Smart Cities: Non Destructive Approach for Water Leakage Detection

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Abstract. Natural resources management is essential, especially of water distribution within cities. In Brazil, water losses in distribution systems go up to around 38%. In the context of "Smart Cities", technologies that use "The Internet of Things" can be applied to reduce such losses. The present article shows that leakages produce distinctive noise ranging from 100 Hz to 1000 Hz. Through digital signal processing techniques, such as the Discrete Fourier Transform and Goertzel Transform, the spectral signals are decomposed, revealing their components of frequency such as the intensity. An architecture that performs the communication between slave nodes through a TCP/IP network is then proposed. The slave nodes are responsible for data collection for leakage identification. The collected data is then sent to the data master where there is greater computing power. The data master will perform the processing according to the paradigm of edge computing, thus obtaining frequency responses and the identification of the leakage itself. It will also make data available through OPC-UA, a standard "Internet of Things" communication protocol widely used in the industrial context.

Keywords: Leakage detection; OPC-UA; Water management; Smart Cities; Water loss control

1 Introduction

Water scarcity is a major problem concerning development requirements, leading to major clashes and potential unrest around the world. The situation on developing countries is more critical as they still need to review their policies related to the rational and sustainable use of water [1]. In 2015, the World Resources Institute (WRI) conducted an analysis based on global climate change data, establishing a water stress rank for 167 countries, projecting it to 2020, 2030 and 2040. According to their study, 33 countries (14 of which are located in the Middle East) will present some worrying water stress by 2040 [2].

Currently, Brazil is a privileged country, where water is an abundant resource. Brazil holds more than half of the available water in South America, summing up 13% of the world´s supplies. However, Brazil faces problems due to faulty distribution, degradation caused by pollution, mismanagement and poor distribution networks maintenance, both preventive and corrective [3], [4]. Figure 1 shows the amount of water consumption per capita and percentage of water loss in the distribution network from 2008 to 2013 [5], [6].

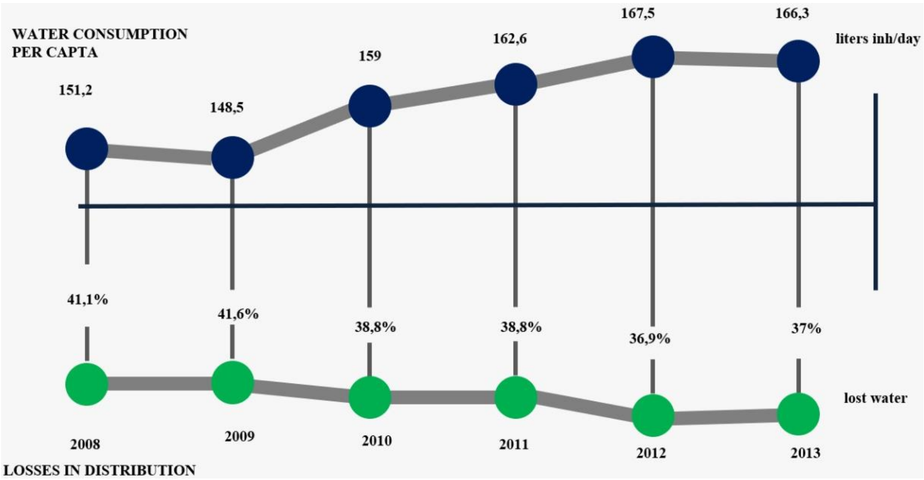

Fig. 1. Amount of *water consumption per capita* and *losses in the distribution* network

The chart on Figure 1 represents the emergency scenery, pointing out a water resources loss of 37% in distribution by 2013, when every individual of the population consumed 166,3 liters of water per day, approximately 151% of the amount considered necessary to each person, according to the World Health Organization (110 liters / day) [5].

Motivated by the scenario above, this article presents the development of an autonomous non-intrusive leakage measurement system connected to a data network using OPC-UA protocol and Edge Computing concepts based on the platform Industry 4.0. Therefore, the article presents the initial state of a doctoral project, whose main objective is the implementation of a non-invasive water-leakage detection system, service oriented (SOA). At the present time, the acquisition and spectral analysis was validated, as it will be demonstrated on this work. The next steps comprehend the development of the proposed architecture, through the study of the protocol OPC-UA, delivering a solution based on SOA. Furthermore, the implementation of protocols to attend the necessity of low consumption on the edge will be studied, i.e. protocols regarding Low Power Wide Area Networks (LPWAN).

