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Multifactor Monitoring and Control System for Intelligent Water Management

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Master in Integrated Business Intelligence Systems

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September, 2024

iscte TECNOLOGIAS E ARQUITETURA

Department of Information Science and Technology

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To the couple whose presence is felt in every step

Acknowledgments

Although this dissertation was mostly a fairly solitary journey, it wouldn't have come together without the help and support of many amazing people. I am incredibly grateful to everyone who played a part in making this possible.

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Resumo

A água, um recurso essencial para a vida humana e para a indústria, encontra-se em risco de escassez devido ao consumo excessivo, à poluição e às alterações climáticas. Para enfrentar este problema, a presente investigação propõe o desenvolvimento de um sistema de monitorização e controlo multiparâmetro utilizando tecnologia de Internet das Coisas (IoT). Combinando diversos sensores, incluindo uma câmara para a leitura dos valores de um contador de água, um sensor de humidade do solo e um detetor de contacto com a água, o sistema visa detetar e prevenir fugas de água, contribuindo assim para a conservação deste recurso. Adicionalmente, o sistema integra dados meteorológicos em tempo real, proporcionando uma solução abrangente para espaços interiores e exteriores. Esta abordagem holística não só mitiga o desperdício de água como também promove a utilização eficiente deste recurso e aumenta a sensibilização dos utilizadores. Esta investigação possui um elevado potencial para várias aplicações, oferecendo benefícios económicos e ambientais.

Palavras-chave: Internet das Coisas; Deteção de Fugas de Água; Conservação de Água; Consumo de Água; Escassez de Água

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 moisture sensor, and an alarm for contact with water, the system aims to detect and prevent water leaks, thereby contributing to water conservation. Furthermore, the system integrates real-time weather data to provide a comprehensive solution for both indoor and outdoor settings. 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

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Glossary of Acronyms

BLE - Bluetooth Low Energy

DSR - Design Science Research

HACS - Home Assistant Community Store

IoT - Internet of Things

iSCSi - International Conference on Industry Sciences and Computer Science Innovation

LDR - Light-Dependent Resistors

LOF - Local Outlier Factor

LoRaWAN - Long-Range Wide-Area Network

LPWAN - Low Power Wide Area Network

MQTT - Message Queuing Telemetry Transport

OCR - Optical Character Recognition

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RPI - Raspberry Pi

RQ - Research Question

SMS - Short Message Service

WI-FI - Wireless Fidelity

CHAPTER 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 traveling a dangerous path. Vampiric overconsumption and overdevelopment, unsustainable water use, pollution and unchecked global warming are draining humanity’s lifeblood, drop by drop.” [1].

Fresh water is one of the most important resources since it is used to maintain several basic human needs, but also because it is vital to several industries. Unfortunately, this resource is limited, and we can predict that its usage is about to increase at a faster rate due to population growth and industries [2]. Furthermore, we can understand that water availability is being reduced due to climate change. Therefore, it becomes extremely important to create new ways to save water and to manage how much is being spent.

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. In a world where fresh 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 can have a tremendous positive impact on the environment. Fortunately, some systems can already detect water leaks, but there is often a margin of error associated with detection. As a result, the implementation of a multifactor system incorporating a variety of indicators will be able to reduce this margin.

Annually, more than 35 thousand litres of water are wasted due to household water leaks [3]. Consequently, we can understand this is a common issue, and it has been witnessed firsthand.

During the summer of 2023, at a secondary house which is not regularly used, a critical incident occurred when the faucet supplying water to the automated irrigation system broke, resulting in a continuous water discharge. Regrettably, due to the irregular use of the house, and the lack of any warning mechanism this issue went unnoticed for several days, leading to the wastage of a significant amount of water.

Considering this personal experience, this research focuses on the implementation of an efficient monitoring system that can proactively prevent and mitigate the occurrence of this kind of issue. 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 situations, such as municipal green spaces, school gardens, and more.

The development of a multiparameter system for detecting water leaks also presents a promising opportunity to explore new revenue streams through the commercialization of this solution to the public. Considering the substantial water-saving and cost-saving potential inherent in such a system, it becomes clear that users may find this product financially beneficial in the long term. Consequently, the proposed system holds considerable potential for success in terms of product sales. Additionally, cities can benefit from the usage of this solution by improving their irrigation schedules and quantities due to the information collected by the system while identifying possible water leakages.

Beyond individual benefits associated with the utilization of this solution, its global impact holds significant potential for substantial cost savings. For example, extracting desalinated sea water is three times more expensive than implementing a solution that allows for actively monitoring water leaks. 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 even has an 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 1,500 kWh/million gallons (0,39 kWh/m^3) are required for a typical water system [4].

Reducing energy usage carries a profound environmental implication, given the substantial carbon footprint associated with energy production. Therefore, reducing energy consumption not only promotes the reduction of 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 from the water source to the tap requires a large amount of energy per million gallon (0,30 kWh/m^3).

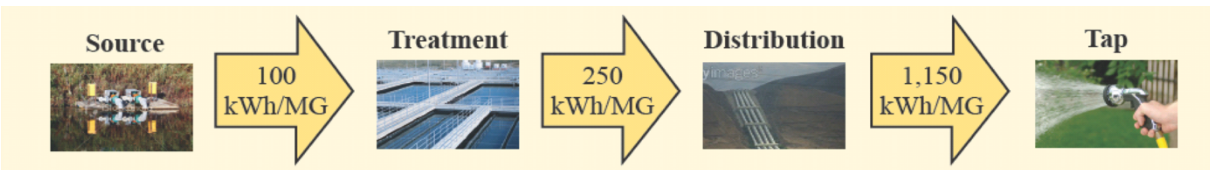


Figure 1 - Average energy consumption in a water distribution system [5]

1.1. Project Idea

In this master's dissertation, the objective is to develop a multifactor 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 the creation of an accurate system for alerting in the event of a water leakage. 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. This research proposes the integration of various sensors, including a camera for reading values from a water meter, a soil humidity sensor, and an alarm for direct contact with water. By correlating all the metrics given by 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 analyse 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 while reducing water wastage.

In addition to its capacity 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 for improving watering schedules for the garden and overall household water usage, thereby functioning as a dual-purpose warning and monitoring system.

1.2. Research Methodology

Design Science Research (DSR) focuses on creating innovative solutions to complex problems. 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 shown on Figure 2.

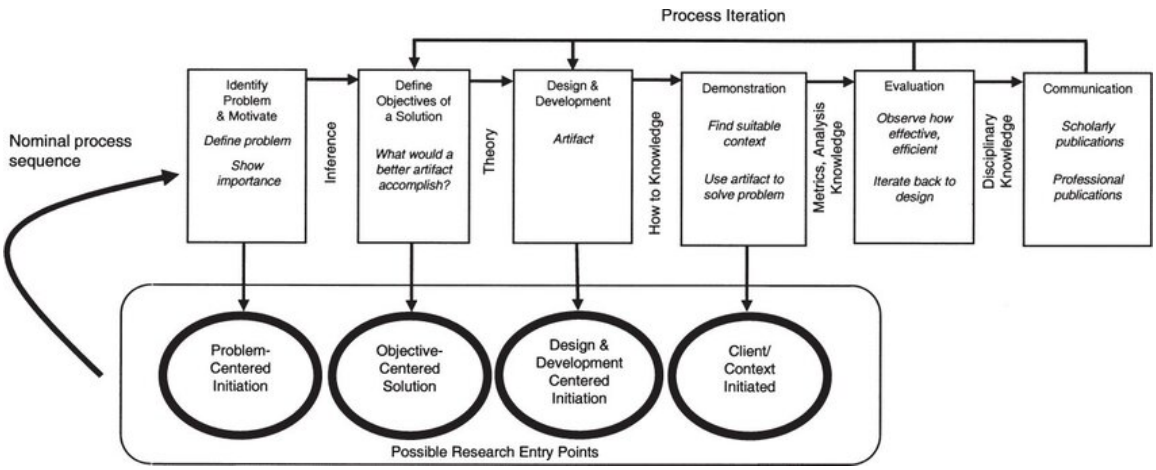


Figure 2 - Design Science Research Process Model [6]

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].

This research will follow the DSR methodology, addressing its key phases. The "Identify Problem & Motivate" phase will focus on understanding the importance of mitigating water leakage in a non-invasive manner, and evaluating how this research can contribute to reducing water wastage. In the "Define Objectives of a Solution" phase, the system's architecture will be established, and the key questions the system aims to answer will be outlined. During the "Design and Development" phase, the first artifact will be implemented aligned with the previously defined architecture. The subsequent phases, "Demonstration" and "Evaluation," will involve testing the system's effectiveness and accuracy. Following this, an improved artifact will be developed and subjected to further demonstration and evaluation cycles until the optimal solution is achieved. Given the potential impact of this research, it is crucial to communicate the results to the scientific community. Therefore, a paper will be developed and prepared for submission to a relevant academic conference in this field, ensuring that the research is disseminated to both professionals and scholars working in similar areas of study.

1.3. Research Questions

In this study, we explore the IoT field, specifically water monitoring and control systems. The research questions below serve as compass, guiding us through this research and helping us achieve the objectives delineated for this project.

RQ1: How effective is the implementation of a multifactor IoT system for water leak detection in preventing/reducing water leaks in the outdoor space?

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

The definition of these Research Questions naturally leads to the formulation of a set of related Hypotheses which aim to provide a scientific response to their corresponding Research Questions. The formulated hypotheses are presented below.

RQ1_H1: Correlating metrics from multiple sensors, such as water meter readings, soil humidity, and traditional water leak detection, will enhance the system's accuracy in identifying and alerting to potential water leaks.

RQ1_H2: 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.

RQ2_H1: Integrating a camera for water meter readings will allow the system to analyse and monitor household water consumption, contributing to water conservation efforts.

The objective of this dissertation shall then be to prove these Hypotheses' confirmation, therefore responding to the Research Questions.

