Development of Inductive Sensor for Control Gate Opening of an Agricultural Irrigation System

Daniel A. Basterrechea, Javier Rocher, Lorena Parra, Jaime Lloret
Instituto de Investigación para la Gestión Integrada de Zonas Costeras,
Universitat Politècnica de València.
Gandía, Valencia (Spain)
dabasche@epsg.upv.es, jarocmo@doctor.upv.es, loparbo@doctor.upv.es, jlloret@dcom.upv.es.

***Abstract*— The monitoring of water level in the agriculture irrigation channels is essential to control the opening gates of these channels. In this way, WSNs (Wireless Sensor Networks) have high relevance to obtain this kind of data. In this paper, we propose a sensor to measure the depth changes in irrigation channels to control the gates opening. It is connected to an Adafruit Feather HUZZAH based on ESP8266, which allows us to build a mobile edge computing system. The developed sensor is based on two coils. Sinus-wave powers the first one, and the second is induced. The coils are winding over a polyvinyl chloride (PVC) that has high resistance for corrosion and low price. Besides, we use copper wire as a conductive metal. We test two different configurations of coils. P1 has five spires for the powered coil (PC) and ten spires for the induced coil (IC). On the other hand, P2 has 40 spires for the PC and 80 spires for the IC. The two prototypes were coiled in one layer. Then, both sensors are tested using a glass bottle where the water column increased with the target to obtain the information of the depth. In both prototypes, the difference of voltage between the maximum and minimum studied depths is more or less the same, 4.46V for P1 and 4.44V for P2. Nevertheless, during the stabilization test, the P1 showed better adaptation for the turbulences than the P2. The P1 shows an oscillation of 0.48V, where the P2 has a maximum fluctuation of 3.2V.**

Keywords*— *Precision agriculture; inductive coils; level coils.

I. INTRODUCTION

Agriculture is responsible for the production of the food that we consume. This activity has suffered various revolutions due to the demands of increasing food production to feed the population. These revolutions have increased production, but they also increased the adverse effects in the environment. The main are (I) Use of pesticides, (II) Use of excessive fertilizers, (III) Use of a large quantity of water, (IV) Wrong soil tillage. Nevertheless, agriculture has positive effects on the environment and positive ecological impacts on the biodiversity of some animals [1].

Regarding the water, different studies indicate that agriculture uses 70% of the water used in the world and over 40% in many OECD countries [2]. The freshwater is a valuable and limited resource due to its availability. The unsustainable use of groundwater and water bodies united to the decrease of water by global warming endangers food security in the future. Different methodologies have been developed to reduce water use in agriculture. Some of them are: drip irrigation, the use of sensors, reduce the amount of irrigation water, reuse of wastewater, etc. The use of technology, methodology of watering, and study of the variability in crops is englobed in the definition of precision farming.

Precision farming can be defined as the management of variability of crops and animal performance to improve benefits and reduce environmental impacts [2]. Even with the advantages of precision farming, many farmers do not apply it. For fostering precision agriculture, it is essential to transfer this knowledge to farmers and boost their participation. Besides, larger farms are more likely to use new technologies than little farms [4]. It is foreseeable that the increase in food production will be linked with precision farming. Precision farming improves the agriculture in two different ways. First, increasing the sustainability of agriculture by the reduction of environmental impacts,. Second, by lowering costs and increasing revenues. Thus, more significant economic margins are produced. This increase of benefits will help to avoid abandonment of fertile lands as it is happening in many developed countries.

One of the leading technologies used in precision farming is WSN. Nevertheless, The WSNs need improvements in power saving energy and data security [5]. In [6], the authors presented an algorithm for energy-saving and fault tolerance of the WSN for precision farming. The WSNs are composed of a physical sensor that takes the measures, and a microcontroller that controls the physical sensor and transmits the data to an access point or Internet. On the Internet, the data is transmitted to the final user. Another available technology for precision farming is remote sensing. Nonetheless, this has essential gaps that are inhibiting their use. The use of satellite and airplanes have problems with the high cost and the frequency of the obtained data. To solve the problem in the periodicity of the collected data, we can use drones. The drones are cheaper than airplanes or satellites. However, weather conditions and their limited batteries prevent real-time control. Due to the gaps mentioned above, WSNs are the best monitoring option. The use of an inductive sensor has been demonstrated as an alternative for monitoring the conductivity of water. This sensor can be used for detecting irregular values of conductivity, which can be related to the illicit discharge [7]. Nevertheless, as far as we know, the use of the inductive sensor for the monitoring water level in open channels has not been studied.

