LOW-COST SYSTEM FOR LEAK DETECTION IN WATER SUPPLY NETWORKS

L. M. C. FAIS*, T. FEITOSA, A. L. S. S. MARTIM, T. S. dos S. XIMENES
Universidade Estadual de Campinas
ORCID ID: https://orcid.org/0000-0002-8612-5415*
laura@ft.unicamp.br*

Submitted June 5, 2023 - Accepted November 27, 2023

DOI: 10.15628/holos.2023.16353

ABSTRACT

With the advancement of technology, sensors have been developed for various applications, including detecting leaks in water distribution networks. This work aims to propose a low-cost system for detecting leaks in water networks. The tests were carried out in a simulated network at the Hydraulics and Fluid Mechanics Laboratory of the Faculty of Civil Engineering and Urbanism at UNICAMP, where sensors were installed to measure flow, water level, noise, turbidity, temperature and an extensometer. Real-time readings were received and processed by a microcontroller board (Arduino UNO), and sent to a web page (PHP language) via a Wi-Fi module (ESP8266). An application was also developed, in Java language, to visualize the readings obtained. In laboratory tests, the sensors proved suitable for detecting leaks and triggering audible and visual alarms in the event of leaks.

KEYWORDS: water supply systems, monitoring, sensors, leak, strain gauge

SISTEMA DE BAIXO CUSTO PARA DETECÇÃO DE VAZAMENTO EM REDES DE ABASTEECIMENTO DE ÁGUA

RESUMO

Com o avanço da tecnologia, sensores vem sendo desenvolvidos para diversas aplicações, dentre elas a detecção de vazamentos nas redes de distribuição de água. Este trabalho tem como objetivo propor um sistema de baixo custo para detecção de vazamentos em redes de água. Os testes foram realizados em uma rede simulada do Laboratório de Hidráulica e Mecânica dos Fluidos da Faculdade de Engenharia Civil e Urbanismo da UNICAMP, onde foram instalados sensores para medição de vazão, nível d'água, ruído, turbidez, temperatura e um extensômetro. As leituras em tempo real foram recebidas e processadas por uma placa microcontroladora (Arduino UNO), e enviadas para uma página da Web (linguagem PHP) por meio de um módulo Wi-Fi (ESP8266). Foi desenvolvido também um aplicativo, em linguagem Java, para visualização das leituras obtidas. Em testes de laboratório, os sensores se mostraram adequados para detectar vazamentos e disparar alarmes sonoros e visuais em caso de vazamentos.

Palavras chave: sistemas de abastecimento de água, monitoramento, sensores, vazamento, *strain gauge*

1 INTRODUCTION

The intense process of urbanization and population growth over the years has made necessary a rapid infrastructure development, especially for drinking water supply systems, as the population has settled farther away from water bodies (Silva, Varanis, Mereles, Oliveira, Balthazar, 2019). The applications of water systems encompass the transportation of water, oil, gas, and effluents. Therefore, it is essential to assess the most suitable material for each type of system based on its length, diameter, transported fluid, among other variables. Additionally, these pipelines are subjected to external forces, causing deformation and, consequently, leaks that result in environmental problems and financial losses (Martim, 2011; Kousiopoulos, Papastavrou, Karagiorgos, Nikolaidis, Porlidas, 2019; Gnatowski, Kijo-Kleczkowska, Chyra, Kwiatkowski, 2021).

In addition to material cost-benefit considerations, it is important to understand how an object reacts to different stimuli or forces to perform measurements in mechanical systems. When this object undergoes physical changes in response to these forces, the deformation process occurs, defined as the ratio between the change in length of a material and its original length.

Technological advancements have made it possible to measure deformations using sensors. According to Santos (2010), these are devices that change their behavior under the action of a physical quantity and can directly or indirectly provide a signal that indicates this quantity. Among them, the strain gauge can be mentioned as one of the most efficient and suitable for measuring various types of deformations. The strain gauge provides an electrical signal in response to deformation, which can be based on resistance, capacitance, inductance, or optical, mechanical, or photoelectric principles.

