Three tier architecture for IoT driven water monitoring system

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Abstract
Water is an essential necessity for all living organisms, and as the human population continues to grow exponentially, the importance of conserving water resources has become increasingly significant. In the past, various water management systems have been proposed, using different technologies that often come with high costs and energy consumption. However, the emergence of Cyber-Physical Systems (CPS), Internet of Things (IoT), and wireless sensor networks (WSNs) has led to the development of smart water management systems. In this work, a smart water management system is introduced, which combines these technologies to monitor and control a water network. The water network is monitored and controlled by this system, which consists of a distribution tank, two consumption water tanks, and various water parameters such as water levels in the tanks and water flow in the pipes are intelligently monitored. A three-tier architecture, comprising of edge, fog, and cloud layers, is used in the system, and it is powered by a SAMD21 microcontroller, two Arduino Uno microcontrollers, and a Raspberry Pi.

Keywords
Smart water management system — RTOS — Trampoline os — CPS — IoT — WSNs — Water monitoring — Three-tier architecture — microcontroller — Raspberry Pi

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Introduction

Water is a fundamental resource that sustains life and plays a vital role in various sectors, including agriculture, industry, and domestic use. As the world's population continues to grow and urbanize, efficient management of water resources becomes increasingly critical[1]. The emergence of the Internet of Things (IoT) offers unprecedented opportunities for optimizing water distribution and consumption through smart water grids[1, 2].

A smart water grid integrates advanced sensing technologies, data analytics, and real-time monitoring to enable intelligent management of water resources. It encompasses the monitoring of water levels, flow rates, and other relevant parameters at different points in the distribution network[1]. By harnessing IoT technologies, such as microcontrollers and edge computing, the smart water grid can improve the efficiency, reliability, and sustainability of water management systems[3].

0.1 Novel Contributions of the Paper

This article aims to provide the design and implementation details of a three-tier architecture for an IoT-based water monitoring system, highlighting the role of each component to ensure effective management of water resources[1, 4]. Our objective is to provide a model for deploying similar smart water networks, fostering sustainability and addressing the challenges associated with water scarcity and resource management.Overall, the paper's contributions includes :

Three-Tier Architecture: A comprehensive three-tier architecture specifically designed for an IoT-driven water monitoring system is presented in the paper. Edge nodes, fog computing, and cloud-based analytics are incorporated in this architecture, enabling efficient data collection, processing, storage, and visualization[4, 5].

Integration of Multiple Sensors: Including ultrasonic sensors for water level measurement, temperature sensors, and flow sensors, is proposed by the system. Comprehensive real-time data on water levels, temperature, and flow rates are provided by this integration, facilitating accurate monitoring and analysis[6].

Trampoline OS Implementation: using Trampoline OS, a real-time operating system, to program the microcontrollers. This implementation ensures task scheduling, enables data synchronization, and enhances the overall performance of the system[7].

Fog Node for Local Processing: The introduction of a fog node, represented by a Raspberry Pi, allows for local data processing and storage. This reduces the reliance on cloud infrastructure, improves response times, minimizes network congestion, and enhances data privacy and security[1].

Integration with Thingboard: The integration of the pro-

posed system with Thingboard, a popular IoT platform, is demonstrated by the paper. Real-time data visualization, advanced analytics, and remote monitoring are enabled by this integration, thereby enhancing the usability and accessibility of the system[8].

0.2 Overall Organization of the Paper

In the subsequent sections of this paper, we will delve into the details of each tier, including hardware components, software configurations, data flow, and the overall system's functionality. Through this comprehensive exploration, we aim to demonstrate the potential of the three-tier architecture for creating robust and scalable water monitoring solutions, paving the way for enhanced water resource management in the era of IoT. The remainder of the paper is organized in the following manner. Section 1 discusses related research and motivation of the article. Section 2 provides an overview of the system design and describes the components and functionality of each level of the three-tier architecture. Section 3 discusses the data flow and communication protocols used to deploy the system. Section 4 gives a brief description of hardware prototype. Section 5 describes practical information on implementing the system, discussing hardware configurations, software configurations, and connections between components. The results of the experiments and tests carried out with the prototype system are discussed in section 6 . Finally, Section 7 includes the conclusion and future work.

1. RELATED RESEARCH AND MOTIVATION

Several studies have been conducted to design and implement IoT-based water management systems. In [2], the authors discuss the components and technologies used in IoT-based water management systems, including sensors, controllers, and IoT platforms. The paper also presents an analysis of different water management systems proposed in the literature, highlighting the parameters used for measuring various properties of water. Additionally, it proposes an IoT-based architecture for a smart water management system and emphasizes the importance of efficiency and smartness in such systems. Furthermore, the paper incorporates machine learning techniques to enhance the accuracy and efficiency of predictions made by the system.

