**A Sensor-Based Robotic System for Leak Detection**

*Every Drop Matters (EDM) Robot*

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To all who believed in us – thank you!**List of Abbreviations and Acronyms**

|  |  |
| --- | --- |
| **Abbreviation** | **Full Term** |
| EDM | *Every Drop Matters* |
| NRW | *Non-Revenue Water* |
| IoT | *Internet of Things* |
| UFM | *Ultrasonic Flow Meter* |
| WSRC | *Water Sector Regulatory Council* |
| AI | *Artificial Intelligence* |
| IPv4 | *Internet Protocol Version 4* |

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# Abstract

Water faces numerous threats, and water leakage has driven us to search for innovative solutions. Statistics in our town of Anabta indicate a 40% loss of water due to a leak (Anabta Municipality - 2021), where a leak went undetected for 20 years, leading to street collapse. In the West Bank, Anata recorded the highest percentage of non-revenue water at 62%, followed by Jenin, Bal’a, and East Sawahra at 51%, 54%, and 55%, respectively. The reasons behind these figures vary: in Anata, illegal connections are the primary cause, while in Jenin, network losses and leaks are the main contributors. In Gaza, the highest loss rate was recorded in Al-Maghraqa at 58%, followed by Deir Al-Balah, Beit Lahia, and Beit Hanoun at 56%, 55%, and 54%, respectively (WSRC, 2020). Globally, Bangalore loses 360 million liters daily due to leaks, and Tokyo faces leakage issues that affect drinking water levels and lead to waste.  
  
 Our robot, EDM, is a system consisting of sensors controlled by an Arduino WeMos D1, distributed at specific points along underground water pipelines. A mobile robot controlled by a Raspberry Pi 4 Model B moves along a path to detect harmful plant roots using a Raspberry Pi Camera Module, then removes them using a TowerPro MG946R Servo. Both the Raspberry Pi and Arduino are connected to the same network. The Arduino sends data via the Raspberry Pi’s IPv4 address to the relevant authorities. If a leak is detected, the pump (the water source) is automatically shut off to prevent further water loss.

Through this project, we contribute to the localization of Sustainable Development Goals in Palestine, mainly *SDG (6) Clean Water and Sanitation* and *SDG (11) Sustainable Cities and Communities.*

# Problem

Water is a vital natural resource that faces significant challenges due to increasing demand driven by population growth, urban expansion, and climate change. Effective water management is crucial to reducing losses and ensuring resource sustainability.

Locally, reports from the World Bank and the Palestinian Central Bureau of Statistics indicate that water distribution networks in the West Bank suffer from losses ranging between 30% and 35% of the total distributed water. In the Gaza Strip, the loss rate reaches approximately 40% to 45%, mainly due to deteriorating infrastructure and escalating economic and political pressures. Unfortunately, most of these leaks occur within the distribution networks, leading to substantial water losses before reaching consumers.

This issue is not limited to Palestine but is a global challenge faced by many countries. For example, in Iran, around 8.4 billion cubic meters of clean drinking water were supplied in 2020, but approximately 2.3 billion cubic meters were lost. About 60% of these losses were due to leaks in transmission lines, reservoirs, valves, and pipelines (Iran Water and Wastewater Company, 2023).

In Malaysia, studies show that non-revenue water (NRW) loss rates have ranged between 35% and 45% of total water supply over the past decade (See & Ma, 2018). This is linked to technological decline, resulting in a 0.72% annual drop in the efficiency of converting resources into services.

In the United States, specifically in California, a study revealed a negative correlation between network length, connection density, and net revenue per cubic meter of water sold, and the amount of non-revenue water. It also confirmed a positive correlation between the number of leaks and the volume of lost water (Güngör-Demirci et al., 2018).

Based on these findings, this experiment aims to demonstrate the efficiency of using robots in detecting water leaks and minimizing the resulting waste. Through precise monitoring, these advanced technologies can contribute to improving water management efficiency, reducing losses, and mitigating the economic and environmental impacts of water leakage—both locally and globally.

# Objectives

1. Accurately identify leakage locations using sensors connected to the robot and reduce water loss by detecting leaks immediately upon occurrence, accelerating the detection process compared to traditional methods.
2. Provide accurate data to support maintenance decision-making, reduce repair and maintenance costs in the long term by preventing water leaks from worsening.

# Scientific Background

The reviewed sources address a highly significant topic: the management of water leakage in distribution networks—a challenge faced by many cities and countries around the world. These sources include experimental studies, theoretical analyses, evaluations of leak detection techniques, and research recommendations.

The study titled “An Innovative Hybrid Technique for Water Pipeline Monitoring and Leakage Detection Using IoT” by Bolu Kehinde & Sola Glroy (2025) discusses the issue of water leakage in pipeline networks, which leads to water waste and increased operational costs. Traditional leak detection methods are considered ineffective, as they rely on manual inspection and routine maintenance, which delays the detection of faults.