In this paper, we present a sensor for measuring the water level in the irrigation channel. We use the sensor with valves that will close or open the irrigation canal gates. The actuators will close the gate (in the primary channel) when it is necessary to send water to a secondary channel (highest) and will open it when it is no longer required to carry more water. Besides, the level sensor is used to verify that the water effectively reaches the secondary channel. This sensor is based on two coils. One of the coils generates a magnetic field and the other one is induced. The coils are wired on PVC pipes which provides greater robustness to the sensors. In this way,

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when it is located in the channel, the sensor is not affected by the hitting of sediments or by other animals that can hit it.

The rest of the paper is structured as follows. The related works are presented in Section II. In Section III, we explain the test bench of the experiment. In Section IV, we show the structure for our system and the microcontroller used. The results and discussions are described in Section V. Finally, in Section VI, we explain the main conclusion and future work.

II. Related Work.

In this section, several papers similar to our proposal are analyzed. First, they are discussed and later compared with our solution.

The inductive sensors have been presented previously to monitor the water level. Rocher et al. [8] demonstrate the use of a similar sensor for monitoring water levels inside pipes. In this paper, the authors defend that this sensor can be used for monitoring illegal dumping, obstruction, and leaks in pipes networks. The sensor consists of two coils (PC and IC) coiled over a semi-cylinder of PVC with 20 mm of diameter. They tested different prototypes coiled in various forms and with a different number of spires. They concluded that the prototype with 55 spires in induced and powered coils was the one with the best performance. In this paper, the authors focus their efforts on pipes, and they did not study the use in open channels. The prototypes tested are not suitable for monitoring irrigation channels due to their semicircular shape. These sensors can be easily misadjusted because they have two separate pieces.

Another alternative is the use of video. Tauro et al. [9] proposed the use of large scale particle image velocimetry. This is a methodology for monitoring the surface flow in the environment with extreme floods. They used a GoPro Hero 3 and two green lasers located in a telescopic bar. The GoPro captures the image and, with an algorithm, detect floating elements and estimates the speed of the water in an area according to the position of the floating elements frame to frame. Two lasers are used for calibrating the system with two fixed points. The video analyzers have two critical gaps that make them unsuitable. The computation needs for processing the video is the first one. The second is the need for the water to transport an object. In many cases, the water does not transport any object that can be used for the camera to control the velocity.

Another alternative is presented by Michailovsky et al. [9]. They studied the use of Satellite radar altimetry (obtained to Earth and Planetary Remote Sensing Lab (EAPRS)) for monitoring the surface water in the Zambezi River basin. The objective was to calculate the discharge of the rivers in the basin. They studied three scenarios (I) with an in situ rating curve available, (II) with one simultaneous field measurement of cross-section and discharge, (III) with historical discharge data available. These scenarios have been compared with the values of the real discharge. They obtained that the first method has an error between 4.1 and 6.5 %, while the other methods have an error of 6.9 to 13.8 %. The significant gap in the use of satellite images is the frequency of the obtained data. The satellites have a return time to the same point, which can go from a few weeks to months. This makes them a lousy method for continuous data collection. In addition, the article mentions that due to the resolution of the satellite image, it could not be used in rivers with a width of fewer than 80 m.

