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Multiparameter Monitoring and Control System for Intelligent Water Management

Ricardo Mendes[a], Carlos Coutinho[b], Bruno Mataloto[c]

[a]*Instituto Universitário de Lisboa (ISCTE-IUL), Lisboa, Portugal*

[b]*Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, Lisboa, Portugal*

[b]*Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, Lisboa, Portugal*

Abstract

Water, an essential resource for both human life and industry, is at risk due to overconsumption, pollution, and climate change. Addressing this issue, this research presents the development of a multiparameter monitoring and control system using Internet of Things (IoT) technology. Combining several sensors, including a camera for reading water meter values, a soil humidity sensor, and a conventional water leak detector, the system aims to detect and prevent water leaks, thereby contributing to water conservation. Furthermore, the system will integrate real-time weather data to provide a comprehensive solution for both indoor and outdoor settings. Initial implementation includes the water detection and humidity modules, with ongoing efforts to integrate the water meter module and refine the system using meteorological data. This holistic approach not only mitigates water waste but also promotes efficient water usage and raises user awareness. This research holds significant potential for several applications, offering both economic and environmental benefits.

Keywords: Internet of Things; Water Leakage Detection; Water Conservation; Water Consumption; Water Scarcity

1. Introduction

"Water is the lifeblood of humanity. It is vital for survival itself and supports the health, resilience, development and prosperity of people and planet alike. But humanity is blindly travelling a dangerous path. Vampiric overconsumption and overdevelopment, unsustainable water use, pollution and unchecked global warming are draining humanity's lifeblood, drop by drop." [1].

Water is one of the most important resources since it is used to maintain several basic human needs, but also

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because it is very necessary to several industries. Unfortunately, this resource is limited, and we can predict that its usage is about to increase due to population growth and industries [2]. Furthermore, we can understand that water availability is being reduced due to climate changes. Therefore, it becomes extremely important to create new ways to save water and to control and manage how much it is being spent.

1.1. Motivation

According to the United States Environmental Protection Agency, a leaking faucet has the potential to waste over 11,300 litres of water annually, when it drips at a rate of one drop per second [3]. Following this reasoning, in the case of a malfunctioning faucet that operates non-stop, the water wastage will quickly rise into millions of litres of water wasted. In a world where water is such a limited resource, reducing the waste of every single drop is mandatory.

For that reason, this research considers that exploring innovative methods for predicting, detecting, and providing alerts for water leakages has a profound significance. This can be applied not only to the detection of substantial leaks, but also to the mitigation of multiple smaller leaks, which collectively will have a tremendous positive impact on the environment. Fortunately, there are already some systems that can detect water leaks, however, there is often a margin of error when it comes to the detection. As a result, the implementation of a multiparameter system incorporating a variety of indicators will be able to minimize this margin.

This research believe that the implementation of an efficient monitoring system can proactively prevent and mitigate the occurrence of unwanted water waste. This not only translates into monetary savings but, more importantly, serves as a crucial mechanism for conserving substantial amounts of water resources. Furthermore, this kind of system can be applied in other ways, like municipal green spaces, school gardens and so on. In this way, cities can benefit from the usage of this solution improving their irrigation schedules and quantities due to the information collected by this system, while controlling possible water leakages.

Beyond individual benefits associated with the utilization of this solution, its global impact holds significant potential for substantial cost savings. Actively controlling leaks incurs less than one-third of the average cost of extracting desalinated sea water. This underscores the considerable economic advantages offered by the widespread adoption of such solutions on a global scale [4].

Water conservation through the prevention and mitigation of water leaks transcends the singular act of preserving water, it has even bigger environmental impact by significantly contributing to energy savings. The extraction, treatment, and distribution of water requires a substantial amount of energy, with the United States Environmental Protection Agency indicating that is necessary 1,500 kWh/million gallons for a typical water system (US EPA, 2013).