This paper is organized as the following: Section 1 presents an introductory look at geophones for leak detection, Internet of Things (IoT) and OPC-UA, which are the concepts that support this solution proposal model. Section 2 presents the contribution of this work in the context of systems directed to services for the industry. Section 3 details theoretical concepts for leak detection in a non-invasive way, concerning the identification of the frequencies components in an acquired signal based on Fourier Discrete Transform and the Goertzel's Algorithm. In the Section 4, the detailed solution is presented: the concept of edge computing and the architecture of a system to monitor the water distribution network of a given system. In section 5, results and analysis are made available. Finally, in the Section 6 are presented the final conclusions and future works.

1.1 Electronic Geophone

Electronic geophones are devices responsible for detecting vibrations generated by water leaks, transforming them into sounds called leakage noises, which are monitored by a human operator. The leakage noise is generated by vibrations from damaged pipes in the distribution network. If there is a leak in a pressurized network, water is expelled from the pipe in direct contact with the soil causing vibration transmitted to the surface [8]. The geophone, which resembles a stethoscope, picks up the vibrations on the surface caused by such leaks. Buried leaks are usually in the range of 200 to 600 Hz and leaks in the distribution network are in the range of 600 to 2,000 Hz [9].

There are two inspection methods using geophones. One method is to use them in direct contact with valves, hydrants, faucets, etc., applying the electronic listening stick to check whether there is leakage noise or not. Another method is to listen to the surface noise using ground sensors [9].

The electronic geophone requires an operator who will classify the detected noise as a leak or not. Therefore, human error can cause uncertainty in some cases. For example, where there are cars or pedestrians in the area. The noise produced by those elements may confuse the operator in his evaluation. Thus, leakage detection depends mainly on the operator's auditory sensitivity [9].

1.2 "The Internet of Things" and OPC-UA

"The Internet of Things" (IoT), a term created by Kevin Ashton, refers to the fusion of the Internet and the physical world, when the frontier between the digital and the physical worlds becomes ever more tenuous [10]. This is due to the constant growth in the number of intelligent machines and objects which communicate and process information autonomously [10]. The use of "IoT" makes the development of collaborative autonomous systems possible, encompassing thematic areas such as artificial intelligence, edge computing and communication protocols in distributed systems, which are the core themes of this work. When it comes to "communication protocols", one of the most used worldwide is the OPC. The standardization of the OPC protocol was defined in 1996 and was originally based on the Microsoft OLE model. OPC is an acronym for OLE for Process Control, which is basically a communication protocol between Windows applications [11]. In 2017, a new OPC specification was developed based on the open XML standard, which is a type of communication with content similar to HTML pages, where data is structured hierarchically [12]. This new open standard allowed the execution of OPC in systems not only based on the Windows Operating System [12].

This new OPC specification based on XML is called OPC-UA. Today, OPC-UA, defined in the standard IEC 62541 as Openness, Productivity Collaboration. [13], [14].

2 Relationship to Industrial and Service Systems

Due to the ever growing demand for water, mainly as a vital element for human survival and for the operation of several production systems, efficient control of water losses caused by non-visible leaks becomes essential.

Some leaks may be easy to detect when they are on the surface. However, when the leak is not visible, that is, when it does not appear on the surface, it is only detectable by changes in the consumption measurement showing extrapolation of the expected consumption average. This way, due to the lack of effective and efficient control solutions, leaks may be recurring for months until they are detected. Thus, in order to achieve a sustainable use of water, it is necessary to develop a control system for leakage inspection that optimizes maintenance process and makes it predictive.

The autonomous system proposed in this work can identify malfunctions caused by problems related to non-visible water leaks at the exact moment they happen, allowing detection in a non-intrusive way. The application of the autonomous system in businesses, industries and residential condominiums optimizes action and repair time when such leaks take place. It also optimizes control of losses in the distribution network. The necessary information will be provided through protocols based on "IoT" and OPC-UA which enable the technological implementation of the system.