The research proposes a hybrid technique based on IoT sensors, which we applied in our project using the controllers Arduino WeMos D1 and Raspberry Pi 4 Model B, along with supporting sensors to detect water leaks early. However, our implementation differs from other experiments and studies in that we integrated a vibration sensor with machine learning algorithms to analyze data—specifically the images captured by the Raspberry Pi camera. Based on these images, the robot decides whether to:

1. Remove small plants if roots are present,
2. Continue moving forward if it detects a clear path or road,
3. Or stop completely when encountering a stop signal.

This approach contributes to:

1. Improving leak detection accuracy,
2. Reducing response time to faults,
3. Minimizing water demand and operational costs.

Addressing issues such as the impact of plant roots on pipelines is a major challenge, especially in urban areas where aggressive roots grow near pipe networks and negatively affect infrastructure. These roots can penetrate pipes or exert abnormal pressure, causing cracks and leading to high water loss, increased maintenance costs, and more frequent service interruptions.

Additionally, a study by Smith and Brown (2018) titled “The impact of herbaceous plant roots on underground water pipelines” discussed the phenomenon of root infiltration into pipes that have fine cracks. It showed that small roots have a high ability to penetrate these small openings, which negatively affects underground networks.

Further research published in the Urban Forestry & Urban Greening journal—such as Costello and Jones (2003), in their study titled “Root growth and its impact on underground infrastructure”—also highlights the impact of small plants on pipelines in urban communities and explains how roots interact with pipes in such environments.

Our integrated system is uniquely designed to consist of two coordinated electronic subsystems: one above ground and the other underground. This synchronization between both subsystems is novel, as such integration has not been implemented before. While underground systems have previously been developed using different sensors and controllers—some of which may be more advanced or more expensive, such as pressure sensors, temperature sensors, or ultrasonic flow meters (UFM)—our project aims to reduce the cost of water leakage detection systems and make them accessible to poorer countries. These nations often suffer from water loss issues or have weak infrastructure and outdated pipelines.

We chose to adopt smart electronic systems to solve the problems mentioned in the “Problem” section, as the world increasingly relies on such technology for its efficiency, time-saving capabilities, and productivity enhancement. Our system will enable water department workers and engineers to manage leak detection with ease and accuracy using real-time data. Its high precision will also improve leak detection quality and address one of the primary causes: invasive plant roots.

# List of Materials

* Robot Car (Raspbot)
* Arduino WeMos D1
* Raspberry Pi 4 Model B
* DC Motor
* Servo Motor (MG996)
* Moisture Sensor (YL-69)
* Water Flow Sensor (YF-S401).
* Vibration Sensor (SW-420).
* Pump (5V).
* Raspberry Pi Camera.
* Raspberry Pi Display.
* Breadboard (Half-Size).
* Male to Female / Male to Male Wires.

# **Procedures\Preliminary Designs**

Table 1: Timeline of Research.

|  |  |  |  |
| --- | --- | --- | --- |
| **Research Stage** | **Objective** | **Actions** | **Time Period** |
| Topic Selection | •Selecting a main idea for the project. | •Research was conducted within the local and global community to identify an issue. One of the selected issues was water leakage for our research project. | 01/07/2024 |
| Problem Identification | •Identifying the problems related to water. | •Reading studies and research papers. | 20/08/2024 |
| Data Collection | • Collecting information about water leakage, its causes, and consequences. • Gathering information from technical and electronic perspectives. • Conducting interviews. | • Reading and researching articles and previous studies related to leakage, causes, and solutions to treat this problem. • Interviewing a technician experienced with electronic components and controllers. | 15–25/08/2024 |
| Robot Design | Exploring how to assemble and connect components with controllers. | • Gathering components and assembling them. • Building a prototype of the robot. • Assembling electronic circuits and connecting them to controllers. • Linking each component to its related controller based on sensor function. | 01–20/09/2024 |
| Research Writing | Writing the report and research plan. | It was written using accurate and scientifically approved methods. | 01–20/01/2025 |

# Build & Test a Prototype

## Prototype:

At the beginning, we positioned our robot **(EDM)** at specific points along the pipelines. The robot consisted of several sensors and a pump, which serves as the water source.

**First**, the **moisture sensor (YL-69)** was placed outside the pipe to detect the presence of leaking water. If water is detected, the first leak condition is fulfilled.

**Second**, the **vibration sensor (SW-420)** senses the vibrations of flowing water — since the movement of water inside pipes generates vibrations due to pressure. If the vibrations decrease or stop, the second condition is fulfilled.

**Third**, the **water flow sensor (YF-S401)** measures the amount of water flowing inside the pipe. If the flow is too low, too high, or stops altogether — i.e., abnormal — all three leak conditions are fulfilled, and the water source (the pump) automatically shuts off.

All of this is controlled by the **Raspberry Pi 4**, which also sends the leak location to the relevant authorities for repair.

Additionally, we integrated a **preventive mechanism**: an AI camera mounted on the Raspberry Pi scans for invasive plant roots that may damage the pipes. If harmful roots are detected, they are removed using a **MG996 servo motor**. In our simplified project, we used a servo motor, but in real-world implementation, this function would be performed by a robotic arm.