Reducing energy usage carries a profound environmental implication, given the substantial carbon footprint associated with energy production. Therefore, diminishing energy consumption not only serves to reduce greenhouse gas emissions but also plays a crucial role in mitigating the adverse impacts of global warming.

As shown in Figure 1 it is possible to understand that the journey between the water source to the tap requires a large amount of energy.

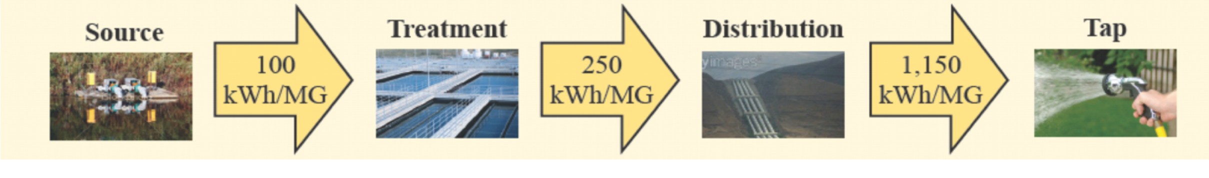

Figure 1: Average energy consumption in a water distribution system [5]

1.2. Objective

The objective of this research is to develop a multiparameter system utilizing Internet of Things (IoT) technology for the detection of water leaks. The primary aim is to investigate which possible combination of IoT sensors allows to create an accurate system for alerting in the event of a water leakage. For instance, traditional water leak detectors, that use water proximity to alert for water leaks, may be effective when used indoors. However, their utility is reduced when applied in outdoor settings, where exposure to rain is inevitable. Consequently, this research proposes the integration of various sensors, including a camera for reading values from a water meter, a soil humidity sensor, and a conventional water leak detector. By correlating the metrics given by all these sensors with real-time weather data, this system aims to offer a solution capable of preventing water leaks in outdoor areas.

This system not only incorporates the advantages of water leak detectors, but also leverages a camera to scrutinize water meter readings. This information can be useful not only to the alert system but to analyze the consumptions of water in the house. Furthermore, the inclusion of a soil humidity sensor allows for a holistic assessment of environmental conditions, contributing valuable insights into the moisture content of the soil.

Moreover, the integration of real-time weather data into the system grants a dynamic element that enables it to respond proactively to changing weather conditions. This adaptive feature ensures that the alert system remains effective under different environmental circumstances. The combination of these diverse sensor inputs aims to create a comprehensive and accurate water leakage detection system, capable of preventing potential damage in outdoor areas.

In addition to its capability for alerting users to potential water leaks, this system is designed to simultaneously gather information regarding water consumptions and soil moisture that can be very useful, thereby functioning as a dual-purpose warning and monitoring system.

1.3. Research Methodology

The research model Design Science Research (DSR) was followed for the development of this project. This methodology is commonly used in information systems and computer science research, where it aims to develop practical solutions that can improve the efficiency of systems and processes. DSR involves a systematic and iterative process that includes problem identification, design conceptualization, artifact development, demonstration, evaluation and communication, as show on Figure 2.

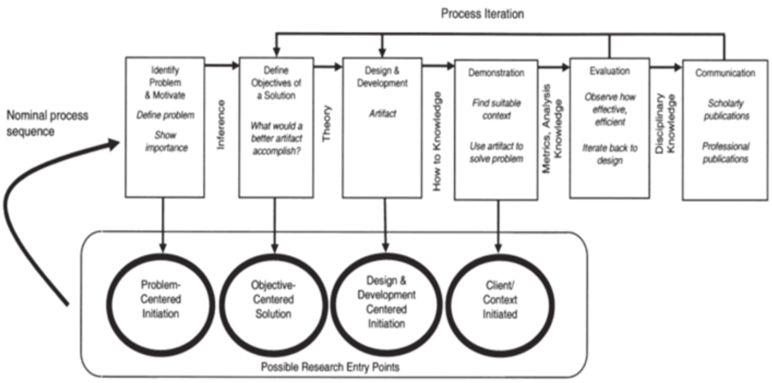

Figure 2: Design Science Research Process Model [6]

The DSR methodology is characterized by a strong emphasis on relevance and impact. It follows a cyclical process, with each iteration aiming for the improvement of the artifacts based on feedback and evaluation results [7].