CHAPTER 2

Literature Review

Once recognized the major significance of water conservation, the global community has collectively tried to create countless innovative solutions to detect and mitigate water wastage, especially for reducing water leakage. These strategies often incorporate IoT due to the effectiveness of this technology [8].

To contribute to this ongoing research, it is essential to comprehend the existing efforts that have already been made. Furthermore, it is necessary to discern best practices and pinpoint areas for refinement in prior studies. Therefore, this exploration lays the groundwork for our project, allowing for the implementation of a unique and pertinent solution in water management.

2.1. Literature Review Method

Preferred Reporting Items for Systematic Reviews and Meta-Analyses, commonly known as PRISMA is a widely recognized and rigorous methodology for conducting systematic literature reviews. Developed to enhance the transparency and quality of literature reviews, PRISMA provides a structured framework to systematically identify, select, and synthesize relevant studies on a particular topic [9]. Therefore, this methodology was applied in this research to acquire relevant information on this topic.

For the purpose of exploring pertinent scholarly literature, Google Scholar [10] was employed. It is important to note that Google Scholar functions as an academic search engine rather than a dedicated database. Unlike traditional databases, Google Scholar uses specialized algorithms to evaluate content quality, which is not the optimal way to do it. Consequently, a more thorough evaluation of the papers was required, prioritizing those sourced from peer-reviewed journals.

Literature for three different research topics was conducted through dedicated databases such as Scopus. The literature research topics are as follows:

- Internet of Things methods for Water Leakage Detection
    - Search query: (Internet of Things) AND (Water AND Leakage AND Detection) AND (Architecture OR Systems OR Methods)
    - Time filter: From 2016 until now
    - Language: English and Portuguese

- Impact of Water Consumption Data in Water Conservation
    - Search query: (Internet of Things) AND (Water AND Conservation) AND (Water AND Consumption)
    - Time filter: From 2016 until now
    - Language: English and Portuguese
- Environmental Impact of Water Conservation
    - Search query: (Water AND Leakage AND Detection) AND (Water AND Conservation) AND (Water AND Scarcity)
    - Time filter: From 2010 until now
    - Language: English and Portuguese

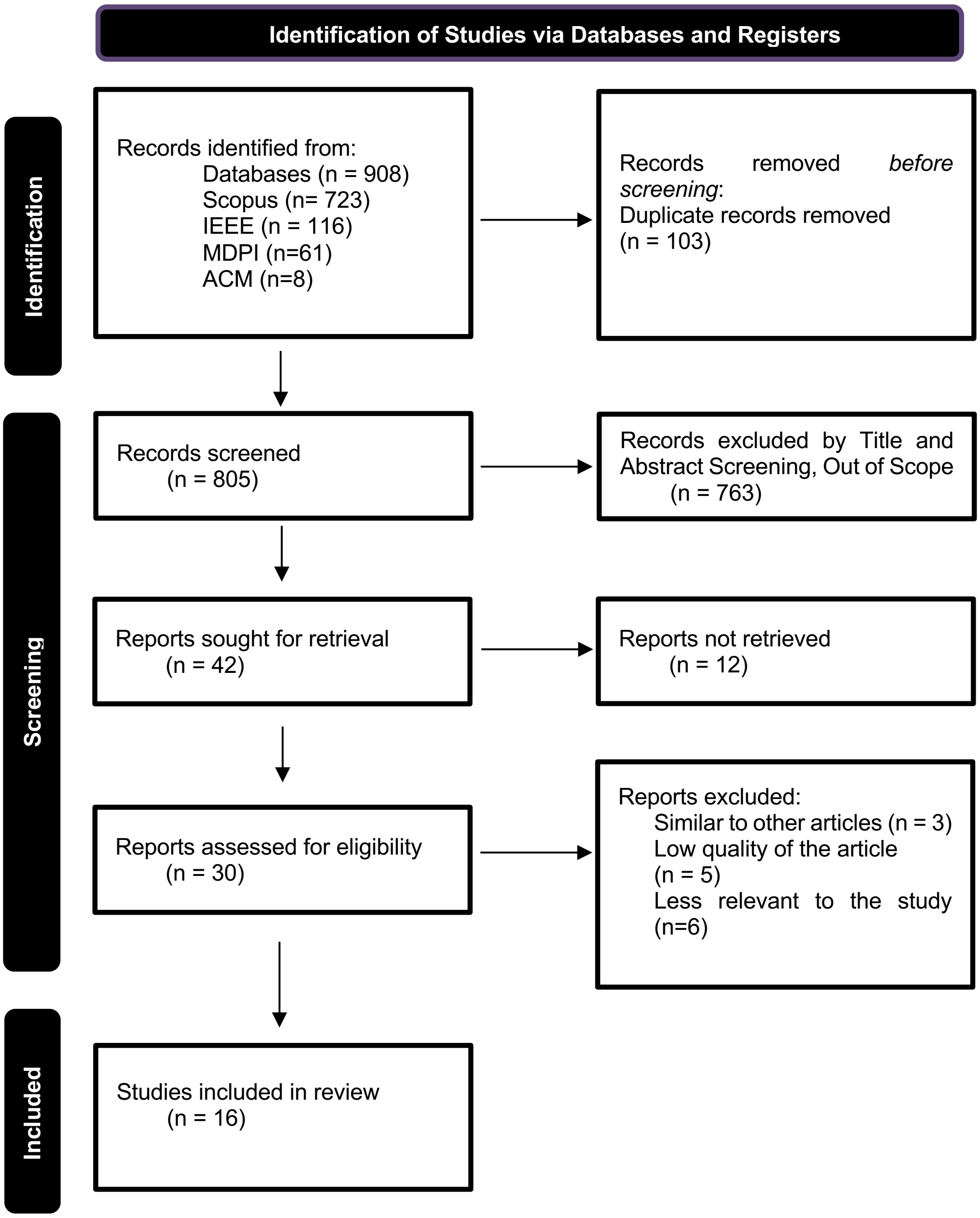


Figure 3 - PRISMA Flow Diagram [11]

On Figure 3 it is possible to analyse the flow diagram of the PRISMA methodology, which outlines the steps undertaken to identify and select the studies included in this research. Initially, 908 studies were identified, but after the screening step, only 30 were selected eligible for further review. Of these, 16 studies were ultimately included in the final analysis.

Table 1 - PRISMA Results

Reference	Title	Year	Source
Shiddiqi et al. [12]	Leak Detection using Non-Intrusive Ultrasonic Water Flowmeter Sensor in Water Distribution Networks	2022	ACM
Daadoo et al. [13]	Optimization Water Leakage Detection using Wireless Sensor Networks (OWLD)	2017	ACM
Nurwarsito e Irsyad [14]	The Implementation of Water Discharge Monitoring and Leakage Detection in an Internet-of-Things-Based PDAM Water Pipe Network With MQTT	2021	ACM
Grace et al. [15]	A Review on the Monitoring and localization of leakage in water distribution system	2019	IEEE
Witham et al. [16]	Batteryless Wireless Water Leak Detection System	2019	IEEE
Boudville et al. [17]	IoT Based Domestic Water Piping Leakage Monitoring and Detection System	2023	IEEE
Chowdhury et al. [18]	IoT-GSM Based Controlling and Monitoring System to Prevent Water Wastage, Water Leakage, and Pollution in the Water Supply	2022	IEEE
Thenmozhi et al. [19]	IoT Based Smart Water Leak Detection System for a Sustainable Future	2021	IEEE
Sithole et al. [20]	Smart water leakage detection and metering device	2016	IEEE

Tewari et al. [21]	Comparative Study of IoT Development Boards in 2021: Choosing right Hardware for IoT Projects	2021	IEEE
Vamsi Thalatam et al. [22]	An IoT Based Smart Water Contamination Monitoring System	2023	IEEE
Arsene et al. [23]	Advanced Strategies for Monitoring Water Consumption Patterns in Households Based on IoT and Machine Learning	2022	MDPI
Teixidó et al. [24]	Low-Power Low-Cost Wireless Flood Sensor for Smart Home Systems	2018	MDPI
Alghamdi et al. [25]	LoRaWAN Performance Analysis for a Water Monitoring and Leakage Detection System in a Housing Complex	2022	Scopus
Seyoum et al. [26]	A Shazam-like Household Water Leakage Detection Method	2017	Scopus
Garlisi et al. [27]	Leakage Detection via Edge Processing in LoRaWAN-based Smart Water Distribution Networks	2022	Scopus

The Table 1 presented above details the PRISMA results, listing the title, year, and source of the studies incorporated into this research.

The PRISMA methodology facilitated the collection of a wide array of studies, enabling a deeper understanding of the research area and the extent of current state of the art. Although a substantial number of studies were initially identified, during the screening phase the final selection was refined by narrowing the focus to the most relevant works. Therefore, the results obtained were highly positive, contributing to the establishment of a solid foundation of knowledge, which proved extremely useful for the development of this research. In the following sub-sections, the studies selected will be analysed outlining the most relevant information gathered.

2.2. Water Demand and Water Management in the World

Water stands as a vital resource, crucial for the sustenance of human life and the viability of most living organisms. Consequently, the demand for this resource is very high, with a consistent annual increase estimated at approximately 25 trillion litres of water per year over the past forty years. This trend results from the combination of population growth, socio-economic development, and changes in consumption patterns [1].

As shown in Figure 4, there is a notable upward trend in water consumption, with agriculture emerging as the principal consumer of this vital resource. Moreover, both industrial operations and municipal entities have exhibited a high demand in their respective water consumption rates. Half of the water withdrawn for domestic uses is provided from groundwater.

