An inductive sensor for water level monitoring in tubes for water grids

Javier Rocher[(1)], Lorena Parra[(1)], Jaime Lloret[(1)], Jesus Mengual[(2)]
[(1)]Instituto de Investigación para la Gestión Integrada de zonas Costeras.
Universitat Politècnica de València,
Gandia, Spain
[(2)] Instituto Universitario de Ingeniería del Agua y del Medio Ambiente,
Universitat Politècnica de València,
Valencia, Spain

***Abstract*— The sensors for monitoring different parameters in smart cities are becoming a hot topic for researchers all around the world. The smart grids are one of the main objectives of the smart city concept. In this paper, we present an inductive sensor for monitoring the water level in tubes for water distribution grids. Different prototypes are proposed and tested. All of the prototypes are composed of two copper coils, which are fed with a sine wave with an amplitude of 3.3V peak-to-peak. The proposed sensor is based on the measurement of the changes in the induced magnetic field when the medium changes. The sensor is placed inside the tube and it is able to detect the amount of water contained in the tube. The prototypes are tested with the tube full of water and the tube empty of water at different frequencies in order to found the best working frequency. Then, more data is gathered with the selected frequencies and different percentages of water amount in the tube. After testing the different prototypes we conclude that the best one is the prototype 4, which presents a voltage variation higher than 1 V. It is formed by two solenoidal coils of 0.4 mm of copper in form of half-circle with 55 spires. This sensor can be used for detecting obstruction in the water distribution network, sewerage, and leaks of water. This sensor can be connected to a node as Arduino Uno in order to transmit the gathered data to the database of the water supplier.**

Keywords- Smart cities, inductive sensor, water level, water grid, level sensor.

I. INTRODUCTION

The Wireless Sensor Networks (WSNs) can be used for many applications such as eHealth, environment surveillance, and industry monitoring, among others [1]. In the smart cities, the sensors can be used for monitoring the health, the utilities distribution systems, the transportation systems, and for surveillance, among others. The main objective of the smart city is to reach the sustainability and to enhance the Quality of Live (QoL) of the population [2][3]. In smart cities the use of all the available technologies and resources for an intelligent and coordinated manner for development is proposed [4][5].

Many authors have presented the use of sensors for monitoring the different parameters of health, quality of drinking water, environment and urban gardens, among others. A smart autonomous vehicle to estimate the amount of water and phytosanitary products need in smart gardens was proposed in [6]. Other authors, proposed a sensor based on two copper coils, for monitoring the water conductivity in aquifers of smart cities [7].

In water grids, the measurement of water level in the tubes is recommended for many reasons. The data related to the water level in the tubes can be used for different purposes. A water level sensor can detect illegal dumping in the sewage tubes. An abnormal rise in the water level on a pipeline can be caused because of the rain or a spill. The illegal dumping may cause damages in water treatment plants due to the unexpected presence of toxins in the biological treatment. Moreover, the sensor can be used to detect obstructions. When the measured level of water in the same pipe at two different points has different values there is an obstruction. In water distribution grids, obstructions can appear in the pipes. In sewage, the obstruction can produce pollution in the landfill area. In a water distribution network, the obstruction can cause cuts in the water supply and pipe bursts because of the augment of pressure inside the pipe. In addition, the water level sensor in the tubes can detect the water leaks. If a diminution of the water level after a section is detected we can conclude that there is a loss of the water in a pipe. This may be caused due to a splice to the pipe or a leak. In conclusion, the pipe obstructions and illegal dumping cause important problems in the wastewater management. For these reasons, the control of water level in pipes can help in detecting these problems and apply the appropriate measures.

To measure the liquid level, the current solutions are based on the capacitance, float-type, radar, ultrasonic, laser and pressure technologies [8]. The capacitance solutions are based on two electrical conductors separated by a dielectric medium. The water inside the tube is the dielectric medium. The float-type solutions consist of the colocation of a float and the measurement of its position. The radar, ultrasonic, and laser solutions are based on the emission of sound or light waves and the measurement of the roundtrip time. Finally, the pressure sensors measure the weight of liquid, and knowing its density, it is possible to know the amount of liquid and the liquid level. The pressure sensor and ultrasound cannot be used because of the small diameter of the tube. In addition, the pressure sensors can have an error when there is a tube full of water.