In the Motivation section, we have detailed the first stage of this methodology. Subsequently, the second stage is addressed in the Objective section, with further discussion in the Research Questions and Hypothesis sections. The third will be comprehensively covered in the System Design and Architecture section.

1.4. Research Questions

The research questions below serve as compass needles, guiding this research and helping to achieve the objectives delineated for this project.

RQ1: What is the effectiveness of implementing a multiparameter IoT system for water leak detection in preventing/reducing water leaks in the outdoor space?

RQ2: How does this multiparameter IoT system impact water conservation by providing information about these metrics?

1.5. Hypothesis

Four hypotheses were developed, with two hypotheses corresponding to each research question. These hypotheses predict the answers to their research question, facilitating the evaluation of the research's accuracy.

H1_RQ1: The inclusion of real-time weather data in the analysis will further improve the accuracy of the water leak detection system, making it more adaptive to changing environmental conditions.

H2_RQ1: The multiparameter system's effectiveness will vary based on different outdoor settings and environmental factors, and identifying these variations will help optimize the system for diverse scenarios.

H1_RQ2: Integrating a camera for water meter readings will allow the system to analyse and monitor household water consumption, contributing to water conservation efforts.

2. LITERATURE REVIEW

This section describes some of the most relevant studies analyzed, regarding the systems used for water leakage detection. These studies were encountered during the systematic literature review, conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology.

Daadoo et al. proposes an IoT-based system applied in residential water pipeline systems, that is meticulously designed to provide continuous monitoring of water pipelines, accommodate diverse flow conditions, and function offline through SMS commands. Furthermore, this system has the capability to cease water flow, due to the solenoid valve, through both SMS commands and the dedicated Android application, offering a multifaceted and efficient approach to water conservation. It employs an Arduino Mega 2560 as the microcontroller and SIMCOM SIM 900 as the GSM module Unit. Arduino Mega has 256Kb of Flash Memory and 54 Pins. This system also incorporates a Water Sensor, Ultrasonic Sensor, Pump, and Solenoid Valve. This project also created a dedicated Android application that allows users to receive notifications about the state of the system and also to control the pump that shuts the water flow [8].

Seyoum et al. study introduces an innovative approach to water pipeline leakage identification using sound signal recordings. The methodology involves capturing sound signals emitted by water pipes and then using them to identify abnormal sounds that indicate the presence of leaks. The process has three key stages: recording, storing, and processing sound signals. The recording phase utilizes a non-intrusive sound sensor for remote data collection, while storage involves cataloguing sound signals in a database. The final step involves processing through sound signal identification software, similar to the Shazam app for music, searching the database for related sounds [9]. This innovative approach holds significant promise as it consists of using an alternative set of sensors with potential applications in water leak detection. The integration of acoustic sensors with specialized software introduces a novel perspective, particularly in discerning the source of water sounds. This system's versatility extends beyond normal leak detection from water pipes, demonstrating its utility in verifying meteorological data accuracy. Notably, it has the capacity to differentiate between artificial water sources, such as taps, and natural occurrences like rainfall. Such advancements contribute valuable insights for enhancing the precision and reliability of water leakage monitoring systems.

Water pipeline monitoring systems can, generally, effectively detect water leaks. Nonetheless, it may not comprehensively address all instances of water leakage, particularly those attributed to dripping taps or malfunctions with devices, as domestic appliances. Furthermore, these systems require invasive assembly procedures, incurring in substantial costs, particularly when not integrated during the initial construction phase. In this regard, alternative methodologies for detecting water leaks are employed, which exhibit reduced assembling procedures and typically are less expensive.