The electrical conductivity of the water can be used to evaluate the water level in an area or a tank. Hernández-Nolasco et al. [11] developed a system for floods based on the electrical conductivity of the water. The system consists of a microcontroller Netduino Plus 2 to process and send the information. On the other hand, the sensing part consists of different open circuits that close when the water touches the two ends of the loop. The circuits consist of a copper wire which is in the base and secondary copper wires, which are located at different heights. When any of the circuits closes, it sends the information to an access point, and from this to a computer. If it is necessary, the computer processes the information and sends an alarm to the smartphones of the population. This method can be used in the case we want to set a threshold value. The proposed system only tells us when the water has reached a point. Nevertheless, this system does not give us information about the amount of water between points.

Capacitive sensors are another alternative to measure the water level. Reverter et al. [12] used a capacitive sensor for monitoring the water level in a metallic tank. The sensor has two electrodes, where one is insulated. The water level can be calculated due to the change in the difference between the dielectric value of air and water. This type of sensors is not a solution for open channels. Due to this, we need to place sensors with a height equal to the height we want to control. Besides, the presence of sediments or rocks, which are deposited in the lower parts of the electrode can affect the measurement.

Other types of sensors are based on acoustic or light reflection. These sensors emit light or acoustic waves that are reflected in the surface of the water. However, these methods have problems when they measure in areas with high agitation or with the presence of waves. For solving this problem, Li et al. [13] proposed the use of multiple-input multiple-output ultrasonic transducers. They used them as transmitting elements and as receiving elements. They achieved an improvement in measurement accuracy. The main problem with these types of sensors is that in our scenario, the differences distance between the emitter and the receiver might be modified due to the presence of animals. These modifications cause the sensor cannot be accurate.

Finally, the last alternative analyzed for measuring the water level is presented by Antonio-Lopez et al. [14]. They showed an optical fiber sensor for measuring the water level. A multimode fiber without cladding was used as an optical fiber. The sensor works because the fiber is submerged in a liquid. In this context, the refractive index is different depending on how submerged it is. They concluded that the more the fiber is submerged in water, the higher the peak wavelength will be shifted to longer wavelengths. This type of sensor has the same problems that we explained for capacitive sensors.

In this paper, we present an inductive sensor for monitoring the water column in irrigation channels. We develop the sensor with two coils (PC and IC). These prototypes produce an electromagnetic field that variates with the surrounded water level, causing changes in the measured signal. One of the characteristics of our sensor is that it can be used for continuous monitoring. Stability is another characteristic of our sensor, which can be observed in the results section. Furthermore, this type of sensors is very robust thanks to its PVC structure.

III. TEST BENCH

In this section, the prototypes that have been used and the necessary devices to carry the experiments are described. The test bench is segmented in two different subsections.

A. Prototype characterization

We created different prototypes that measure the depth of the agricultural irrigation system using low-cost sensors. The prototypes were designed using different sizes of PVC material, using 2.2 cm long and 1.7 cm of diameter for the P1. Besides, 5.2 cm long and 2.5 cm of diameter were needed for the P2. Copper wire was used to coil the different prototypes. The P1 was coiled using 0.2mm thickness copper. Nevertheless, a 0.4 mm copper coil was selected for the P2.

Otherwise, the P1 and P2 were distinguished in two different sides, the PC and IC. The P1 was designed with ten winds for the PC part and five winds for the IC. Likewise, 40 winds for PC and 80 winds for IC were selected for P2. This information is represented in Table 1.

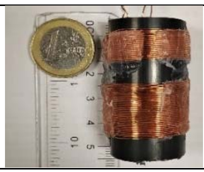
The two tested coils are represented in Figure 1. The prototypes were coiled against the hands of the clock, trying to make the spires as close as possible, to obtain the best results. Besides, the P1 and P2 were powered in the same direction. In this case, upside-down of the coiled way, using the clockwise direction. This helps to maintain a similar basis for all prototypes and to obtain more relevant data.

B. Performance of the experiment

We powered the coils in a clockwise direction, using the end of the coil as a negative part or ground reference. Besides, we applied 10 voltage peak to peak (Vpp) to feed the P1 and P2 using the generator AFG 1022 [15]. We measure the output voltage (*Vout*) by using the oscilloscope TBS1104 [16].

