A combined Wenner-array/heat dissipation sensor for measuring electric conductivity and moisture of soils.

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ABSTRACT

This paper presents the characterization results and proposes a technique for the compensation of measurement drifts observed in heat dissipation soil moisture sensors when repeated measurements with a small time interval (less than 15 minutes) is used. A heat dissipation sensor was fabricated using the center probes of a conventional electrical conductivity Wenner-array probe. Several experiments were conduct, using two types of soils, with different sampling frequency of data, from 5 to 15 minutes. It is observed that the drift of the measured values depends strongly on the type of soil, since for a clay loam soil the errors due to the repetition of measurements with short time intervals result in a much more humid soil indication than the correct value, while for a sandy loam exactly the opposite behavior is verified. Based on experimental measured data for each type of soil, it is proposed a correction technique to compensate for errors present in repeated measurements.

Keywords: soil moisture sensor, heat dissipation sensor, correction curve for repeated measurements, Brazil

1. INTRODUCTION

Dual probe heat dissipation (or heat capacity) sensors are an interesting technique for measuring soil water content and soil temperature (Campbell et al., 1991), (Valente et al., 2004). The soil water content is determined by applying a heat pulse to a probe and measuring the temperature increase in another probe, usually 3 – 6 mm distant from the heat source (Siqueira Dias et al, 2008).

Although simple and cheap to be fabricated, these sensors can present a serious drift problem if repeated measurements with short time intervals are taken (J. M. Ham et al.), 2004 and Roque et al, 2008). Thus, these type of sensors cannot be used in applications where frequent moisture data sampling is required, as in the measuring of the movement of water in soil. Furthermore, these drift errors were found to be dependent on the humidity of the soil, what makes it very difficult to use them in fields where a large spacial variation is present.

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In this paper a combined sensor (a Wenner-array for measuring the electrical conductivity of the soil, and dual heat probe capacity for measuring soil moisture) was fabricated (Roque, 2008), and the dual heat probe was characterized for two types of soils: clay loam and sandy clay loam. Several laboratory measurements with different times intervals repetitions, from 5 minutes to 15 minutes, and different water contents were used to obtain calibration curves for the sensors.
The analysis of the measured results showed that an special technique for compensation of the errors can be developed, using a look-up table stored in a microcontroller IC which is needed to perform the Analog to Digital conversions of the temperature measurements in the sensor.

2. MATERIAL AND METHODS

Two samples of soils (clay loam and sandy loam) were prepared and saturated for 48 hours. The water content was measured using the gravimetric method. The dual heat dissipation capacity sensor was inserted in the soil, and measurements of soil moisture were made, for 5 to 15 minutes time intervals between two consecutive measurements. The soils were dried in a an open oven, and the soil moisture measurements routine was performed for different humidities, always obtained using the gravimetric method.
The characterization of the sensors on the clay loam soil were obtained for soils humidity in the range of 35% to 26%. Three experiments were conducted at each humidity, with sampling frequencies of 5, 10 and 15 minutes. The temperature data was measured with an AD590 semiconductor temperature sensor (Timko, 1976) inserted in the probe, and the results were collected in a PC running an LabView application.
It was noticed that the drift of the soil moisture measurements were much higher in the sandy clay loam soil, and much more data needed to be collected to obtain a correction curve. The sensors were characterized in this soil for a larger humidity the range (43% to 10%). As with the clay loam soil, three experiments were conducted at each humidity, with sampling frequencies of 5, 10 and 15 minutes. The temperature data was measured with the same set-up described previously.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Experimental Results Measured in the Clay Loam Soil

The measured results obtained from the characterization of the sensors in the clay loam soil with 35% for sampling frequencies of 5, 10 and 15 minutes are shown in Fig. 1, Fig. 2 and Fig. 3, respectively. It can be seen that, in all experiments, even with the 15 minutes sampling frequency, the temperature in the measuring probe does not return to the initial temperature observed in the previous pulse heat.
Nevertheless, since the sensor measures the temperature difference ΔT between the time of the application of the pulse heat and the maximum temperature detected, this should not be a problem if the measured ΔT is constant. For the clay loam soil with 35% of humidity, as shown in Fig. 1, the measured values of ΔT during all repetitions is constant and equal to 0.5° C. However, with the same soil humidity, as the sampling frequency is increased (with repetitions every 10 and 5 minutes), the value of ΔT changes (Fig. 2 and 3), resulting in an erroneous indication of the sensor.