In this paper, we are going to show the design and development of a sensor to measure the amount of water in a tube. The sensor is based on two copper coils. The powered coil generates a magnetic field, which induces an electric current in the other coil. The induced field depends on the dielectric constant of the environment where the coil is located. Thus, we can determine the level of water inside the tube. Because of the magnetic field induced when the air is present, is different than when water is present, it is possible to calculate the amount of water. The sensor is proposed for monitoring the water level in tubes. Different prototypes are tested in order to found the one that can be used as a water level sensor in tubes.

The rest of the paper is structured as follows; Section 2 presents some approaches that try to measure the liquid level. Section 3 shows the test bench. The proposed sensor is presented in Section 4. Section 5 details the results of the developed sensor. Finally, Section 6 summarizes the conclusion and future work.

II. RELATED WORKS

In this section, we are going to analyze the available solutions for monitoring the water level. As far as we know, there are no sensors for monitoring the presence of water inside a tube. Though, there are sensors for monitoring the liquid level in tanks. We are going to analyze different alternatives to measure the level of a liquid.

Bimpas et al. [9] developed a technique for detecting the water leaks. Their proposed system uses a continuous wave Doppler sensing unit operating at 2.45 GHz. Their sensor was composed of a low power transmitter, a digital signal processing, and a homodyne receiver. The sensor measured the movement of water that leaks of the pipe because it causes a Doppler frequency shift.

Abdullah-Al-Mamun et al. [10] presented a system for monitoring the water level in a tank. The system was based on two modules: a transmitter module and a receiver module. The two modules were controlled by two Atmega 8L. The data acquisition of water level was obtained by an ultrasonic distance sensor (parallax ping). The system had been tested in continuous condition and demonstrated a low energy consumption and it is low-cost.

Atef et al. [11] showed a new method based on ground penetrating radar (GPR) and infrared (IR) photography. They used GPR for detecting the pipes and the IR is used for detecting the leaks. With this information, an algorithm labels the images as no leakage detected or as detected leakage. The centroid of each leakage is calculated using the theorem of Green. The GPR and IR images were overlapped to detect the leaks. The proposed method was used with a small margin of error (2.9-5.6%).

Martini et al. [12] proposed the measurement of the vibration transmitted along water pipes to detect leaks in the water supply network. The authors proposed an algorithm based on the measurement of the standard deviation of acceleration signals. Their proposal includes a sound filter to avoid environmental perturbations, saturation effects, etc.

Those solutions [9, 10, 11 and 12] are used to detect leaks. Nevertheless, they do not measure the level of water in the tubes. Our sensor cannot detect directly the leaks. However,, it can detect the variation of the water level in the tube.

Reverter et al. [13] described the design and implementation of a liquid-level sensor. Their proposal is based on a capacitive sensor. The materials used for the electrodes were a rod of stainless steel and polytetrafluoroethylene insulated wire. The sensor was tested in a metallic tank. The results were over the range of 70 cm, the system has a non-linearity error smaller than 0.35 mm and a resolution of 0.10 mm.

Chetpattananondh et al. [14] showed a capacity sensor for measuring the water level. The sensor worked in a range of 0 to 30 cm with a resolution of 0.2 cm. The capacity sensor is a comb electrode in copper material, with measurements of 70-80 mm width, 300 mm height and 1-2 mm spacing between each comb. The sensor is a low-cost technology and has a high sensibility, good repeatability, and a low energy consumption. In the test, the maximum error was 0.7 cm and the minimum error of 0.1 cm. The cost is 10 $/feet, including the sensor and signal conditioning circuit.

The capacitive sensor has a good resolution and precision. However, these cannot be used in environments with high pressure [8].

To solve the problem of pressure we can use a non-contact capacitive sensor. Pal and Barik [15] presented a low-cost non-contact semi-cylindrical capacitive sensor to detect the water level. The sensor was designed with two semi-cylindrical metal plates separated by a gap distance. The measured capacitance variation is linear. The variation from 0 to 33 cm water column was 0.065 to 0.130 nano faraday. Nevertheelss, the difference in the measured capacitance between 0 and 33 cm is too low for the requirements of our sensor. Li et al. [16] showed a sensor based on optical fiber. The sensor was formed by an integration of fiber Bragg grating (FBG) and asymmetrical fiber Mach-Zenheder interferometer (aFMZI). The sensor used the property of FBG for measuring the temperature. The aFMZI was realized by concatenating a fiber taper and a lateral-shifted junction. The sensor can be measured in a range of liquid level from 0 to 7.5 cm. The resolution of the sensor is 1.01 ºC in temperature and 0.15 cm in liquid level. The measured is produced because of the variation of refraction of the light in the core mode and the dominant low-order cladding mode. This variation depends on the temperature and the water level.