The circuit we have used is composed of a resistance of 47 Ohms serially located to the coil, to reduce electromagnetic noise and obtain a reliable value of *Vout.* Moreover, the induced part of the circuit has a capacitator of 10 nF in parallel to capture the energy and maintain the magnetic field.

TABLE 1. DEVELOPED PROTOTYPES.

Prototype	**P1**	**P2**
Image		
Spires of PC	10	40
Spires of IC	5	80
Layers	1	1

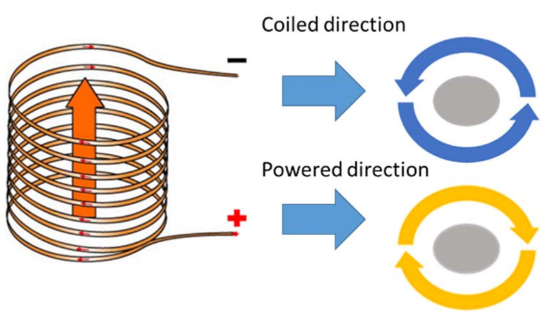


Figure 1. Coiled direction and powered direction.

The experiment was done using a glass bottle where measure marks were drawn every 2.5cm, from 0 to 15cm, see Figure 2. The glass has a height of 16.2 cm and 8 cm of diameter. Following, the coil was placed suspended between two different marks. The P1 was located among 5 cm and 7,5 cm and P2 between 5 cm and 10 cm. Once the coil was placed, we began to fill the bottle with water measuring the *Vout* for each mark. The water volume that we use is 1L. The reason to perform the experiments with a reduced amount of water is related to the findings of L. Parra et al. [17]. In this paper, the authors present that the induced voltage of a similar sensor (composed by two copper coils) is affected by the volume of water, but this effect follows an asymptotic progression and after a few cms, the output voltage does not vary when the water volume increases. The authors showed that the output value remains almost constant when 1, 3.25, and 4.5 L are used. Therefore, the tests of the prototypes can be performed with a reduced volume, 0 to 1L.

Finally, we test the stability of the P1 and P2. For this, we put each coil into the glass bottle, and we fill the bottle up to the mark of 15cm. Then, we introduce the sensor between 5cm and 7.5 cm, in the case of P1 and 5cm and 10 cm for P2. Next, a tool was used to shake the sensor with intensity, changing the variation of movements to simulate the real environment of an irrigation channel. The objective of this final part is to verify the optimal behavior of the sensor in hard conditions where the prototype has a continuous movement.

IV. SYSTEM PROPOSAL

In this section, the proposed WSN is presented. For reaching this target, our system is going to base in inductive sensors for measuring the changes in depth of water columns in irrigation channels. The objective of these sensors is to indicate when it is necessary to open or close the gates of this channel. This is very important to control sustainable irrigation in agriculture.

Additionally, this type of sensor is to be part of the European Project SMARTWATIR, smart wireless sensor network to detect and purification water salinity and pollution for agriculture irrigation. The sensor is going to be part of a system with more prototypes that will be measuring different parameters for detecting and monitoring pollutants in agriculture irrigation.

A. WiFi node

In this subsection, the used wireless node is presented. The function of the node is to obtain and gather data from the sensors. Then, the induced voltage is transformed into water level values, and it will send the data wirelessly. We select the use of Wifi versus Lora because the sensor is placed as part of a local area network that uses WiFi and includes other deployed nodes measuring the water quality, the soil parameters, and weather conditions.

For the WSN, the used node is the Adafruit Feather HUZZAH based on ESP8266, see Figure 3. This is one of the best nodes for this system because of the low cost, easy programming (it can be programmed using IDE Arduino), one analog input of 1.0V max, and 3.3V regulator with 500 mA peak current output [18]. In this module, we connect a DC-DC module for transforming the signal of 3.3 V to 10 V.

The prototypes were connected to the analog input of the Adafruit Feather HUZZAH (the fifth pin starting from the right at the bottom of the board shown in Fig. 3).