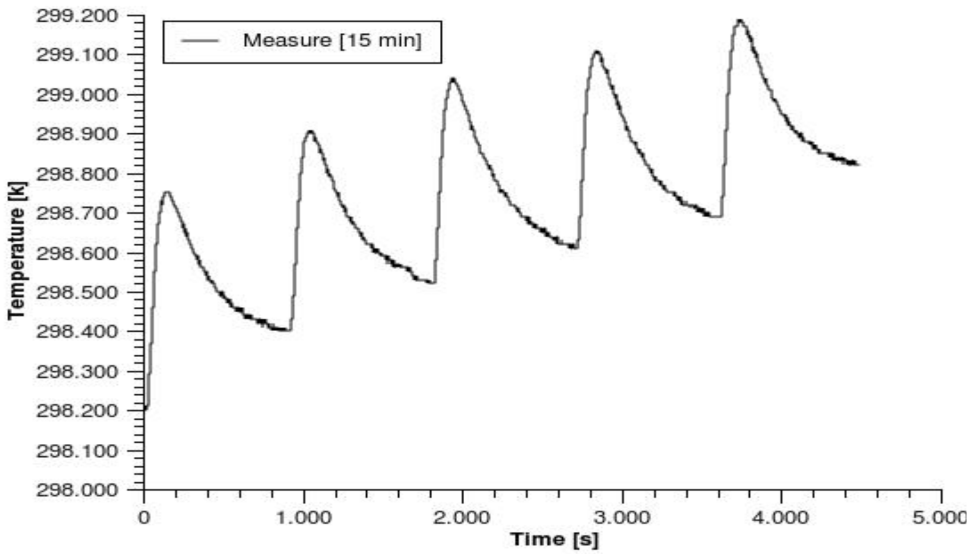

Figure 1. Temperature measured in the sensor for repetitions with 15 minutes interval

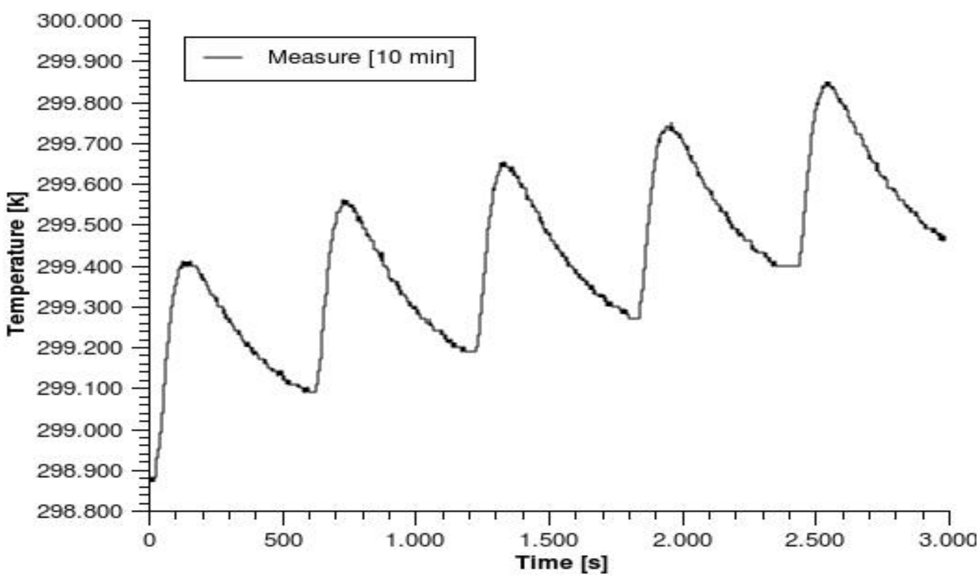

Figure 2. Temperature measured in the sensor for repetitions with 10 minutes interval

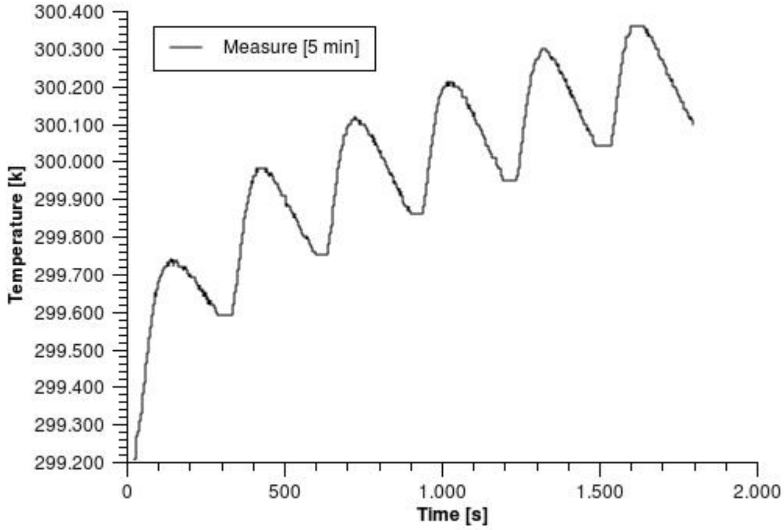

Figure 3. Temperature measured in the sensor for repetitions with 5 minutes interval

In Fig. 4 it is shown the variation of ΔT for the three sampling frequencies, where it is noticed that an error of 0.11° C is observed after 6 measurements with 5 minutes sample interval. Since the full scale value of ΔT is 0.5 ^{o}C, this error represents more than 20% of full scale, making it impossible to use the sensor without a correction mechanism.

