A Novel Low-Cost Conductivity Based Soil Moisture Sensor

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Abstract. Water management for irrigation purposes is especially decisive in places prone to droughts because soil moisture sensors are economically unattainable for farmers. The sustainable usage of water should not be restricted by the elevated price of the system. In this paper, we present a low-cost sensor for the monitoring of soil moisture, which can be part of a smart irrigation system. The sensor is composed of two coils, one is powered with alternate current and the other one is used to measure the induced voltage. It is based on conductivity and uses the method of mutual inductance. We study five prototypes, which have different numbers of turns in each coil. We compare them in order to determine the best model. The best sensor is the one that consists of one coil with 40 turns (which is powered) and one with 100 turns (which is induced). The best frequency is 260 kHz, the coil is induced with 10 peak to peak voltage and the induced voltage, which is measured with an oscilloscope, changes with the soil moisture. At this frequency, the sensor presents the biggest difference in volts. The differences are 1.2 V between 0 and 6% of water volume in the soil; 0.8 between 6 and 8% water volume in the soil; and 1.6 V between 8 and 17% of water volume in soil. Considering these differences, we can safely formulate an equation to extract the soil moisture values with high accuracy.

Keywords: Precision agriculture; Solenois; Soil moisture; Conductivity sensor; Water management

1 Introduction

Considering the demand for food, there is an undeniable necessity for monitoring agricultural fields. This necessity is most present in countries and areas prone to droughts, where water is a scarce resource and cannot be wasted. In these places, rather than irrigate the fields periodically, they should be monitored in order to know their water demand to adjust the irrigation. This information should be passed to the farmers, who play a key role in the water management, as Urquijo et al [1] proved.

Nowadays, there are several sensors that monitor the water content on the ground. The most common used method, and the one we will use as well, is through conductivity. It is a reliable method, as Martini et al [2] showed. Most sensors used nowadays are too expensive for local farmers. This neglects them the opportunity to better manage the water.

Other parameters are often monitored in order to manage agricultural fields. Temperature is a key factor that affects both water availability and performance of crops. Some soil moisture sensors include a temperature sensor. The productivity of the crops is affected by the solar radiation they receive, while other important factors are their levels of chlorophyll and nitrogen. Biddoccu et al [3] demonstrated that the monitoring of these parameters is of utmost importance to secure the yield and the integrity of the soil.

The aim of this paper is to design and develop a low-cost conductivity-based soil moisture sensor. The sensor is based on the changes in the dielectric constant of the soil when the water content of the soil changes. The sensing element is composed of two copper coils, one of them is powered and generates a magnetic field. The second one is induced with this field and the induced voltage changes with the value of the dielectric constant of the soil. We test 5 different prototypes, the powered coils were powered with a sine wave of 10V at different frequencies, from 40 to 480 kHz.

The rest of the paper is structured as follows. Section 2 presents how soil moisture has been monitored by other authors. The test bench, including schemes of the sensor and the circuit, is thoroughly explained in Section 3. Section 4 shows the results of the tests that were conducted. Section 5 explains the conclusion and future works.

2 Related Work

In this section, we will discuss other papers that bring up the needs which agriculture presents in terms of water management. Different Wireless Sensor Networks (WSN) will be analyzed as a method for the aforementioned water management. Furthermore, the utility of mutual inductance coil sensors will be proved.

Katsigiannis et al. [4] remarked the importance of monitoring fields in order to keep the crops in top health condition. They developed an autonomous multi-sensor unmanned aerial vehicle imaging system. It was able to process the images it took and determine different parameters, being one of them the water stress.

A WSN which could determine the water needed for a field was developed by Nikolidakis et al. [5]. It used historical data, as well as the change of the climate values, and was completely automatized. Thresholds were set so if the datum did not change greatly from the previous one the sensor did not take another one for a longer period of time. This was done in order to improve the energy consumption of the sensor.

Navarro-Hellín et al. [6] reflected the water consumption for agriculture in areas prone to drought, like Spain. They delved into the developing of a WSN which sends the information to a remote database. Users could access the database using different devices (phones, laptops, tablets…), and their goal was to offer the information everywhere. They used commercial sensors though, which are expensive and unattainable for local farmers.

