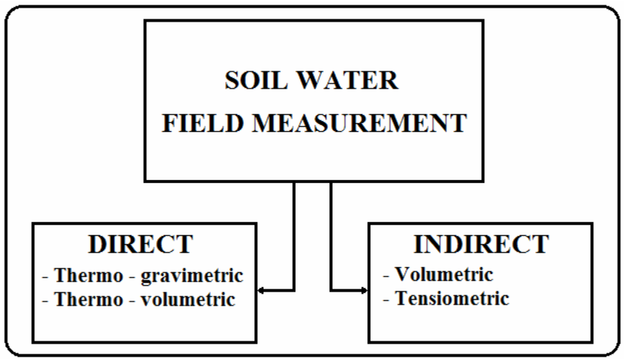

Figure 1. Methods for soil moisture measuring

Our purpose was to implement a soil moisture sensor to measure the temperature and humidity from the soil on green house or agriculture field. The sensor is able to perform an initial calibration for better results.

II. MEASURING PRINCIPLE [2]

The main principle underlying this sensor is the simple observation that the soil that is touched by the hand produces a cold feeling, the more intense as the soil is wetter. The explication of this subjective finding is related to the thermal conductivity of the soil, the conductivity ensured primarily by the water contained in the soil. In conclusion, to estimate the amount of water in the soil, we will measure its thermal conductivity.

Estimating the thermal conductivity is not an easy task, source [2] containing a detailed analysis of the phenomenon and establishing different formulae and practical correction coefficients to achieve the level of accuracy required by different measurements configurations and types of soil.

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Different previous model exist, for example [3], with a slightly different approach.
A simplified model is adopted for our experiments, optimized in a set of experiments to calibrate the sensors.

To measure the thermal conductivity, a certain amount of heat is injected into the soil and after that is measured the increased temperature. The schematic diagram on which this sensor operates is shown in Figure 2.

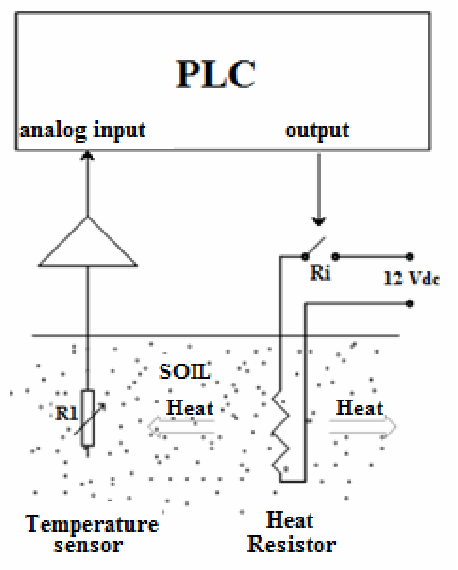


Figure 2. Sensor working principle schematic diagram

In order to facilitate the understanding the phenomenon an simplified electronic equivalent of the principle is presented in Figure 3, where the current source is I represents the heat injected into the soil, Rss represents the thermal resistance of contact between the soil and the sensor and the last Rs represents the thermal resistance of the wet soil. The value should be directly determined and can provide information about soil moisture is thermal resistance Rs. The contact resistance between the sensor and the soil is a parasitic element whose influence must be eliminated or reduced as much as possible.

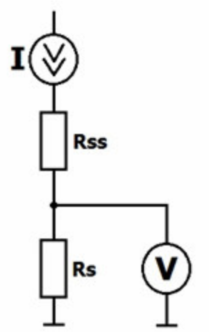


Figure 3. Electric equivalent of measuring principle

In real conditions some parasitic elements exist as shown in Figure 4. RP1 materializes the direct effect of the heat source on the temperature sensor and it is a parasitic element whose value should be increased as much as its effect is small as possible. This can be realized by increasing the distance between the temperature sensor and heat source. But on the other hand by placing the temperature sensor away from the heat source have a secondary effect, lowering the sensitivity.
RP2 represents the heat transfer resistance from the soil to the temperature sensor, and RP3 is resistance to heat loss from the sensor to the soil. RP2 and RP3 are quite correlated with each other and influence the signal by lowering the level without distorting this signal.