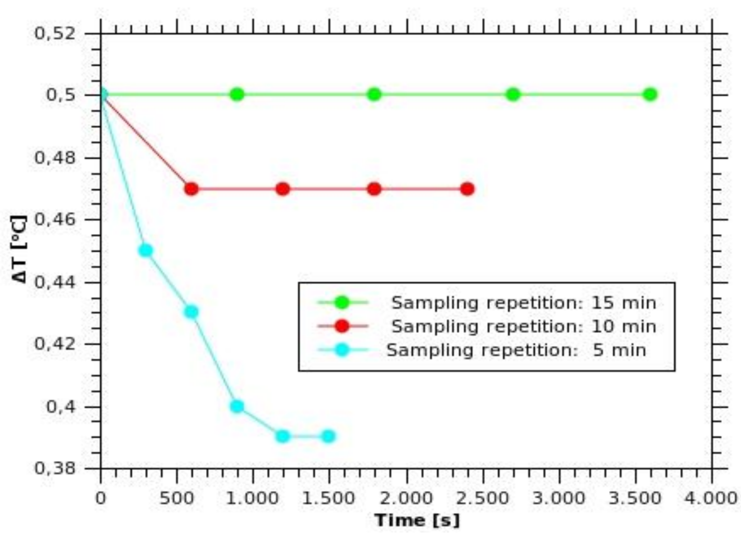

Figure 4. Variation of measured temperature difference ΔT as a function of the time interval between measurements

It was also observed that the drift of the measured values of ΔT also presented a dependence on the soil humidity, as can be seen in the plot shown in Fig. 5.

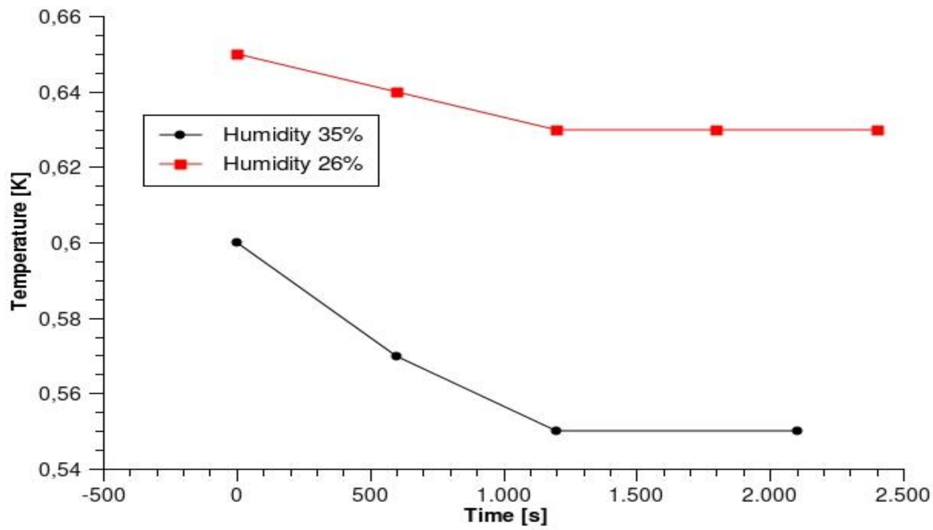

Figure 5. Variation of the measured ΔT for the clay loam soil as function of the repetition interval, for different soil humidities.

Developing a correction technique for the measured values is very simple, because the data presented the same type of behavior: a saturation after the second "5 minutes repetition", and the first two repetitions showing a linear decay, which depends on the soil humidity. Thus, calculating the slope of the first three measured points and checking the saturation value of the measurements, it is possible to calculate correctly the humidity of the soil.