The use of optical fiber is not recommended because the water force can cause deformation in the structural of optical fiber and therefore it is not a reliable method.

Currently, there are systems for detecting the leaks in the tubes. However, the available systems cannot measure the amount of water in the tubes. For this reason, these technologies cannot be applied for monitoring the water level in the tube, which is our purpose. Other solutions are based on the capacitated sensors, which has a good resolution and precision. Nevertheless, they cannot work in a pressured environment as some tubes work. Thus, they are not useful for our purpose. The non-contact capacitor sensors have a bad resolution. Finally, the sensors based on optical fiber can have deformations for water pressure. Thus, the current solutions are not able to measure the water level in a tube. There is a gap in the available technologies and we propose a new sensor to cover it in this paper.

III. TEST BENCH

In this section, we show the materials that we use and the tests that we perform. First, we detail the used materials for the tests. Then, we explain the different assays performed in the laboratory. Finally, we will present the employed materials used to connect the proposed sensor to the wireless node. The different prototype that we use they are in section IV proposal

A. *Used materials in laboratory assays*

In this subsection, we show the selected material for the assays performed in the laboratory.

We propose the use of two copper coils, one coil is powered by a sine wave and the other coil is induced. The electrical circuit of the proposed sensor in the tests is represented in Fig.1. We use a resistance of 47Ω in the powered coil and a capacitor of 10nF in parallel of the induced coil. The signal generator used is the AFG1022 and the oscilloscope is the TBS1104, both of Tektronix. In Fig 2 we observed the assembly in the laboratory. The coils are inside the pipe. The powered coil is connected to signal generator and the induced coil is connected to an oscilloscope.

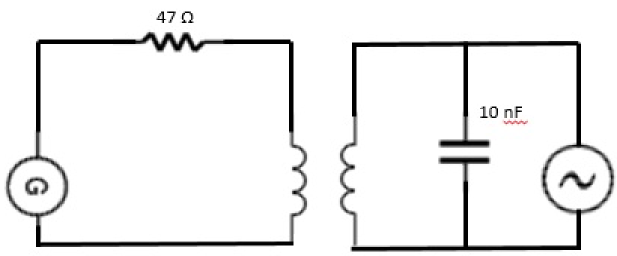


Fig. 1 The electrical circuit used for the test

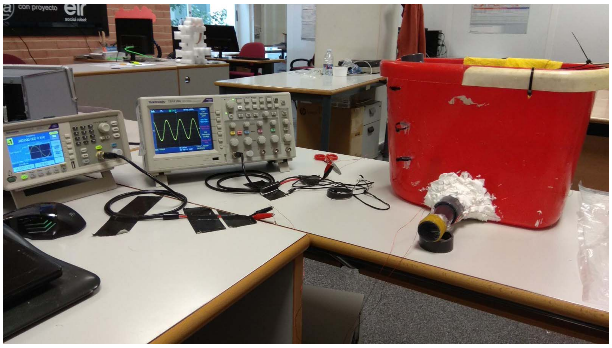


Fig. 2. Experimental test

B. *Test to found the working frequency of each prototype*

In this subsection, we are going to describe the first test that we will perform. This test will be done to find the working frequency.

We will introduce the different prototypes on a pipe of PVC with 32 mm of diameter, 3 mm thick and a length of 100 mm. The extreme of the coil will be 2 cm from the end of the large pipe. We add a transparent plastic at the end of the pipe to be able to see the inside of the pipe. The pipe will have two holes where we will pass the copper wire. The two coils will be placed on the opposite walls of the pipe that contains them. Thus, the wires that come out of the pipe will be tense to ensure that the coil stays fixed while the holes are sealed with hot-melt glue. Once the glue has dried, the cables will be untensioned since the coils will have been fixed to the pipe (see Fig. 3).

