# Smart Water Management: a Self-Sufficient IoT-Based Application for Pressure and Flow Monitoring in Water Distribution Systems

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***Abstract*—Water distribution in municipalities involves various challenges, such as maintenance of pipelines, pressure and flow control, water quality monitoring, among others. In this sense, measuring the flow and pressure of a system is a key issue for optimizing water distribution in cities. Therefore, this information is important to ensure that water is delivered with quality and in adequate quantity to consumers. With the advent of technology, some advanced solutions have been proposed in the literature to address these challenges, such as hydraulic modeling software, intelligent sensors, and automated control systems. Among these, one of the most commonly used techniques to increase system efficiency is wireless sensor networks. However, monitoring in a wide coverage area, such as metropolises, becomes difficult to implement, involving high costs and infeasibility of large-scale sensor installation. Therefore, applications involving IoT (Internet of Things) have been proposed as a low-cost and low energy consumption alternative. Thus, this article describes the steps, challenges, and solutions necessary for the development of a self-sufficient IoT application aimed at monitoring pressure and flow in a water supply network.**

***Index Terms*—Water Pressure, Water Flow, Internet of Things, Self-sufficient system, Micro Hydro Turbine.**

## I. INTRODUCTION

Currently, water distribution is a critical aspect of modern urban life. But this is not a simple task, considering that the water supply system involves various processes, from the collection, conveyance, treatment, and distribution of potable water to homes. In this context, water is captured from sources, whether surface or underground, and transported to water treatment plants, where filtration, coagulation, and chemical correction processes are carried out. After this stage, the potable water is stored in reservoirs, the location where pressure and flow control is conducted, and subsequently distributed to homes through residential service lines, [1].

In this regard, municipalities face many challenges in managing their water distribution systems, including maintaining pipelines, controlling pressure and flow, and monitoring water quality. Therefore, accurate measurement of flow and pressure in the system becomes essential to optimize water distribution and ensure that consumers receive water of the highest quality and in the required quantities, [2]. As technology advances, solutions have emerged to address these challenges, such as hydraulic modeling software, as proposed in [3], intelligent sensors in [4] and automated control systems, [5]. Among these, wireless sensor networks are increasingly being employed to enhance the efficiency of water distribution systems.

Monitoring water distribution systems across urban areas poses implementation challenges. The costs associated with large-scale sensor installation and maintenance can render these systems unfeasible for many municipalities. Consequently, there is a growing interest in leveraging the capabilities of the Internet of Things (IoT) to develop low-cost, energy-efficient solutions: IoT applications enable real-time communication and data collection from a multitude of devices, offering an alternative to traditional sensor networks, [6].

Therefore, this work aims to design and implement a self-sufficient IoT-based system for monitoring pressure and flow in a water supply network, using wireless sensors and low-energy techniques to collect and transmit data in a cost-effective and energy-efficient manner. Furthermore, this approach allows monitoring through an supervisory platform, facilitating improved management and optimization of water distribution processes. Lastly, the following sections will be developed: Proposed System, Theoretical Foundation, Internet of Things, Developed Hardware, Energy-Saving Techniques, Data Processing, Results, and Conclusions.

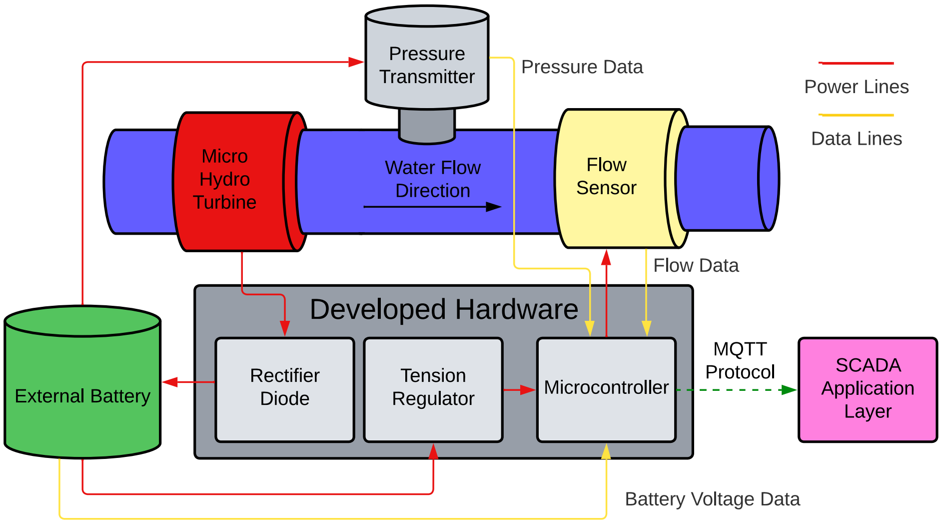


Fig. 1. System Schematic.

