Smart Irrigation Tube: a Wireless System for Water Detection in Precision Agriculture

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***Abstract*- The tubes are the best option for transporting the water in tree fields. However, due to the large size of the tubes networks and the fact that they are under the ground, their control is usually very difficult. In precision agriculture the tubes are used for irrigation. For this reason, the use of wireless sensor networks (WSNs) is a good option for monitoring the water network. In this paper we present a system for monitoring the soil humidity content and the tubes conditions. The presented system is able to monitor the tubes state and humidity content in the ground. This system is based on a commercial humidity sensor and a new sensor for tubes monitoring. The tube sensor is composed by two coils. A coil is powered by an alternate current which induces a current, as a function of the medium, in the other coil. Our results show that this sensor is able to differentiate between an empty pipe and a pipe filled with water. Any abnormal situation is detected and the system sends an alarm. As a result of our proposal we obtain a Smart Irrigation Tube able to monitor the irrigation needs of an area and to detect any obstruction or breakage in the tubes.**

I. Introduction

Our society needs to transport the water from the rivers, wells, and another source until where it is used. The most important way of transport it is by tubes. The tubes are used in drip irrigation to transport the water until the trees. But the drip tubes can present obstructions or breakages due to its use. In addition, due to the last droughts, the amount of water used in irrigation has to be minimized.

In precision agriculture, it is common to use wireless sensor networks (WSN) for monitoring the plant, soil, and tubes are common. In the last years, use of WSN has had a great grown and it is expected to continue in the future [1].Thanks to WSNs, we can monitoring farming [2], aquaculture [3], the elderly and disabled people [4], etc. To take profit of WSN, we should also consider the use of sensors to obtained data from the environment. We can find many types sensors to monitor turbidity [5], conductivity [6], water level [7], etc.

In this paper, we propose a Smart Irrigation Tube based on a new inductive sensor for determining the content of water in a tube. The sensor is based on two coils which one of them is powered by an alternate current. It causes an induced current in the other coil which generates an electric current. This current depends on the dielectric constant of the environment between the two coils which will be water or air.

The rest of paper is structured as follows; Section 2 presents some approaches that try to measure the content of a pipe. The proposed Smart Irrigation Tube is shown in Section 3. Section 4 details the results of the developed sensor and the network performance. Finally, Section 5 summarizes the conclusion and future work.

II. Related Work

This section presents some sensors focused on determining the water level. As far as we know, there are currently no sensors to monitor the presence of water inside a pipeline. However, there are sensors for monitoring the liquid level in tanks. We are going to show different alternatives to measure liquid levels.

Chetpattananondh et al. [7] showed a low cost capacitive sensor for water level measurement in the range of 0 to 30 cm with a resolution of 0.2 cm. Authors used a comb electrode of 70–80 mm width, 300 mm height and 1–2 mm spacing between each comb. According to results, this sensor is highly sensitive. It presents good repeatability and a low energy consumption. This sensor is bigger than ours and its size does not allow to be used on pipes.

Miček et al. [8] proposed the measurement of the acoustic signal generated by the water flow for measuring the water level. This system can be used in the natural environment but on pipes, the water flow sound is absorbed by walls of the pipe and many acoustic waves are not generated.

Fisher and Sui [9] proposed the measurement of water level with a system composed of an ultrasonic sensor, a temperature sensor, and a microcontroller. The ultrasonic sensor measures the distance from the sensor to the liquid surface. The temperature sensor is used to compensate the change of acoustic waves. This system cannot be used in our application because the acoustic sensor should be in contact with the water for measuring it.

Li et al. [10] developed a sensor based on fiber optic formed by the integration of an asymmetrical fiber Mach–Zehnder interferometer (aFMZI) with a fiber Bragg grating (FBG). This sensor was able to measure the liquid level (0 to 7.5 cm) and temperature. The sensors' resolution is 0.15 cm in liquid level and 1.01 ºC in temperature. This sensor has a good resolution and work within the range of pipes' diameters we need. However, in our opinion the materials used can suffer a rapid deformation by water force.

To monitor the water on pipes can be used two copper electrodes. When the water surrounds the electrodes, the electrical circuit formed by electrodes will be closed. We cannot apply this method to our system because the wires can get dirty and therefore cannot perform the measurements correctly and because the pipes of drip irrigation can suffer blows by animals, work tools, persons etc. Instead of using electrodes, we use coils which are rigid.

III. Proposal

In this section, we detail the proposed system. The system is composed by a Smart Irrigation Tube which is based on humidity sensors and water content sensors.