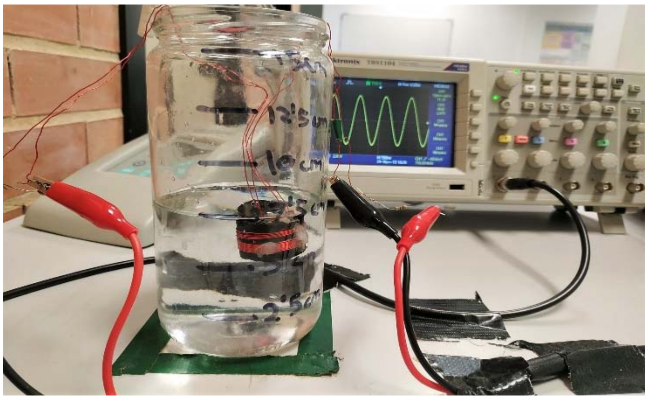


Figure 2. Experimental setup.

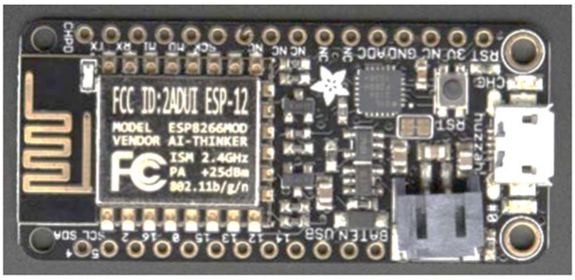


Figure 3. Adafruit Feather HUZZAH ESP8266 development board.

B. *Deployment and architecture.*

In this subsection, we present the deployment of the developed system, including the nodes, the function, and the used architecture.

Our proposal is based on controlling the changes in the water column in an agriculture irrigation system to open or close the gates to provide the necessary water to the crops. These sensors are going to be deployed with other ones that detect pollutants in agricultural irrigation water.

Figure 4 represents the deployment of the sensors in the irrigation channel for agriculture. The channel has a grid, which is required to remove bulky material to the water flow. Behind the grid, depth sensors are placed in different depths to obtain as best accuracy as possible. Then, the turbidity sensor is deployed. This last sensor is part of the sensors for pollution tracking, nevertheless, this paper is focused on the depth sensors. Likewise, the used sensors are collocated inside of a watertight box. This box is partially buried in the soil near the irrigation channels. Inside of this cash, we will place the node, the battery, and the communication module. Data will be sent through WiFi. A pipe connects this container with the channel, where the sensor is deployed in the water. Moreover, this system will use a solar panel to charge the battery.

On the other hand, the gates will be opened using Artificial Intelligence (AI). In this case, data from two sensors are need: level sensor and turbidity sensor. The turbidity is an indicator of pollution, according to the pollution value and the water level in the main channel and in the irrigation channel, the AI will decide to open or close the gates. In addition, sensors will be placed in the agriculture lands to monitor the irrigation needs of the fields. The AI will consider this information in the future as another input of data for decision making. The data of all these sensors will be combined to apply the best decision to control the irrigation channel gates. Therefore, it will not be necessary to replace the power, and we eliminate the requirement of maintenance. Moreover, this sensor is going to be more sustainable since it will use solar energy.

Figure 5 displays the architecture of the WSN. The sensors get the electrical values of the difference in water level. The nodes transformed the electrical values into depth values. Likewise, the nodes are provided with WiFi, which is used to send data wirelessly. Additionally, these data are stored. Then, AI is applied for decision making decisions when it is necessary to open or close the gates in the irrigation channel.

V. RESULTS

In this section, we detail the results of the prototypes that we have used for the measurements. First, the test of each prototype with a different quantity of water is detailed. Successive, the prototypes are used to verify the stability of the measures that are obtained by the sensors. Finally, the best sensor is tested in different water column position.

A. *Depth Tests*

First of all, the working frequency (WF) was found. The WF for P1 was detected at 770kHz and for P2 in 130 kHz. Following, the P1 was located between the marks 5cm and 7.5 cm, and the glass bottle starts to fill each 2.5cm. Then, the same was done for the P2.

