Practical Study of the Temperature Effect in Soil Moisture Measurements

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***Abstract*—Precision agriculture is a current tendency whose goal is to increase the crop production while reducing the water and fertilization use. The use of low cost sensors and Wireless Sensor Networks (WSNs) are frequently used to implement complex systems to control the irrigation process in crops. Taking into account the importance of developing these low cost systems, in this paper we present a practical study that compares a commercial soil moisture sensor with the prototype of our inductive soil moisture sensor, which is based on two solenoid coils. Additionally, we measure its performance as a function of the soil temperature to quantify the effect of this parameter in the sensor measurements. The results show that the temperature greatly affects the sensors measurements and, although our sensor could be used to measure the soil moisture as a function of the temperature, the configuration of two solenoids is not the most suitable to perform this kind of measurements.**

Keywords-Inductive sensor; temperature; moisture sensor; wireless sensor networks (WSNs); inductive sensors; water consumption saving.

I. INTRODUCTION

In the last years, the use of sensors in agriculture has experienced a very important growth. Its use has allowed to develop more efficient and precise methods of cultivating. Precision Agriculture is related to the use of technologies (remote sensing, sensors, irrigation strategies, etc.) to enhance the production of the crops and reduce the use of water and fertilizers [1].

The reduction of water usage in agriculture is an important challenge to ensure food security and water resource in the future. Currently, it is estimated that 70% of the water extracted in the world is intended for agriculture. Nowadays, there are different investigations related to the development of water saving techniques since it is foreseeable that the Global Warming will reduce the available water. For this reason, future irrigation systems should be based on the use of moisture sensors and the development of new and more efficient irrigation strategies. Irrigation strategies consist of an improvement in irrigation systems, i.e., the use of drip irrigation instead of flood or sprinkler. It is also interesting to reduce the amount of water in the soil to avoid percolation losses. These are not unique. Any technique and method to control the use of water will help to increase the production of crops. An example of applying new irrigation techniques can be found in the strawberry crop where the application of an irrigation threshold of about -10 kPa, inside the range from -8 kPa to -35 kPa seems to have better results in production and benefits while reducing the water usage [2].

The irrigation strategies are complemented by using different sensors. Many authors propose the use of moisture sensors for controlling the irrigation. An interesting idea to combat the problems in irrigation is to combine the values of soil moisture with environmental parameters such as rain, wind, light or photographic analysis, among others, for calculating the evapotranspiration or detecting disease in plants. For example, Parra et al. [3] propose the use of sensors to monitor water quality, soil moisture, and meteorology. Their system estimates the irrigation needs of citrus plots considering the status of soil and the historic data of measurements.

In regards to soil moisture sensors, we can mainly find two different models, i.e., sensors based on Capacity, Frequency Domain Reflectometry (FDR) and Time Domain Reflectometry (TDR). FDR sensors are based on the measurement of the working frequency of an oscillating circuit. TDR sensors are based on the echo measurement of an electrical signal sent through a material with water. FDR sensors are cheaper than TDR sensors. However, TDRs do not need new calibrations for different soils and it is more precise.

Another method to measure the soil moisture is the use of inductive sensors [4], which have the advantage of not being in contact with the soil, compared to the traditional ones, such as FDR and TDR sensors that must be completely in contact with the ground. The contact of metallic parts of sensors with the ground usually generates problems of corrosion and wrong reading of sensor measurements. The inductive sensors are based on a primary coil that generates a magnetic field which induces a current in the secondary coil. One of the main gaps of this type of sensor is that they are not widely developed. The effects of the temperature, the type of salts or other parameters have not been studied.

This paper presents a practical study to quantify the effect of the temperature in the inductive sensors for monitoring the soil moisture. We test your own prototype based on two coils compared to a commercial sensor. To measure the soil moisture, we measure the induced current which depends on the environment where it is. Finally, the results are related to the soil temperature.