## II. PROPOSED SYSTEM

The proposed monitoring system, depicted in Fig. 1, integrates an array of hardware and software technologies. The system's operation hinges on a pressure transmitter, a flow sensor, and a mini hydroelectric generator. The generator is connected to a rectifier diode, which serves as a bridge to charge an external battery, an integral component for maintaining system stability.

This system is designed to acquire data from a pipeline and the battery voltage level, then transmit this information via WiFi for remote monitoring and subsequent storage in a database. A notable feature is its self-sufficiency, deriving energy from the movement of the water itself.

Delving into more detail, the rectifier diode plays a crucial role in managing the charging of the battery, utilizing energy harnessed from the microturbine (signified by the red wires, which represent power supply). This battery, in turn, powers a pressure transmitter and a voltage regulator. The latter then supplies power to a microcontroller.

The external battery serves a dual function: it supplies power to the system's components and also acts as an energy reservoir. This energy storage guarantees continuous system operation, even during periods of low water flow when the mini hydroelectric generator might not yield sufficient power.

The microcontroller, a key component, collects data (represented by the yellow wires) on pressure, battery voltage, and water flow. It also processes and transmits this data via the Internet to a remote application layer. It acts as the system's brain, reading the data from the sensors, processing it, and then transmitting it over WiFi. It also monitors the battery level to ensure that it remains within operational limits. Finally, in the following sections, the operation order of the microcontroller is detailed and visually represented.

### A. Experimental Setup

For the successful execution of all experiments, the comprehensive setup presented in Fig. 2 was meticulously employed. This setup was the cornerstone of the experimental framework, playing a pivotal role in ensuring the validity of the results.

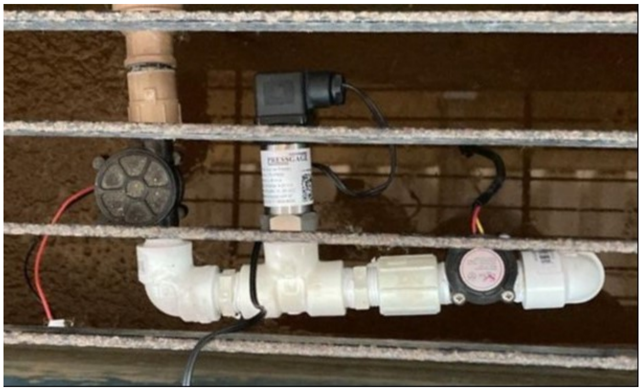


Fig. 2. Experimental Pipeline.

This configuration is centered around a half-inch pipe. It is important to note that the order of placement for the three devices within the system is not random, but rather strategically planned: Firstly, the mini hydroelectric generator was purposefully placed before the right angle curve, this is due to the fact that this location causes a substantial pressure loss. Following this, the pressure transmitter, the heaviest element in the assembly, was situated in the middle to tactically reduce the torque arm generated by its substantial weight. Finally, the flow sensor was carefully positioned at the very end of the pipe, conveniently next to another right angle curve that efficiently directs the water flow towards the laboratory's drainage system.

## III. THEORETICAL FOUNDATION

In this section, the theoretical concept inherent to the main device used for the development of this research is addressed.

### A. *Micro Hydro Turbine*

A mini hydroelectric generator (Fig. 3), also known as a micro-hydro or pico-hydro generator, is a device that harnesses the energy of water from small falls or currents to generate clean and renewable electricity, thus presenting a viable alternative for power generation in remote and isolated areas where access to electricity may be limited, a key theme of this research and, due to these features, such devices can be used in a variety of applications.

Fig. 3. Mini Hydro Generator DB-268.

In this regard, the theoretical concept behind a mini hydroelectric generator starts with potential energy. In the case of hydroelectric power, this potential energy is provided by a water source located at a higher elevation. This is why most hydroelectric power plants are located near dams or waterfalls.