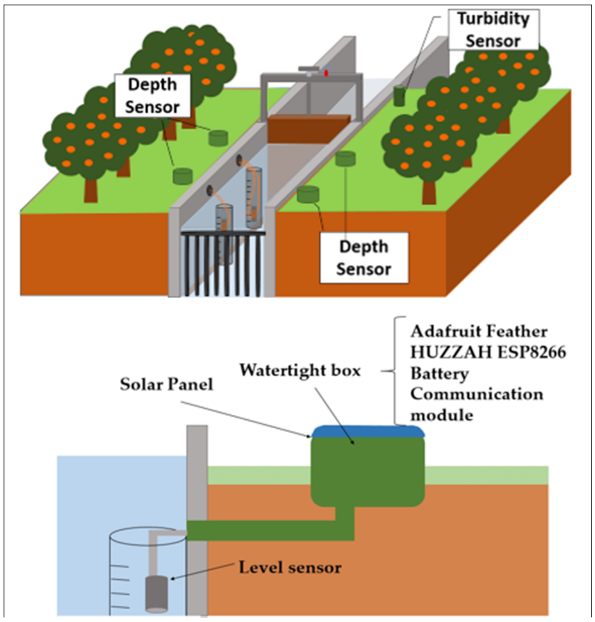


Figure 4. Deployment of the sensors in the irrigation channels.

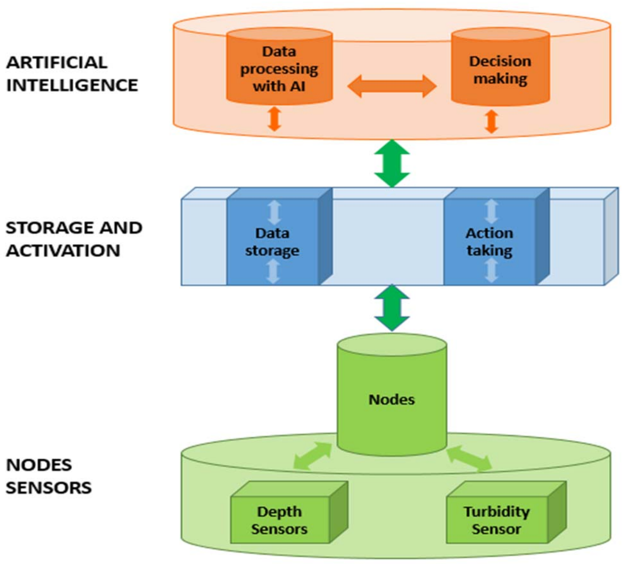


Figure 5. Architecture of the WSN.

The P1 shows an initial Vout of 14.18V for 0 cm depth and a final Vout of 9.72 V that exposed the tendency of voltage to decrease as the water layer increases. However, the P2 represents the opposite situation, where the initial Vout is 23.80V and the final is 28.23V. In this situation, the voltage growth with the increase of the water layer. The two prototypes behave differently to each other because the magnetic field that is produced by each one is not the same. Additionally, the performance of the magnetic coil is closely related to the structure of the prototypes.

In Figure 6 is displayed the model adjusts for each prototypes using the Eureqa [19] and Statgraphics software [20]. The Vout of the sensors is contrasted with the depth of the different marks of the glass bottle. Likewise, the mathematical models of the two kinds of prototypes are shown in Eq. (1) and Eq. (2). Where V is the Vout in volts and D is the Depth in cm. These equations are necessary to calibrate the device that we use. Moreover, the variations in depth will change the output voltage.

The correlation obtained between the values is very high, being the R2 for the P1 equal to 0.923 and 0.999 for the P2. The R2 is a statistical parameter that indicates the adaptation of the model for each measured point.

B. Stability Tests

After obtaining the mathematical model, the stability of the sensors is tested. This is necessary to choose the best prototype that will be used in the field. The signal of the sensor must remain stable in hard conditions. We perform the stability test to ensure that the current of the irrigation channel does not affect the data, contributing like this to have reliable values.

