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MASTER'S THESIS SUMMARY

Intelligent system for management and optimization of residential water consumption

Student: *Uriel Amado Ramirez-Hernández*
Polytechnic University of Pachuca
urielramirez@micorreo.upp.edu.mx

Advisor: *Francisco Rafael Trejo-Macotela**
Polytechnic University of Pachuca
trejo_macotela@upp.edu.mx

Advisor: *Daniel Robles-Camarillo*
Polytechnic University of Pachuca
danielrc@upp.edu.mx

Abstract. The project involves the development of an intelligent system for managing and optimizing water consumption in residential settings, addressing the significant loss of this vital resource due to leaks in domestic pipelines, particularly in toilets. To mitigate the issue of silent water leaks in toilets, a mechanism based on Hall effect sensors was implemented, allowing real-time monitoring of water flow in the toilet tank, detection of irregularities, and user notification through a real-time communication network. The designed system integrates a PIC18F4550 microcontroller, YF-B10 flow sensors, and a solenoid valve, all interconnected to a cloud database and linked to a graphical interface accessible from mobile devices. To evaluate its performance, water flow tests were conducted, obtaining data on the relationship between the pulses generated by the sensor and the actual flow rate. Through machine learning models, anomalous consumption patterns were identified, establishing a reliable method for early leak detection. Preliminary results demonstrate that the system can significantly reduce water wastage by promptly alerting users to potential leaks, thereby contributing to water conservation and environmental sustainability.
Keywords: Intelligent system, Water management, Smart-meter, IoT, Machine learning, Water leak detection, Flow sensors.

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1 Introduction

Water wastage due to leaks in domestic systems represents a significant challenge in water resource management, particularly in urban environments where demand is high and availability is limited. In Mexico, it has been estimated that leaks in residential installations can lead to losses ranging from 20% to 60% of the total water supply, with toilets being one of the primary sources of wastage (La Jornada, 2022). In response to this issue, an automated water consumption detection and management system was developed, based on a flow sensor and a real-time monitoring system.

The proposed system integrates a PIC18F4550 microcontroller, YF-B10 flow sensors, and a solenoid valve that transmits information to a cloud database, enabling continuous water flow analysis and anomaly detection. Through experimental testing, the system's efficiency is evaluated to demonstrate its ability to detect leaks in a timely manner and minimize water wastage. This work contributes to the development of intelligent technologies for water conservation, providing an innovative and scalable solution that can be applied in residential and commercial settings to promote efficient water use and support environmental sustainability.

1.1 Motivations

The development of this project was driven by the growing concern over water wastage in urban environments, particularly in residential settings, where leaks in domestic installations result in significant water resource losses. Within this context, the toilet was identified as one of the primary sources of waste, as leaks in its filling system can go unnoticed for extended periods. In response to this issue, the need arose to develop an intelligent system capable of monitoring and detecting leaks in real time to reduce unnecessary water consumption and promote more efficient water use. The integration of sensors and automation technologies provided a viable alternative to address this challenge, offering users an early detection and consumption management tool. Furthermore, the project aims to contribute to environmental sustainability by encouraging the adoption of innovative technological solutions that optimize water use in residential and commercial spaces.

1.2 Description of the research problem

The primary contribution of this work focuses on the inefficiency in detecting water leaks in domestic systems, specifically in toilets, where resource wastage can go unnoticed for extended periods. In most households, leak detection relies on visual observation or increased water bills, making early identification and timely corrective actions challenging. This situation not only raises costs for users but also contributes to the depletion of water sources in the context of increasing scarcity. The lack of accessible and automated technologies for water flow monitoring represents a significant obstacle to efficient resource management. Although water consumption measurement devices exist in more advanced infrastructures, their implementation in residential settings remains limited. Therefore, the need for an autonomous system was identified, one that, through the use of sensors and real-time data processing, could detect anomalies in water flow and alert users to mitigate unnecessary losses. This research addresses this deficiency by developing a technological solution capable of enhancing leak detection efficiency and optimizing water use in urban environments.

1.3 Objectives of the thesis

The objectives of this research project are:

1. Develop a system to measure water flow using an electromagnetic pulse sensor as a technique for detecting potential leaks in a residence, enabling the monitoring of water flow continuity in toilets.