This particular model is a three-phase generator that incorporates a design where magnetized teeth are housed inside the generator. As water flows over the generator, it causes these teeth to rotate, creating a changing magnetic field. This changing magnetic field induces an electrical current in the coils present within these teeth, a principle based on Faraday's law of electromagnetic induction, [7].

The electrical current generated in this way is alternating current (AC). However, for many applications, direct current (DC) is required. Therefore, the generator includes 6 diodes, 2 for each phase, which serve as rectifiers. These diodes allow current to flow in only one direction, effectively converting the AC output of the generator into DC, Fig. 4.

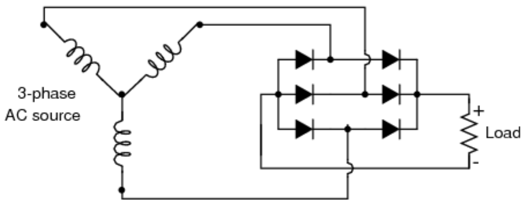


Fig. 4. Mini Hydro Generator representation.

To ensure a stable output voltage, the generator also includes a 12V voltage regulator. This component takes the input DC voltage, which can vary due to changes in the flow rate of water and other factors, and outputs a constant 12V DC.

Lastly, to further smooth out the output voltage and reduce ripple, a capacitor is incorporated into the design. The capacitor stores electrical charge and releases it when the voltage drops, acting like a small, temporary battery to keep the voltage level more steady. Thus, the mini hydroelectric generator provides a compact, efficient, and environmentally friendly solution for electricity generation in this research project.

## IV. INTERNET OF THINGS (IOT)

As communication technologies evolved, the Internet of Things emerged and rapidly became integrated into various applications. The Internet of Things (IoT) is a system of interconnected computing devices with unique identifiers (UIDs) that can transfer data across a network without the need for human-to-human or human-to-machine interaction. In the field of instrumentation, IoT can be applied by connecting sensors and microcontrollers to the internet, utilizing a machine-to-machine (M2M) communication protocol.

With the progress in wireless communication technologies, there is a growing interest in implementing alternatives that incorporate IoT into daily life, bridging the gap between the digital and physical worlds and revolutionizing the communication between physical objects and their users. This aims to enhance safety, protection, comfort, communication, technical management, and autonomy. Nowadays, supervisory and monitoring systems are becoming more interconnected. Consequently, IoT offers cost-effective solutions with low power consumption and straightforward installation and configuration, [8].

### A. *MQTT Communication Protocol*

With the local measurement system operational, the next step is to provide this data to an online platform for accessibility via the internet. Consequently, the MQTT communication protocol was selected due to its simplicity and excellent performance. This protocol is based on a Publish-Subscribe model (Fig. 5): each client communicates with a central broker, forming a many-to-many connection, where the broker manages and distributes messages to the subscribers. At the same time, clients have the role of connecting to the broker, publishing messages, and subscribing to receive messages from other clients. In this sense, clients never directly connect to other clients, instead relying on the broker for message handling, [9].

In the proposed system, the broker was established in a hosted manner, using the MQTT library for the ESP32 microcontroller, which was chosen because it is a low-cost, low-energy solution with built-in Wi-Fi and Bluetooth modules.

## V. DEVELOPED HARDWARE

In this section, the designed hardware is presented, ranging from the conceptualized printed circuit board to the planned encapsulation.

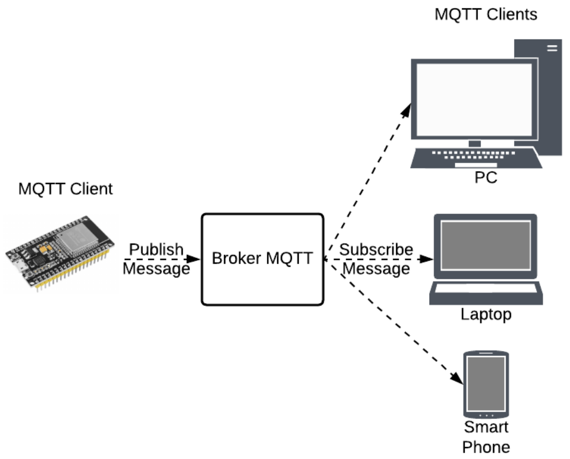


Fig. 5. MQTT Protocol Representation.