The rest of the paper is structured as follows. Section 2 shows different papers related to our work. The proposed system is detailed in Section 3. Section 4 describes the communication protocol used to transmit the data between nodes and the algorithm that controls the message exchanges. The obtained results are presented in Section 6. Finally, Section 7 summarizes the conclusion and future work.

II. RELATED WORKS

This section analyzes different papers related to the use of moisture sensors for irrigation crops and gardens.

Haley and Dukes [5] study the water usage in controllers of gardens in four different scenarios, i.e., (1) soil moisture sensor with an automatic controller that does not initiate the irrigation if the volume of water in the soil is over 10%, (2) rain sensor and educational materials with an automatic timer, (3) rain sensor with automatic timer, which stops the system after 6 mm of rainfall, and (4) automatic timer only, which is typical for the region under study. Their results show that the system that reduces the water usage is the moisture sensor with the automatic timer irrigation (scenario 1). In addition, the use of education material (scenario 3) initially reduces the use of water. However, the water consumption increases as a function of the time.

Buttaro et al. [6] study the effect of the irrigation in tomatoes and cucumbers in the cycles of fall-winter and spring-summer. Author use tensiometers to assign the values of water in the soil and analyze two set points, tomatoes in -100 hPa and -400 hPa and Cucumber in -100 hPa and -300 hPa. In the fall-winter cycle, the tomatoes are not affected by the low irrigation while cucumber present a reduction of 8% in the production. In the spring-summer cycle, the cucumbers do not present difference between the two points. However, the tomatoes present a reduction of 40% of production. So, the use of tensiometers with the knowledge of the effect of poor irrigation could be used to reduce the use of water without affecting production.

Kizito et al. [7] study the use of capacity sensors for measuring the moisture and electrical conductivity of soil. To perform the experiments, authors use the ECH2O sensor in the working frequency range from 5 MHz to 150 MHz. Results show that the sensor, working at 70 MHz, could be used in different mineral soils independently to the soil conductivity. However, it is required a specific calibration to measure the conductivity while temperature has low effect on the values of conductivity and moisture thanks to the internal sensor compensation.

Nevertheless, Varble and Chávez [8] compare three sensors (CS616/625, TDT, and 5TE) to measure the permeability of an environment for monitoring the water content. The results show big fluctuations due to temperature, soil texture and conductivity. Moreover, Mittelbach et al. [9] compare three low cost moisture sensors (two of them based on FDR sensors and a capacitive sensor) and a high-accuracy moisture sensor (based on TDR sensor) to see the effect of temperature and the drift over the measurements. The results show that the low cost sensors require a correction to compensate the temperature effect and specific calibration that the TDR sensor does not need.

Nolz et al. [10] compare the use of moisture soil sensor with the soil matrix potential sensors in a vineyard. According to the authors' conclusions, the moisture soil sensor presents faster response to the water evolution and it does not require calibration. Meanwhile, the matrix potential sensor shows the contrary behavior. However, the matrix potential sensors present absolute values. Authors propose the use of the two sensors for obtaining better results during the irrigation monitoring.

Cardell-Oliver et al. [11] describe a wireless sensor network for measuring the soil moisture with a reactive and more robust network. They used Decagon Echo-20 dielectric sensors to measure the soil moisture and a Decagon Echo rain to detect the rain. The objective of this paper is to calculate the evolution of soil moisture. For this reason, the time between measurements changes according to the detected rainfall by the rain sensor. In dry weather, the evolution of water in the soil does not present big variation. With this system, the hydraulic recharge of aquifers and water transport in a field can be estimated the hydraulic recharge of aquifers and water transport in a field

Now, the moisture sensors have an important paper in the reduction of water use in agriculture. The sensors based on capacitive or FDR are the less expensive devices than the TDR ones. Nonetheless, capacitive and FDR sensors are affected by temperature. Therefore, they need to be corrected with a temperature sensor for the correct monitoring of soil moisture. Moreover, they need to be calibrated for the different sort of soil. On the other hand, the TDR are more robust and do not need specific calibration. However, TDR is more expensive than FDR and capacitive sensors. The matrix water sensors are another alternative. However, this type of sensor has high costs and do not provide a rapid response to changes in soil moisture. The sensor presented in this work is cheap and the effect of temperature in the measures is low. This allows the reduction of costs in the deployment of the system in great extensions.