2. Design a set of experimental tests to analyze and correlate the data obtained from the electromagnetic pulse sensor with the water flow rate in liters passing through the pipeline, aiming to determine the relationship between pulses and water flow.

3. Develop a machine learning model capable of detecting potential leaks in the toilet filling system through continuous analysis of water flow patterns.

4. Provide real-time water consumption information to the user through an interface, allowing visualization of flow data to take preventive measures against potential leaks, thereby optimizing efficient water use in their residence.

1.4 Brief description of the contribution of the thesis

The main contribution of this project lies in the integration of intelligent monitoring technologies for the automated detection of water leaks in toilets, an area that has been relatively unexplored in the optimization of residential water consumption. Unlike traditional systems, which rely on visual inspections or increased water bills to detect anomalies, the proposed solution enables real-time leak identification through continuous water flow analysis.

Furthermore, this work contributes to the development of autonomous systems capable of processing data in the cloud and applying machine learning algorithms to enhance the accuracy of irregularity detection. The implementation of these methods opens the possibility of scaling the technology to other water consumption devices, promoting more efficient water use across various applications. Additionally, automating leak detection facilitates waste reduction without requiring constant user intervention, representing a significant advancement in the accessibility of technological tools for sustainable water management.

2 Background

2.1. Real-Time Monitoring Technologies for Water Management.

The efficient monitoring of water consumption in residential settings has evolved with the implementation of intelligent systems that enable real-time leak detection. Water loss due to leaks represents a critical issue in water resource management, as it is estimated that approximately 40% of the water allocated to cities is lost during distribution due to infrastructure deterioration and lack of maintenance (García-Espinosa & Benavides-Muñoz, 2019). In response to this problem, technologies such as flow sensors and automated measurement systems have been developed to identify anomalies in water consumption and send alerts to users.

Smart meters have proven effective in reducing water wastage by providing real-time data and predictive analysis of consumption patterns (Rodríguez, 2024). Through flow sensors connected to communication networks, these devices can record the amount of water used and detect unusual patterns that may indicate leaks. Continuous monitoring through these systems represents a key strategy for improving water use efficiency and reducing the impact of leaks on urban water supply.

2.2. Internet of Things in Water Leak Detection.

The Internet of Things (IoT) has revolutionized water leak detection and prevention by integrating sensors connected to digital platforms. These systems enable automated data analysis and real-time responses to anomalous water consumption events (León Lazo & Macancela Sumba, 2024). In residential environments, the implementation of IoT devices facilitates early leak detection by collecting and processing information on water flow and pressure at various distribution points.

Research has shown that using flow sensors connected to IoT platforms can significantly reduce water wastage in homes and commercial buildings (Yacelga et al., 2023). These devices generate instant alerts to users through mobile applications, providing accurate information on their consumption status and facilitating decision-making to prevent unnecessary losses. The combination of IoT and data analysis offers an innovative approach to improving water resource management and optimizing water use in urban contexts.

2.3. Related Works.

Several studies have explored the use of advanced technologies for detecting and monitoring water consumption in domestic and industrial systems. (Apaza et al., 2022) proposed a predictive model based on decision trees to assess water potability and detect anomalous consumption patterns. This approach improved efficiency in identifying contaminants and managing water resources.

In another study, (Kleiman et al., 2016) analyzed the implementation of smart water meters in Valencia, Spain, aiming to optimize consumption monitoring and reduce losses caused by leaks. The results indicated that these devices enhanced measurement accuracy and facilitated early detection of irregularities in water supply.

Similarly, (Paredes Paucar, 2022) developed a remote water consumption monitoring system using sensors and IoT technology, leading to better resource management and optimization of service billing. These studies highlight the importance of automation and artificial intelligence in water management, emphasizing the need to develop innovative solutions that contribute to water resource sustainability.

3 Proposed Solution Approach

The proposed approach was based on the development of an intelligent monitoring system for detecting water leaks in residential environments, integrating a flow sensor, real-time data processing, and an algorithm for predictive analysis. A model was implemented using a programmed microcontroller to manage data acquisition from the sensor, analyzing water flow variations in toilets and identifying deviations that could indicate a leak.