Along the tube, we have several nodes. Each node contains the water content detector sensors and the humidity sensor. The node is placed inside a plastic box to avoid damages due to the weather conditions. Inside the plastic box are placed the battery, the node and the connections to the sensors. The plastic box is crossed by the tube, where the water sensor is placed. The boxes are placed over the soil under each tree to avoid damages but ensuring the WiFi signal propagation. The Access Point (AP) is placed in the utensils shed (see Fig. 1). The router used in this case is the WRT320N from Linksys [11] to receive the data from nodes.

To implement each node, we use an Arduino Uno [12] node to gather the data from the two sensors. The node has an ESP8266-ESP01 module, which can work with 802.11 b/g standards. The Arduino is used to feed the sensors and to wirelessly transmit the data to the AP. With the PWM pin we can feed the powered coil. We use the same code and electronic components that were applied in [13]. The sensors and its connections are shown in Fig. 2.

The system is able to detect the water inside the tube and the humidity content in the soil. There is a threshold value for the humidity sensor which can be adapted as afuntion of the tree species. If irrigation is needed, according to the gathered values from the humidity sensor and the lower threshold value, the system starts the irrigation and a message is sent to the water pumping system. When irrigation starts, it is expected that all tubes contain water. To control the irrigation tube, the water sensors start to measure the water presence in the tube. If water is not detected in a tube, the sensor sends an alarm indicating the node identification. The threshold value for the water sensor will be set at the end of the results section. If the data from the water is lower than the set threshold, we assume that the tube is correctly working. Then, the system starts to check the values from humidity sensor to decide when to stop the pumping system. The operation algorithm can be seen in Fig 3.

IV. Results

In this section, we are going to show the results of the analyses of the different prototypes.

To select the best prototype, we tested different combination of coils. We introduce the different coils in a vertical pipe. The coils are made with copper of 0.4 mm Ø. The powered coil is powered by a sine wave which has 4 V of amplitude, at different frequencies (from 1 kHz to 25 MHz). The induced voltage is measured with an oscilloscope. The induced voltage is measured with the empty pipe and with the pipe full of freshwater. The test bench, including the oscilloscope, generator and tube can be seen in Fig. 4.