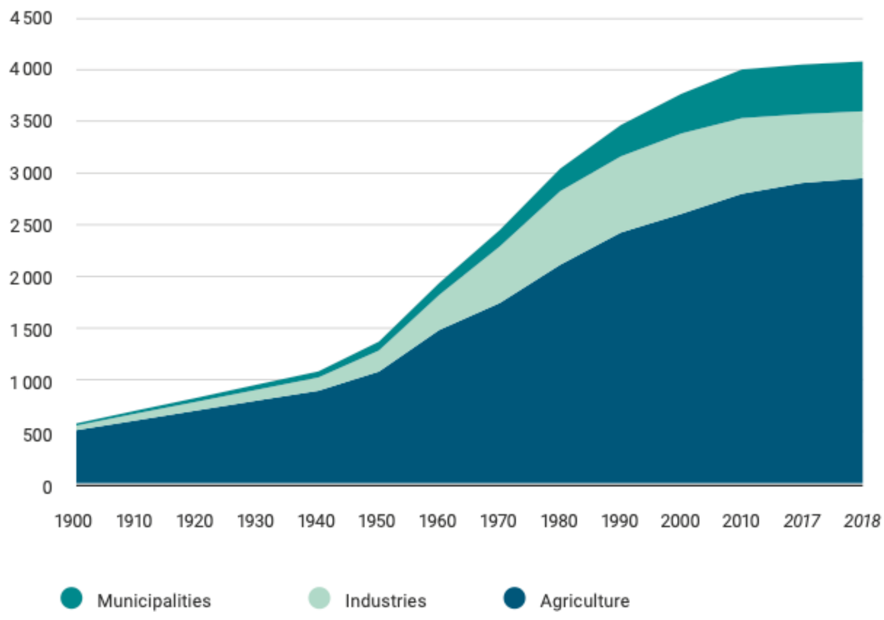


Figure 4 - Evolution of global water withdrawals, 1900–2018 (km3/year) [1]

Hence, given the scope of this project, it is imperative to investigate the water consumption within the municipalities. Consequently, a study [28] conducted with data from the Cascais City Council was analysed, which provided insights into the identification and quantification of primary fluxes within both the natural and urban water cycles. This analysis revealed that a significant proportion of the municipality's water consumption is attributed to the irrigation of green spaces, representing 67% of the municipality's total consumption. Further research has shown that the Cascais City Council aims to implement more efficient irrigation systems, as well as controllers capable of adjusting the volume of irrigation water according to the weather conditions and the soil's needs [29].

2.3. Solutions for Water Leakage Detection with IoT

Various kinds of solutions can be applied for the detection of water leaks employing IoT technology. The selection of a specific approach depends on the intended purpose of the system, which could involve detection at the supply network level, individual household level, or other specified targets. Therefore, several papers addressing different kinds of solutions to mitigate water wastage were analysed.

One of the common methodologies employed for the detection of water leaks is based on the monitoring of water pipes. Certain methodologies encompass the inspection of pipelines within the distribution network to identify leaks, while other approaches focus on the analysis of leaks manifesting within the internal piping system of residential structures. These methodologies include the utilization of flow sensors, thermal cameras, hub sensors (sensors connected to a central device for data transmission called hub), light-dependent resistors (LDR), among other techniques that allow for the detection of water leaks [15].

Daadoo et al. [13] propose 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.

Another research uses data gathered from flow sensors implemented in the pipeline system and then employs the Local Outlier Factor (LOF) Algorithm to successfully detect sudden flow changes indicative of leaks. This algorithm demonstrates robustness by effectively addressing small and gradual leaks. The developed system integrates ultrasonic sensors and a Modbus for efficient data communication, storing and displaying real-time water flow data on a dashboard [12].

Tina et al. [30] propose an IoT-based solution for water leakage detection, using two sensors placed at the source and destination points of the distribution pipe to measure water flow rates. The prototype demonstrates that comparing the volume of water at the starting point with that at the endpoint can effectively identify leaks. However, the article concludes that further research is needed, particularly focusing on distance calculation, to pinpoint the exact location of leaks and enhance the efficiency of this system.

Thenmozhi et al. [19] introduced a system that uses IoT for the precise localization of water leaks within a pipeline infrastructure. This innovative approach relies on resistance and distance metrics, to accurately pinpoint the district where the leak is happening. Incorporating these metrics not only facilitates the identification of the affected district but also allows the shutdown of the water supply at that point.

Seyoum et al. introduce 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 cataloging sound signals in a database. The final step requires processing through sound signal identification software, similar to the Shazam app for music, searching the database for related sounds [26]. This innovative approach holds significant promise as it uses an alternative set of sensors with potential applications in water leakage 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 standard 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 [24].

Another project proposed a system that enables the tracking of water usage and the detection of potential water leaks within specific water consumption thresholds. The core of this system lies in the usage of a cost-effective flow meter, strategically positioned to collect comprehensive data, subsequently analysed in real-time. This research highlights an interesting mindset— that even by using low-cost components, it is possible to develop an effective and practical device [20].

An alternative approach was based on the implementation of a system utilizing energy-generating leak detection sensors. A customized printed circuit board has been developed to autonomously power a Bluetooth Low Energy (BLE) beacon directly from sensor outputs, thereby surpassing the necessity for external power sources like batteries. The BLE beacon transmissions are seamlessly integrated into an innovative Bluetooth mesh network tailored for endpoint user notifications [16].

Arsene et al. [23] 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. 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 analyse 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 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.

2.4. Technologies used for IoT Systems

The relevance of IoT has exhibited exponential growth, which leads to the expansion of the array of IoT components, such as sensors and boards available. These components exhibit variations in aspects such as material quality, features, and cost. Therefore, determining the most suitable components for a specific project becomes a complex task. The selection process requires a strategic approach to ensure the seamless integration of components allowing the development of efficient and cost-effective IoT systems [21].

Consequently, a comprehensive analysis of commonly used architectures in IoT projects, particularly within the domain of water consumption management and water leakage detection, is essential to ensure the optimal selection of sensors and components for this project.

Daadoo et al. [13] project employs an Arduino Mega 2560 as the microcontroller and SIMCOM SIM 900 as the GSM module Unit. This unit enables SMS to be sent and received with the user, allowing for the interaction with the system due to according to the data provided. Arduino Mega has 256Kb of Flash Memory and 54 Pins. This system also incorporates a Water Sensor, Ultrasonic Sensor, Pump, and Solenoid Valve. Nurwarsito e Irsyad [14] project also requires an Arduino Mega 2560 as the microcontroller along with 3 modules: a 3G Module, a GPS Module, and a Sensor Debit Air.

Sithole et al. [20] system is composed of an Arduino EEPROM, Water Flow Meter, LED indicators, LCD Display, and a GSM/GPRS Module, all powered by solar energy. The GSM Module sends the data acquired from the flow meter by the Arduino microcontroller to the internet.

Zehui et al. [31] system integrates a variety of components, including the STM32G030F6P6 as the main control chip, along with modules for water flow detection, water pressure detection, a PH detection module, a Temperature detection module, TDS detection module and solenoid valve for remote control. The STM32G030F6P6 has 32Kb of Flash memory, 8Kb of RAM, and 20 Pins.

Arduino Uno is used in several papers analysed in this study. This board has 32Kb of Flash memory, 2Kb of Ram and 14 Pins [32]. Vamsi Thalatam et al. [22] combines Arduino Uno with Analog to Digital Converter, pH sensor, turbidity sensor, temperature sensor, and other electronic components, to estimate water contamination. Tina et al. [30] utilize Arduino Uno connected to two water flow sensors and an LCD Display, to calculate the difference in water quantity between the source and destination.

ESP8266 is a microcontroller with a Wi-Fi module that allows for sensors and other components to connect with the internet, generally known as NodeMCU. Therefore, it is commonly used in IoT projects, and many systems analysed in this research require this module. Zehui et al. [31] system uses ESP8266-01S WI-FI module to communicate the information gathered in the STM32G030F6P6 through the internet. Vamsi Thalatam et al., Tina et al., Arsene et al., 2022, Thenmozhi et al., 2021 all require the ESP8266 sensor to connect with Wi-Fi and transmit the information gathered by the sensors.

Raspberry Pi is a micro-computer widely adopted and cost-effective component for IoT architectures, offering a compact yet powerful single-board computer solution. It facilitates data collection, gathering information from several sensors and then connecting with external systems or cloud services [15].

The Message Queuing Telemetry Transport Protocol (MQTT) is composed of 3 components: publisher, broker, and subscriber. Several publisher's nodes can publish data collected by the Arduino microcontroller. After that, the broker saves the information from publishers and then sends the data to the subscribers per topic request [14].

Low Power Wide Area Network (LPWAN) technologies are extremely used for monitoring and controlling smart systems at large scale. This kind of connection has several advantages, like wide coverage and low power consumption, with batteries lasting up to 10 years [27]. The Long-Range Wide-Area Network (LoRaWAN) is one of the most common LPWANs. LoRaWAN has the characteristic advantages of LPWAN (wide range cover and low power), but it is also characterized by its bandwidth scalability, high robustness, and overall improved network capacity. LoRaWAN presents a coverage of up to 2-5km in urban areas, 15km in suburban and 45km in rural areas [25].

2.5. Data Analysis and Storage Platforms used for IoT Systems

Once every component of the IoT system is established, it is crucial to choose a method for both storing and analysing the acquired data. This process is essential for the extraction of relevant information from the data that was collected and to act upon this information. In pursuit of this objective, a comprehensive investigation was conducted to identify platforms conventionally used for storage, analysis, and visualization of sensor-derived data.

OneNet Cloud Platform allows to receive, process and store the data collected by an IoT system. This platform has a powerful big data analysis that enables real-time monitoring of the data. At the same time, this platform can provide several data interfaces, useful for developers to create secondary applications. Thus, users can view monitoring data, and set alarm thresholds and remote control switches [31].

Vamsi Thalatam et al. [22] introduce a different platform for Cloud storage of the collected data, named ThingSpeak. ThingSpeak is an IoT analytics platform that allows the data analysis and data visualization in the cloud, providing instant visualizations of data posted by sensors into the platform, which enables real-time data visualization [33].