For data processing and analysis, an anomaly detection algorithm was applied to identify irregular consumption patterns. A machine learning approach based on neural networks was selected to enhance system accuracy, optimizing predictive capability and reducing false positives. The collected information will be stored in a cloud database, allowing remote access to records and the transmission of alerts to users through a digital interface.

This approach offers several advantages, such as real-time monitoring capability, water waste reduction, and seamless integration with IoT devices. However, certain limitations have been identified, including the need for sensor calibration under different pressure conditions and the optimization of energy consumption to ensure long-term operational efficiency.

4 Experimental results

To evaluate the precision and efficiency of the water leak detection system, experimental tests were conducted in a controlled environment. The process involved measuring the pulses generated by the sensor when specific volumes of water were allowed to pass, using reference tools such as graduated cylinders and measuring scales to validate the obtained data.

The collected data is presented in Table 1, where the number of pulses detected by the sensor is shown in relation to different water volumes, ranging from 250 ml to 2500 ml. Initially, it was estimated that each pulse corresponded to 0.250 ml of water; however, as the volume increased, this ratio became variable, decreasing to 0.2055 ml per pulse, which ruled out the possibility of establishing a fixed equivalence between pulses and volume.

In Table 2, the pulses generated as a function of water liters are presented. Multiple measurements were taken with volumes between 1 and 5 liters, repeating each test 10 times to evaluate data consistency. It was observed that the data points aligned almost perfectly in Figure 1, indicating a linear relationship between pulses and the recorded water volume.

Additionally, in Table 3, the time in seconds taken to complete the discharge flow for each measured volume was recorded. The data revealed that, while a predictable trend existed, the dispersion in the measurements increased with the volume, resulting in a standard deviation of 7.10 and an estimated error margin of 6.22 ml per second. Figure 2 shows the relationship between time and liters discharged, highlighting that variability in time measurement impacts the accuracy of the model.

To improve detection accuracy, a correction algorithm was implemented on the sensor based on the TIMER0 interrupt technique, shown in Figure 3. Although initial tests indicated that readings still exhibited some variability, the optimization of the algorithm enhanced the reliability of the system.

Finally, the conversion of pulses to liters was evaluated using the formula $L = P \times 0.0017$, where P represents the detected pulses. Figure 4 shows the representation of proper water consumption, where the values recorded in the graphical interface align with the theoretical calculations. In contrast, Figure 5 illustrates a scenario where "pulse" input data is assigned to the system to visually simulate a leak when consumption exceeds expected values, triggering automatic alerts for the user.

5 Conclusions

The water leak detection system developed proves to be an efficient solution for the automated monitoring of water consumption in residential environments. Experimental results confirm that the use of the flow sensor enables leak

detection with high precision, reducing the margin of error and improving the system's reliability. Integration with a cloud database and an accessible user interface facilitates remote monitoring of water consumption and the activation of real-time alerts, allowing users to take immediate action in the event of potential leaks. Despite its effectiveness, areas for improvement have been identified, such as sensor calibration under varying pressure conditions and optimizing the system's energy consumption.
Therefore, this technology represents an advancement in efficient water management and early leak detection, with potential for implementation in both residential and commercial infrastructures, contributing to the sustainability and conservation of water resources.

6 References

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Additional aspects:

Tables

Table 1. First test of the amount of sensor pulses in relation to ml of water.

Water quantity	1st measurement	2nd measurement	3rd measurement	4th measurement
250ml	61	65	58	65
500ml	108	108	106	111
750ml	156	157	158	157
1000ml	205	208	206	206
1500ml	306	306	306	307
1750ml	359	360	359	359
2000ml	414	414	415	414
2250ml	465	465	469	469
2500ml	516	514	514	511

Table 2. Second test to associate pulses per liter.

	Pulses										
Liters	Meas1	Meas 2	Meas 3	Meas 4	Meas 5	Meas 6	Meas 7	Meas 8	Meas 9	Meas 10	Mean
1	578	549	581	582	586	576	570	580	582	588	577.2
2	1141	1175	1181	1182	1174	1167	1172	1191	1172	1178	1173
3	1775	1779	1793	1779	1776	1791	1776	1772	1778	1785	1780
4	2498	2364	2370	2343	2370	2372	2381	2364	2381	2357	2380
5	2954	2892	2963	2955	2930	2922	2914	2888	2896	2792	2911

Table 3. Seconds measurements with respect to water discharge.