Ferrández-Pastor et al. [7] showed the efficiency of a Ubiquitous Sensor Network (USN) platform which used the Internet of Things (IoT) in precision agriculture. They discussed the need for a method, which could be less expensive, easier to operate, and uses less energy. They developed one and tested it on hydroponic crop production in a greenhouse, proving important benefits, both economic and ecologic.

The utility of mutual inductance solenoid coil sensors for the detection of conductivity variations was demonstrated by Parra et al. [8]. They tested different prototypes and developed a system to manage groundwater in smart cities. This type of sensors was widely explained in their paper. A similar system, based on other prototypes was proposed in [9].

In this paper, we will try to satisfy the need for an affordable monitoring system for water management in crops. This will be achieved by the design and development of a low-cost sensor which can be integrated into the system proposed in [10]

3 Test bench

The proposed sensor will use conductivity as a mean for determining the soil moisture. We will use mutual inductance to accomplish this purpose. Mutual inductance is based on the principle that when a coil is powered with alternate current it creates a magnetic field. If we put a second coil, the lines of the magnetic field from the first coil go through the second one, generating magnetic flux.

The prototypes will be composed of two copper coils. Depending on the prototype they will have the same or a different number of turns in the powered coils (PCs) and in the induced coils (ICs). These coils should be isolated from the ground. Nevertheless, they will have an empty space inside, so it can be filled with soil. The differences in the soil moisture will alter the dielectric constant of this medium. The sensor must be completely buried in the soil. The casing for the coils will be made of two PVC tubes. The thickness of the outer one will be 1 mm, and the inner one will have a thickness of 3 mm. The diameters of the PVC tubes will be of 25 mm for the inner one, and 30 mm for the outer one. We can observe a diagram of the sensor in Figure 1.

In order to obtain the measures, we will need to set up the oscilloscope model TBS1104 and the wave generator model AFG1022. One of the coils will be powered with a sinus-wave current with a voltage of 10 peak to peak voltage (Vpp) and the positive wire will need a resistance of 47 **Ω**. For the output signal, we will need a capacitor of 10 nF which will be connected to both the positive and the negative wire, see Figure 2.

The first prototype (P1) will have 40 turns on both coils. The second prototype (P2) will have 40 turns on one coil and 80 on the other one. The 40 turns one will be powered meanwhile the 80 turns one will be the one connected to the oscilloscope. The third prototype (P3) will be structured the same way as P2, powering the 80 turns coil instead. The one connected to the oscilloscope will be the 40 turns one. The fourth prototype (P4) will be composed of a 40 turns coil and a 100 turns coil. In a similar way to the P2, the 40 turns coil will be the powered one. The fifth prototype (P5) will be arranged as P4, with a 40 turns coil and a 100 turns coil. The 100 turns coil will be powered while the 40 turns coil will be induced. To better understand these prototypes, see Table 1.

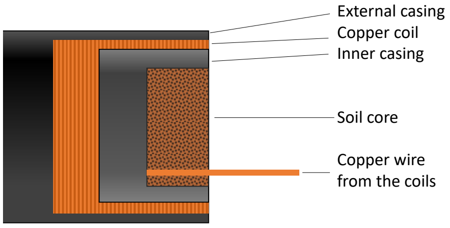

Fig. 1. Diagram of the sensor

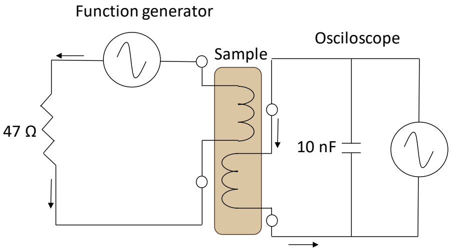

Fig. 2. Electric circuit of the sensor

To determine which sensor works better, five samples of soil, with different volumes of water, will be utilized. Since this goal of the experiment will be to test the utility of this kind of sensors in the soil, we will use a substrate for plants as the soil. The pots will be filled with three liters of the substrate, and water will be added afterward. The pots will be filled with the following volumes, see Table 2.

The range of frequencies in which they will be tested goes from 40 to 500 kHz, the measures will be taken every 40 kHz. We look forward to finding a sensor that has a frequency in which the difference in conductivity is big enough to be of use it for the detection of changes in the soil moisture. We can observe one of the experiments being conducted in Figure 3.