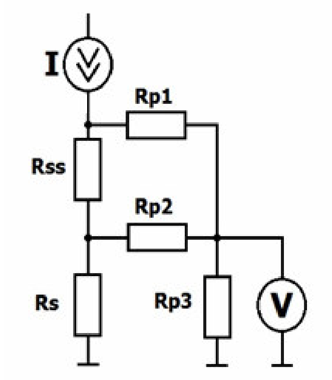


Figure 4. Parasitic elements in the model of measuring principle

III. HARDWARE IMPLEMENTATION

In Figure 5 is presented a prototype of the sensor, and the placement of components. The temperature sensor and the heating element are placed in the front of the board at an optimum distance. To reduce the direct influence of the heat source on the temperature sensor, these elements have been mounted remotely and between them is interposed the tested soil. The sensor is based on dsPIC30F3012 [4] microcontroller in order to perform the post-processing of the acquired signal, so that the useful information (temperature and soil moisture) can be transmitted to the programmable machine.

The communication between the sensor and the automatic is realized via the RS485 industrial serial interface. The programmable machine will initialize the communication by a request. The request protocol contains information about the number of variables which are transmitted and received between the devices.

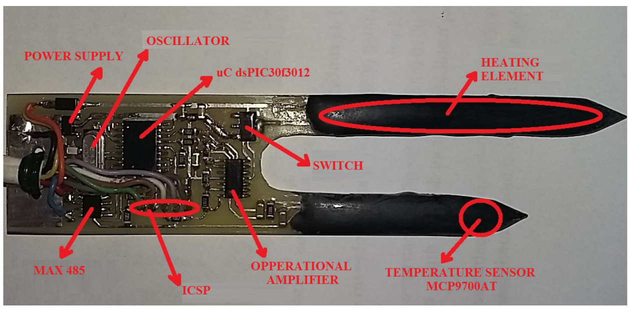


Figure 5. Sensor prototype

The protocol contain four long (64 bit) variables to receive information from sensor and one word (16 bit) variable is used in order to send commands. These variables contain information about elapsed time, humidity,

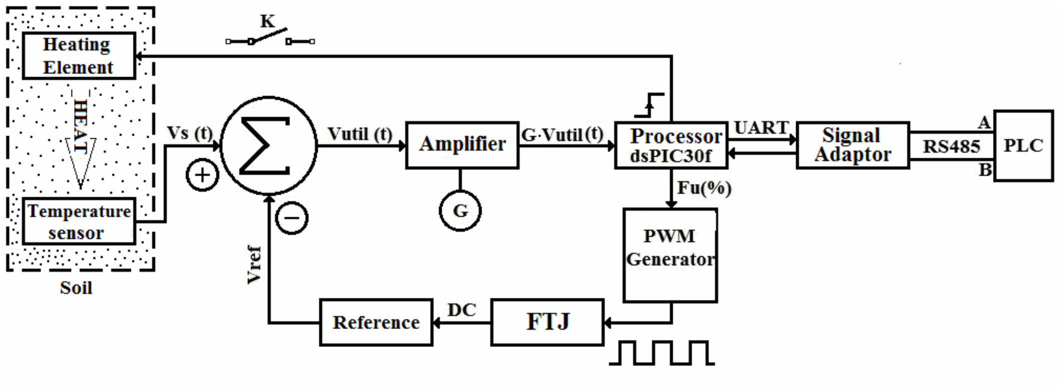


Figure 6. Sensor block diagram

temperature and reference temperature.

Determination of the thermal conductivity of the soil is realized by using a cyclic algorithm. The initial temperature of the soil is measured then the heat is injected in soil for a couple of minutes. The final temperature is measured in the area of the sensor after a sufficiently long cooling-off period. Based on those two temperatures, initial and final, it is determined the thermal conductivity of the soil which is direct proportional with the quantity of water from soil.

The sensor initialization was made by using a PWM control signal for imposing a fixed reference point. The further measurements will be related to this point. Also the sensor ca interpret commands came from a master device via a serial communication for start a measurement or to stop a measurement.

The signal from the sensor along with the reference voltage value (result from calibration) will enter into a differential amplifier block, the useful signal resulted from the differential block will pass through an amplification block.

Based on the acquired signal, the processor will run a specialized algorithm for moisture calculation. Useful information will be transmitted to the Serial RS485 port to a programmable machine.

The temperature variations obtained are quite small, being in the range of 2-3 degrees Celsius, it is necessary to amplify the signal from the temperature sensor.

Since the initial soil temperature may vary by several times the variation produced by heating, it is very likely that in some situations, in the case of very high or very low initial temperatures, the analog amplifier becomes saturated. For this reason, it has been provided as a special function of a PIC family microcontroller to bring at zero the amplifier.