According to Martim (2011), with a resistive strain gauge combined with a Wheatstone bridge, it is possible to measure the difference in their resistances when subjected to different levels of deformation, obtaining a result with adequate precision that presents the combination of longitudinal and circumferential stresses to which the pipeline is subjected. From these measurements, reliable rupture prediction models can be developed.

Gnatowski et al. (2021) made numerical and experimental investigations of the deformation of polyethylene pipes for different values of applied external load. The deformations of the lower and upper surfaces of the pipe were measured during loading using strain gauges located at equal distances along the pipeline, and the results obtained from numerical analysis were comparable to those obtained from the experimental study. The measurement of stresses was based directly on the relationship between electrical resistance and the length of the sensor wire, as described by Equation (1)

$$R = \delta \frac{L_d}{A} \tag{1}$$

Where:

R =Electrical resistance of the sensor (Ω);

δ = Specific resistance of the sensor (Ω);

L_d =Sensor length (mm);

A = Cross-sectional area (mm^2).

Furthermore, according to the authors, the relative increase in resistance (ΔR) is proportional to the material's deformation (ΔL), and it can be determined from the relationship expressed by Equation (2):

$$\frac{\Delta R}{R} = \frac{\Delta_\delta}{\delta} + \frac{\Delta L_d}{L_d} - \frac{\Delta A}{A} \qquad (2)$$

Where:

$\frac{\Delta_\delta}{\delta}$ =Relative increase in specific resistance;

$\frac{\Delta L_d}{L_d}$ =Relative deformation of the sensor;

$\frac{\Delta A}{A}$ = Relative deformation of the sensor's cross-sectional area.

Deformations that occur in pipelines can lead to circumferential ruptures, and in such cases, an electret microphone can be used for acoustic leak noise verification. Sabzevari and Javadpour (2023) proposed a new technique for locating artificial leaks in gas pipelines, whether buried or not, by implementing two simple electret microphones on just one side of the leak and analyzing the attenuation of recorded signals. The experiment was conducted in a pressurized carbon steel pipe to validate the proposed method, and the experimental results demonstrated the effectiveness of the proposed technique in low sampling rate data.

Kousiopoulos et al. (2019) presented an Acoustic Emission method for detecting and locating a leak in a pipeline by employing acoustic sensors mounted on the external surface of the pipeline, which receive acoustic signals generated by the presence of a leak. Leak location can be determined by calculating the time difference between the arrival of such acoustic signals at two adjacent sensors. Various results were obtained related to the localization of cracks in the conduits as well as the spectral contents of the noise based on their findings.

The use of sensors and microcontrollers has applications not only in Hydraulics, but in several areas. Medeiros, André, Valcacer and Barbosa (2020) used a microcontroller to carry out a shading board project based on the Arduino platform. With this system, the authors had a gain in the conversion of solar energy into electrical energy, compared to a fixed system.

Therefore, this research project aims to evaluate and monitor data in water pipelines using water flow and temperature sensors, associating them with leak detection and rupture prevention through the use of an electret microphone, strain sensor, and electronic components. The feasibility of monitoring from a web page, as well as an audible alarm system in the event of a leak detection, was also assessed. Considering that the project was conducted in a laboratory setting, the system has shown to be viable for use. In the next phase, tests will be conducted on real networks with larger diameters.

2 METHODOLOGY

For the development of this project, a functional system was applied with 6 different types of sensors that together collect water flow data. A working prototype collected data that was received by a microcontroller board and via a Wi-Fi module, this data was sent to a Web page, as it is shown in Figure 1.

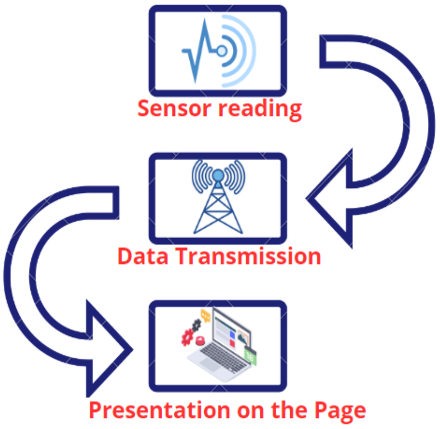


Figure 1: Schematic of the developed system.