III. SYSTEM DESCRIPTIONS

This section presents the scenario and the architecture proposed in this work. This work is developed in a natural environment where elements like vegetation and orography can influence communications between sensors and all nodes included in the architecture. This architecture will combine sensing devices, communication nodes, and a gateway.

The architecture must be able to collect all data provided by the sensors, to communicate it in a reliable way and to connect to the Internet. Data must be sent from the different sensing devices along the network to reach a Base Station (BS) that works as a Gateway and will be connected to the internet via Ethernet. The Base Station will upload all the data received to a database located on the Internet. The information stored on the Data Base (DB) will be studied and used to extract conclusions about the use of this type of sensors.

Figure 1 shows the architecture of the proposal. It is a Wi-Fi network composed of different Internet of Things (IoT) networks, each one connected to a single BS. On each IoT Network several sensing devices will communicate all his information to a Network Head (NH) that will communicate with the BS. The BS will upload the information to a DB located on the Internet. The information will be uploaded to the DB depending on where the information arrived from.

The sensor modules are divided into two parts, the humidity sensor and the communication module. The humidity sensor is underground, and the communication module is outdoors. Both parts are connected by a wire in order to send the information from the sensor to de communication module. The communication module is an Arduino Wi-Fi module. This module will be programmed in order to read the sensor value and send it to the NH with an Id that relates the sensor value with the sensor that took the value. That Id will permit separate the information to upload it to the DB. Figure 2 is an example of how the sensor is used.

As explained before, sensing devices communicate with an NH and it communicates with the BS. This organization results in a star network where the hub is the BS-Gateway. Using this type of network has the advantage that if some Wi-Fi module stops working it will not affect the entire network. All the information will pass across the BS so it must be enough robust to not stop working. The entire network depends on it. Arduino Wi-Fi modules are programmed to establish a Wi-Fi communication with the nearest NH. Once communication is established, the module will be responsible for generating a package for each value that arrives from the sensor. The package will contain a sensor ID, the sensor value and a time stamp. The time stamp is not going to be used in our study but will help to find out if the sensor stopped working at some point. Each package will be sent to the NH.

The Network Head will be located strategically to take advantage of the low Wi-Fi range. NH will be as near as possible to each sensor and also to the BS to ensure good communication. In cases where the distance or the orography can affect to the Wi-Fi range communication, could be possible the necessity to add one more hop to reach the BS. Talking about the function of HN, it only has to receive every package and transmit them. In this proposal, there are not priorities and the most important aspect is not to lose packages so NH will have enough memory to store a large number of packages queued to be sent.

As shown in Figure 3, the proposal implements the BS by using a Raspberry Pi module gateway. The Raspberry Pi must support Wi-Fi and Ethernet. The BS must be able to receive all the information from different NH using Wi-Fi communication. Once the BS has received the information, it must read it and obtain which sensor the information belongs and depending on that the BS will upload the data on the corresponding table of the DB located on the Internet. The Raspberry Pi will be programmed using SQL sentences in order to upload the DB.

In order to obtain enough and different data to be compared and to extract conclusions about how useful our prototype is, different types of sensors will be used in this architecture, the sensor prototype presented in this paper and also different commercial sensors. In addition, they will be located in different types of soil. This variety of sensors and locations where sensors will be makes the amount of data uncertain. It is also possible that the time between measurements could change from each sensor to others depending on the placement of the sensor.

For all these reasons, the BS must be programmed to be able to process a great amount of data. Moreover, in cases when the BS cannot process all the information and upload it to the Internet, it must have an algorithm that when there is an overflow of information not to lose always the information of the same sensors. That will permit to obtain a regular amount of data of all the sensors.