Once set up, the sensor will perform a quick calibration. This calibration is based on imposing a starting point (reference) towards which the measurements will be performed, this principle leads to the elimination of the thermal anomalies that can occur at the ground level and also to the scalability of the measure interval in relation to the existing weather conditions.

The reference point is obtained by modifying the duty cycle of a PWM (Figure 6) signal generated by a microcontroller, in which case the duty cycle increases until the reference point is at an acceptable level. The reference threshold is considered to be fair if it is below the software threshold to have a sufficiently large measurement interval.

IV. EXPERIMENTS AND RESULTS

To test the sensors effectively, a default address has been set, and there is also an explicit one (can be set by the user), which is currently unusable. The addresses of the sensors used in the test mode are C0, C1, C2 and C3. The ModBUS protocol needs an address for communication.

The Humidity Sensor will transmit to the PLC four long-term variables, structured in the following way:

- Timer, used to measure the time elapsed since the sensor is active [s];
- Humidity, calculated empirically over a 20 minute interval based on the results obtained during the tests [ml / 500g];
- Reference temperature, initially measured temperature (on commissioning of the sensor) [degrees C];
- Instantaneous temperature is the temperature measured once per second [degrees C].

Due to a relatively large measurement period (20 min.) and correlated with an instant display, a word variable was used to initiate a request to the sensor in order to initiate a measurement. If the variable is set to 1 (logic), a measurement will be initiated until the heating element will be deactivated and the humidity or the maximum temperature reached during the period of the warm-up interval will be displayed. When it is in the 0 (logic) state, the sensor will transmit the instantaneous temperature to observe the cooling rate of the soil.

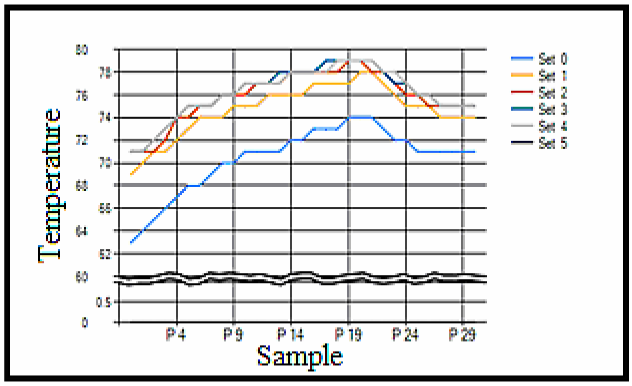
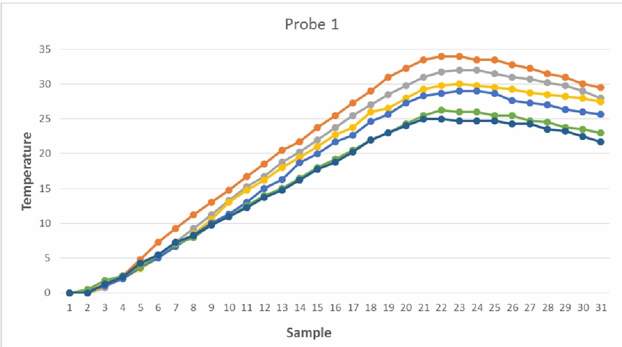


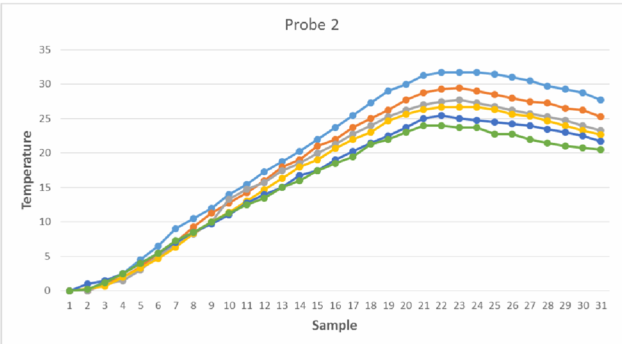
Figure 7. The screen of the application displaying and controlling the sets of measurements

The measurements were carried out by using four probes in parallel (Figure 7), with a controlled humidity regime. For each probe, more sets of measurements were made, repeated to test the repeatability of the measurements. The results of several sets of measurements for the four probes are shown in the diagrams from Figure 8 (a,b,c,d).