One of these methodologies involves the implementation of a Wireless Sensor Network consisting of multiple nodes (flood sensors) connected to Wi-Fi through a Gateway. These sensors are intended to be strategically positioned on floors or walls to detect the presence of water in their immediate surroundings. Beyond merely detecting water leaks, these sensors can distinguish the type of liquid being detected. Although the method is not flawless, there is potential for refinement, particularly in distinguishing between rainwater and tap water, which can be useful for this research. This refinement would significantly enhance the system's overall utility and reliability [10].

Arsene et al. explored the implementation of an IoT system designed for the comprehensive monitoring of water consumption. The system employed flow meters in four distinct water outlets, namely a sink faucet with cold water, a faucet with hot water, a toilet, and a shower, to gather data. Then with this information, it was possible to obtain a dataset with information gathered from 33 sources, from these kinds of water outlets, over one week, with a sampling interval of 60 seconds. The primary objective of this research is to analyze patterns in water consumption across these various outlets. Firstly, clustering methods were applied, specifically the K-means algorithm, followed by the implementation of classification methods, including Decision Tree, Random Forest, Dense, and Recurrent Neural Network (RNN) models. With this information about normal water consumption in the house, it is possible to detect what is abnormal water usage that might lead to the existence of a water leak. Therefore, the application of Modelling techniques to the data obtained with the IoT system allows for a new way of water leakage detection [11].

3. SYSTEM DESIGN AND ARCHITECTURE

After a comprehensive examination of the relevant studies concerning the monitorization of water consumptions and the detection of water leaks, it is imperative to delineate the selected solution for implementation within this study. This selection is informed by a thorough understanding of the current state of the art, since various approaches have been scrutinized. Therefore, it will be proposed the architectural framework that will be applied in this research. This framework will be the backbone of our investigation, designed to make sure we detect and monitor leaks effectively and reliably.

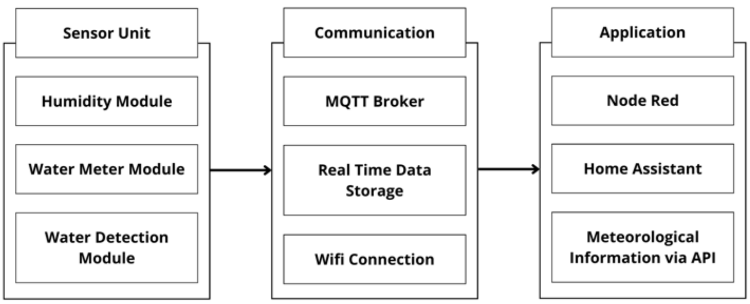

Figure 3: System Architecture

Upon the presentation of the system's overall architecture, it is necessary to dig into the constituent layers, starting with the sensor unit. This layer plays a pivotal role in gathering the information necessary for detecting water leakage, while at the same time collecting relevant insight about water consumptions. Therefore, this unit is composed by three modules that collect data about soil moisture, household water consumption, and the presence of water in outdoor settings.

While the sensor unit collects data, it seamlessly shares it with the internet throughout a Wi-Fi connection, which establishes the communication layer. This enables real-time storage of data gathered by all modules, facilitating comprehensive information aggregation. Subsequently, the application layer undertakes the responsibility of analyzing and presenting this data. The Communication and Application layers are hosted on a Raspberry Pi 3, which enables continuous and efficient data storage using a MySQL database.

4. IMPLEMENTATION

The implementation of the sensor unit has been successfully completed, and the system's communication protocols, along with data storage mechanisms, have been fully established to ensure reliable data transmission and effective storage. Furthermore, the integration of meteorological data through a well-established API has been successfully incorporated into the system and is also being stored in the database.

A comprehensive description of the structure of each module, along with the methodologies employed for data collection, will be provided in the upcoming sections.