To find the working frequency, the powered coil of each prototype will be powered by a sine wave with amplitude of 3.3V peak-to-peak. We will tests different frequencies from 1 kHz to 25 MHz. In the range of 1 kHz to 1,000 kHz, we will record the values every 20 kHz. However, in the range of 1 MHz to 25 MHz, we will record the values every 0.5 MHz. The induced voltage will be measured with the oscilloscope. We will use the electrical diagram present in Fig 1. The prototypes will be tested in two conditions: empty pipe and full water pipe. The frequency that presents the greater difference between the two conditions will be set as the frequency of work.

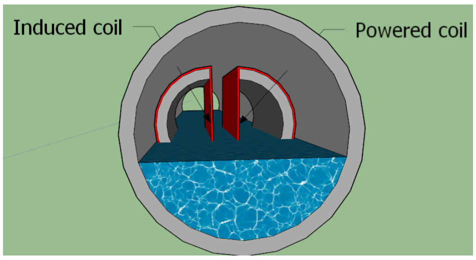


Fig 3. Placement of the coil inside the tube.

C. *Test to determine the best prototype as a water level sensor*

In this subsection, we are going to describe the second test, which is aimed to find the best prototype

We will test the different prototypes in the same conditions used in the first test. To test the prototype we will place the coils inside the pipe (as explained in the previous section), fill it with water, and record values of induced voltage when water reaches a height of the 0%, 20%, 40%, 80% and 100% of the diameter of the pipe. Once the pipe is full, we will remove the water and we will start the process again. This test will be done 3 times to analyze the mean values to find the best prototype.

The best prototype will be the one that combines a big difference between the different percentage of water on the pipeline and that has the best adjustment equation.

IV. PROPOSAL

In this section, we explain the proposed sensor. It is a new inductive sensor for monitoring the water level inside the tube. Moreover, we present the wireless node and its deployment.

A. *Physical sensor*

The sensor is composed of two copper coils. Each coil has been created with enameled copper of 0.4 mm Ø coiled over a semi-cylinder of PVC with a diameter of 20 mm and 1 mm thick. The prototypes are shown in Table 1, which includes the characteristics of the coils used in each one.

We propose six different prototypes. The prototype 1 (P1) is done with copper coils forming two toroids. The two coils have the same inner diameter, outer diameter, number of spires, and height. The prototype 2 (P2) is composed of two coils in solenoid shape. The induced coil has 55 spires and the powered coil has 30. This prototype has the same height of PVC in both coils but due to the induced coil has more spires, this coil has more height. For this reason, the beginning of the induced coil is placed at the same point that the powered coil but the finish not. The prototype 3 (P3) is the P2 but changing the powered coil by induced coil and vice versa. The coils of prototype 4 (P4) are in solenoidal form like the P2 and P3. In this case, the two coils have the same number of spires, 55 spired. The PCV of the P2 to P4 measures 48 mm height. The prototype 5 (P5) is formed by two coils in toroid shape. The powered coil has 30 spires and the induced coil has 55 spired. The coil with 55 spires covers all the PVC but in the case of 30 spires it does not happen. Therefore, we cover with copper the center of PVC, leaving the same PVC distance uncovered on both sides. Like the P2 and P3, the prototype 6 (P6) is the P5, but changing the powered and induced coil. In Table 1 we can observe the parameters of different prototypes.

B. *WiFi node*

In this subsection, we present the used wireless node. The node is employed to gather the data from the sensor, to convert the induced voltage into water level values, and to send the data wirelessly.

The selected node is the Arduino UNO compatible node with a WiFi module based on ESP8266. We select this node due to its low-cost, easy to programming, one analogic input, and its possibility to generate a sine wave using the analog output pins. In a previous work, we have presented how to create the sine wave [17]. As only one analog input is needed to connect the induced coil, this module can be used.

C. *Deployment*

In this subsection, we present the deployment of the proposed system including the location and functions of the nodes.

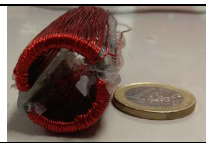
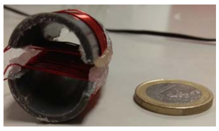
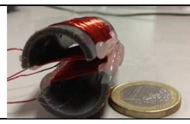
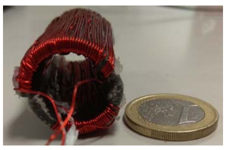
The proposed system will be deployed at different points of the water distribution network and the sewage tubes. We evaluate the different possibilities to communicate the nodes. The best option is to use WiFi in the nodes and divide the deployed network into different clusters, see Fig. 4. The cluster nodes (CN) send the data to the cluster head (CH) using WiFi technology. The CH receives the data from the different CN. Then, the CH aggregates the data and sent it via cellular technologies as 3G. Moreover, the CH is in charge of sending an alarm if a threshold value is exceeded or abnormal situations are detected by any node in the cluster. The CH will be placed in the sewer covers they will have a WiFi and 3G modules. In addition, they will be connected to a bigger sensor that monitors the sewage tube. The CH has a battery to supply energy for the entire system and a solar plate for energy harvesting. The CNs will be placed in the water supply tubes that arrive at each home and business. Each CN measures the data from one tube because the employed node has only one analog input.