The developed system comprises two microcontroller boards programmed in C++ language to control sensor readings and data transmission to a web page created using HTML (Hypertext Markup Language).

In addition to the microcontroller board, sensors are used for detecting possible leaks in pipelines, including the electret microphone, turbidity sensor, and strain gauge, as well as monitoring water flow and temperature.

A web page was developed for real-time visualization of the values read by the sensors, along with an audible alarm (buzzer) in case a possible leak or rupture was detected. For this monitoring, a Wi-Fi module was used for data transmission. Before choosing to use this module, signal tests were conducted with satisfactory results, eliminating the need for a GSM module.

Connections are made on the ATmega328 microcontroller (contained in the Arduino UNO board) and the ESP8266 Wi-Fi module, which is capable of both hosting an application and offloading all Wi-Fi functions from another application processor.

Initially, all sensors were tested separately to validate their functionality for implementation in the prototype. Then, all sensors were tested together, and readings from all sensors were verified by the microcontroller. After testing the sensors in smaller homemade devices, a web page was created to display these values. Consequently, the results were presented in real-time on the web page.

Subsequently, comprehensive tests of the complete system were conducted in the Hydraulics and Fluid Mechanics Laboratory of the Faculty of Civil Engineering, Architecture, and Urbanism at the Universidade Estadual de Campinas (FECFAU/UNICAMP). Some modifications were necessary because the board used to transmit data was the ESP8266, which has only one analog port. Therefore, multiplexing was implemented to allow multiple sensors to send data simultaneously.

Following that, continuous analyses and improvement tests of the system and web page programming are being studied for better data presentation. With the electronic system implemented in the pipeline, results of deformation incidence are already under analysis for a better understanding of ruptures and leaks.

Figure 2 shows the complete system of the developed prototype.

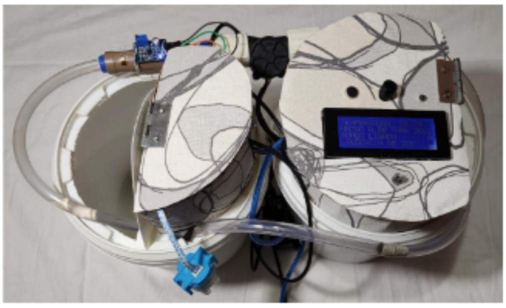


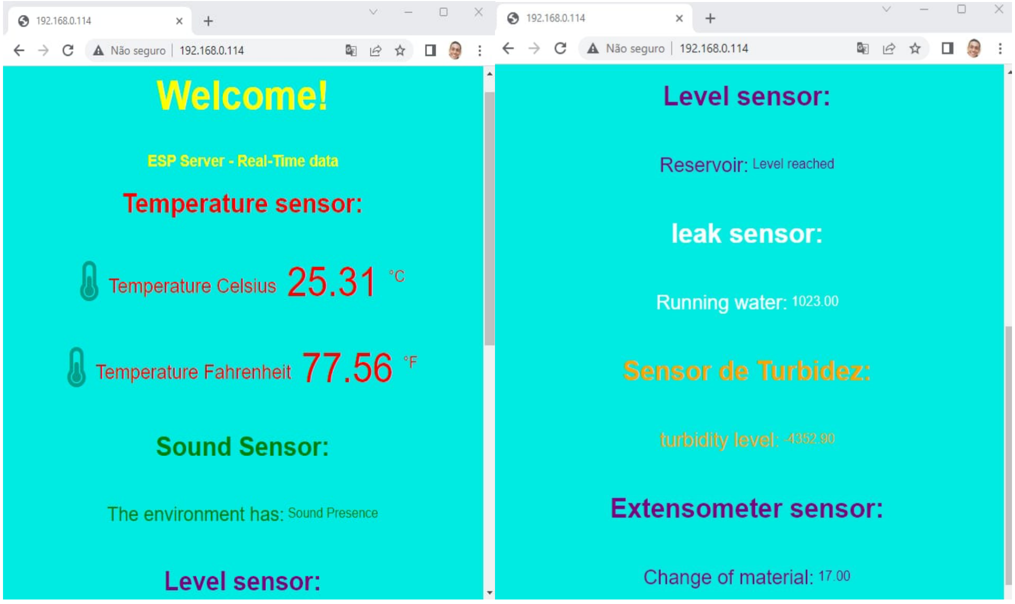
Figure 2: Prototype for testing the functionality of the complete system.