To test the stability of the signal, we shake very hard the prototypes. The sensors were shaken for 1 minute, and we took the signal value every 1 second. Likewise, the standard deviation between the real value and measured value in the experiment of P1 is represented in Figure 7. Besides, in Figure 8 are discussed the results of the P2.

The P1 demonstrates very high adaptability for the hard conditions of the test. We have started with an initial value of 9.2 V, which represents the starting point. This starting point is indicated as 0, and we record the variation between the new data - initial data. Once we have finished the test, we obtained that the maximum change is 0.25V. This shows that P1 has good stability since the maximum variation represents a deviation of less than 3%.

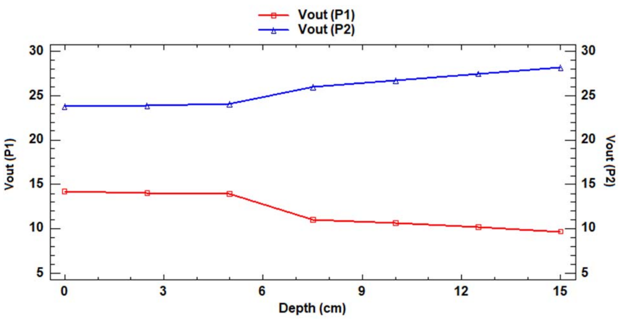


Figure 6. Model of depth changes

$$V = 14.248 - 8.030 \times e^{-8.592/D)} \quad (1)$$

$$V = 23.82 + 0.03 \times D + 0.26 \times D \times e^{-14582/0.2^{\wedge}D} \quad (2)$$

In the case of P2, the original value was 28.2 V, this is represented as point 0. In the highest changes, the values turn to 2.6 V, which corresponds to a deviation of 9.2% from the initial data. Figure 8 displayed very well how the values of P2 are very far from the initial values in all of the experiments. This trend indicates that the sensor has low stability against time. The effect can be even higher in the future since the gathered deviation is not stable. Besides, the frequency of the gathered values, or histogram, from the stability tests are displayed in Figures 9 and 10. In P1 we can appreciate that the highest values are around the initial value in the range of 9.1V and 9.3V. Besides, the maximum frequency of values is found in this range of data. On the other hand, P2 has the utmost values far away from the starting value. Most of the data are found between 26V and 27V. This means that the highest frequency of the data is placed below the initial value, displaying changes when the turbulence is high. The values are summarized in Table 2.

For P1, the maximum difference between the gathered values in the experiment is 0.48V (from -0.24 V to 0.24 V). For P2, the extreme values are -2.6 V and 0.2 V, which supposes a range of data of 2.8 V. Besides, Table 2 displays that the P1 has a lower standard deviation than the P2. The error is also smaller in P1 with 0.013 compared to the error of P2, which is 0.092. This data means that the P1 shows the best operation in environmental conditions.

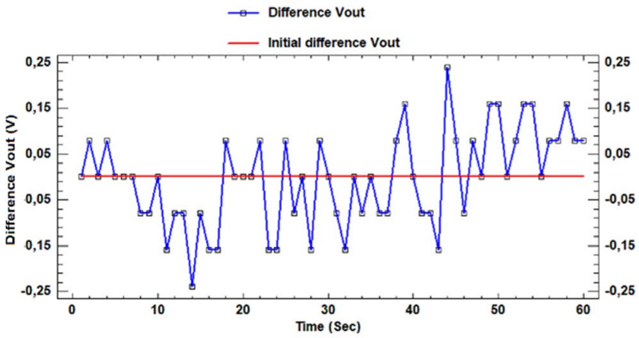


Figure 7. Stability test of the P1.

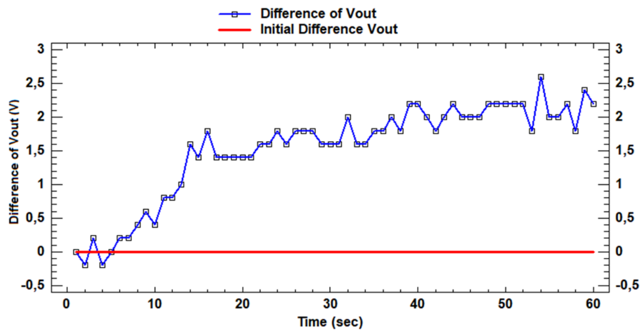


Figure 8.Stability test of the P2.