We select this architecture because the modules that use 3G or 4G have a higher cost than the modules that work with WiFi. Thus, we minimize the number of nodes that need to use cellular technologies, reducing the installation cost. In addition, using clusters we can save energy.

V. Measurement results

In this section, we are going to detail the obtained results in the different performed test. First, we present the results of the test done to select the working frequency. Next, we show the results of the test done at the working frequency.

Table 1. Characteristics of the 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: solenoid Nº Spires: 30 High: 15 mm Diam: 20 mm	Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm
P3		Type: solenoid Nº Spires:55 High: 28 mm Diam: 20 mm	Type: solenoid Nº Spires:30 High: 15 mm Diam: 20 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: 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
P6		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

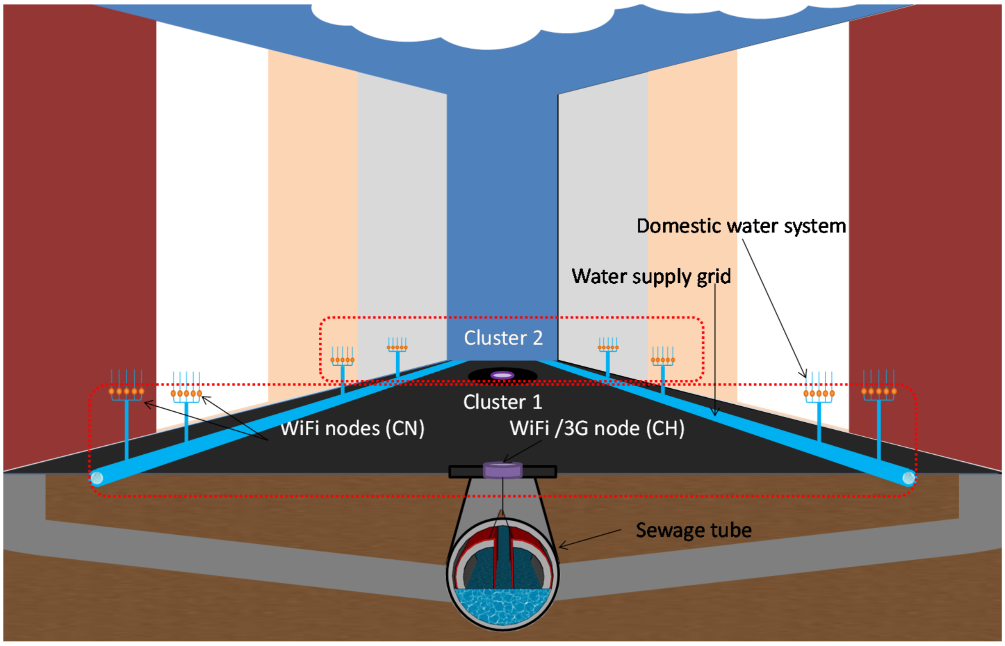


Figure 4. Deployment of the proposed system

A. Test to found the working frequency of each prototype

First, we present the data from the test performed to find the working frequency of each prototype. Fig. 5 presents the data gathered with P1 at different frequencies with the tube full of water and full of air. The frequencies, 300 to 340 kHz and 24.5 to 25 MHz, present the higher differences between both situations and are shown in Fig. 5. The maximum difference was found at 320 kHz. The frequencies where there are differences between both situations for P2, from 320 to 370 kHz, are shown in Fig 6. The maximum difference was found at 340 kHz. For P3, the frequencies with different induced voltages are between 450 and 550 kHz and at 25MHz, see Fig. 7. The maximum difference is found at 490 kHz.