3 Fundamental Concepts

The development of the sensors is based on the use of a piezoelectric transducer and an electronic signal conditioning board which will provide the frequencies of the leakage vibrations in the form of acoustic signals. By analyzing the frequencies of such leakage noise, it is possible to identify leakage frequencies through signal processing techniques.

3.1 Identification of Frequencies

Sound signals detected by microphones or vibrations captured by piezoelectric sensors can be converted to frequency by means of Discrete Fourier Transform, described by equation 3.1 [15], [16].

$$X_k = \sum_{n=0}^{N-1} x_n \, e^{-\frac{j2\pi kn}{N}} \tag{1}$$

In the context of optimization, the Discrete Goertzel Transform takes place; a more simplistic approach of the DTFT, according to equation 3.2.

$$X[k] = \sum_{n=0}^{N-1} x[n] W_N^{nk}, W_{N=} e^{-j\frac{2\pi}{N}nk} \tag{2}$$

The Goertzel Transform, or Goertzel's algorithm, enables the investigation of a spectral range, opposite to the whole spectrum. That is, in the case being studied, it would be possible to analyze the signal in detail, in search of signals ranging from 100 to 1000 Hz only, which, according to the presented results, are characteristic of leaks. In addition, there is no component phase calculation, thus reducing computational complexity [17].

4 Proposed Architecture

The proposed architecture developed in this work consists in the utilization of devices able to detect the vibrations originating from leakage in the pipes. To attend the features of a monitoring system, we propose the utilization of such devices positioned over a water distribution system. Every device is responsible for the local monitoring of the vibrations utilizing piezoelectric sensors. It is worth emphasizing that the mentioned devices are sensor elements connected to low-consumption microcontrollers, acting like nodes on a network. Figure 2 presents in focus the piezoelectric sensor along with the microcontroller.

In this architecture, the data processing and the generation of useful information is carried out in an application server, based on a microprocessor type Cortex A. To attend this specification, every monitoring device is composed of connectivity modules, which enable the information be sent to the server.

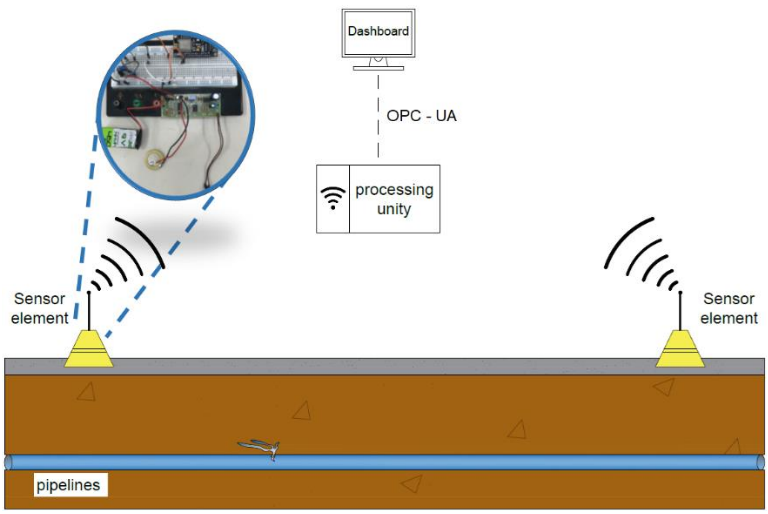

Fig. 2. Proposed architecture and prototype used for the signal acquisition

On the server, the vibration data is processed and analyzed on the domain frequency. The data analysis on this domain allows the identification of the characteristics of a pipeline leakage. Finally, it becomes possible to utilize the information on a monitoring system, generating alarms and notifications according to what is mentioned on the next section. In this case, the protocol OPC-UA was chosen due to the standard proved by the IEC 62541, a well-stablished standard protocol in the Industry 4.0.

5 Results and Analysis

The noise produced in the field may present different frequency components. The materials used in this experiment were HDPE (High Density Polyethylene) and PVC (Vinyl Polychloride) and sizes ½ " and ¾".