	Seconds										
Liters	Meas1	Meas 2	Meas 3	Meas 4	Meas 5	Meas 6	Meas 7	Meas 8	Meas 9	Meas 10	Mean
1	10.8	10.4	10.8	10.4	10.5	10	10.2	10.4	10.3	10.6	10.7
2	19.2	19.3	19.4	19.2	20.1	19.4	19.9	19.4	19.8	19.2	19.6
3	29	27.6	27.7	27.1	27.6	27.5	26.5	26.5	26.5	26.5	27.3
4	35.92	37.3	36.4	36.9	36.9	37.1	36.8	37.3	37.8	37.3	37
5	45.4	45	44.7	45.3	45.6	45.5	45.4	44.6	44.9	45.4	45.2

Figures

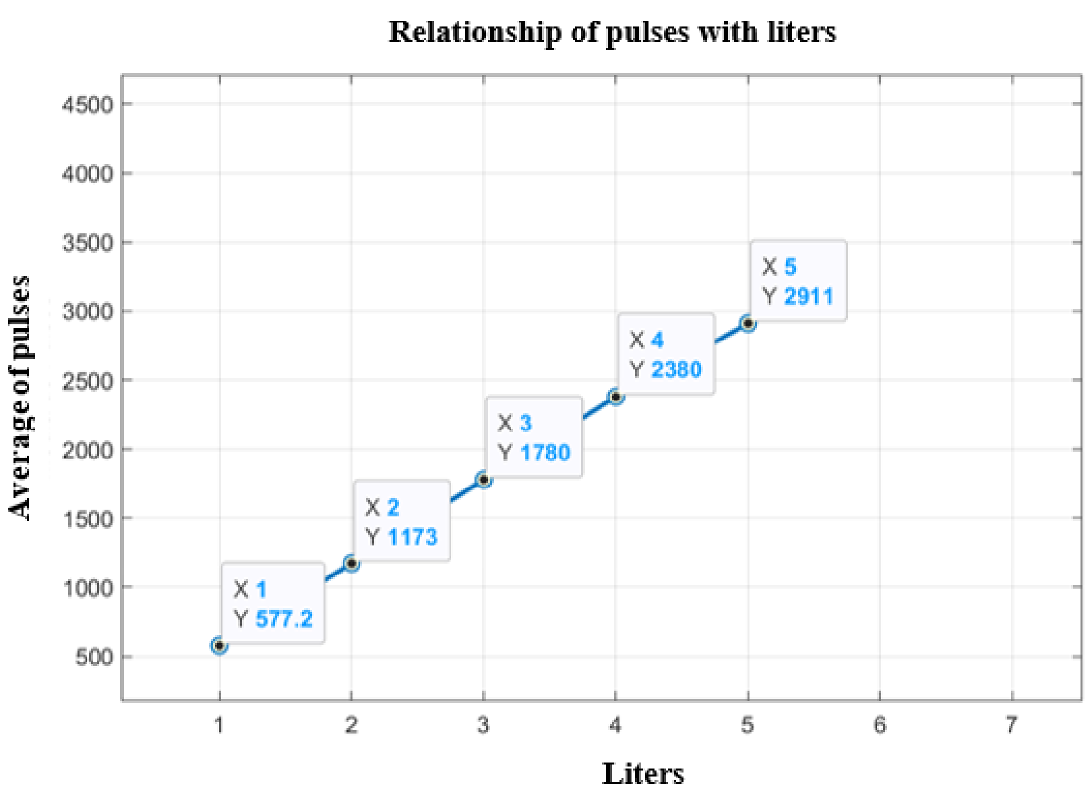

Figure 1. Relationship between pulses per liter.