In the prototypes P4, P5 and P6, the differences of induced voltage in different environments can be seen in Fig 8, 9, and 10. Fig 8 shows the induced voltages of P4 at different frequencies. The frequencies shown are 300 to 360 kHz. The maximum difference was found at 340 kHz. For the P5, the values of the first test are presented in the Fig. 9. In this case, the frequency in which we have seen differences are between 300 to 380 kHz. The highest difference was observed at 340 kHz. Finally, for P6 (Fig. 10), the frequencies where we detect different induced voltage are between 440 to 500 kHz and at 25 MHz. The maximum difference was found at 460 kHz.

B. Test to determine the best prototype as a water level sensor

In this subsection, we present the results of the different prototypes when the water level on the pipe changes. Previously, we have determined the working frequency of each prototype and now we use that frequency in the corresponding prototypes.

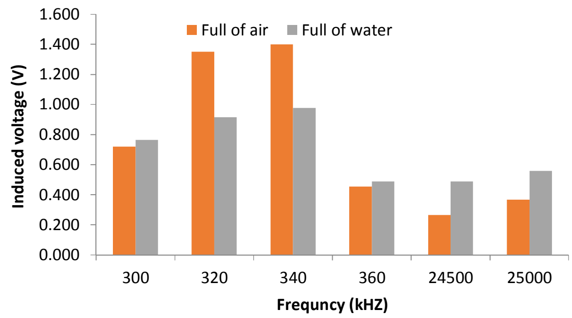


Fig. 5. Gathered data with P1 at different frequencies

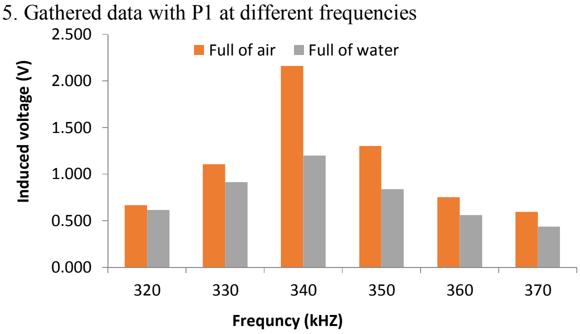


Fig. 6. Gathered data with P2 at different frequencies

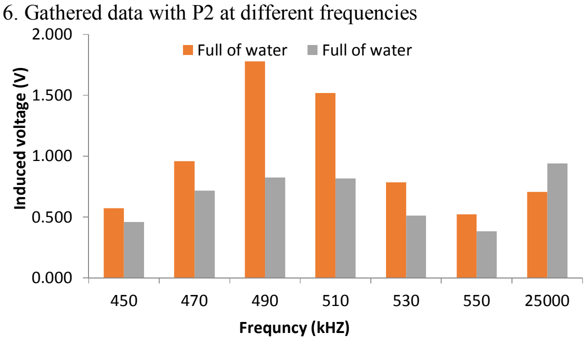


Fig. 7. Gathered data with P3 at different frequencies

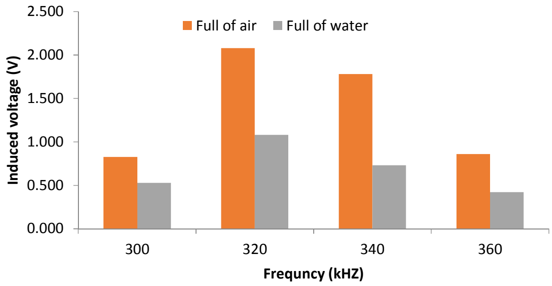


Fig. 8. Gathered data with P4 at different frequencies

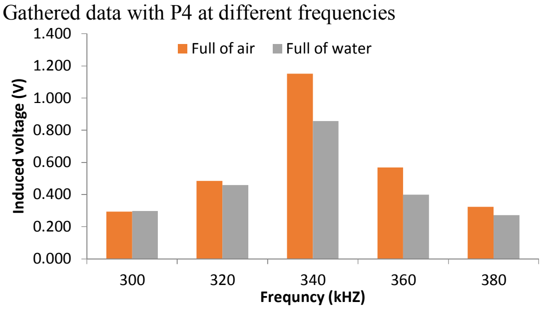


Fig. 9. Gathered data with P5 at different frequencies

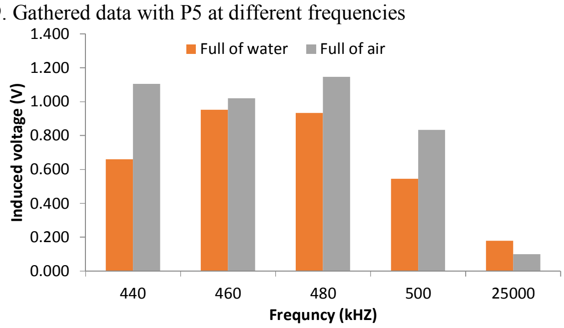


Fig. 10. Gathered data with P6 at different frequencies

In Fig 11 we can see the means of values of the induced voltages (we do three repetitions) for each prototype and different amounts of water in the pipe. We observed in almost all the prototypes (except P6) that, the values of induced voltage decrease when the water level inside the pipe increases. We can observe that, data from P4 present the biggest difference of all the prototypes. The difference of induced voltage between empty and full tube has a value of 1.05 V. The P2 and P3 have a similar difference, with values of 0.95 V and 0.96 V between empty and full pipe. The P1 has a difference of 0.38 V and P5 has a difference of 0.29 V. Finally, the P6 has the worst difference of the tested prototypes. The P2, P3 and P4 have a significant difference in the induced voltages compared to the other prototypes tested. These have in common that they are prototypes based on solenoidal coils. The best prototype will be selected between these.