4 Results and discussion

In this section, the test bench results are shown. With the purpose of showing the results in a more polished manner, this section is structured in two sub-sections. The first one deals with the process to choose the most accurate sensor. The second one presents an equation to roughly estimate the soil moisture based on the conductivity detected by the chosen sensor.

4.1 Sensor analysis

In this subsection, we show the results of different prototypes, detailing their working frequency and the Voltage output (Vout) of the induced coil in different cases. Moreover, we discuss the capability of each prototype as a soil moisture sensor.

First, P1 is able to differentiate when there is a quantity of water superior to a value contained between 175 and 250 mL. Nonetheless, we cannot find any frequency in which the differences between different concentrations are significant. P1 reaches its peak voltage at 280 kHz, where the differences between the observed values are higher. We observe values of 17.6 Vpp for 0 mL, 17.4 Vpp for 175 mL, 12.7 Vpp for 250 mL and 12.6 Vpp for 500 mL. Although this prototype shows an interesting difference between 175 mL and 250 mL, it does not show this kind of reaction to other moisture changes; see Figure 5.

Table 1. Characteristics of the prototypes.

Name	Turns PC	Turns IC
P1	40	40
P2	40	80
P3	80	40
P4	40	100
P5	100	40

Table 2. Characteristics of the different pots.

Pot	Water (mL)	Volumetric water content (%)
1	0	0,00 %
2	175	5,83 %
3	250	8,33 %
4	500	16,66 %

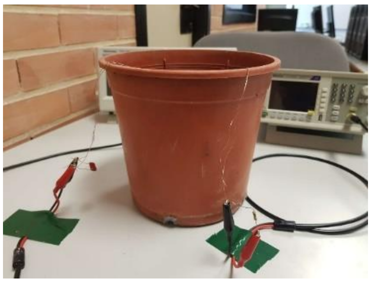

Fig. 3. Pot with the sensor inside, ready for the measures

Secondly, P2 presents a behavior with fewer differences in Vout than P1. The peak frequency for this sensor is found at 160 kHz. This frequency, however, is not appropriate to formulate an equation to determine the concentration. The values observed for this frequency are13.8 Vpp for 0 mL, 14.0 Vpp for 175 mL, 14.0 Vpp for 250 mL and 15.0 Vpp for 500 mL. The voltage difference between the concentrations is too small and would not be useful for the purpose of this paper. Other frequencies are not mentioned due to the small differences they show, see Figure 6.

Subsequently, P3 presents its peak frequency at 280 kHz. Furthermore, the Vout for 240 kHz is high as well. These two high values suggest that there might be a peak between them. That frequency may be the best to determine the equation to calculate soil moisture. The values for 260 kHz will be analyzed and discussed on the next sub-section. As for the Vout values for 280 kHz they are 11.3 Vpp for 0 mL, 11.3 Vpp for 175 mL, 11.0 Vpp for 250 mL and 10.2 Vpp for 500 mL. The differences presented by this frequency are not big enough for the purpose of this paper, see Figure 7.

Next, P4 shows a peak frequency of 160 kHz with small differences between the values of Vout. The Vout this frequency presents are 8.88 Vpp for 0 mL, 8.00 Vpp for 175 mL, 8.72 Vpp for 250 mL and 8.64 Vpp for 500 mL. The data for this frequency shows even differences. However, these differences are too small to develop an accurate equation for the determination of soil moisture. Upon further analysis, we can verify that the Vout is almost the same in most of the points for all the water concentrations, see Figure 8.