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| --- |
| Figure 1: Prototype Design Phase. |
| Figure 2: Prototype Programming Phase. |

# Redesign & Retest

## **Current Prototype**

After development, we did not change the sensors, the pump, or the idea of placing them at specific points along the pipeline. However, we replaced the controller with an Arduino D1 (Wemos D1). We kept both the camera, and the servo motor connected to the Raspberry Pi. However, the Raspberry Pi was mounted on a mobile robot that moves along a designated path above the ground and removes harmful roots affecting the pipes.

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| Figure 3: A Point in the Fixed Leak Detection System. | Figure 4: The Mobile Robot. |

# Data Analysis

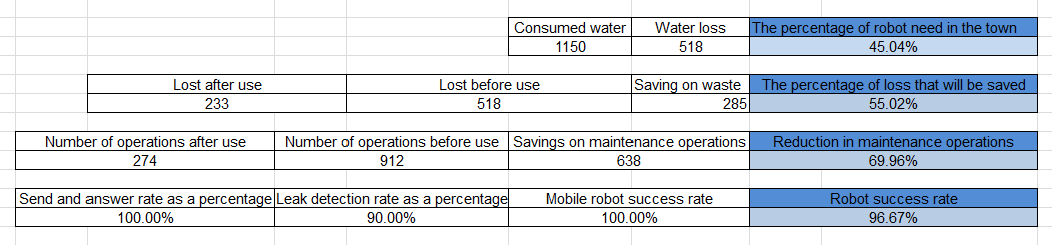


Figure 5: Results from the Data Analysis

|  |  |
| --- | --- |
| Figure 6: Robot success rate. | Figure 7: The percentage of robot need in our town. |
| Figure 8: Percentage of water loss that the robot will save | Figure 9: Percentage of maintenance operations reduced after using the robot. |

Table 2:Comparison Between Results of Different Sensors.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Usage Method** | **Effectiveness in Problem Detection** | **Water Saving** | **Accuracy in Water Data** | **Accuracy in Readings** |
| Moisture Sensor Only | The problem is not detected; water may be leaking but not in high quantity to be sensed. | No water savings achieved. | Low accuracy due to limited sensitivity. | Low accuracy due to partial readings. |
| Moisture Sensor and Water Flow Sensor | Leakage can be detected better. If flow is abnormal, this confirms leakage. | Can save water moderately depending on sensor sensitivity. | Moderate accuracy. | Moderate accuracy. |
| Moisture, Water Flow, and Vibration Sensors | More accurate detection of the problem and its location. Data is confirmed through sensor integration and cross-verification. | Water savings can reach up to 55%. | Very high accuracy. | Very high accuracy. |

# Results

Our project has a positive impact on all aspects of life — including humans, animals, plants, and the climate. Among the most important of these positive effects:

1. Preserving resources: By quickly detecting leaks and automatically shutting them off, the robot reduces water waste caused by leakage, contributing to the conservation of valuable water resources.
2. Reducing environmental damage: Water leaks can cause serious environmental damage, such as erosion, mold, and excessive moisture. By preventing such leaks, the robot minimizes their negative impact on the local environment.
3. Reducing costs from leaks: By detecting leaks at an early stage and shutting them off automatically, major property damage can be avoided, saving potentially high repair costs.
4. Increasing comfort and safety: The robot operates continuously without the need for human supervision, providing convenience for users and ensuring a fast and effective response to any leak.
5. Improving public health: By preventing water leaks that can lead to bacterial and mold growth in homes and buildings, the robot contributes to better public health conditions.

# Applications

* Robot: accelerate the detection process compared to traditional methods, and provide precise data to support repair decision-making.
* Moisture Sensor (YL-69):Detects moisture by reading conductivity, identifies leakage areas to trigger an alert or guide the robot accordingly.
* Water Flow Sensor (YF-S401):Measures the water flow rate and detects abnormal changes to pinpoint possible leak locations.
* Vibration Sensor (SW-420):Detects vibrations caused by water leakage or pressure on surfaces, helping to identify the leak’s location.
* Raspberry Pi Camera:Monitors invasive plant roots harmful to pipelines and removes them using a servo motor.

# Future work

This project has a strong potential for future implementation with the support of relevant Palestinian institutions, along with the contribution of municipalities and governorates. This involves providing all the necessary tools, advanced and upgraded sensors, and analyzing the results in terms of water convervations data.

This model also proposes replacing regular electricity and internet power sources with renewable energy, utilizing an advanced robotic arm to remove invasive plant roots, and adopting modern technologies for early leak detection—such as sensors and artificial intelligence. Environmentally friendly solutions could be applied to treat NRW. For instance, solar energy can be used to power the robot that operates above ground. Since this robot removes plant roots, it is possible to generate energy from those roots. The chemical interaction between roots and microorganisms produces organic compounds that can be converted into electrical energy when roots are present. When roots are not available, the system would rely on solar power.

As for the robot operating underground, it can be powered by electricity generated from the turbine movement within the water flow sensor (YF-S401).

We aim, as much as possible, to rely exclusively on clean energy, and we are committed to finding tools and components of higher quality and precision than those currently used.

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