In order to ensure that no information is lost in wired communication, the data will be sent using the TCP protocol. The ACK confirmation will permit to resend lost packets. The database, which has been mentioned throughout the document, will store all the data obtained for each detection device. For each sensor, there will be a different table on the DB in order to save the information separately and to have it easily accessible. The information stored in that DB will be used in next section to analyze it.

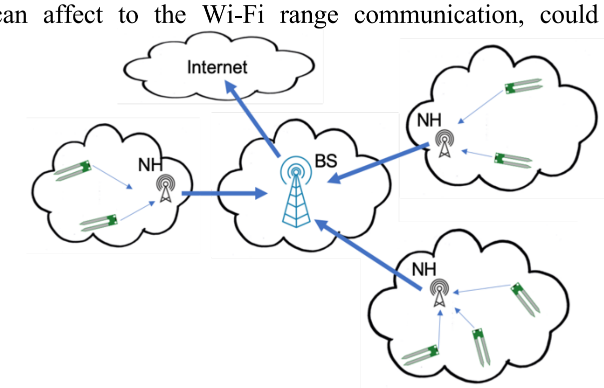

Figure 1. Proposed architecture.

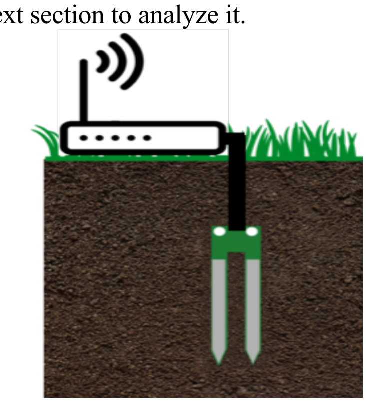

Figure 2. Sensor and Arduino Wi-Fi module

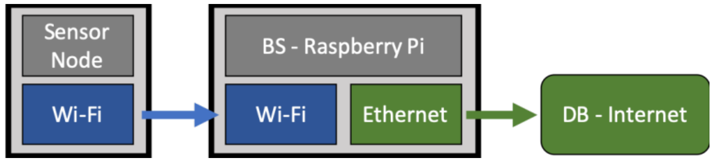

Figure 3. Base Station as Gateway supporting Wi-Fi and Ethernet

IV. PROTOCOL DESCRIPTION

When a new sensor joins the network, it sends a Hello message informing that he wants to join the network. Due to the importance of knowing which sensor is sending the information, all sensors will be programmed with a different ID from the rest, before joining the network. The sensor will include its own ID in the Hello message.

All Network Heads who receive this message will forward it to the BS. When BS receives this message, it will verify if it is the first time this sensor joins the network and, in that case, the BS will create an entry in the DB. BS will respond to the NH with a Hello ACK and the NH will forward it to the sensor.

BS will respond all received Hello messages, even if they are not the first (only one DB entry will be created) due to the possibility of different communication channels. It is the sensor who will finally set the path. The sensor will only accept the first Hello ACK received, learning what NH should communicate. The sensor will send a keep-alive message to this NH and it will forward it to the BS. Now BS also knows what path the sensor will use. The sensor will discard the rest of Hello ACK messages. Once the communication is established, the information exchange is only from sensor to BS. For each data received, the BS updates the DB on the Internet. Figure 4 illustrates how the protocol works.

After the first keepalive message, every data message will also actuate as a keepalive message. In case no data is received in BS for a long time, BS will delete information about path, but not DB information. Because DB information is not deleted, when a sensor wants to join the network for the second time, BS could check that this sensor has already an entry in the DB.

V. ALGORITHM

When sensing devices join the network, they send a Hello Message in order to initiate the connection with the BS. Once the path is set, they begin sending messages. In case of NH, their operation mode consists of forwarding packets between sensing devices and BS, and vice versa. Finally, BS-Gateway operation mode is more complex than other entities operation mode. In this section, we are going to explain the operation algorithm applied in the BS.

