Global Science Research Journals

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Research Article Open Access

Global Journal of Agricultural Research and Reviews

ISSN: 2437-1858 Vol. 11 (1). pp. 1-5 June, 2023

Smart irrigation system using a corrosion-resistant polymer-based sensor

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Received: 22-Aug-2023, Manuscript No. GJARR-23-110928; **Editor assigned:** 25-August-2023, Pre QC No. GJARR-23-110928 (PQ); **Reviewed:** 08-Sep-2023, QC No. GJARR-23-110928; **Revised:** 15-Sep-2023, Manuscript No. GJARR-23-110928(R); **Published:** 22-Sep-2023, DOI: 10.15651/2437-1858.23.11.016

ABSTRACT

Several smart and efficient irrigation techniques have been introduced by engineers and researchers over the last few decades. These techniques can be divided into three main categories: Laboratory, *In situ*, and Remote sensing methods. Focusing on the *in situ* moisture sensing methods, in this research we built two smart efficient irrigation systems using two methods where each one is based on a different physical phenomenon. The first phenomenon is the electrical conductivity, where we used two separated probes of conductive materials to measure the conductivity of the soil. Having high conductivity measurements is an indication of high moisture in the soil, and it will direct the irrigation system to stop watering. The effectiveness of this method does not last for long time due to the corrosiveness of the conductive electrodes. The second fundamental physical concept is wireless power transfer. In this method, a novel polymer-based technique is proposed to increase or decrease the distance between power coils and consequently varies the amount of wireless power transfer. The power variations at the receiver end will allow the system to manage the irrigation process. We showed the effectiveness of the wireless method compared to the conductivity measurement method and we introduced a new technique to manipulate the wireless power transfer using soil moisture.

Keywords: Irrigation, Soil moisture, Electrical conductivity, Wireless power transfer, Resizable polymer

INTRODUCTION

Water is a key factor in crop production. Optimum soil moisture is essential for effective agricultural processes. Hence, several soil moisture measuring methodologies have been proposed by researchers in the literature. These soil moisture-sensing techniques classified into three categories: Laboratory, *in situ*, and remote sensing methods (Kashyap and Ratnesh, 2021). In this research work, we are focusing on the *in situ* or at-site soil moisture sensing methods where the measuring instrument is taken in the field and is placed in direct contact with the soil medium. The *in situ* methods can provide point-based real time moisture measurements with high resolution.

These measurements are particularly useful for agricultural applications since the used measuring instruments are easier to calibrate, control, and more accessible to farmers. Some of the presented at-site soil moisture sensors in the literature are tensiometer sensor (Leib et al., 2003), gypsum block sensor (Muñoz-Carpena, 2004), single-probe heat sensor (Dias et al., 2013), dual-probe heat sensor (Giovanni, 2017), multi-probheat sensor (de Morais et al., 2018), neutron probe sensor (Berrueta et al., 2023), time-domain reflectometry sensor (Skierucha et al., 2012), impedance-based sensor (Gunjan et al., 2014), and capacitance-based sensor (Kojima et al., 2016).

In general, Impedance and capacitance-based soil moisture sensors require using conductive materials, which are highly corrosive. After a while, the conductive materials will lose their conductivity and the sensor will give false readings to the system, which results in wrong reactions during the watering periods. Some of the sensors can hardly last for a day where the metal will no longer be on the sensor, but it will be dissolved in the soil.

To overcome this problem, many solutions were proposed in the literature. One of the common solutions is through replacing metal rods with graphite plates which are not corrosive like metals but still very conductive (Surya et al., 2020; Yao et al., 2011; Palaparthy et al., 2018; Kalita et al., 2016; Arvas et al., 2019). In this paper, we first used the traditional impedance-based sensing method using metal electrodes. After many attempts in the laboratory, we found a novel alternative sensing method that can be used to sense the amount of water in the soil without any direct contact between the sensor plates and the wet soil. This innovative method is based on the concept of wireless power transfer. The initial results were impressive and showed that this method is more robust and effective than the traditional voltage difference method.

MATERIALS AND METHODS

This research relies on two fundamental concepts: electrical conductivity and wireless power transfer. Electrical conductivity is a material property that shows the material's ability to carry an electrical current. The conductivity of pure elements like metals can vary by manipulating temperature or pressure. In case of having a mixture of impure substances like soil, the conductivity can mainly change due to salt concentration and soil moisture. In agriculture, the most common unit used to measure Electrical Conductivity (EC) is Deci Siemens per meter (dS/m). The EC of soil (ECs), can be calculated using the following equation:

$$EC_s = EC_w \times \alpha \quad ....(1)$$

Where EC_w is the EC of the irrigation water and α is a constant between 1.3 and 1.5 depending on the soil texture (Brevik et al., 2006).