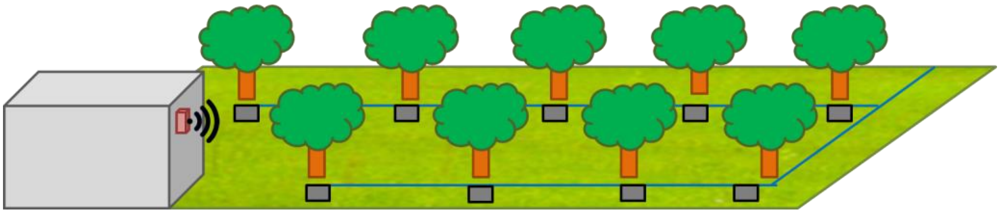


Fig. 1. System deployment in an agricultural field

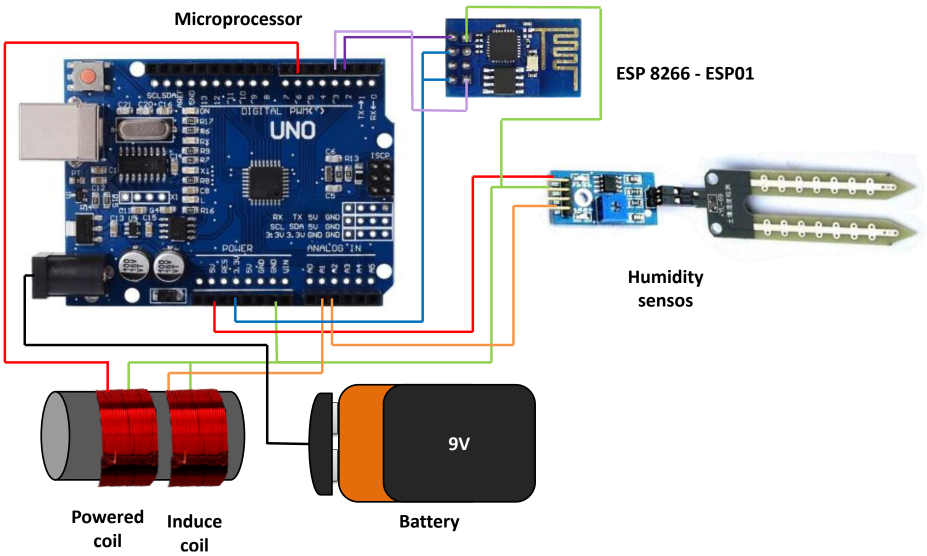


Fig. 2. Connections in the plastic box

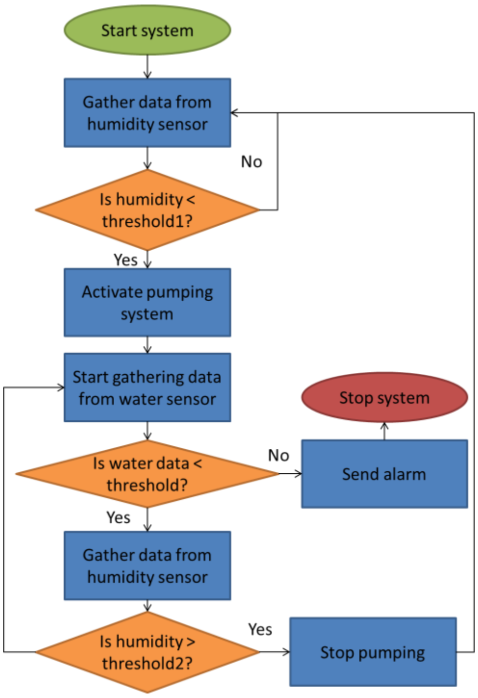


Fig. 3. Operation algorithm

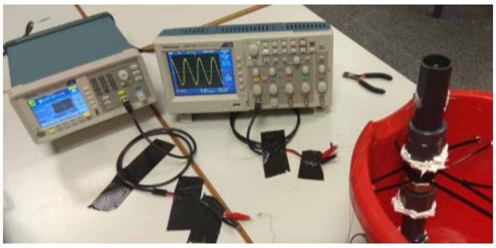


Fig. 4. Test bench for sensor calibration

We test different combinations of coils. In the first test, we use two coils on the PVC pipe. This combination is based on 2 coils with 80 and 40 spires; we powered and measure the induced voltage. First, we powered the coil with 80 spires, and then we measured the induced current in the coil of 40 spires. The maximum voltage difference between induce voltage with empty pipe and pipe with water was registered at 120, 140, and 300 kHz. The difference is of 0.032 V. The difference is very small and indicates that this combination is wrong for our goal.

Another combination was based on a copper coil, coiled over the PVC pipe and a screw going through the pipe. The screw was placed after the coil and between the spires of the coil. We measured the induced voltage in the screw. In this case, no frequency showed a voltage difference big enough to differentiate both cases.

Finally, we tested the last series of prototypes. We coiled the copper wire over on two half-cylinder of a PVC pipe of 20 mm diameter. Prototype 1 (P1) has two coils with 55 spires forming a toroid. Prototype 2 (P2) has two coils forming a toroid; the powered coil has 55 spires and the inductive coil has 30 spires. The prototype 3 (P3) is as P2 changing the induced coil by the powered coil and vice versa. The prototype 4 (P4) has two coils with 55 spires forming a solenoid. Prototype 5 (P5) is formed by two solenoidal coils. The powered coil has 30 spires while the induced coil has 55 spires. Finally, the prototype 6 (P6) is as P5 changing the induce coil by the powered coil and vice versa. Table 1 shows a summary of the prototypes characteristics.

Table 1. Characteristics of prototypes

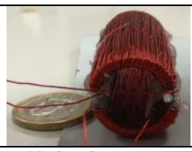
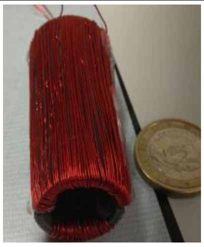
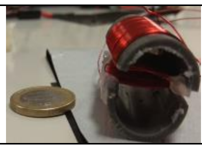
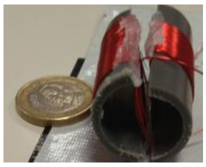
		Powered coil	Induced Coil
P1		Type: Toroid Nº Spires: 55 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm	Type: Toroid Nº Spires: 55 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm
P2		Type: Toroid Nº Spires: 55 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm	Type: Toroid Nº Spires: 30 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm
P3		Type: Toroid Nº Spires: 30 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm	Type: Toroid Nº Spires: 55 High: 48 mm Inner Diam: 18 mm Outer Diam 21 mm
P4		Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm	Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm
P5		Type: solenoid Nº Spires: 30 High: 15 mm Diam: 20 mm	Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm
P6		Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm	Type: solenoid Nº Spires:30 High: 15 mm Diam: 20 mm

Fig. 5 shows the values of induced voltage when the pipe is full and when it is empty. The P4 is the one that presents the biggest voltage difference (1.54 V) between both situations. P5 presents a voltage difference of 0.92 V. Finally, the rest of the prototypes present differences around 0.5 V. We observed that the biggest differences are in prototypes based on the solenoids. Moreover, we can observe that, in exception of P2, the value of induced voltage in air is higher than the value of induced voltage in water.