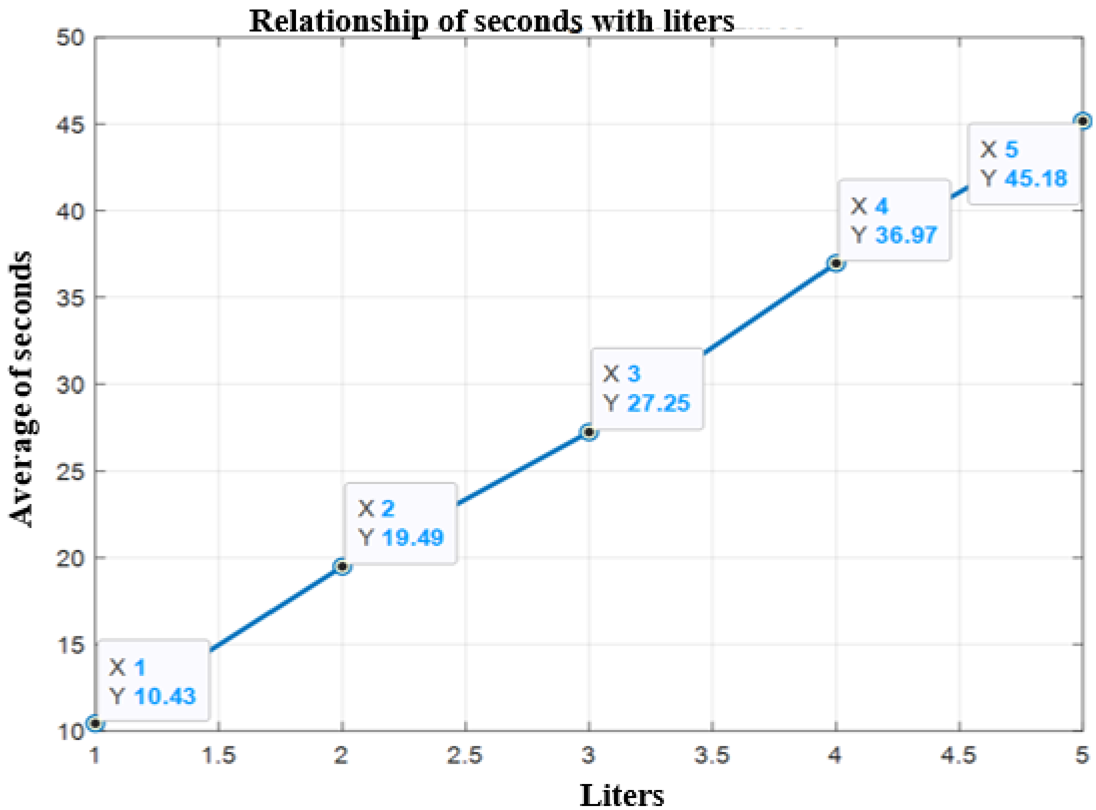

Figure 2. Relationship between seconds and liters

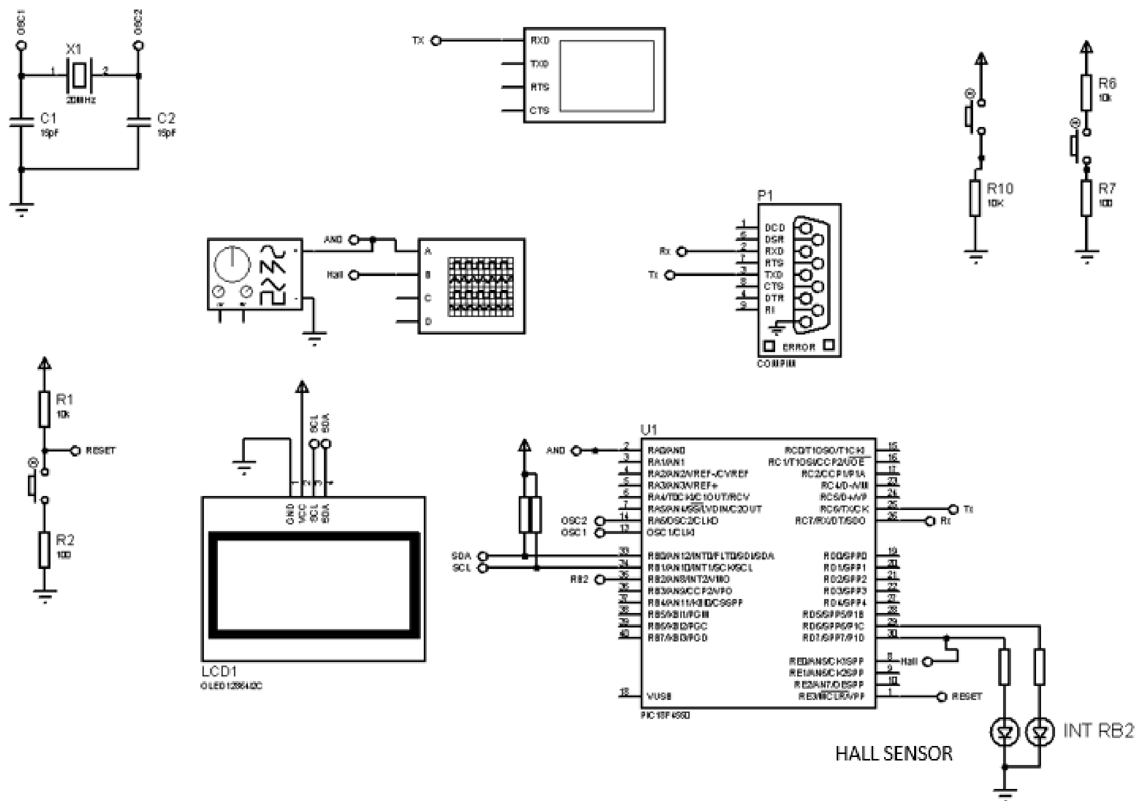

Figure 3. Electrical circuit of overflow interruptions.