4.1. Humidity Module

The first module of the sensor unit implemented was the soil moisture sensor, complemented by the integration of a temperature and humidity sensor to enhance the information available to the user. This setup is managed by an Arduino MKR WiFi 1010 board, which facilitates seamless connectivity of the sensors to a Wi-Fi network. Both sensors are powered by a solar panel, ensuring continuous operation in an energy-efficient manner. The Arduino board transmits the collected data via Wi-Fi using the MQTT protocol. This data is then visualized and managed through Node-RED. Information is gathered at 5-minute intervals and is systematically recorded in two distinct tables within the database: one dedicated to soil moisture, and the other to temperature and humidity data.

Figure 4: Humidity Module

4.2. Water Meter Module

Following the deployment of the humidity module, we proceeded to implement the water meter module. This module employs an ESP32-CAM to continuously capture and record images of the water meter. Due to the water meter's location, which lacks access to an electrical supply, the ESP32-CAM is powered by a portable power bank. To address the low-light conditions, a custom structure was designed to support the camera which incorporates an LED strip to illuminate the water meter's display, with the LED strip being powered by batteries.

The live video feed from the ESP32-CAM is accessible via a specific IP address and is integrated into Node-RED for further processing. Within Node-RED, a flow is designed to capture a photograph of the water meter display every 5 minutes. This image is then analyzed using a node equipped with the Tesseract Optical Character Recognition (OCR) algorithm to extract the numerical data from the image. The extracted water meter readings are subsequently recorded in a dedicated database table, thereby facilitating a detailed and continuous record of water consumption. This module plays a crucial role in measuring and monitoring water usage, which is essential for the overall functionality of this project.

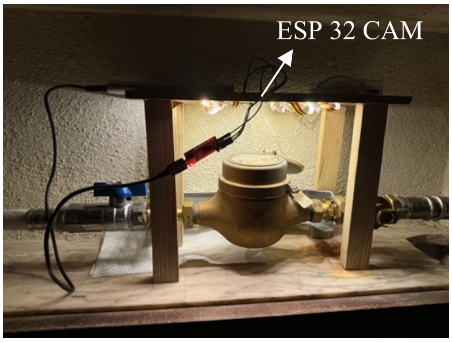

Figure 5: Water Meter Module

4.3. Water Detection Module

The final module integrated into the system is a water leak alarm. This sensor is designed to emit an audible alarm upon contact with water. It features Wi-Fi connectivity that allows it to integrate with the Tuya application. The setup process for this device is straightforward, as it is battery-operated and requires only the installation of the Tuya application and device connection. Then, a Node-RED node was configured to interface with the Tuya data. Consequently, whenever the sensor detects the presence of water, this information is transmitted to Node-RED and subsequently recorded in the database.

4.4. Meteorological data via API

To enhance the system's robustness, meteorological data, including air humidity and weather conditions, has been integrated. This addition allows for the identification of rainfall events, which allows for a more accurate leak detection in outdoor settings. The OpenWeatherMap API was employed to facilitate the integration of meteorological data into Node-RED, recording this information in the database at 5-minute intervals.

5. FUTURE WORK

Projecting forward, since all modules have been successfully integrated, the research will shift focus towards the iterative refinement of the detection system. This phase will involve a thorough analysis of the collected metrics to identify and optimize the combinations of data that enhance leak detection accuracy.

Subsequently, an interface will be developed within Home Assistant to offer users comprehensive access to the collected data and to facilitate the timely receipt of water leak alerts. This user interface will be designed to present data in an intuitive manner, ensuring that users can easily interpret and act on the information.

Furthermore, the project will address the limitations identified during the development process. This includes improving camera image quality or enhancing the responsiveness of the Raspberry Pi (RPI), by looking for some alternatives of camera and computer that can be more efficient.

Ultimately, the goal is to develop a robust and intelligent detection system that leverages a variety of data sources to deliver precise, actionable information. This system will provide accurate leak detection and actionable insights, thereby offering a comprehensive solution for effective water management.

6. ACKNOWLEDGEMENTS

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