Once the best combination of coils is determined (P4 has been selected), we perform 3 replicas to check the sensor's reproducibility. The results of the verification tests are shown in Table 2. Table 2 shows the obtained values, the mean and the standard deviation (σ) of the data. We can see that induced voltage in water is the same in the 3 replicas. In case of the air, there is a little dispensation in the 3 replicas. So, we can ensure, the sensor has a good repeatability in measurement. Fig. 6 presents the data from the verification test as means and the confidence intervals. The ANOVA analysis is done with the data from the verification. The result of the ANOVA concludes that the observed differences are statistically significant.

Finally, we show the consumed bandwidth by one node when it is sending data to the AP. The maximum consumed bandwidth in two minutes is less than 7kbps (see Fig. 7). As the consumed bandwidth is low, this allows us to include several nodes in the same field, connected to the same AP. It is not expected problems on the delay or packets loss due to the low bandwidth. However, we can have some network problems because the number of clients that can manage one AP, thus we would use some additional Aps. The router WRT320N has a maximum bandwidth of 54Mbps and a maximum number of clients of 253. Then, the network problems will be caused by the number of clients. We do not expect to include more than 253 nodes in the area covered by the AP. Then, no network problems are expected.

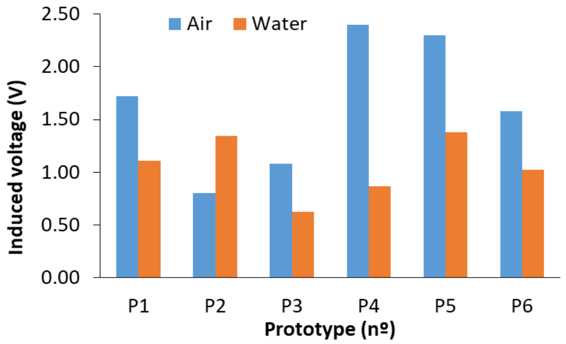


Fig. 5. Induced voltage in prototypes

Table 2. Replicas of P 4 in a frequency of 340 KHz

Replica		1	2	3	Mean	σ
Induced voltage (V)	Air	2.04	2.10	2.12	2.09	0.0416
	Water	0.83	0.83	0.84	0.83	0.0046
	Difference	1.21	1.27	1.28	1.26	

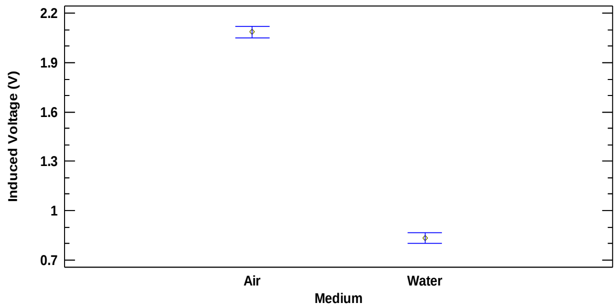


Fig. 6. Data from the verification test

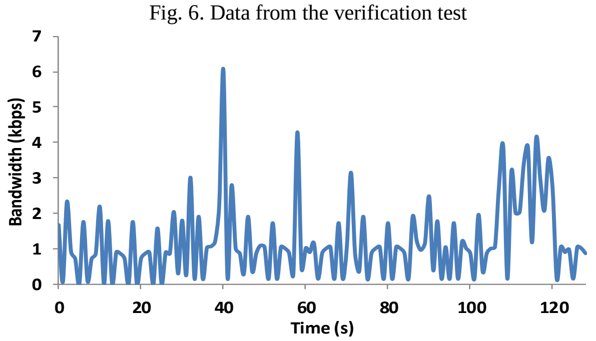


Fig. 7. Consumed Bandwidth by one node

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented a system for detecting the water presence in pipes for smart irrigation. The system is based on two sensors. The humidity soil sensor is a commercial sensor used to determine when the watering is required in an area. Moreover, the sensor is used to control the irrigation process by measuring the humidity value in the soil. The other sensor is a new device able to monitor the water presence in tubes. This sensor is based on two copper coils forming a solenoid. The sensor is able to differentiate between an empty pipe and a pipe filled with water. We use this to detect any obstruction or breakage in the tubes. In case of detecting some problem, the system sends an alarm to the data center. In addition, we have shown the consumed bandwidth by each node when it is sending data.

The prototype that presents better performance is P4 with the biggest difference between empty and full pipes. The statistical analysis also shows very promising results for implementing this intelligent irrigation system.

In future works, we will add others commercial sensors or development others sensors to improve monitoring in the precision farming. In addition we will study the performance of the network when we include several nodes working toghether.

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