Blynk is a platform that allows for monitoring and controlling several IoT Devices and at the same time store the data collected by them. This system is capable of connecting with Google Sheets, and integrating the data with the Google Cloud system [17]. Blynk also has a dedicated cloud that can store the data collected by the system [18]. Blynk's App simplifies the access to this information and control of the IoT devices. Blynk also provides libraries and code examples for various hardware platforms such as Arduino, Raspberry Pi, ESP8266, ESP32, and others. These libraries enable developers to easily connect their hardware to the Blynk platform and implement several functionalities like controlling actuators or sending notifications.

2.6. User Interfaces for Sensor Data Visualization

Following the data collection and data analysis of the information obtained by the IoT system, the critical phase unfolds, delivering the insights to the end user. Seamless accessibility is extremely important in this process, aiming to provide the user with an interface that not only ensures convenience but also allows for easy comprehension and fast decision-making. Consequently, it is crucial to analyse other research approaches to this topic.

One possible way to deliver the information obtained to the end user is to develop a dedicated application. Some of these applications allow users to observe the information while others also allow for users to take action and control the system through the application. Daadoo et al. 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 [13].

Teixidó et al. [24] IoT System also integrates an application, available for Android and iOS, that lets the user monitor and control the system.

Zehui et al. [31] also integrate an application that allows the user to connect to the OneNet cloud platform to access real-time data, receive alerts, and remotely control the system. At the same time, this app can be used to monitor water consumption.

Daadoo et al. [13] introduces another unique way to deliver information to the end user, by sending Short Message Service (SMS).

CHAPTER 3

System Architecture

After a comprehensive examination of the relevant studies concerning the monitorization of water consumption 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.

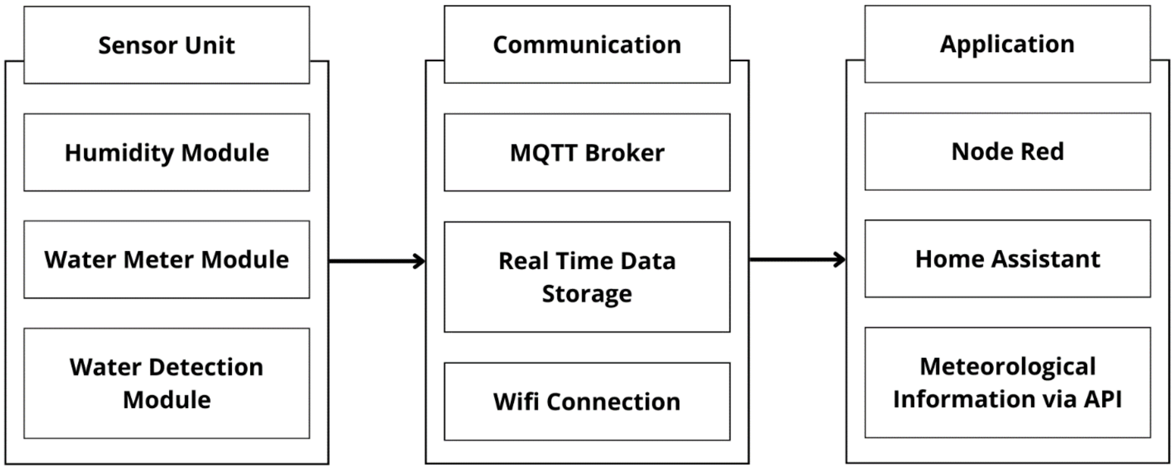


Figure 5 - System Architecture

Upon the presentation of the system's overall architecture (Figure 5), 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 humidity, household water consumption, and the presence of water in outdoor settings.

3.1. Humidity Module

The humidity module is composed of a soil moisture sensor (A0131MS), which measures soil moisture based on changes in capacitance. A temperature and humidity sensor (DHT 22 sensor) was also integrated to enhance the information available to the user. This setup is managed by an Arduino MKR Wi-Fi 1010 board, which facilitates seamless connectivity of the sensors to a Wi-Fi network and a connection to a Node-Red instance using an MQTT Broker. Both sensors are powered by a solar panel, ensuring continuous operation in an energy-efficient manner (Figure 6).

Figure 6 - Humidity Module

3.2. Water Meter Module

This module employs an ESP32-CAM to continuously capture and record images of the water meter and consequently gather water consumption data. 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 (Figure 7).

Figure 7 - Water Meter Module

3.3. Water Detection Module

The water detection module employs 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 [34]. 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 (Figure 8).

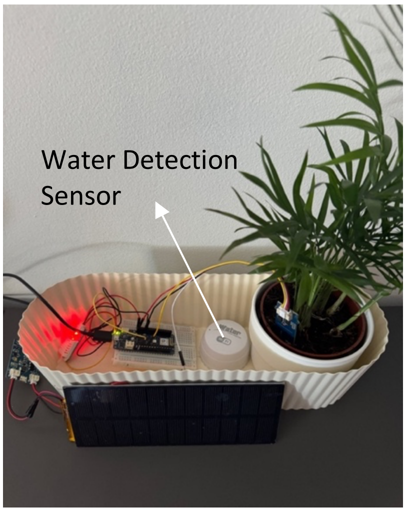


Figure 8 - Water Detection Module

While the sensor unit collects data, it seamlessly shares it with the internet through 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 analysing and presenting this data. The Communication and Application layers are hosted on a Raspberry Pi 3. Node-Red consolidates and allows for data management within a unified platform, facilitating seamless and efficient data collection. Additionally, it ensures the continuous and effective storage of this data in a MariaDb database, used as a backup for all the metrics being collected. Home Assistant enables real-time visualization of the data gathered on Node-Red and offers an intuitive interface for monitoring various parameters. Moreover, this platform allows the configuration of automations, which will be used to alert the user in case of a water leak. Consequently, end-users gain access to several valuable metrics concerning their water consumption and primarily access to an alerting system for potential water leakages.

To ensure the robustness of this system, meteorological data is integrated to mitigate false alarms arising from precipitation. This integrated approach not only enhances the system's reliability but also allows for continuous refinement, ensuring its effectiveness in addressing water leakage concerns while providing valuable insights into consumption patterns.

After presenting the three modules that comprise the sensor unit, it is essential to emphasize the overall system flow, which integrates all the collected information with the communication and application units. The diagram below (Figure 9) illustrates the process flow, starting from data collection through to its presentation to the end user, including the generation of alerts in the event of a detected leakage.

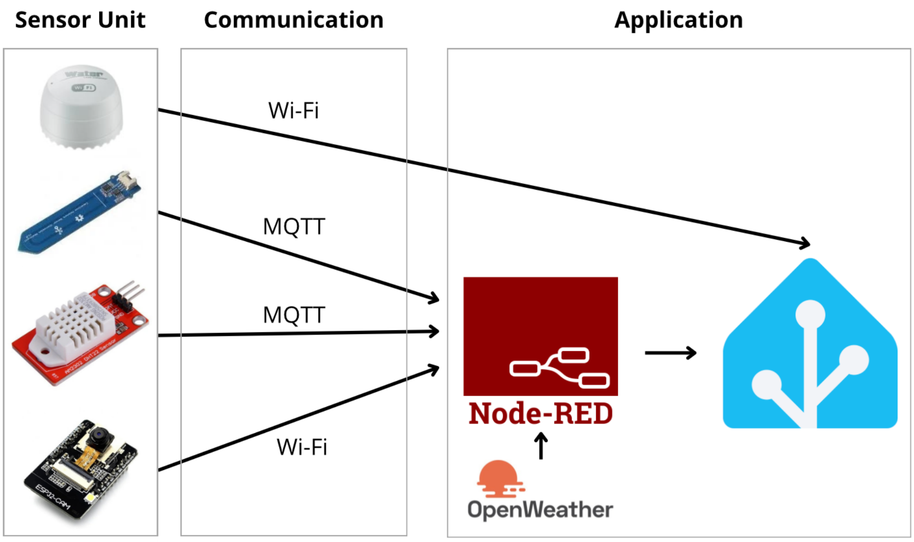


Figure 9 - Diagram of the System Architecture

The data collected by each sensor is transmitted to Node-RED and subsequently forwarded to Home Assistant. The exception is the water detection module, which connects directly to Home Assistant. Additionally, meteorological data is retrieved via an API, integrated into Node-RED, and then sent to Home Assistant for centralized management.

CHAPTER 4

System Implementation

This chapter will outline all the procedures undertaken to implement the water leakage detection system, as well as highlight some of the challenges encountered. Upon finalizing the system architecture and the necessary materials were gathered, followed the assembly process.

Recognizing that the Raspberry Pi (RPI) would function as the core component of the entire system, the first step was to configure and prepare it to receive all the collected information. For that, the Raspberry Pi OS was installed on the Raspberry Pi 3, following the set-up of RealVNC, a tool that enables remote access to the Raspberry Pi from another computer [35]. This tool is freely available and comes pre-installed on the RPI, only requiring activation through the system settings. It allows remote access to the Raspberry Pi from outside the configured Wi-Fi network, providing a valuable means to ensure that everything is functioning as intended.

Subsequently, Node-RED was installed, as it will be used as the platform for accessing and managing the data collected from the majority of components of the system [36].

Thereafter, Home Assistant was integrated into the system. Home Assistant is versatile and can be operated on various hardware platforms, such as a Raspberry Pi, although it is typically installed with a dedicated operating system, known as Home Assistant OS. Given that the Raspberry Pi was already configured with Raspberry OS for Node-Red, it was necessary to install a different version of Home Assistant, specifically the Home Assistant Container [37].

To install Home Assistant Container, Docker was required. Docker is a platform that enables applications to run in isolated environments known as containers. The installation process involved pulling the Home Assistant image from Docker Hub and running it as a container. This approach offers a lightweight and flexible method for running Home Assistant, allowing its use without the need for a full Home Assistant OS installation.

However, this version of Home Assistant is somewhat limited, as it does not support the built-in installation of Add-ons. To accomplish this, it was also necessary to install HACS (Home Assistant Community Store) [38]. This step was crucial for the system, as it enabled the installation of the Node-Red Companion Add-on, which is essential for accessing Node-Red data within Home Assistant.