If we observe the induced voltage when there are different amounts of water in the prototypes, they have a similar evolution. For this reason, we select the P4 as the best prototype because P4 is the one that presents the higher difference on the induced voltage.

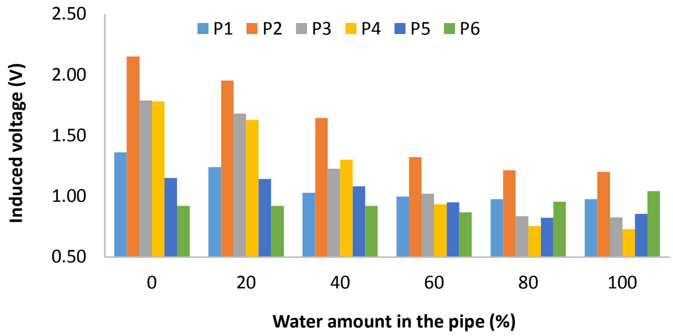


Fig. 11. Gathered data with the different prototypes at its working frequency.

Subsequently, an adjustment equation is sought to explain the differences between the induced voltage and the amount of water in the pipeline. In Fig 12, we can see the values of induced voltage in P4 and a representation of the adjustment equation as a mathematical model. The adjustment equation is present as equation 1. The Eq. (1) has a correlation coefficient of -0.97, which indicates that there is a negative correlation. As this value is close to 1, it indicates that both variables have a good relation. Finally, the standard error is 0.086 V. The good relationship and the small standard error indicate that this prototype can be used to monitor the water level in pipes.

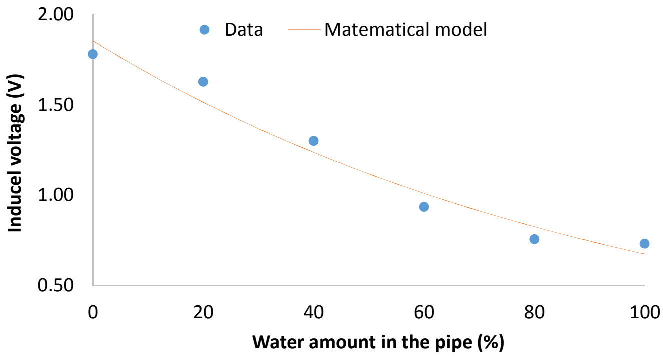


Fig. 12. Gathered data with P4 and the mathematical model.

$$Induced\ voltage = e^{0.617 - 0.0101 \times \%\ of\ water} \quad (1)$$

VI. CONCLUSIONS

The use of sensors is very important in the smart cities to achieve the objectives of QoL and sustainability. In this paper, we present a new sensor for monitoring the water level in tubes of water distribution grids. This sensor can be used for detecting leaks, obstructions, and illegal dumplings. The sensor is composed of two cooper coils. A coil is powered with sine current and the other is induced. Depending on the water level inside the pipe the value of induced current will change. The sensor is connected to a microcontroller type Arduino. A WiFi module is used to send the data to the CH with a 3G module for sending the abnormal values to the computer with SCADA.

In future works, we would like to work to adapt the prototype in other diameters of pipe for use in more applications [18].