5.1 Frequency Results

To evaluate the proposed system, two test scenarios were created. The first one contains a PVC pipeline and the second one a HDPE pipeline. Then, a signal analysis (Goertzel's algorithm explained in Section 3.1) was applied with the acquired signals with and without leakage.

Figure 3 illustrates the frequency spectrum of leakage noise in a water distribution network with PVC pipes.

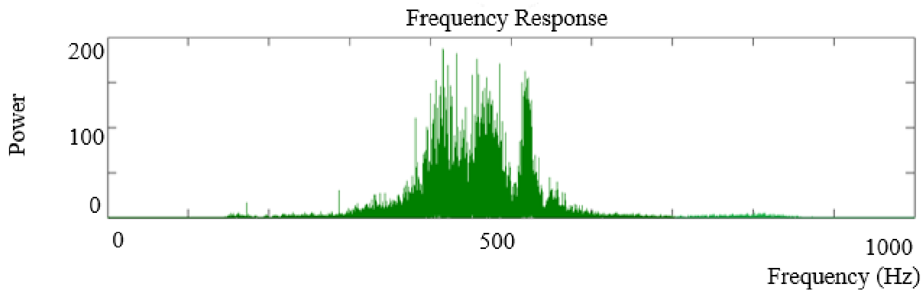

Fig. 3. Frequency spectrum of water leakage noise, amplitude of noise record and *frequency of response power.*

It was observed that the frequency range of the noise analyzed is within 100 Hz to 1,000 Hz. Different types of soil interfere in the signal strength, but not in the frequency. In Fig. 4 the material used was HDPE.

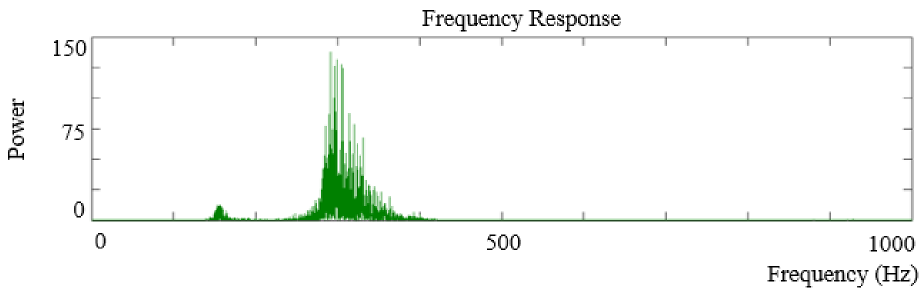

Fig. 4. Frequency spectrum of leakage noise in a water distribution network with HDPE pipe.

Fig. 5 shows the case of the system with HDPE pipes without leaks.

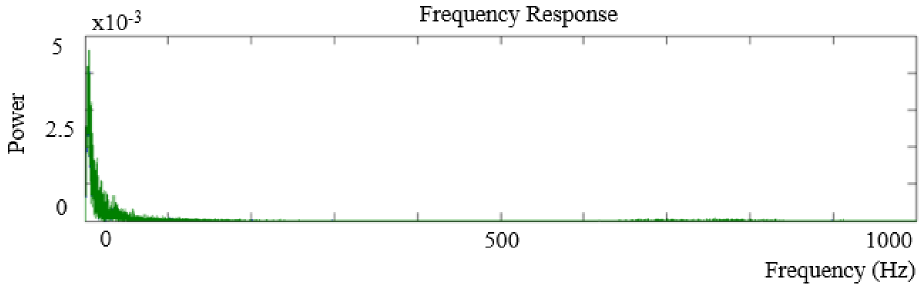

Fig. 5. Frequency spectrum of noise in a distribution network with HDPE pipes that does not present water leaks.

The results presented above show that the frequency components obtained from the Goertzel's algorithm represent a useful feature for the leak detection. Regardless the materials tested (PVC and HDPE), for situations with anomalies in the pipelines, it is possible to observe that the components have a module of higher intensity between 100 and 1000Hz.

6 Conclusion

This article presents an architecture model for a distributed network of sensors, capable of detecting and identifying noise from water leaks contributing to the proposal of a monitoring system for water loss reduction, based on the concepts of signal analysis and processing and the use of technologies based on “IoT” and Industry 4.0. The stages of acquisition and processing of the signal, whose results were presented, lay on the foundation of the proposed architecture, with the future implementation of the protocol OPC-UA between the central unit and the dashboard, and the studies of LPWAN between the sensor devices and the central unit.