Finally, MariaDB (open-source relational database management system that is based on MySQL) was installed on the Raspberry Pi to facilitate the storage of all collected data in a database [39].

4.1. Humidity Module

Once all the required tools were installed on the Raspberry Pi, the sensor unit was implemented incrementally, beginning with the humidity module. Both sensors were configured using Arduino code to collect data on temperature, humidity, and soil moisture and to transmit this information via Wi-Fi. Therefore, the Arduino board transmits the collected data via Wi-Fi using the MQTT protocol. This data is then visualized and managed through Node-RED. The following diagram illustrates the Node-Red flow responsible for this process (Figure 10). Upon receiving the data, a flow variable is created for each metric, which is then sent to Home Assistant as its own separate entity.

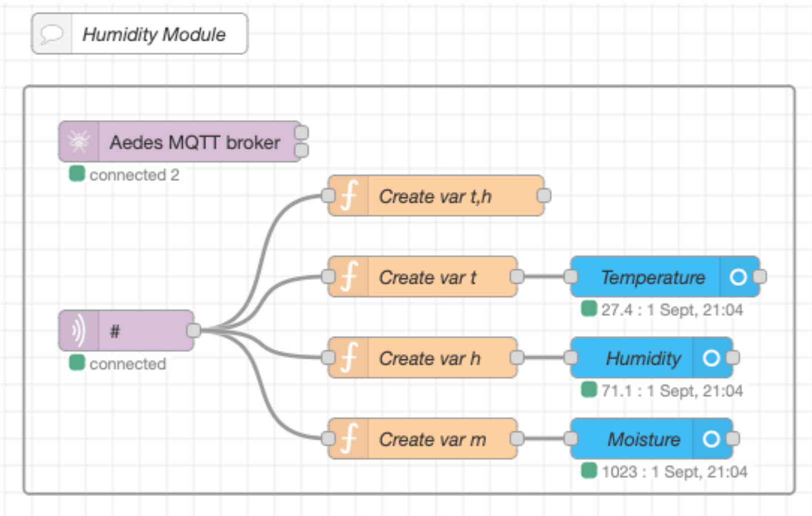


Figure 10 - Humidity Module Node-Red Flow

Information is stored at 5-minute intervals in two distinct tables within the database: one dedicated to temperature and humidity data (Table TH), and the other to soil moisture (Table M), as shown on Figure 11 and Figure 12.

MariaDB [teste]> select * from TH_2 order by id desc limit 5;

ID	TIME_KEY	TEMPERATURE	HUMIDITY
386402	2024-09-01 21:16:58	27.3	71.1
386401	2024-09-01 21:11:58	27.4	70.8
386400	2024-09-01 21:06:58	27.4	71
386399	2024-09-01 21:01:58	27.4	71.1
386398	2024-09-01 20:57:57	27.4	71.3

Figure 11 - Example of Data Stored in Table TH

MariaDB [teste]> select * from M order by id desc limit 5;

ID	TIME_KEY	MOISTURE
334547	2024-09-01 21:16:58	1023
334546	2024-09-01 21:11:58	1023
334545	2024-09-01 21:06:58	1023
334544	2024-09-01 21:01:58	1023
334543	2024-09-01 20:57:57	1023

Figure 12 - Example of Data Stored in Table M

4.2. Water Meter Module

Having established the collection of humidity data, the effort shifted to acquire data about water consumption from the water meter using the ESP32 CAM. The camera was employed above the water meter to constantly record its display. 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 analysed using a node equipped with the Tesseract Optical Character Recognition (OCR) algorithm to extract the numerical data from the image. After that, the data collected is sent to Home Assistant in a dedicated entity. Below the diagram exemplifies the process occurring in Node-Red (Figure 13).

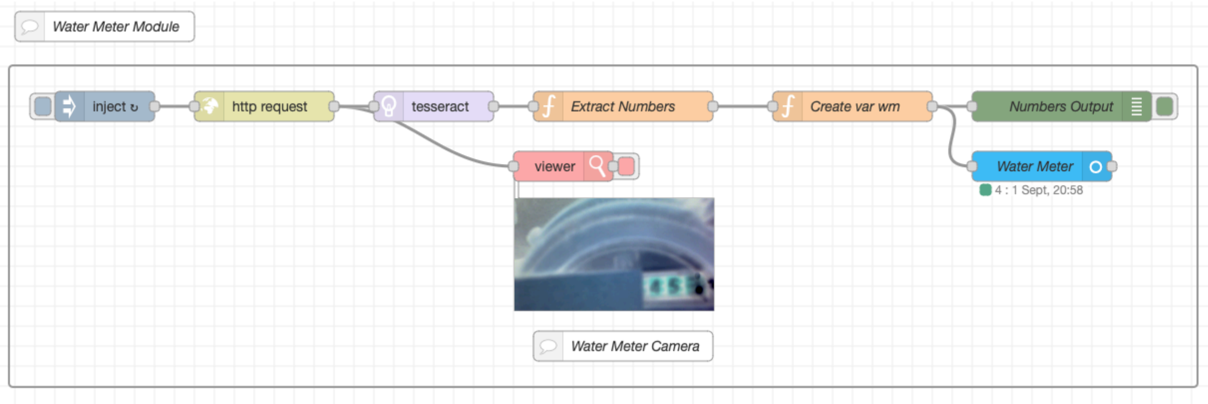


Figure 13 - Water Meter Module Node-Red Flow

To enhance the accuracy of the Tesseract OCR, it was essential to improve the quality of the images captured by the camera. Given the low quality of the ESP32 CAM, it became necessary to configure a set of specific parameters for this purpose. Multiple tests were conducted to determine the optimal combination of these settings. The table below details the final camera settings that were established (Table 2).

Table 2 - Camera Configurations

Settings	**Value**
Resolution	HD (1280x720)
Quality	4
Brightness	-2
Contrast	-2
Saturation	-2
Special Effect	Negative
WB Mode	Home

The extracted water meter readings are subsequently recorded in a dedicated database table (Table WM), thereby facilitating a detailed and continuous record of water consumption (Figure 14). This module plays a crucial role in measuring and monitoring water usage, which is essential for the overall functionality of this project.

```
MariaDB [teste]> select * from WM order by id desc limit 5;
+------+---------------------+-------------+
| ID   | TIME_KEY            | WATER_METER |
+------+---------------------+-------------+
| 7415 | 2024-09-01 21:16:58 | 4           |
| 7414 | 2024-09-01 21:11:58 | 4           |
| 7413 | 2024-09-01 21:06:58 | 4           |
| 7412 | 2024-09-01 21:01:58 | 4           |
| 7411 | 2024-09-01 20:57:57 | 4           |
+------+---------------------+-------------+
```

Figure 14 - Example of Data Stored in Table WM

4.3. Water Detection Module

The water leak alarm detects the presence of water when it reaches the sensor, providing the earliest indication of a potential water leak. Therefore, it is essential to integrate this information into the system. The sensor employed in the system is integrated with the Tuya platform, which facilitates the development, management, and customization of IoT devices. Every time the alarm detects the presence of water, it registers that information, which is stored in the cloud via the Tuya Smart application. This data can be accessed through Tuya's integration with Home Assistant, allowing seamless interaction between the two platforms. Additionally, the data can be queried in Node-Red through nodes that are integrated with Home Assistant.

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 and a more accurate leak detection in outdoor settings.

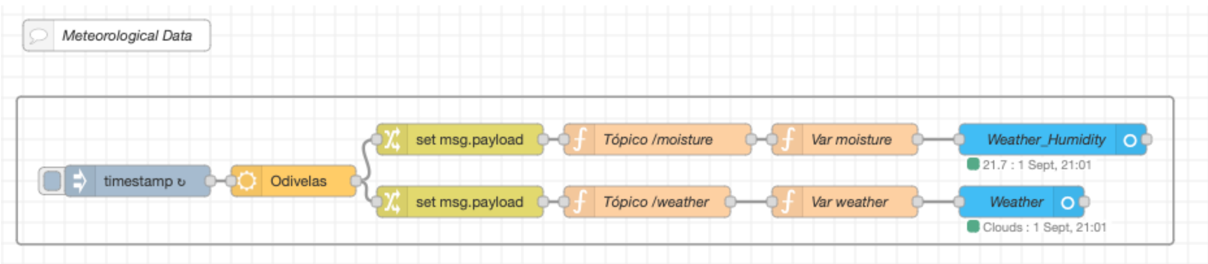
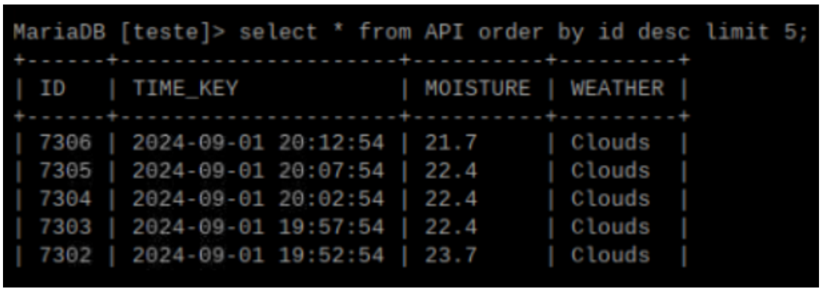


Figure 15- Meteorological Data Node-Red Flow

The diagram above represents the Node-RED flow that executes this process (Figure 15). The OpenWeatherMap API was employed to integrate meteorological data into Node-RED. Following this, a specific topic is created for each metric, and a corresponding flow variable is established. These variables are then sent to Home Assistant as two specific entities. This process is repeated every five minutes, and the collected data is recorded in the database (Table API), as shown in Figure 16.



```
MariaDB [teste]> select * from API order by id desc limit 5;
+------+---------------------+----------+---------+
| ID   | TIME_KEY            | MOISTURE | WEATHER |
+------+---------------------+----------+---------+
| 7306 | 2024-09-01 20:12:54 | 21.7     | Clouds  |
| 7305 | 2024-09-01 20:07:54 | 22.4     | Clouds  |
| 7304 | 2024-09-01 20:02:54 | 22.4     | Clouds  |
| 7303 | 2024-09-01 19:57:54 | 22.4     | Clouds  |
| 7302 | 2024-09-01 19:52:54 | 23.7     | Clouds  |
```

Figure 16 - Example of Data Stored in Table API

4.5. Node-Red Configuration

To ensure the proper functioning of the system, it was essential to configure Node-Red. To enhance the functionality of Node-RED, it is essential to install collections of nodes, referred to as Node-RED Palettes. These palettes are useful to integrate various systems and devices, expanding the platform's capabilities. Table 3 lists the Node-Red palettes that were required for the system, along with their respective usage.