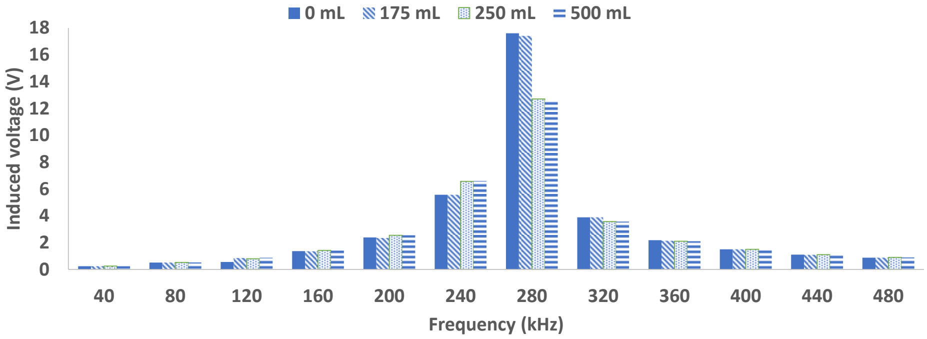

Fig. 5. Results of P1

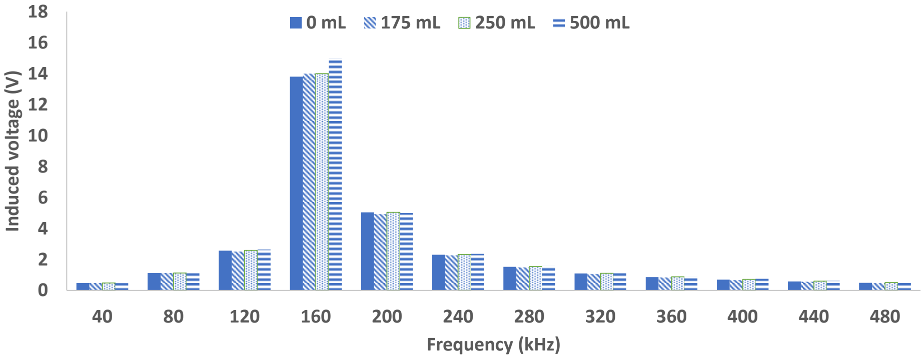

Fig. 6. Results of P2

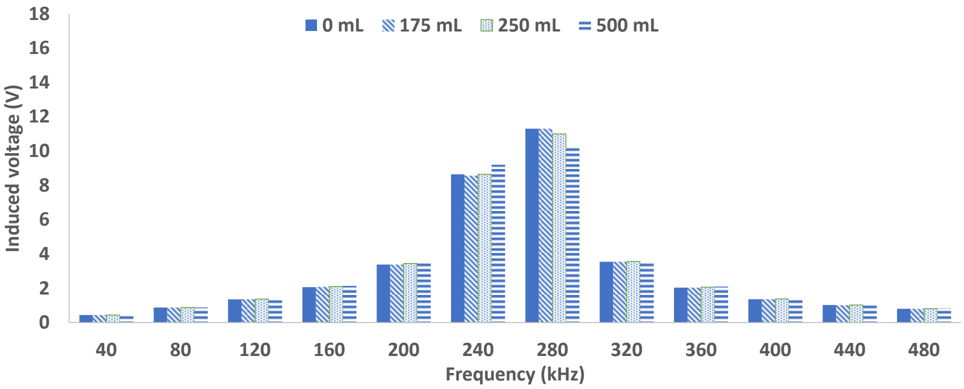

Fig. 7. Results of P3

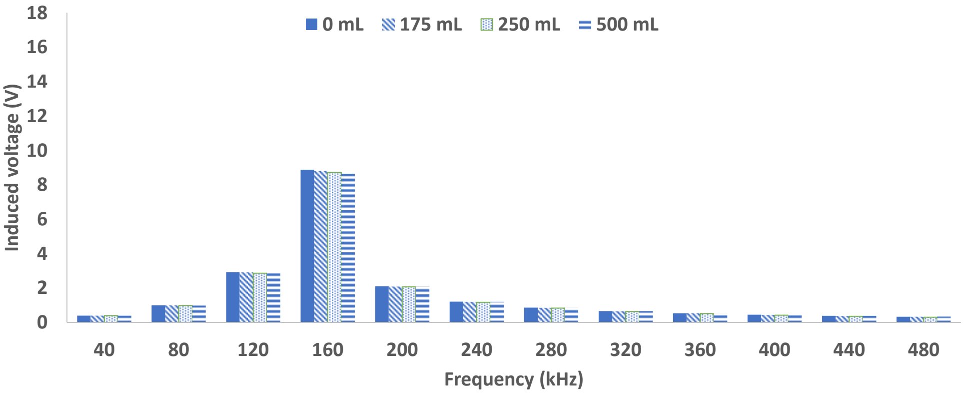

Fig. 8. Results of P4

Lastly, the results of the P5 are inconsistent. The peak frequency is 280 kHz, which presents values of Vpp of 9.68 Vpp for 0 mL, 9.92 Vpp for 175 mL, 9.76 Vpp for 250 mL and 9.44 Vpp for 500 mL. This sensor does not seem fit for the intended purpose, neither powering one coil or the other has proven useful. Most of the results are the same for all the tested concentrations. The ones that are different do not follow a decreasing or increasing trend. Furthermore, they do not show big differences between the values, see Figure 9.