3.2 Experimental Results Measured in the Clay Sandy Loam Soil

It was noticed that the sensors' sensitivity to repeated measurements in the clay sandy soil was much more intense and extremely dependent on the soil humidity. Therefore, it was necessary to perform more experiments, with several humidity values, from 43% of humidity (saturated) to 10% (dry). The measured results obtained from the characterization are shown in Fig. 6, where the value of ΔT is plotted for various humidity values, as a function of the time interval between the measurements. It can be seen that the drift of the measured values for ΔT as a function of the number of repetitions is greater for drier soil conditions. This was expected since in sandy and dry soils the water can move away from the sensor vicinity with the application of the heat pulses.

It is very important to notice that for humidities between 19% and 34%, which is the most interesting range for agricultural applications, the slope of the curve *ΔT x 5 minutes repetitions sampling* is practically constant (0.0125 ^{o}C per repetition with 5 minutes interval), allowing to elaborate a compensation curve for the sensor readings.

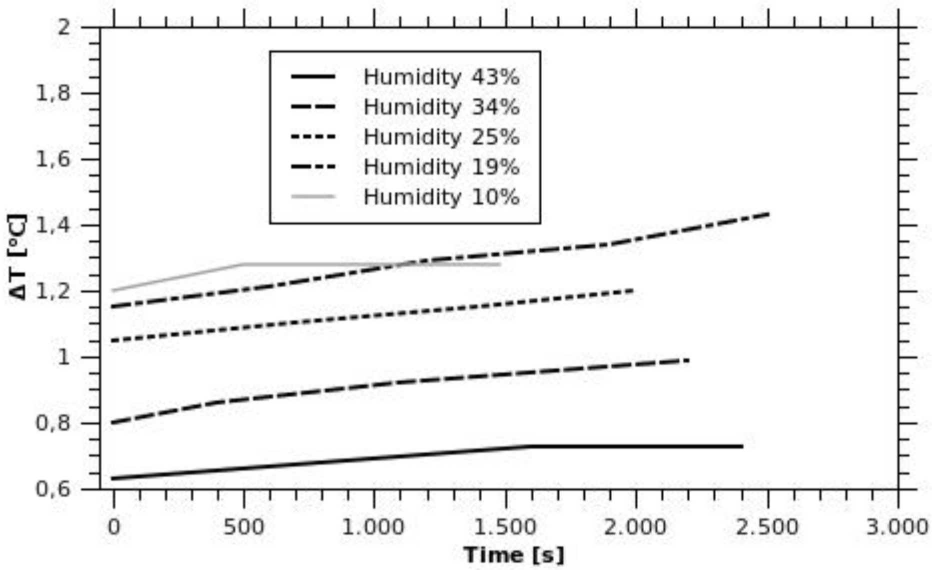

Figure 6. Variation of the measured ΔT for the sandy clay loam soil as function of the repetition interval, for different soil humidities.

Thus, a simple linear compensation equation can be written to correct for the repetitions errors. This equation, for 5 minutes repetition interval, is given by:

$$\Delta T = \Delta T_{measured} - 0.125 \cdot N_i \quad \text{(Eq. 1)}$$

where:

- $\Delta T_{measured}$ is the value of ΔT measured by the A/D converter circuit in the sensor, compensated value to be used to obtain the humidity value;
- N_i is an integer equal to the repetition number ($1 \leq N_i \leq 8$);
- ΔT is the compensated value of the temperature difference, which must be used to obtain the humidity of the soil.

4. CONCLUSIONS

A dual probe heat dissipation sensor was fabricated and characterized using two soils: a clay loam and a sandy loam. The experimental set-up was controlled by a PC running a LabView software, which was responsible for the data acquisition.

The temperature was measured using an AD590 integrated circuit, which together with the instrumentation used, resulted in a 0.01 ^{o}C error in the measured ΔT, which represents a 2% error in the humidity value.

It was observed that the measurand (temperature difference) used to obtain the values of soil humidity presents a large drift when the sampling frequency of the measurements are smaller than 15 minutes. Each soil presented a different behavior, and a custom compensation technique must be employed for each type of soil.

The measured data obtained for both soils at different humidity levels allowed to develop a technique for correction of the inherent error of the measurement technique. The correction technique can be easily implemented using a microcontroller IC, included in the sensor electronic circuit. In the clay loam soil it is necessary to write a look-up table in the microcontroller, since a more elaborated mathematical processing is required. In the case of clay sandy soil, a simple linear equation can be programmed in the microcontroller, resulting in a very effective error correction for the 19% - 34% humidity range.
The increase of ΔT with frequent repetition, as measured in the clay sandy soil, can be easily explained by the expected migration of water in the vicinity of the probes (due to the heat pulse). However, the decrease of the measured ΔT with frequent sampling, observed in the clay loam soil, is reported for the first time in the literature, to best knowledge of the authors, and needs to be studied with more detail in order to explain the physical phenomena which is involved and causes this unexpected behavior.

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