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REFERENCE

[1] D. Bri, M. Garcia, J. Lloret, and P. Dini, “Real deployments of wireless sensor networks,” in 3rd Int. Conf. Sens. Technol. Appl. SENSORCOMM 2009, pp. 415–423, June 2009.

[2] G. P. Hancke, B. de C. de Silva, and G. P. Hancke, "The role of advanced sensing in smart cities", Sensors, vol. 13, no. 1. December, 2012.

[3] L.-G. Cretu, “Smart Cities Design using Event-driven Paradigm and Semantic Web.,” Informatica Economica, vol. 16, no. 4, pp. 57–67, 2012.

[4] E. Commission, “Smart Cities". Available online on: https://ec.europa.eu/digital-agenda/en/smart-cities (Last accessed on 26 April 2018).

[5] J. M. Barrionuevo, P. Berrone, and J. E. Ricart, “Smart Cities, Sustainable Progress,” Expert insight, no. 14, pp. 50–57, 2012.

[6] J. Marin, J. Rocher, L. Parra, S. Sendra, J. Lloret, and P. V. Mauri, “Autonomous WSN for Lawns Monitoring in Smart Cities,” in 2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA), pp. 501–508, november 2017 .

[7] L. Parra, S. Sendra, J. Lloret, and I. Bosch, “Development of a conductivity sensor for monitoring groundwater resources to optimize water management in smart city environments,” Sensors, vol. 15, no. 9, pp. 20990–21015, August 2015.

[8] Z. Niu, Y. Zhao, B. Tian, and F. Guo, “The novel measurement method of liquid level and density in airtight container,” Rev. Sci. Instrum., vol. 83, no. 12, December 2012.

[9] M. Bimpas, A. Amditis, and N. Uzunoglu, “Detection of water leaks in supply pipes using continuous wave sensor operating at 2.45 GHz,” J. Appl. Geophys., vol. 70, no. 3, pp. 226–236, March 2010.

[10] Abdullah-Al-Mamun, N. Ahmed, N. U. Ahamed, S. A. M. Rahman, Matiur, A. Badlishah, and K. Sundaraj, “Use of Wireless Sensor and Microcontroller to Develop Water-level Monitoring System Use of Wireless Sensor and Microcontroller to Develop Water-level Monitoring System,” Indian J. Sci. Technol., vol. 7, no. 9, 2014

[11] A. Atef, T. Zayed, A. Hawari, M. Khader, and O. Moselhi, “Automation in Construction Multi-tier method using infrared photography and GPR to detect and locate water leaks,” Autom. Constr., vol. 61, pp. 162–170, January 2016.

[12] A. Martini, M. Troncossi, and A. Rivola, “Automatic Leak Detection in Buried Plastic Pipes of Water Supply Networks by Means of Vibration Measurements,” Shock Vib., vol. 2015, January 2015.

[13] F. Reverter, X. Li, and G. C. M. Meijer, “Liquid-level measurement system based on a remote grounded capacitive sensor,” Sensors Actuators, A Phys., vol. 138, no. 1, pp. 1–8, July 2007.

[14] S. Pal and R. Barik, “Design, Development and Testing of a Semi Cylindirical Capacitive Sensor for Liquid Level Measurement,” Sensors & Transducers, vol. 116, no. 5, pp. 13–20, May 2010.

[15] K. Chetpattananondh, T. Tapoanoi, P. Phukpattaranont, and N. Jindapetch, “A self-calibration water level measurement using an interdigital capacitive sensor,” *Sensors Actuators, A Phys.*, vol. 209, pp. 175–182, 2014.

[16] C. Li, T. Ning, C. Zhang, X. Wen, J. Li, and C. Zhang, “Liquid level and temperature sensor based on an asymmetrical fiber Mach-Zehnder interferometer combined with a fiber Bragg grating,” Opt. Commun., vol. 372, pp. 196–200, 2016.

[17] S. Sendra, L. Parra, J. Lloret, J.M. Jiménez, Oceanographic multisensor buoy based on low cost sensors for Posidonia meadows monitoring in Mediterranean Sea. Journal of Sensors, vol. 2015, 2015.

[18] Hyder Khaleeq, Ali Abou-ElNour, Mohammed Tarique, A Reliable Wireless System for Water Quality Monitoring and Level Control, Network Protocols and Algorithms, Vol 8, No 3 (2016). Pp. 1-14