Table 3 - Node-Red Pallets

Node-Red Pallete	Usage
Node-red-contrib-aedes	Node-Red module that provides MQTT broker functionality directly within a Node-Red environment
Node-red-contrib-home-assistant-websocket	Integration for Node-Red that allows real-time communication with Home Assistant
Node-red-contrib-image-tools	Collection of nodes used for handling and processing images within a Node-RED flow
Node-red-contrib-tesseract	Integration of Tesseract OCR (Optical Character Recognition) engine into Node-Red flows
Node-red-node-mysql	Collection of nodes that allows the interaction of MySQL databases directly within Node-Red flows
Node-red-node-openwearthermap	Node-Red module that allows the integration of OpenWeatherMap API inside Node-Red, to access real-time weather data

Additionally, specific configurations are required to integrate the data collected by Node-RED into Home Assistant. This involves creating new devices and entities within Node-RED, which will be automatically added to Home Assistant using the Sensor node. These configurations ensure seamless data exchange and synchronization between Node-RED and Home Assistant, enabling enhanced control and automation within the smart home environment.

4.6. Home Assistant Automations

Once the sensor data is consolidated into Home Assistant, the configuration of the water leakage detection alarm followed. This was accomplished using Home Assistant's Automations, which allow to define specific triggers, conditions, and actions based on the collected data, creating a highly customizable alarm system. To elevate the system's effectiveness, were created some artifacts leveraging different conditions to detect water leak. In the next chapter each artifact will be accessed to determine which combination of metrics creates the most accurate alert system.

CHAPTER 5

System Evaluation and Data Analysis

Since the water leakage detection system was implemented, it became crucial to assess its effectiveness and explore different variations to identify the most optimal combination of metrics for improved leak detection. This evaluation will help determine which specific metrics or configurations enhance the system's performance, ensuring more accurate and timely leak detection. The Water Detection Module was employed as the trigger mechanism in all artifacts, since it is the first to detect the leakage. Upon moisture detection, a series of predefined criteria are evaluated, which, if met, generate the appropriate alert for the user.

Given that the system is being implemented within a controlled indoor environment, as opposed to an outdoor setting such as a garden, it will be necessary to simulate a water leak for testing purposes.

5.1. First Artifact

The initial artifact integrates all relevant metrics collected. In this context, the automation implemented in Home Assistant is described in the table below (Table 4).

Table 4 - Home Assistant Automation for the first artifact

Trigger	Water Leak Alarm became moist
Condition	Soil Moisture above 1000
	Humidity in that Location below 40% (Not Raining)
	Water Consumption increased
Action	Send a Notification to the iPhone Home Assistant App

After implementing the first artifact, ten water leakage simulations were conducted to evaluate the system's performance and behaviour. All the conditions above were guaranteed to simulate the occurrence of leakage. The system was able to detect 4 of the 10 water leakages simulated.

Unfortunately, the water consumption metrics captured by the camera system have proven to be insufficiently accurate and occasionally unavailable. Consequently, during simulations of water leaks, the system was unable to detect the corresponding increase in water consumption. The problem lies on the data quality rather than in the automation conditions applied. As a result, this artifact should not be deemed ineffective. To provide a more accurate evaluation of the automation's performance, reliable and precise water consumption data would be required.

5.2. Second Artifact

Considering the low accuracy of the automation when used the consumption of water as condition, in the second artifact it will not be considered. The table below represents the automation settings for this artifact (Table 5).

Table 5 - Home Assistant Automation for the second artifact

Trigger	Water Leak Alarm became moist
Condition	Soil Moisture above 1000
	Humidity in that Location below 40% (Not Raining)
Action	Send a Notification to the iPhone Home Assistant App

After eliminating the misleading data from the water meter, another 10 simulations of water leakage were conducted. This artifact functioned correctly, successfully detecting each simulated water leak. Consequently, a notification was sent to the designated mobile device, alerting the user to the potential occurrence of a water leak.

By excluding the data from the water meter, the system becomes slightly less accurate, as it no longer considers abnormal water consumption. However, given that the recorded values are often unreliable, it is preferable for the system to disregard this data to maintain overall effectiveness.

5.3. Data Analysis

After accessing both artifacts, another way to evaluate the system was to analyse the data by all the sensors. The data stored in the MariaDB database was extracted and organized into three separate CSV files: one containing Temperature and Humidity data, another focused-on Soil Moisture measurements, and a third dedicated to Water Consumption data. Each file included the following variables: the ID of the entry into the corresponding database table, the timestamp of the measurement, and the recorded value or values. This dataset comprised five weeks of collected information, from August 5th to September 8th (Weeks 32 to 36). The results of this analysis are presented in the following graphs, offering a comprehensive overview of the system's performance and the environmental conditions monitored.

The collection of data through sensors is sometimes subject to the occurrence of outliers, which can arise from various factors such as power failures, sensor malfunctions, or environmental interference. However, in the case of temperature and humidity, the data was accurately collected, eliminating the need for extensive data preparation. As illustrated in Figure 17, over the five-week period, a consistent trend was observed: temperature gradually decreased, while humidity increased correspondingly.

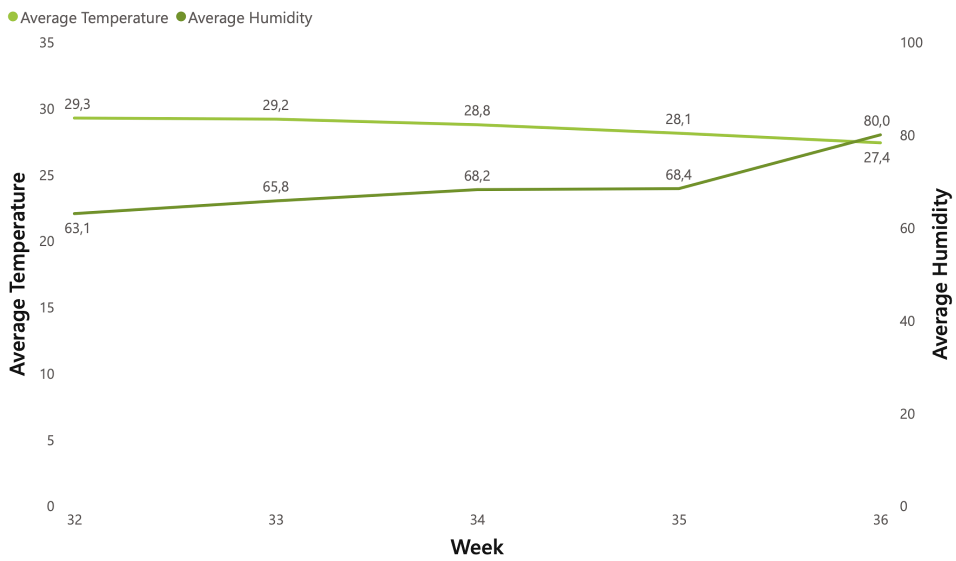


Figure 17 - Temperature Evolution in 5 Weeks

Regarding the soil moisture data, it was necessary to execute some pre-processing to address outliers caused by incoherent readings. However, the majority of the data was reliably collected. In the graph below (Figure 18) it is possible to understand that the soil mostly levels generally declined over the observed period.

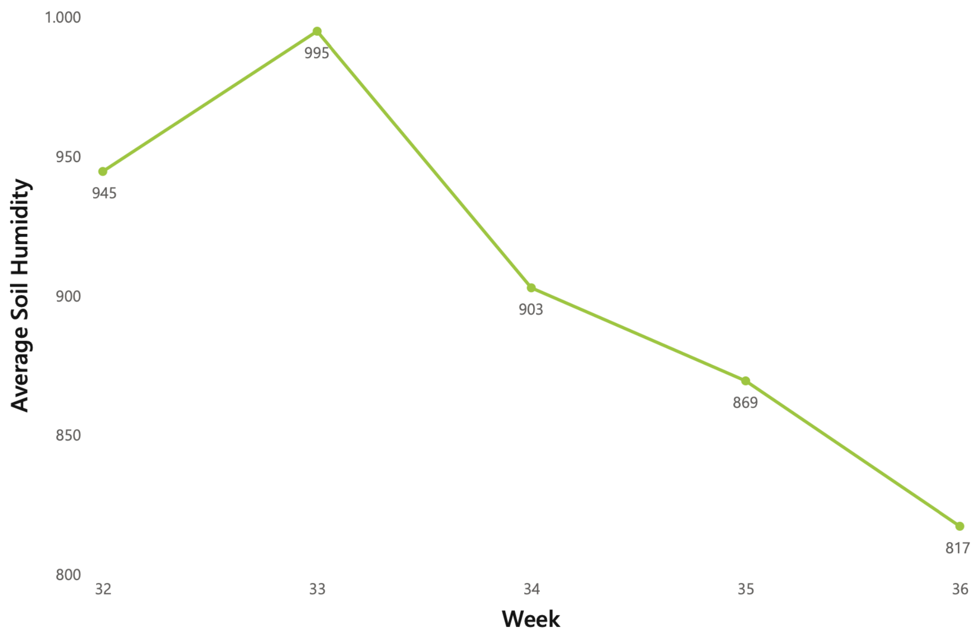


Figure 18 - Soil Moisture Evolution in 5 Weeks

Finally, the analysis of the water consumption data revealed several missing values, which were removed to ensure data consistency. Unfortunately, the reduced dataset limited the accuracy and reliability of the analysis. Despite these constraints, Figure 19 presents the average water consumption for each week during the five-week period. While the results provide some insight into usage trends, the gaps in the data result in unprecise information.