### A. *Printed Circuit Board*

With the circuit tested on a breadboard, it became possible to manufacture the printed circuit board for this project, Fig. 6. In general, the board is a unifying element of the modules used:

- ESP32: low-cost microcontroller that features a WiFi communication module, a dual-core processor system, hybrid Bluetooth, and multiple built-in sensors, making the construction of IoT systems much simpler and more compact.
- Voltage Regulator LM2596: high-efficiency step-down voltage regulator, capable of converting input voltages ranging from 4.5V to 40V into adjustable output voltages from 1.25V to 37V, has a high conversion efficiency, which can reach up to 92% (the main reason for its choice). In addition, the device features protections against overload, short-circuit, and overheating, ensuring safe and reliable operation.

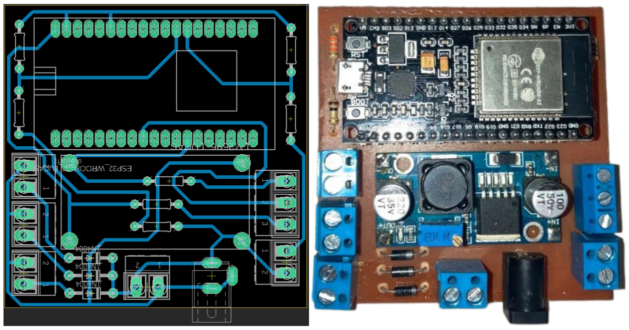


Fig. 6. Developed Hardware.

To save energy, the goal remained to use only passive components, that is, elements that absorb, store, or dissipate electrical energy. Therefore, to read the battery voltage and water pressure, two simple resistive dividers were used (for the flow sensor, this was not necessary). This project supports the simultaneous use of up to 3 microturbines. As a result, the board is equipped with 3 rectifier diodes. Additionally, a P4 connector has been utilized, enabling the use of both batteries and common commercial power sources, if provided a local electrical grid.

### B. *Encapsulation*

The encapsulation of the prototype was carried out using a ready-made commercial model. Thus, through specific perforations, it was adapted to accommodate the printed circuit board as well as the necessary conductors for sensing and powering. For this type of project, due to the high humidity in the probable installation locations, it is highly recommended to have the maximum sealing of the external environment in addition to using covers. The final result is shown in the Fig. 7

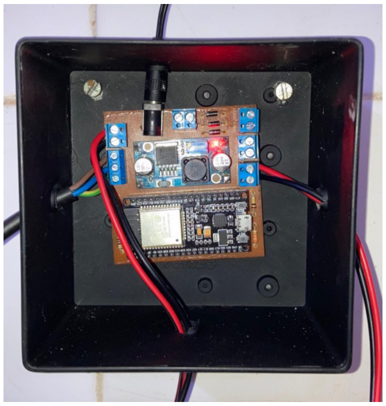


Fig. 7. System Encapsulation.

## VI. ENERGY-SAVING TECHNIQUES

Considering the desired self-sufficiency feature, it is necessary to use energy-saving tools. Thus, in addition to the prior choice of low-consumption components, some techniques were employed.

### A. *DeepSleep Technique*

The DeepSleep mode of the ESP32 is a feature that allows the microcontroller to enter a low-power state, with the purpose of saving battery energy and extending the device's lifespan, [10]. During this mode, most of the ESP32 components, including the processor, are turned off to minimize power consumption. In this mode, the ESP32 can consume as little as 10 uA, which allows the device to operate for an extended period of time, even with a small battery. Therefore, to use it, it is necessary to program the microcontroller to enter the low-power mode when appropriate and set specific events that should wake up the device. Additionally, it may be necessary to reconfigure the device peripherals and temporarily interrupt processing to ensure the lowest possible energy consumption.

Initially, for the system proposed in this research, a reading every 1 minute was envisioned, meaning the microcontroller ”sleeps” for 1 minutes, ”wakes up” and takes a reading.

### *B. Storage and Transmission of Data Packets*

The initial plan was to transmit data to the application layer every minute, which meant activating the microcontroller's WiFi module 60 times an hour. Yet, this approach was power-intensive due to the ESP32 WiFi module's constant connection and transmission requirements. Thus, we considered bundling 60 readings of each of the three variables into one packet per hour. An SD card module was proposed for this, but the added power load led us to explore the ESP32's RTC memory as an alternative. This non-volatile memory has an 8 KB storage capacity, making it a fitting solution for this project. As a result, we devised a data reading and sending operation, outlined in Fig. 8, which only requires the WiFi module to activate once per hour and if the WiFi network is not found, the microcontroller enters a loop until the network is found, without discarding any data. Ultimately, this implementation logic allows for significant energy savings.