3 RESULTS AND DISUSSIONS

An initial outcome of this project is the creation of the web page. The language used for building the page was HTML. Figure 3 shows displays screens of the developed page, showcasing real-time data collected by the sensors.

For the construction of the prototype, two plastic recipient were used, which together simulated the real water flow from one container to another. Figures 4 to 6 show the position of the sensors and their labels, as per the legend, attached to the developed prototype.

The developed cycle allows water to pass through each sensor and collect the action and impact it has on the environment and/or material, generating data that are remotely displayed on a web page through transmission with the Wi-Fi module (internet).



Welcome!

ESP Server - Real-Time data

Temperature sensor:

Temperature Celsius 25.31 °C

Temperature Fahrenheit 77.56 °F

Sound Sensor:

The environment has: Sound Presence

Level sensor:

Level sensor:

Reservoir: Level reached

leak sensor:

Running water: 1023.00

Sensor de Turbidez:

turbidity level: -4352.90

Extensometer sensor:

Change of material: 17.00

Figure 3: Screens of the web page with real-time sensor readings.

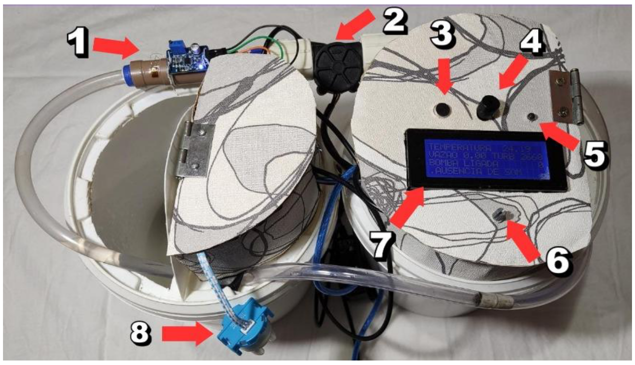


Figure 4: Components attached to the prototype: 1- strain gauge; 2- flow sensor; 3- sound sensor; 4- buzzer; 5- LED; 6- potentiometer; 7- LCD display; 8- turbidity sensor.

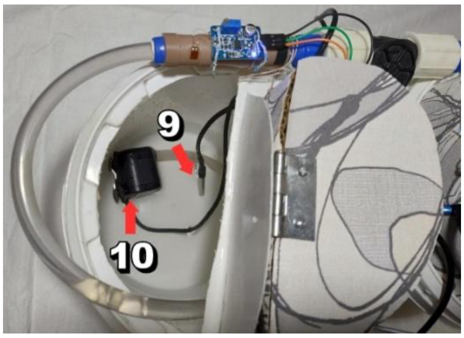


Figure 5: Internal components attached to the prototype: 9- temperature sensor; 10- water pump.

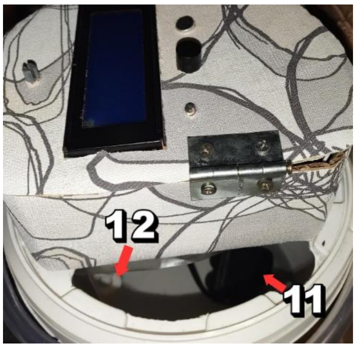


Figure 6: Other internal components attached to the prototype: 11- water pump; 12- level sensor.