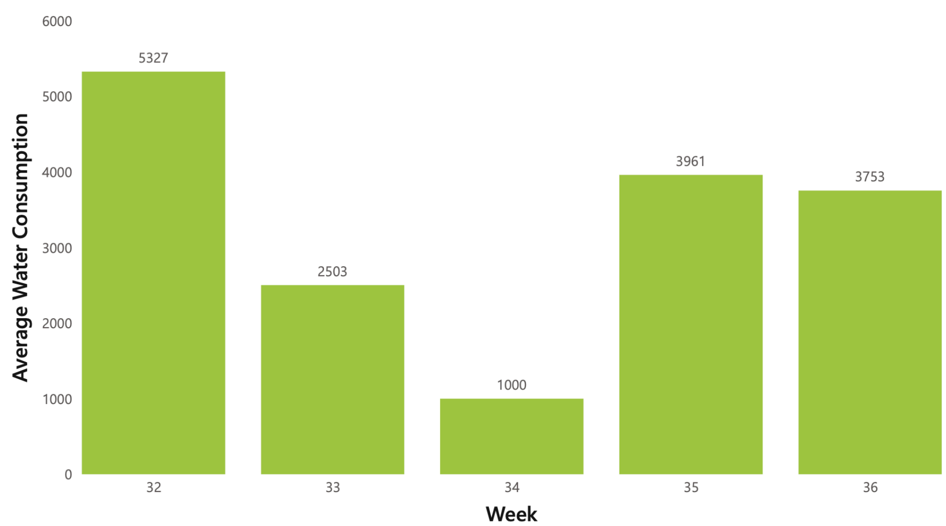


Figure 19 - Average Water Consumption in 5 Weeks

CHAPTER 6

Conclusions

Upon implementing and evaluating the system, it is necessary to find out what conclusions can be drawn from this study, as well as its limitations and future work. This study systematically applied the Design Science Research (DSR) methodology, following a structured process to address the identified research problem and objectives. The introduction chapter presented the problem and motivation, alongside the formulation of the research questions. The subsequent chapters on system architecture and implementation provided the details of the design and development of the initial artifact. The evaluation phase involved the demonstration and rigorous assessment of this artifact, which led to the development and evaluation of an improved second artifact.

Two research questions were defined previously, each accompanied by specific hypotheses, which served as the guiding framework for the investigation. At this stage, it is necessary to analyse the extent to which these questions have been answered and whether the results have validated the formulated hypotheses.

RQ1: How effective is implementing a multifactor IoT system for water leak detection in preventing/reducing water leaks in the outdoor space?

This research demonstrates the utility of a multifactor IoT system for detecting water leaks in outdoor settings, as the system successfully identified leakages during testing, effectively alerting the user when such occurrences were detected. However, it is important to note that the system's accuracy was not flawless, particularly when relying on imprecise water meter data. As a result, the first hypothesis, RQ1_H1, could not be fully validated since the water meter readings regress the overall system. On the other hand, the integration of weather data played a crucial role in enhancing leak detection, confirming the importance of incorporating this data. Consequently, the second hypothesis, RQ1_H2, was validated, reinforcing the significance of weather data in improving detection accuracy.

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

While it was not possible to gather exact data on water consumption, this does not mean that it is impossible to have a positive impact on water conservation. By integrating soil moisture data, the system enables users to optimize garden irrigation, reducing unnecessary water use by watering only when moisture levels are low. However, due to limitations in accurately measuring overall water consumption, it was not possible to provide users with detailed insights on indoor water usage, resulting in the non-validation of the corresponding hypothesis RQ2_H1. Despite this, the system still contributes to water conservation, though its overall impact is lower than initially anticipated. Nonetheless, the potential for water savings is tangible, particularly in outdoor settings.

To disseminate the results of this study to the scientific community, a paper was submitted to a relevant conference in this field. The research culminated in the acceptance of a paper titled “Multiparameter Monitoring and Control System for Intelligent Water Management” for publication in the proceedings of the International Conference on Industry Sciences and Computer Science Innovation (iSCSi) that will take place between October 29th and 31th in Porto.

6.1. Research Limitations

Throughout the development of this research, several limitations of this study can be identified and highlighted. The primary limitation of this research pertains to the site conditions where the system was implemented. Due to the absence of outdoor space, the system had to be installed indoors within a controlled environment. Moreover, the location of the water meter presented a logistical challenge, as it lacked access to a reliable power source. Consequently, to address this, the camera was powered by portable power banks, and the LED strip utilized batteries. These constraints significantly reduced the system's autonomy and required continuous monitoring.

Another significant limitation of this system was the camera utilized (ESP32 CAM with OV 2640). Even under optimal lighting conditions, the camera's quality was inadequate, which reduced the effectiveness of the OCR process with the Tesseract algorithm. Consequently, this often led to challenges in accurately capturing or retrieving the water meter data. Unfortunately, the camera employed was the only one available for the system at the time. However, we believe that upgrading to an OV5640 camera would significantly enhance the accuracy and reliability of the results.

While the Raspberry Pi 3 (RPI 3) has proven valuable for implementing the system, particularly in integrating sensor data via Node-Red and enabling the use of Home Assistant, its limited computing capacity presented significant challenges. These limitations resulted in slower performance and increased complexity during the system's implementation. The RPI 3 was the only microcomputer available for the system at the time, however, utilize a more powerful version of the Raspberry Pi or consider an alternative micro-computer with greater computational capabilities would improve the system.

Overall, the majority of the limitations of this study are related to the materials and resources available for its execution, as well as the constraints of the location where it was implemented. Nevertheless, with the same architecture and methodology, but under different conditions, we consider that the system could be implemented much more effectively.

6.2. Future Work

Looking ahead, a comprehensive plan of action is outlined to guide the next steps of this study, highlighting the essential tasks, timelines, and resources needed to improve this research and maximize the overall impact of the system.

Therefore, the initial step in this process involves conducting a comprehensive evaluation of alternative camera options, as the quality of the camera significantly impacts the overall accuracy of the system. The focus will be on identifying and comparing several camera models, assessing key factors such as image quality (megapixels) and price. Following the camera assessment, a similar evaluation will be conducted for micro-computers. This phase will involve compiling a list of various micro-computer models, with a focus on comparing their computing capabilities, including specifications such as RAM and storage capacity, alongside their corresponding prices.

Based on these benchmarks, we will prioritize investments in the camera and micro-computer models that offer the best cost-benefit ratio. These selected components will then be integrated into the system, replacing the existing hardware. This approach will allow us to measure how much these investments improve the system's performance, thereby allowing us to assess whether the upgrades are justified or not.

To further evaluate the performance of the system, it is essential to test it in a different location, both the current configuration with existing hardware and with the newly proposed hardware. On top of that, the system should be tested in an outdoor environment to better simulate a real application of the system. Additionally, we must ensure that the water meter location has reliable access to a power source, enabling continuous camera operation for 24 hours a day without reeling on power banks. A steady electrical supply for the camera and an electric-powered light source rather than battery-operated lighting will enhance the system's autonomy and effectiveness. Moreover, it is crucial to assess the impact of relocating the system on its overall accuracy, as well as to analyse the correlation between the change in hardware and location on system performance.

In addition, integrating the data from the garden's irrigation system would significantly enhance its functionality. By incorporating irrigation data, it would be possible to optimize watering practices and simultaneously refine the leak detection system. Correlating this data with other metrics would provide a more comprehensive understanding and improve overall system performance.

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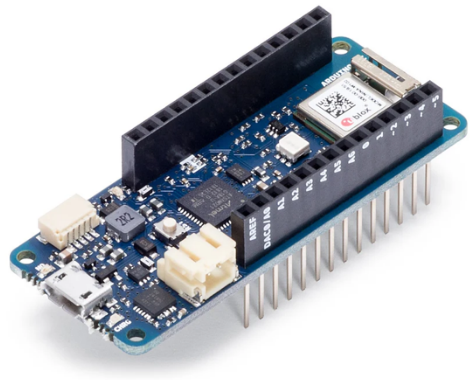
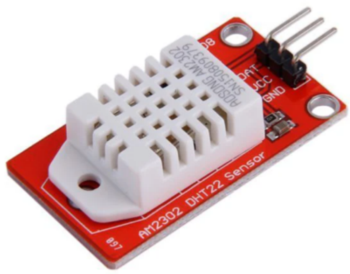
Appendices