During 10 minutes, the sand temperature (y- axis) will increase, after this time the measurement will take place as the difference between the instantaneous temperature and the initial temperature (the point at which the heating was started). With this time running, there is a 10-minute period for the sensor cooling. The variations are not uniform because the soil once warmed will not be able to cool so much in a relatively short time. Therefore, a variable threshold algorithm has been implemented. Thresholds will change as time goes by. The measured values database contains a reference record for dry sand as well as measured values for different degrees of moisture obtained by introducing limited (measured) quantities of water (marked curves).



a



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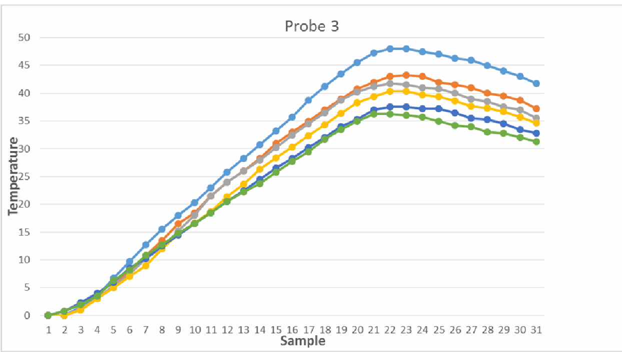

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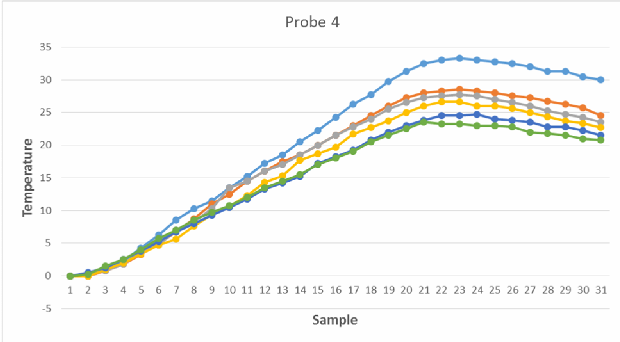

d

Figure 8. Results of the measurement using 4 probes (sensors)

IV. CONCLUSIONS

We have presented in this paper the basic steps of a research work conducting to the development of a soil moisture measurement sensor. The sensor has a built-in DSP processor and a number of processing and communication tasks implemented in software. The system can be controlled remotely via a RS485 interface, allowing complex configurations of data acquisition and control.

The measurement principle used in this sensor is relatively unusual but with good results applied in industrial sensors indicated in the literature [5]. The industrial sensors for moisture are available in different implementations, for soil or for air [6], and one of the future directions of our research will be to compare and evaluate the performance of our work using such references. We intend to integrate wireless possibilities in the updated version of the sensor, inspired by the architectures of our biosensors developed lately and presented in [7], [8].

REFERENCES

[1] Alvarez-Benedí, J. and R. Muñoz-Carpena (eds). *Soil - Water - Solute processes in environmental systems. Monitoring, characterization and modeling*, CRC Press LLC, Boca Raton, 2004.

[2] Carles M. Rubio, "Effects on the relationship between thermal conductivity and moisture for a stony sandy soil", European Journal of Environmental and Safety Sciences, Vol.3(1), 2015, ISSN 1339-472X, European Science and Research Institute, pp. 10-16

[3] Campbell GS, Jungbauer JD, Bidlake WR, Hungerford RD, "Predicting the effect of temperature on soil thermal conductivity", Soil Science, 1994; Volume 158(5), pp.307-13.

[4] ***, dsPIC30F2011/2012/3012/3013 Data Sheet, High-Performance, 16-bit Digital Signal Controllers, 2010 Microchip Technology Inc.

[5] Burak Okcan, Tayfun Akin, "A thermal conductivity based humidity sensor in a standard CMOS process", Proceedings of the IEEE International Conference on Micro Electro Mechanical Systems (MEMS), DOI10.1109/MEMS.2004.1290644

[6] http://www.electronicshub.org/humidity-sensor-types-working-principle/ (Last accessed 28.11.2017)

[7] Teodor Sumalan, Eugen Lupu, Radu Arsinte; Emil Onaca, "Low-cost wireless system for patient monitoring", E-Health and Bioengineering Conference (EHB), 2015, pp.1-4, DOI: 10.1109/EHB.2015.7391540

[8] E Lupu, R Arsinte, T Sumalan, "Prototype of a wearable system for personal health control", E-Health and Bioengineering Conference (EHB), 2017, pp. 345-348, 10.1109/EHB.2017.7995432