It is important to demonstrate and verify that we have an LCD display available, which provides real-time data on temperature, flow rate, turbidity; whether the first water pump is on or off, and the presence of sound in the environment, as signal loss may occur at some point. In fact, this occurred during some tests at the Hydraulics and Fluid Mechanics Laboratory at Unicamp. Figure 7 shows the LCD screen with these mentioned data.


```
TEMPERATURA  33.06
VAZAO 0.00 TURB 1884
BOMBA LIGADA       0
.AUSENCIA DE SOM
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Figure 7: LCD display screen during laboratory tests.

During the tests, it was possible to confirm that the sensors operated correctly due to the values read and the conditions of the water, reservoir, and local pipelines. As a result, the developed prototype can be validated.

4 CONCLUSIONS

In this work, a prototype of a system for monitoring water supply networks to detect potential pipeline leaks was developed. The prototype utilized flow sensors, water temperature sensors, liquid level sensors, sound sensors, a strain gauge, a microcontroller board for processing sensor results and controlling water pumps, and a Wi-Fi module for real-time data communication and visualization on a web page. If any sensor reading reached a level considered abnormal, a buzzer is activated as an audible alert.

It is worth highlighting the low cost of the system, approximately R$ 180.00 (U$ 37, as of 08/03/2023, with U$1 = R$ 4.92), when compared to the cost of dye for leak detection or equipment like geophones used by technicians for leak detection in water supply networks.

In the next phase, the sensors will be tested in a real environment, and the results will be used to propose a rupture prediction model. Additionally, the feasibility of installing a motor to actuate the closure of a valve in the event of a leak detection and implementation in a real-world setting will be tested.

5 ACKNOWLEDGMENTS

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) for their financial support of this research.

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HOW TO CITE THIS ARTICLE:
Canno Ferreira Fais, L. M., Feitosa, T., Sotero Salustiano Martim, A. L., & Simões dos Santos Ximenes, T. (2023). LOW-COST SYSTEM FOR LEAK DETECTION IN WATER SUPPLY NETWORKS. HOLOS, 5(39). https://doi.org/10.15628/holos.2023.16353

ABOUT THE AUTHORS

L. M. C. F. FAIS

Doutora em Engenharia Civil pela Universidade Estadual de Campinas (2007); Professor Doutor MS 3.2 na Faculdade de Tecnologia da Unicamp (FT/UNICAMP). É docente do Programa de Pós-Graduação em Tecnologia, na FT/UNICAMP. Seus principais interesses de pesquisa são Obras Hidráulicas e Segurança de Barragens.

E-mail: laura@ft.unicamp.br
ORCID ID: https://orcid.org/0000-0002-8612-5415

T. FEITOSA

Aluno do quinto ano de Engenharia de Telecomunicações na Faculdade de Tecnologia da Universidade Estadual de Campinas (FT/UNICAMP). Seus principais interesses de pesquisa são automação e controle.

E-mail: t224830@dac.unicamp.br
ORCID ID: https://orcid.org/0009-0008-8450-5765

A. L. S. S. MARTIM

Doutor em Engenharia Civil pela Universidade Estadual de Campinas (2011); Professor Doutor MS 3.2 na Faculdade de Engenharia Civil, Arquitetura e Urbanismo da Unicamp (FECFAU/UNICAMP). Docente no Departamento de Recursos Hídricos da FECFAU/UNICAMP. Seus principais interesses de pesquisa são redes de abastecimento de água e transporte de sedimentos.

E-mail: sotero@fec.unicamp.br
ORCID ID: https://orcid.org/0000-0002-3578-0719

T. S. dos S. XIMENES

Doutora em Engenharia Elétrica pela Universidade Estadual de Campinas (2012); Professor Doutor MS 3.2 na Faculdade de Tecnologia da Unicamp (FT/UNICAMP). É docente do Programa de Pós-Graduação em Tecnologia, na FT/UNICAMP. Seus principais interesses de pesquisa são automação e controle, controle de sistemas com folga, modelagem de sistemas, microcontroladores, mecatrônica e bioengenharia.

E-mail: talia@ft.unicamp.br
ORCID ID: https://orcid.org/0000-0003-1425-3001

Editor: Francinaide de Lima Silva Nascimento
***Ad Hoc* Reviewer:** Maurício Andrades Paixão e Tiago De Vargas

Submitted June 5, 2023
Accepted November 27, 2023
Published December 19, 2023