Appendix A – System Constituents

A1: ESP32 Cam



A2: Arduino MKR Wi-Fi 1010 board

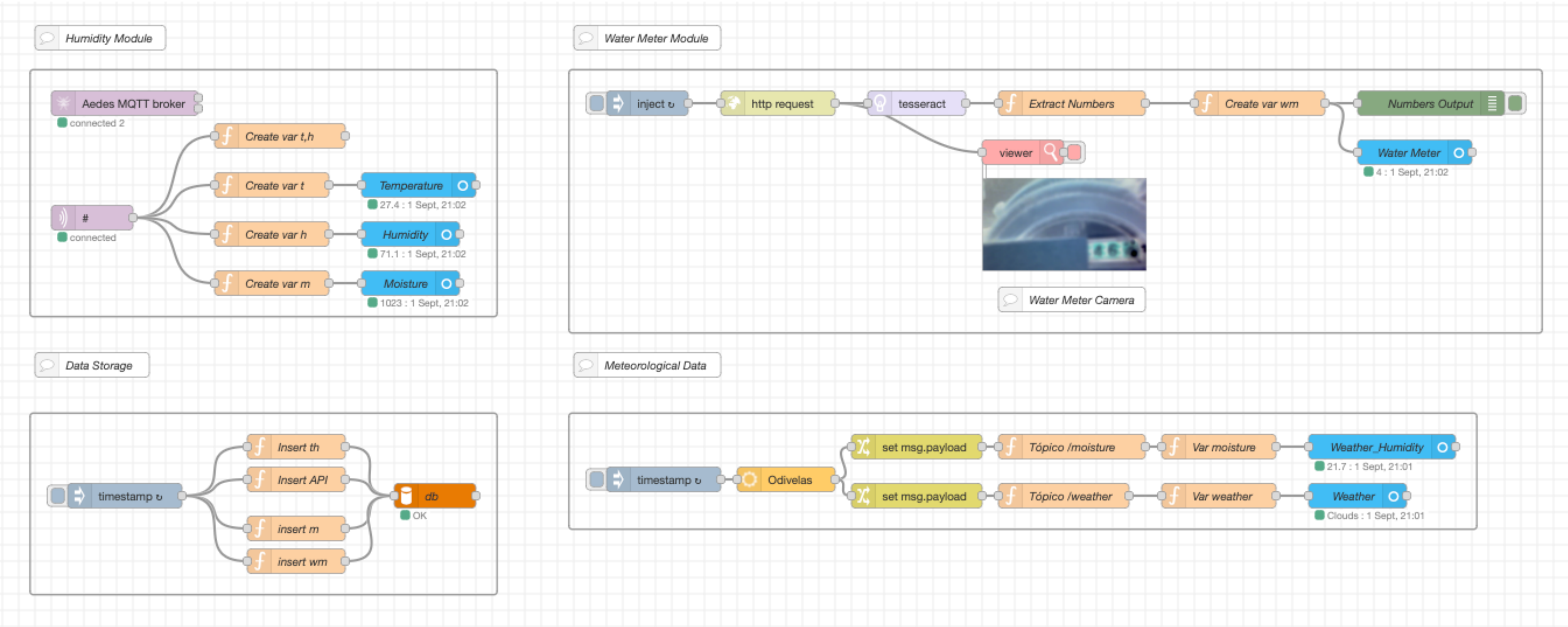


A3: DHT 22 Sensor

A4: Soil moisture sensor - A0131MS

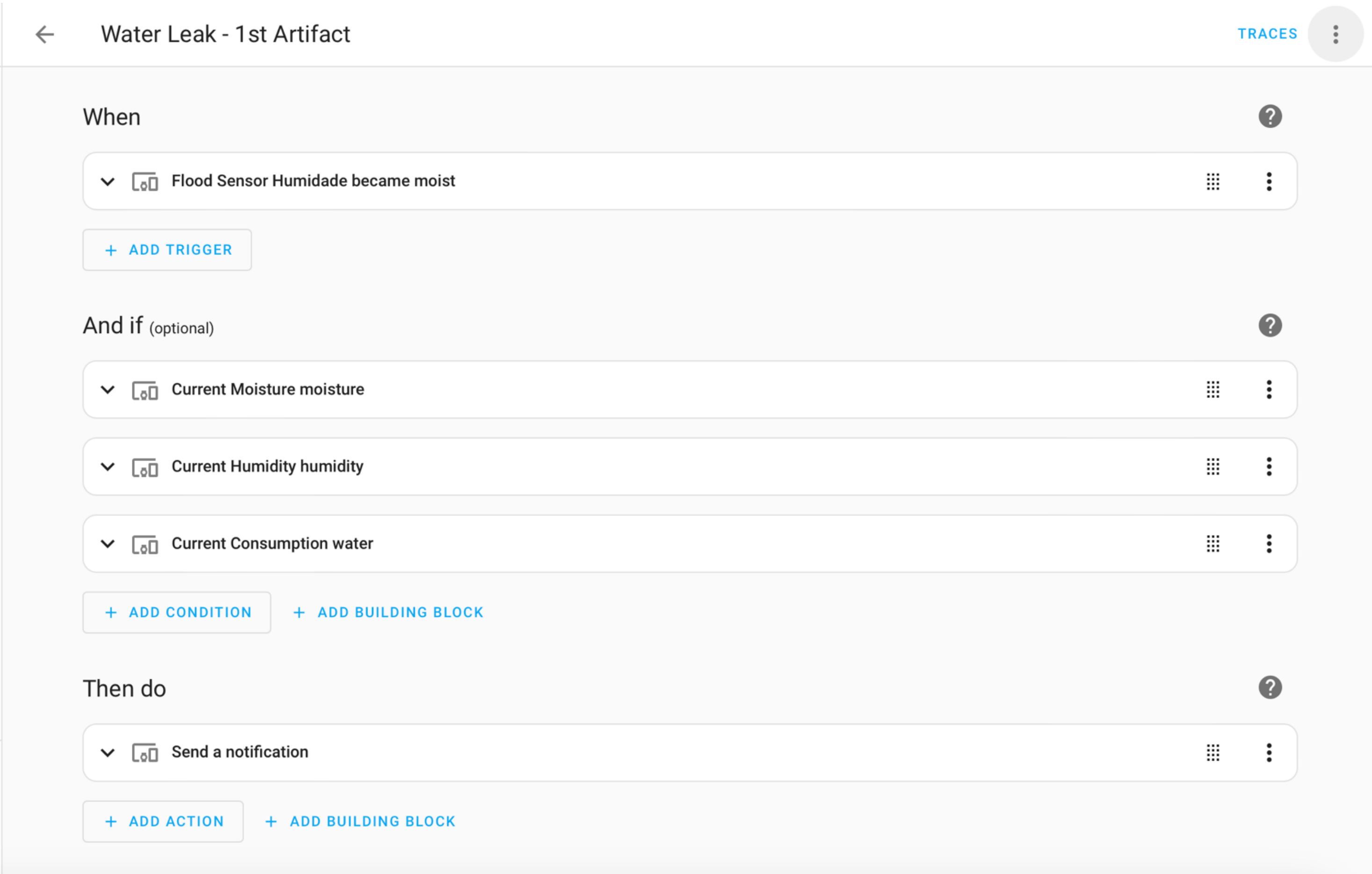
A5: Water Leak Detector – Sporway

Appendix B – Node Red Flow

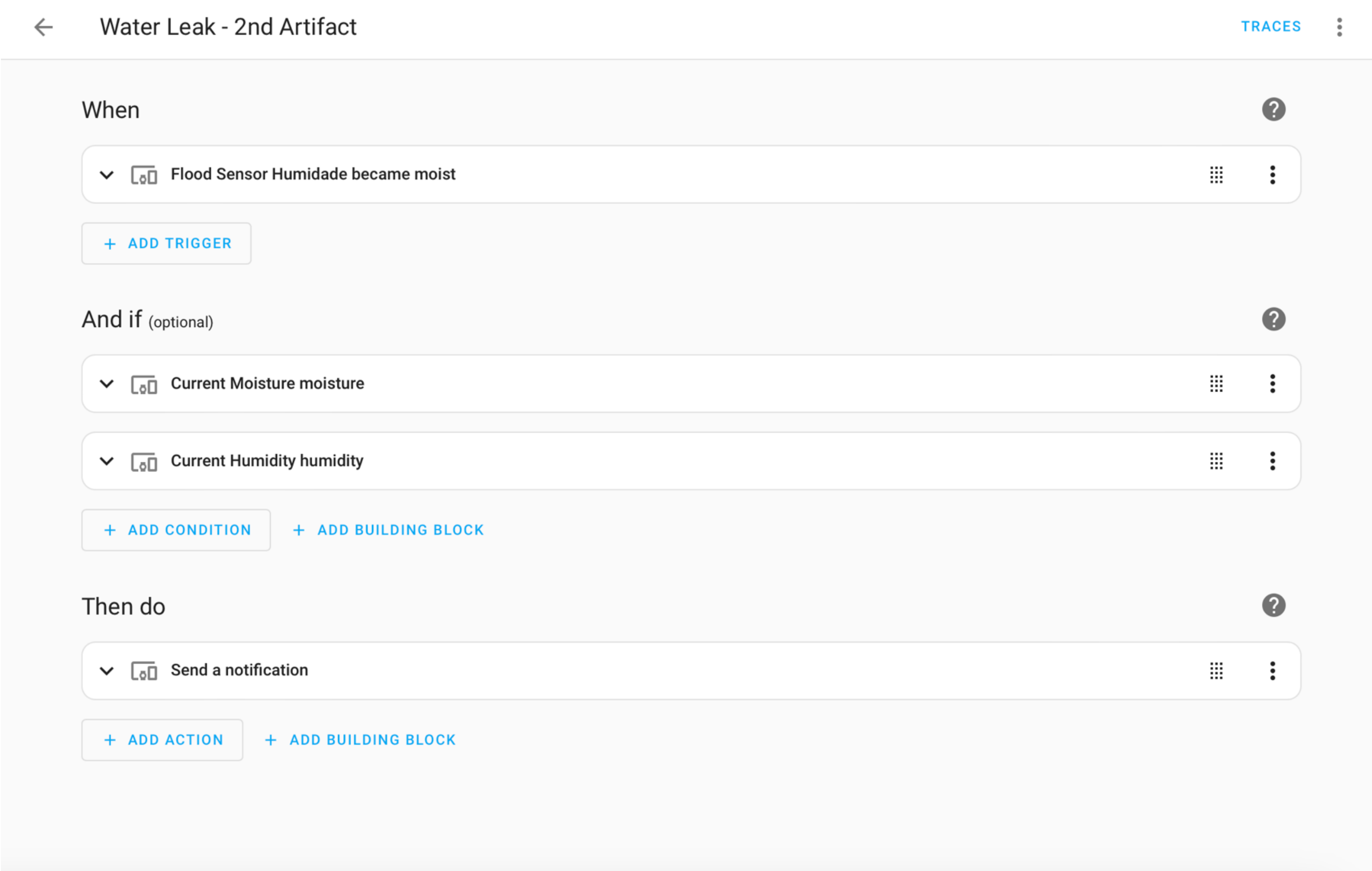


B1: Node Red Flow

Appendix C – Home Assistant Automations



C1: Home Assistant Automation for the First Artifact



C2: Home Assistant Automation for the Second Artifact