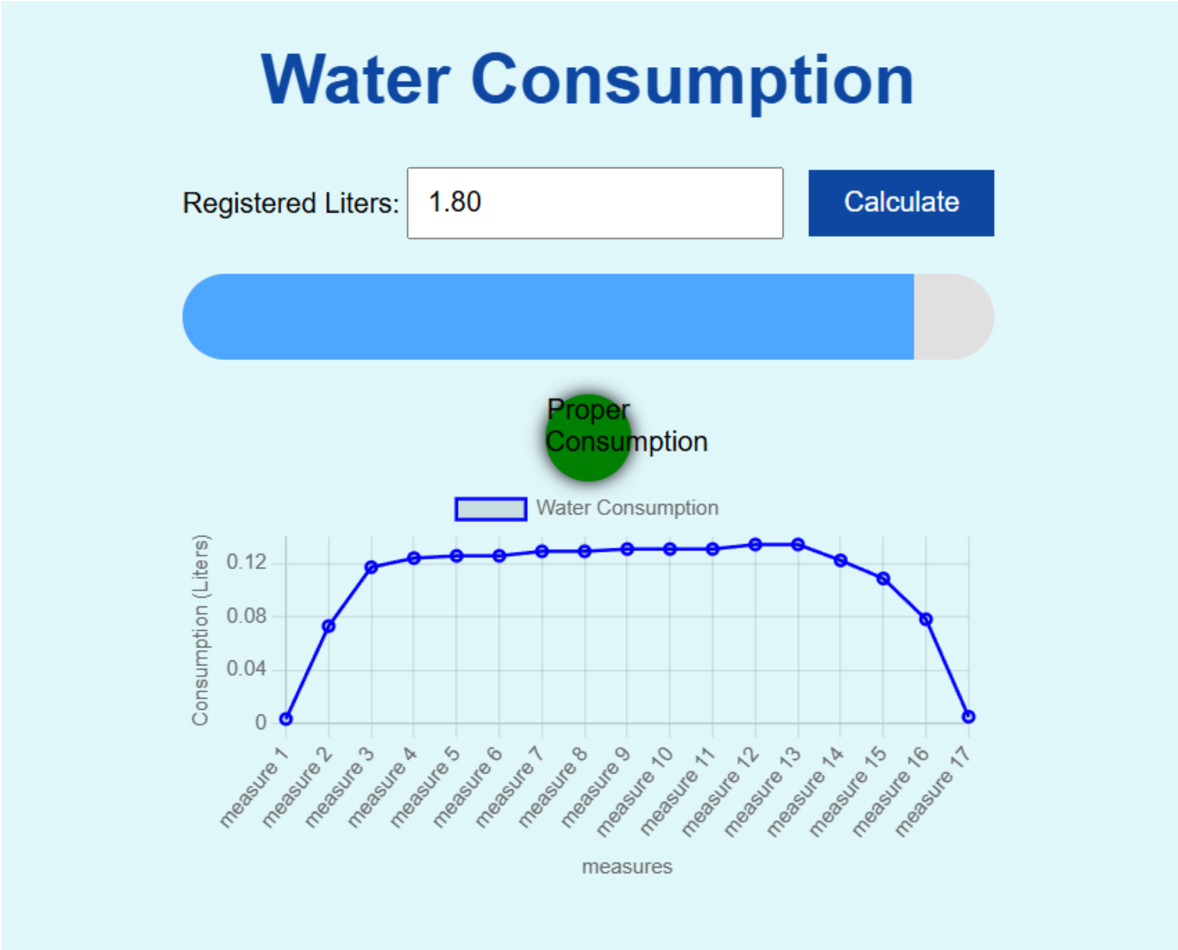

Figure 4. Proper water consumption.