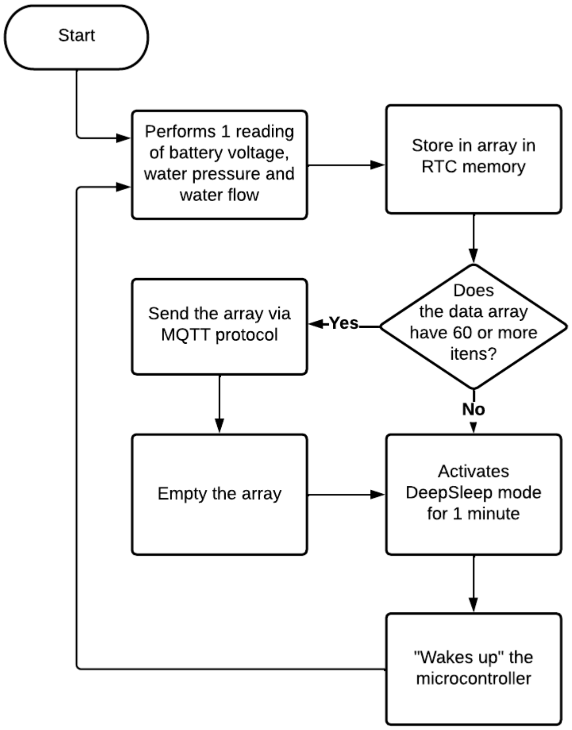


Fig. 8. Operation Logic.

## VII. DATA PROCESSING

In this section, the topics necessary for understanding the processing and visualization of data gathered from the transmitting terminal are explained.

### *A. Integration to External Database*

To capture and store the microcontroller's data, It was developed a script that creates an MQTT client subscribed to the broker's topic where the data is published. As in any measurement system, it is necessary to obtain the timestamp of each measurement. This can easily be done on the microcontroller, however, it would require activating the Wi-Fi module to connect to the internet and perform this query every minute, which would significantly increase the power consumption of the prototype. In this sense, this script also organizes the received data in a database with a timestamp for each reading. The applied logic is as follows:

$$T_{\text{Nth reading}} = T_{\text{Data packet}} - (60s)(60 - N) \tag{1}$$

where: $\text{T}_{\text{Nth reading}}$ represents the measurement time of the Nth reading in the 60 readings of the data packet, and $\text{T}_{\text{Data packet}}$ represents the arrival time of the entire data packet.

In this regard, this script was created using the Python language and the SQLite database model was used due to its lightweight, file-based nature and its ability to support high levels of concurrent read operations, which is advantageous for IoT applications with extensive data traffic, [12].

## VIII. RESULTS

This section will be neatly partitioned into two distinct areas, focusing on the advancements achieved in both the software and hardware projects.

### *A. Pipeline Monitoring System*

*1) Software:* The constructed monitoring system is based on the sampling of various metrics corresponding to the current and previous states of the water pipeline, as demonstrated in Fig. 9. In this regard, in addition to displaying the latest readings of each variable and the time of receipt of the last data packet, the average, maximum and minimum value of each variable in the last day and month are also calculated. Finally, an indicator has been added to signal the existence or absence of a water flow through this structure.