After the system starts, it will be receiving messages all the time. Messages can be Hello messages or Data messages. Depending on the type of received message, the BS will actuate in a different way.

When the BS receives a Hello message, it will look at the DB in order to know if it is the first time that the incoming Sensing Device joins the network. The BS will check if this Sensing Device has an entry on the DB. In case of not having an entry, it means that it is the first time that the sensor joins the network, and the BS will create a new table on the DB to store the information of this sensor. BS will always respond to a Hello Message sending a Hello ACK to the sensor through the same path that it arrived from.

In case BS receives a Data Message it will carry out an overflow prevention protocol. Overflow emergency will start with 85% of store occupation. BS keeps track of the number of messages of each sensor that are waiting to be processed. Based on the number of messages the base station will organize the sensors from high to low number of messages waiting to be processed.

In case of an overflow emergency, if the message arrives from a sensor that belongs to the half of the sensors that have more packets waiting, the message will be discarded. If there is no overflow emergency or the message arrives from a sensor that belongs to the half of the sensors that have less packets waiting, BS will put the message in the buffer and will update the count of the number of messages coming from that sensor.

Figure 5 shows the operation algorithm applied when a message arrives to the BS. Once there are packets to be processed, the BS takes the message that first arrived. BS will obtain the Sensor ID from the message and will upload the sensor value to the corresponding table of the DB.

VI. RESULTS

In this section, the results of the aforementioned tests are presented. In order to better understand them, this section is divided into two subsections. The first deals with the results from the first type of soil, the one with 95 % of sand. The results from the soil with 90 % of sand are presented in the second subsection.

A. Results from the first soil

After cooling the soil, with the sensors inside, it reached 1.2 ºC. The soil absorbs heat slower than the air, therefore that temperature is highly probable during the coldest months of the year. Data was collected every 0.1 ºC until the temperature of the soil reached 20 ºC.

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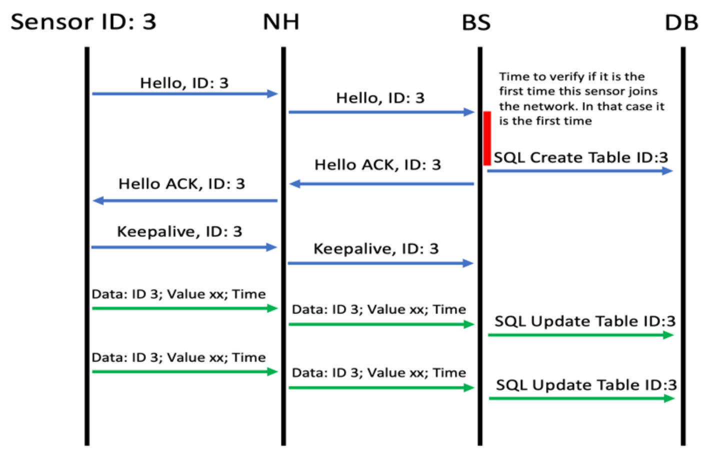