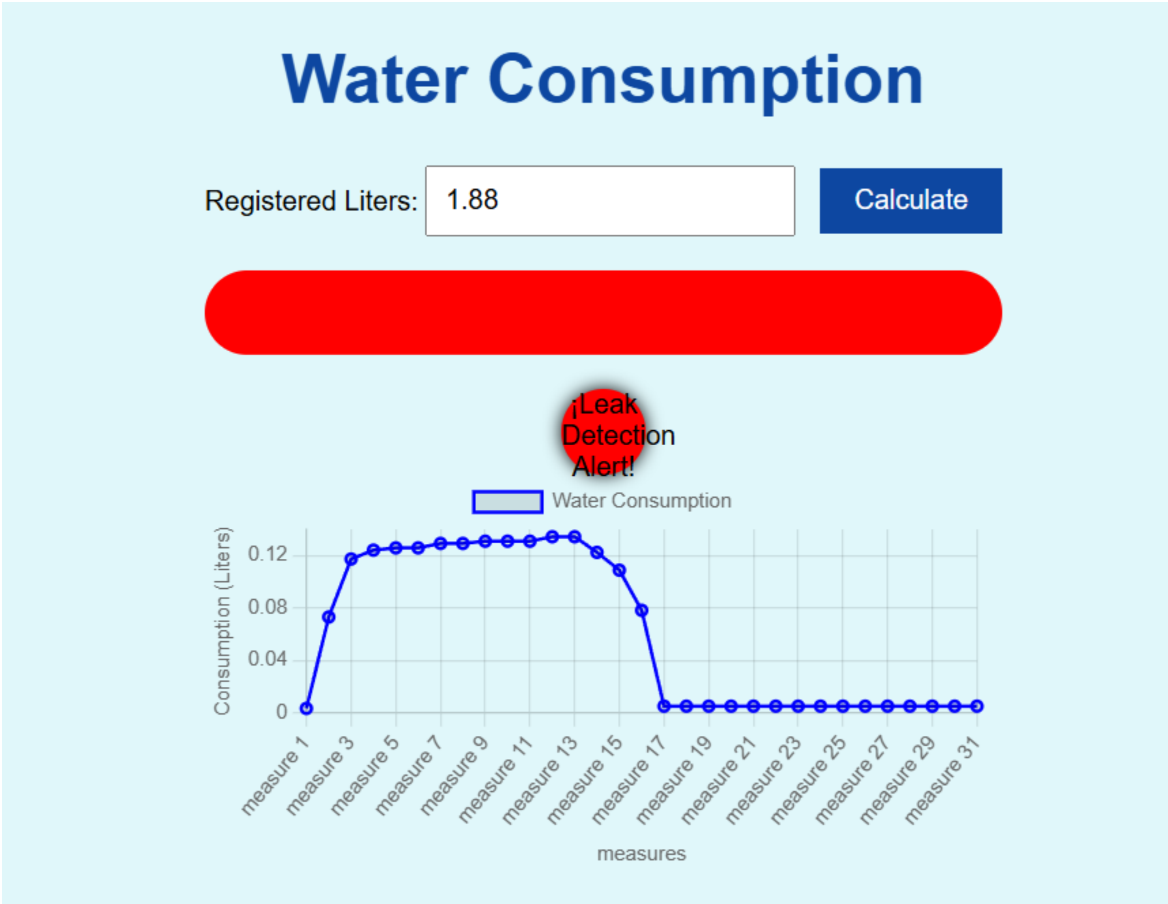

Figure 5. Graphical representation of a water leak.