The second fundamental principal used in this project is the wireless power transfer. This technology permits the transmission of electric energy through an isolation gap, usually air. In this wireless system, a transmitter device generates an alternative electromagnetic field. The generated field transmits power through space to a receiver. Then, the received power will be supplied to an electrical load. Increasing mobility, convenience, and safety of electronic devices are some advantages of wireless power transfer (Beeby et al., 2023). One of the most popular applications of this technology is wireless power charging of electronic devices like smartphones. The efficiency of the wireless power transfer between the Transmitter (Tx) and the Receiver (Rx) was well formulated as:

$$\frac{P_r}{P_t} = \frac{G_t G_r}{\left(\frac{4\pi R}{\lambda}\right)^2} \quad ....(2)$$

Where, P_r is the received power at R_x, P_t is the transmitted power at T_x, G_r is the antenna gain of R_x, Gt is the antenna gain of T_x, R is the distance between T_x and R_x, and λ is the wavelength in free space (Friis, 1946).

As discussed in the theory, two different moisture sensing methods were proposed and implemented in this research: the corrosive conductive method and the anti-corrosive wireless method. Using two conductive electrodes immersed in soil, we measured the current transfer between the two rods to control the operation of the watering valve. In this method, we used copper, stainless iron, silver and aluminum as conductive materials for the electrodes. One of the electrodes is exposed to a voltage of 5 volts and then placed in the soil. The second electrode is immersed 10 cm away from the first and connected to a controller. When there is enough moisture in the soil, water and salt will allow the current to pass through the soil and connect the two electrodes. The controller is used to analyze the received electrode signals and then send the correct order of opening or closing to the watering valve. As shown in Figure 1, we utilized an Arduino UNO microcontroller, a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) (K4019), and four resistors (220 KΩ, 10 KΩ, 5 KΩ, 1 KΩ).

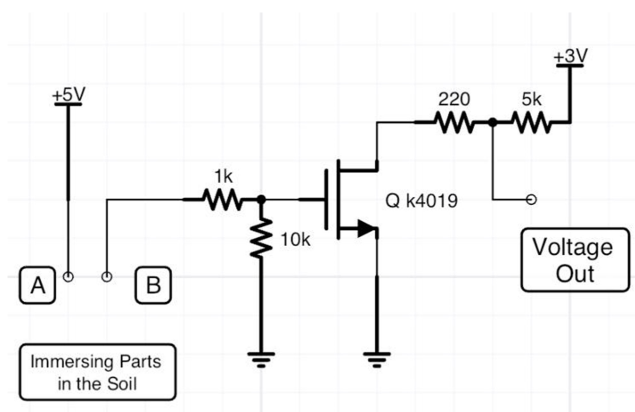

Figure 1: Circuit diagram of the impedance-based soil moisture sensor.

While in the first method conductor rods were used, in the second method non-conductive coils were used as the sensing material. Like the previous circuit, the emitter is exposed to a voltage of 5 volts and the receiver is linked to a microcontroller system. In this method, a polymer material is placed between the receiver and the transmitter. This polymer expands and increases in size if it is exposed to moisture and decreases in size if it dries. After plant watering, soil moisture stimulates the polymer material to expand. Then, the separation distance between the emitter and the receiver devices increases, and the amount of transferred power will be different. At that point, the controller will distinguish the signal difference and it will open or close the watering valve. The whole sensor setup is placed inside a metal or plastic cage covered with a porous cloth to allow water penetration without dust. The setup and operation of this sensor are shown in Figure 2 and 3.

RESULTS AND DISCUSSION

As discussed in the previous section, we used copper, stainless iron, silver and aluminum electrodes in the impedance-based method. For all types of probes, the applied voltage was 5 volts. We measured the resistance and the current transfer between the electrodes at the starting time of the experiment and after 3 days. The results are shown in Table 1.