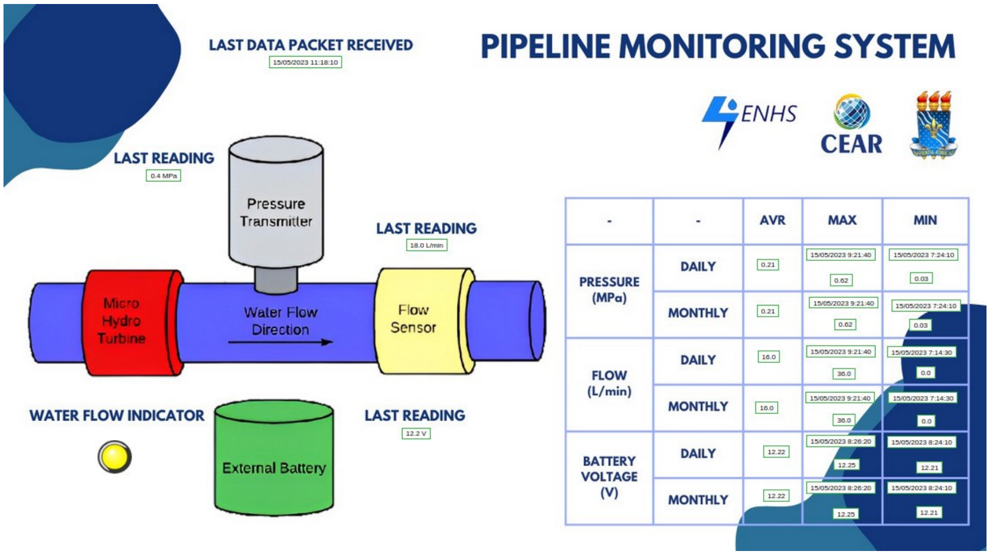
To achieve a centralized, unified, and efficient monitoring experience, SCADA LTS was employed as the supervisory control and data acquisition system. This choice is motivated by the platform's robust capabilities and adaptability, allowing integration between each subsystems within the laboratory under a single umbrella program.

*2) Hardware:* In Fig. 10, the physical installation of the system in the pipeline of interest to be monitored is shown, in addition to the battery used: 12V 7Ah (A smaller capacity battery could easily be used).

## IX. CONCLUSIONS

Effective water distribution is crucial in urban life, and its multifaceted nature from collection to distribution presents significant challenges. This work introduces an IoT-based solution, which is self-sufficient, cost-effective, energy-efficient, and capable of remotely monitoring pressure and flow in a water supply network.

Utilizing advanced technologies, including wireless sensors and low-energy techniques, this system gathers and transmits data, simplifying the monitoring and management of water distribution. Furthermore, the inclusion of a supervisory platform


PIPELINE MONITORING SYSTEM

LAST DATA PACKET RECEIVED
15/05/2023 11:18:10

LAST READING
0.4 MPa

LAST READING
18.0 L/min

LAST READING
12.2 V

| - | - | AVR | MAX | MIN |
|---|---|---|---|---|
| PRESSURE (MPa) | DAILY | 0.21 | 15/05/2023 9:21:40<br>0.62 | 15/05/2023 7:24:10<br>0.03 |
| | MONTHLY | 0.21 | 15/05/2023 9:21:40<br>0.62 | 15/05/2023 7:24:10<br>0.03 |
| FLOW (L/min) | DAILY | 16.0 | 15/05/2023 9:21:40<br>36.0 | 15/05/2023 7:14:30<br>0.0 |
| | MONTHLY | 16.0 | 15/05/2023 9:21:40<br>36.0 | 15/05/2023 7:14:30<br>0.0 |
| BATTERY VOLTAGE (V) | DAILY | 12.22 | 15/05/2023 8:26:20<br>12.25 | 15/05/2023 8:24:10<br>12.21 |
| | MONTHLY | 12.22 | 15/05/2023 8:26:20<br>12.25 | 15/05/2023 8:24:10<br>12.21 |

Fig. 9. Monitoring System.

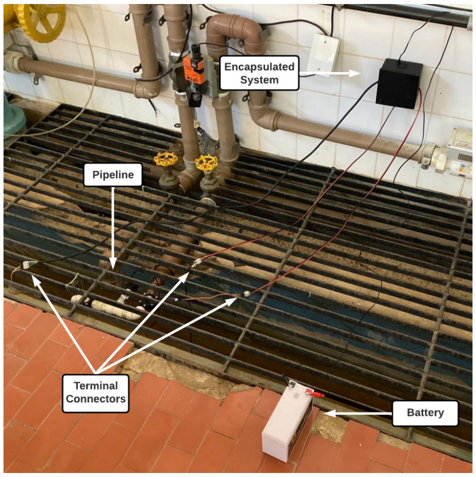


Fig. 10. System operating.

increases the system's utility by providing real-time insights and facilitating optimization of water distribution processes.

This research illustrates that IoT applications can offer practical alternatives to traditional sensor networks, particularly in large-scale urban environments where cost and feasibility are key considerations. By leveraging IoT, cities can address prevailing challenges in water distribution, ensuring consistent access to clean water for all residents. Future work will focus on refining and expanding this solution, aiming towards a more efficient, sustainable, and resilient water supply system.

## ACKNOWLEDGMENT

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