Figure 4. Communication protocol

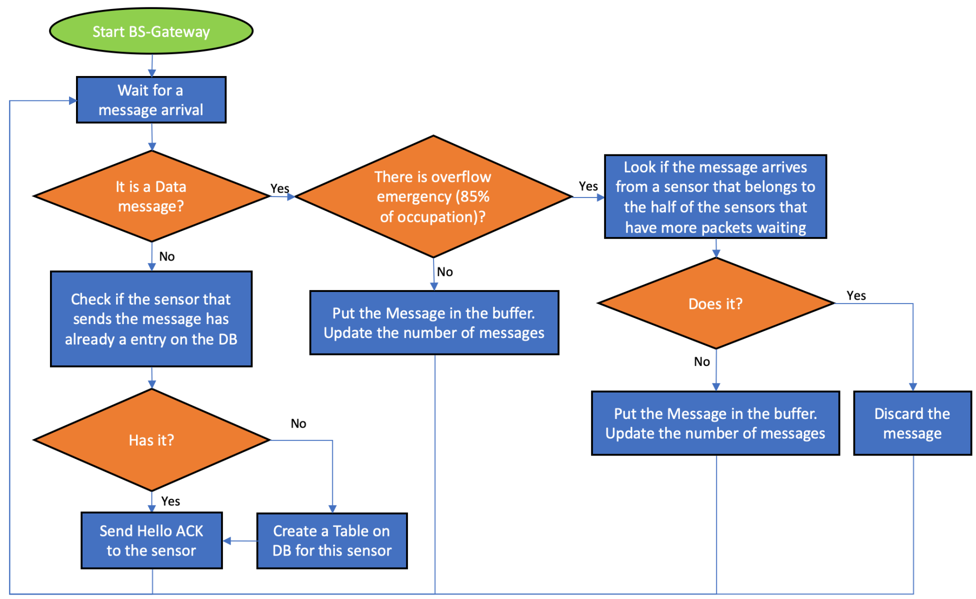

Figure 5. Operation algorithm applied in the BS when a message arrival

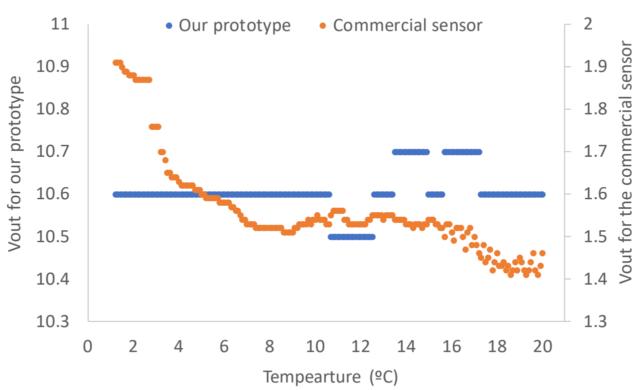

Figure 6. *V*out of both sensors for the first soil form 1.2 ºC to 20 ºC.

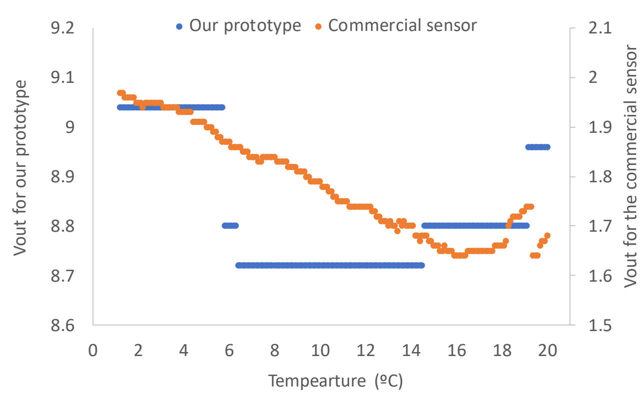

Figure 7. *V*out of both sensors for the second soil form 1.2 ºC to 20 ºC.

The first soil is composed mostly of sand (95%) and has about 45% of soil moisture. For our prototype, the frequency used to measure the Vout is 770 kHz, which is close to the peak frequency. We compare it to the Vout of the commercial sensor.

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The results from both can be seen in Figure 6. In order to compare the variation of each sensor, two axes have been developed. Both of them are divided every 0.1 V in their correspondent Vout range.

As we can see in Figure 6, the difference between the readings of our prototype is 0.1 V and the value of 10.6 is almost constant through all the heating process. The amplitude of the data ranges from 10.7 V to 10.5 V, changing barely 0.2 V. Moreover, most of the readings are the same, 10.6 V. The sensitivity of the device used to measure the Vout, in this case, is 0.1 V, thus explaining the variation between the data. Nevertheless, we can affirm that our prototype gives consistent outputs.