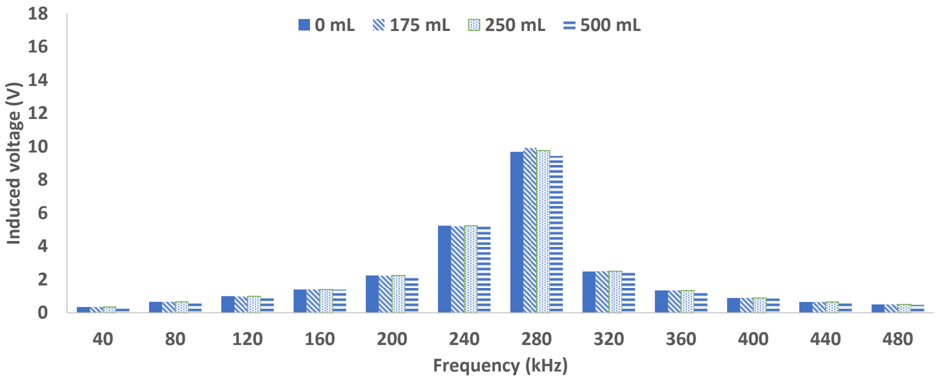

Fig. 9. Results of P5

4.2 Soil moisture equation

In this subsection, we study a wider and more specific range of frequencies for P3. It is done in order to formulate an equation able to determine the soil moisture based on the conductivity.

As shown in Figure 7, the point between 240 and 280 kHz on the P3 should be studied. To do this we tested every 20 kHz between the frequencies of 200 and 320 kHz, see Fig. 10. We assert that 260 kHz is the best frequency to work with. Regarding this data, we can obtain a mathematical model that predicts the values of Voltage according to the water percentage, see Eq (1). Its R2, a statistics parameter that proves the fitness of a tendency line, is equal to 0.9944.

$$\text{Water percentage (\%)} = -21.765 \cdot 4\text{Induced Voltage (V)} + 25.978 \qquad (1)$$

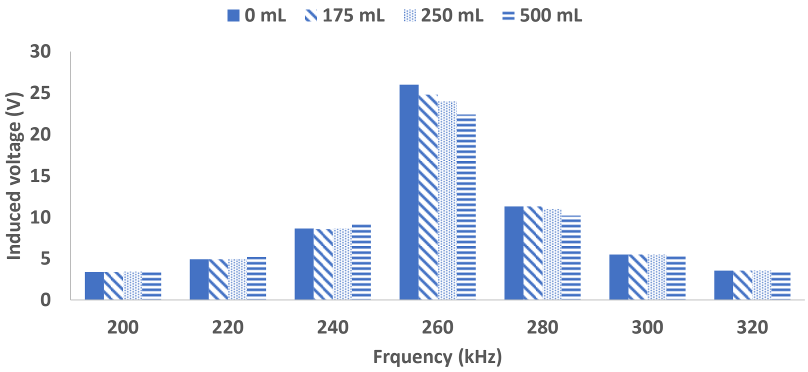

Fig. 10. Best working frequencies of P3

5 Conclusion and future work

The correct management of water resources is a problem that should not be taken lightly, especially in countries that suffer droughts regularly. What we have attempted to achieve is the design and development of a low-cost conductivity-based soil moisture sensor. If this kind of sensors was available for the general public it would benefit not only the farmers, the environment too.

Out of the five sensors that have been tested, one of them presented adequate results for the formulation of an equation. This sensor was the P3 and the most significant differences were found when it is powered at 280 kHz.

As future work, we will polish the equation. This will be accomplished by testing the frequencies from 240 to 280 kHz for P3. Furthermore, we will work with different percentages of water and test other sensors. The sensors that will be tested will have a different number of turns on each coil. Now we plan to add these sensor to a wireless sensor node and program it in order to forward the information to a base station using an efficient routing protocol [11][12][13].

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