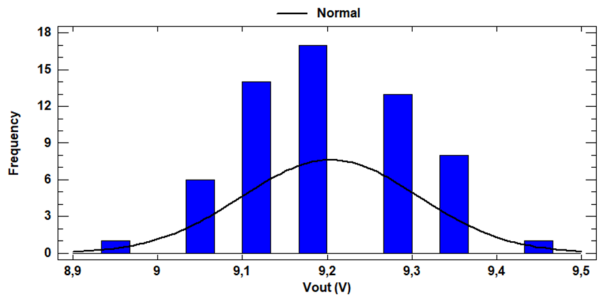


Figure 9. Distribution frequency of values in P1.

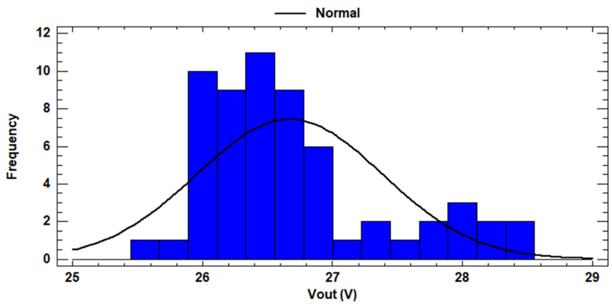


Figure 10. Distribution frequency of values in P2.

TABLE 2. ANALYZE OF STABILITY VALUES.

	P1	P2
Count	60	60
Standard Desviation (V)	0.104	0.713
Coefficient Variation (V)	1.14%	2.68%
Standard Error	0.013	0.092
Standard Geometric Desviation (V)	1.011	1.026
Absolute Average Desviation (V)	0.008	0.020
Minimum (V)	8.96	25.60
Maximum (V)	9.44	28.40
Range (V)	0.48	2.80

VI. CONCLUSION AND FUTURE WORKS

In this paper, we have proposed the use of an inductive sensor to measure the water depth in irrigation channels for agriculture. The proposed sensor aims to control when it is necessary to open or close the channel gates to irrigate the crops. It is connected to an Adafruit Feather HUZZAH building a WSN, and allowing us to create a mobile edge computing system. It brings many advantages to agriculture systems like the automation of the processes and sustainable use of resources. In this case, the control of the gates is necessary to adjust the use of water that is a very scarce resource nowadays.

Once we have performed the measurements, we determine that the P1 works with the lower values of voltage than the P2. Likewise, the P1 shows a maximum Vout of 14.18V and a minimum of 9.72 V when the water depth changes. On the other side, P2 shows the highest value of 28.4 V and the lowest data of 23.8V. Thus, the P1 has a 4.46 V of difference between the 0cm depth and 15cm depth, where the P2 has a 4.44 V.The stability of the prototypes tested in harsh conditions was very different. In P1, the maximum difference between the values was 0.48V, which is very low, reversely of P2, which presents the most significant change, 3.2V. These results prove that the prototype that works better in adverse conditions is the P1.

In future works, we will test more prototypes using another type of sensor to measure a more significant range of water columns with better accuracy. Besides, the effect of turbidity, temperature, and other environmental parameters in the laboratory and real scenarios will be studied.

ACKNOWLEDGMENT

This work has been partially supported by European Union through the ERANETMED (Euromediterranean Cooperation through ERANET joint activities and beyond) project ERANETMED3-227 SMARTWATIR by the Conselleria de Educación, Cultura y Deporte with the Subvenciones para la contratación de personal investigador en fase postdoctoral, grant number APOSTD/2019/04, and through the "Ayudas para contratacion predoctoral de Formación del Profesorado Universitario FPU (Convocatoria 2016)". Grant number FPU16/05540.

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