When analyzing the data from the commercial sensor it is obvious that the Vout decreases as the temperature increases. We observe that the changes between each temperature are not as extreme as the ones from our prototype, as seen in Figure 6. Nevertheless, this is probably due to the sensibility of the oscilloscope, as mentioned in the previous paragraph. The amplitude of the data goes from 1.9 V to 1.41 V, changing almost 0.5 V. This variation, as well as the inconsistency of the readings makes, the commercial sensors a poor choice for cultures exposed to temperature changes. First, the readings from the commercial sensor increase and decrease with changes of 0.01 V. Later on, when the temperature of the pot reaches 15 ºC, the changes get bigger and they start to increase and decrease with more frequency than they did before.

Seeing the readings from this type of soil, the commercial sensor is not very promising. The changes from the temperature could very easily interfere with the changes from soil moisture and give false readings. On the contrary, our prototype shows a constant value for the Vout, which only changes 0.1 V on some occasions. Depending on the calibration of the sensor this variation could affect in a greater or smaller way. Nevertheless, most of the readings, including both extremes, gave the same output. A total of 139 out of 188 readings gave as Vout 10.6, which is a 73.94 % of the readings.

B. *Results from the second soil*

As in the experiment done on the first soil, the lowest temperature achieved for this soil was 1.2 ºC. Moreover, it was heated up to 20 ºC as well. This soil, as the first one, is composed mostly of sand. Nevertheless, the percentage of soil composed by said component is 90 %, different from the 95 % of the first soil. It presents a 47% soil moisture, slightly higher than the first soil. The frequency chosen for our prototype is 755 kHz, close to the peak frequency. The readings from our prototype are compared to the readings of the commercial sensor in Figure 7.

We can observe the data represented with a double axis. The axis on the left is for the Vout of the commercial sensor whereas the axis on the right is for the Vout of our prototype. Both show divisions of 0.1 V in the range of each sensor. Our prototype presents bigger differences for this soil. The highest Vout is 9.04 V and the lowest is 8.72 V. The change is of 0.32 V, too big to consider our prototype to be unaffected by the temperature. Moreover, the data shows no consistency in the Vout readings. Both 8.72 V and 8.80 V are the most frequent data with 82 and 52 readings each. They account for 43.61 % and 27.66 % of the readings respectively. Nevertheless, the last data suggest another increase, as seen in Figure 7.

The data from the commercial prototype can be seen in Figure 7. It shows a decrease in the Vout as the temperature increases. Unlike the behavior showed for the first soil, the changes do not get bigger and more frequent after 15 ºC. They do, however, start increasing after 16.5 ºC. At 19.4 ºC the data decreases drastically and starts increasing again. The highest Vout reading for this sensor is 1.97 V and the lowest is 1.64 V. The difference between these readings is of 0.33 V, only 0.01 V bigger than the difference for our sensor. The irregular behavior at higher temperatures makes impossible the modeling of and adjusting equation for the Vout based on the temperature. It is also noted that the sensitivity of the oscilloscope used to measure the Vout of our sensors is of 0.08 V for Vout readings between 1 V and 10 V, which explain the differences between the readings.

VII. CONCLUSION AND FUTURE WORK

Water consumption for agriculture must be efficiently controlled to avoid wasting without reducing the productivity of a crop. To do this, researchers usually use soil moisture sensors. However, their measurements are sometimes affected due to the effect of temperature. Therefore, in this paper, we have performed a practical study to quantify the effect of temperature on soil moisture measurements with inductive sensors. The results have shown that the temperature effect over the soil moisture measurements is quite important and taking into account this data, none of the sensors used for this experiment would be the ideal model for this kind of soil. Nevertheless, it should be noted that a difference of 0.3 V on readings around 9 V is not the same as a difference of 0.3 V on readings around 1.8 V. This change would affect in a greater manner the readings from the commercial sensor.

As future work, we will extend our research by adding group of sensors mechanisms [12] or using clustering techniques [13].

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