The distribution of devices and the use of edge computing allow detection of problems throughout the water distribution network in a systematic way. Therefore, it contributes directly to control the use of water in industrial systems or residential condominiums, optimizing maintenance and repairs. The concepts of applied "IoT" and "OPC-UA Communication" enable the implementation of the autonomous system within the scope of Industry 4.0.

This study allowed the validation of a concept that the authors can use in the future and evolve to the development of an autonomous system using able to identify the exact location of water leaks.

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References

1. Cirilo, J. A.,:Crise hídrica: desafios e superação. Revista USP, São Paulo, n. 106, p. 45-58 (2015).
2. Maddocks, A.; Young, R. S.; Reig, P.: Ranking the World's Most Water-Stressed Countries in 2040. World Resources Institute, http://www.wri.org/blog/2015/08/ranking-world%E2%80%99s-most-water-stressed-countries-2040 (2018).
3. ABES: Controle e Redução de Perdas nos Sistemas Públicos de Abastecimento de Água. São Paulo, SP, 100 p. (2015).
4. Barifouse, R.,:Maior crise hídrica de São Paulo expõe lentidão do governo e sistema frágil. BBC Brasil, https://www.bbc.com/portuguese/noticias/2014/03/140321_seca_saopaulo_rb (2014).
5. Eduardo, A.: Água no Brasil. Folha de S. Paulo. São Paulo, SP, http://www1.folha.uol.com.br/infograficos/2015/01/118521-agua-no-brasil.shtml (2015).
6. Oliveira, G.; Marcato, F. S.; Scazufca P.; Pires, R. C.: Perdas de Água 2018 (SNIS 2016): Desafios para Disponibilidade Hídrica e Avanço da Eficiência do Saneamento Básico. Instituto Trata Brasil, http://www.tratabrasil.org.br/images/estudos/itb/perdas-2018/estudo-completo.pdf (2018).
7. Zaniboni, N.: Equipamentos e Metodologias para o Controle e Redução de Perdas Reais em Sistemas de Abastecimento de Água. Universidade Politécnica, Universidade de São Paulo. São Paulo, Brasil (2009).
8. S. J.; S. F.; D. A.; M. V.; S. P.: Active WaterLossControl: EPAL TechnicalEditions. EPAL – Grupo Águas de Portugal. 2ª Edição. Portugal (2017).
9. Xuesong. S.; Min L.; Chenwei H.: Application of Fuzzy Inference in the Confience Analysis on the Sound Wave Data of Water Leakage. 8th International Conference on Electronic Measurement and Instruments.Xi'an, China (2017).
10. Miorandi, D.,Sicari S., Pellegrini F., Chlamtac I.: Internet of things: Vision, applications and research challenges. Elsevier. Varese, Italy (2012).
11. Imtiaz J., Jaspemeite, J.: Scalability of OPC-UA Down to the Chip Level Enables "Internet Of Things".IEE, Lemgo, Alemanha(2017).
12. Schwarz M.H., Borcsok J.: A survey on OPC and OPC-UA. XXIV International Conference on Information, Communication and Automation Technologies (ICAT), IEE. Kassel, Alemanha (2013).

13. Bonomi, F., Milito R., Zhu J., Addepalli S.: Fog Computing and Its Role in the Internet of Things. Proceedings of the first edition of the MCC workshop on Mobile cloud computing, pages 13-16. Helsinki, Finland (2012).
14. Gezer V., Ruskowski M., Um J.: An Extensible Edge Computing Architecture: Definition, Requirements and Enablers. The Eleventh International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies. Barcelona, Espanha (2017).
15. Smith, S. W.: The Scientist and Engineer's Guide to Digital Signal Processing. San Diego, California (1998).
16. Lathi, B. P.: Sinais e Sistemas Lineares. 2ª edição. 856 p., Bookman. Rio Grande do Sul, Brasil (2017).
17. Joe F. C., Kilabi M. T.: A Sliding Goertzel Algorithm. Signal Processing vol. 52, Issue 3, Pages 283-297 (1996).