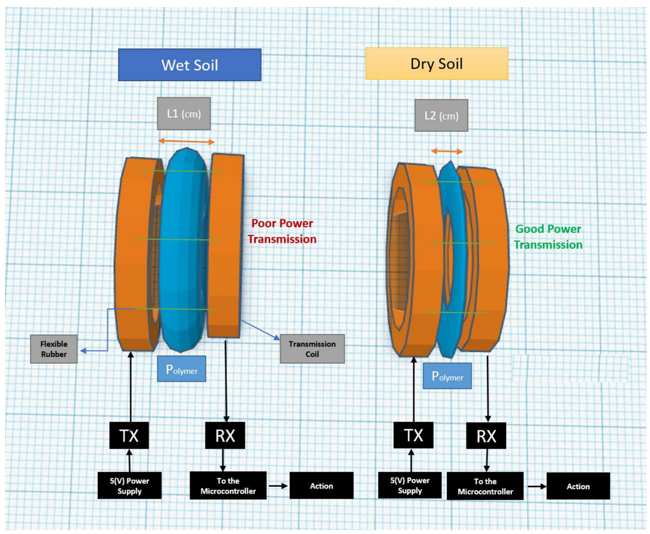

Figure 2: The 3D diagram illustarting the setup and operation of the polymer-based sensor. **Note:** Tx-Wireless Transmitter; Rx-Wireless Receiver.

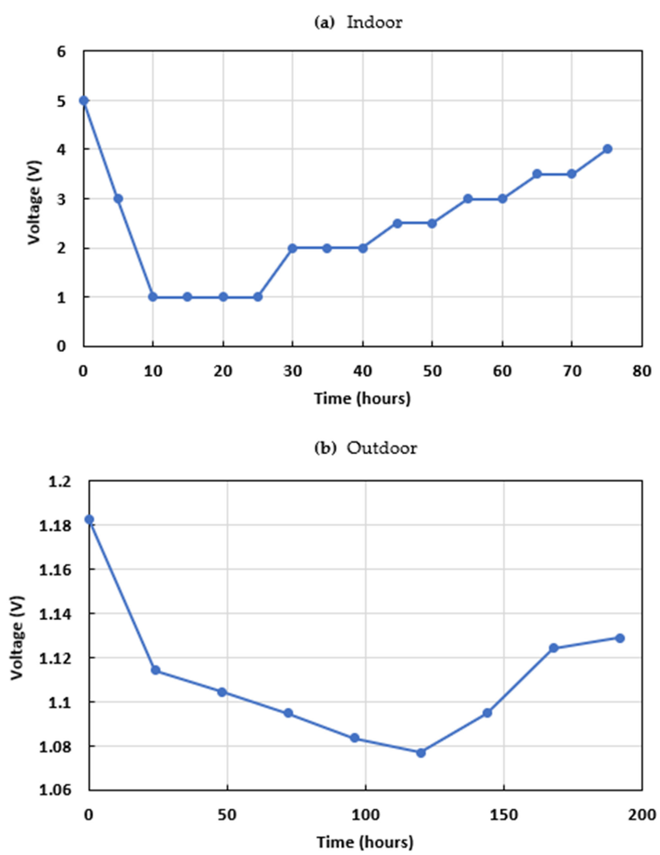

Figure 3: Voltage readings at Receiver (Rx) after watering **Note:** a) Indoor; b) Outdoor.

Table 1: Resistance and current transfer measurements between two electrodes made of different type of metals at the starting time of the experiment and after 3 days while applying 5 volts across the probes.

Types of metals	Electrode voltage difference (V)	Starting resistance Ω)	Resistance after 3 days (Ω)	Starting current transfer (uA)	Current after 3 days (uA)
Brass	5	0.9	1.6	57.18	14.57
Aluminum	5	13.1	339.3	57.77	12.04
Stainless steel	5	1.5	41900	57.81	26.19
Silver	5	1.2	124	54.22	13.15

In the second method, we used a transmitter coil, a receiver coil, and a polymer in between for sensing the soil moisture. The voltage at the receiver end will be different if we vary the distance between the coils. As illustrated in materials and methods, distance variation naturally occurs due to having the resizable polymer which is sensitive to any moisture in soil. Figure 3 shows two plots demonstrating voltage measurements at the receiver coil after watering the plant. The readings of the first plot were measured indoor while the readings of the second one were taken outdoor. However, both plots exhibit an overall increase in the voltage readings when the soil becomes drier.

CONCLUSION

We actively explored two different methods for smart water irrigation systems for indoor and outdoor applications. Both methods showed promising results. However, the introduced power transfer method showed to be more robust than the traditional impedance-based technique, which is not reliable after a while due to the corrosion build up on the conductive electrodes. After demonstrating the proof-of-concept, we characterized a new polymer-based sensor by taking voltage readings of the indoor and outdoor plants. The results showed the effectiveness of this methodology for measuring soil moisture and managing the irrigation system.

ACKNOWLEDGMENTS

This research was funded by the Deanship of Scientific Research (DSR) at King Faisal University in Saudi Arabia, grant number INST138. The authors would like to thank the Deanship of Scientific Research (DSR) at King Faisal University for their support.

CONFLICT OF INTEREST

No conflict of interest.

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