Another study [9].The study discusses the implementation of an IoT-based system for monitoring water levels, detecting water leakage, and controlling motors in smart water tanks. The authors used the Arduino IDE, ATOM, and Ionic framework for development and validation. Additionally, they devised an algorithm based on Bernoulli's principle to detect water leakage. The system acquires water level readings every 30 seconds and transmits the data to ThingSpeak for analysis.

A different approach is presented in[10], where the authors propose an IoT-based smart water quality management system. It addresses the challenges of water scarcity and water stress by proposing a solution that utilizes IoT technology. The traditional manual meter reading method is considered inefficient, and the paper emphasizes the need for a sustainable approach. The system described in the paper offers several advantages. It enables the measurement of water flow and the generation of corresponding bills. It incorporates a corridor impact sensor to accurately measure water flow and a pH meter to monitor water quality. Real-time information analysis is achieved, and immediate billing is generated based on water usage. The system is reliable and controlled through an Android application, making it easy to install and use.

However, while these studies provide valuable insights into the design and implementation of IoT-based water management systems, the proposed three-tier architecture offers a more comprehensive solution that addresses water distribution and consumption monitoring, incorporates fog computing for improved latency and bandwidth management, and leverages cloud-based visualization and analytics for decision-making.

2. PROPOSED SYSTEM

The proposed system is designed to implement a smart water grid, which is a prototype of a automatic water monitoring system for one distribution water tank and two consumption water tanks. The distribution tank is responsible for distributing water to the other two consumption tanks. The system is built on a three-tier architecture, consisting of edge, fog, and cloud tiers, each with specific components and functionalities.

The system architecture in shown in figure 1

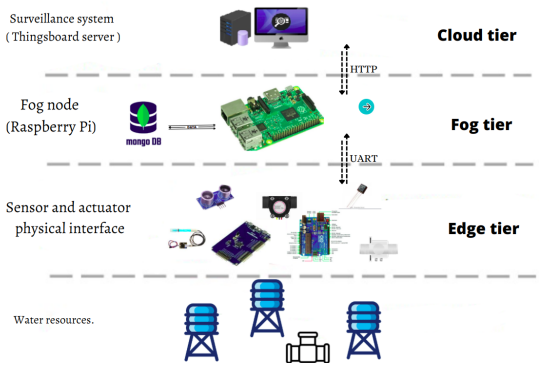


Figure 1. system architecture.

In the edge tier, the system employs a SAMD21 Xplained Pro microcontroller to acquire data from an HC-SR04 ultrasonic sensor, which measures the water level in the distribution water tank[9]. Additionally, the microcontroller acquires temperature data from an LM35 sensor installed in the same tank. Furthermore, two Arduino Uno microcontrollers, programmed with Trampoline OS, act as edge nodes. The first Arduino Uno reads data from two flow sensors: one located

at the distribution water tank's pipe outlet[9], and the other at the first consumption tank's pipe entrance. The second Arduino Uno is responsible for reading data from a flow sensor installed at the second consumption tank's pipe entrance, as well as an HC-SR04 ultrasonic sensor for measuring the water level in the second consumption tank. This second Arduino Uno also controls an electrovalve connected to the second consumption tank's pipe entrance, which closes when the water reaches a predetermined level[11].

The fog tier is composed of a Raspberry Pi that receives data from the SAMD21 Xplained Pro microcontroller and the two Arduino Uno microcontrollers via serial connection. The Raspberry Pi processes the incoming data, stores it in a MongoDB database[12], and forwards the data to the cloud tier for further analysis[13, 14, 15, 16].

The cloud tier is responsible for data visualization and analysis, utilizing Thingboard, an open-source IoT platform[8]. The Raspberry Pi transmits the data to Thingsboard via the HTTP protocol, allowing for user-friendly data visualization and in-depth data analysis and processing.

3. Data Flow and Communication Protocols

Different protocols are employed at each level of the three-tier architecture in the proposed system. Within the first tier, a collection of wired sensors interfaces with microcontrollers, which, in turn, establish a connection with a Raspberry Pi via the UART protocol[17]. The second tier, represented by the Raspberry Pi, handles tasks such as data processing, storage, and wireless communication between the system and the third tier, which involves the Thingsboard server[8]. The exchange of information between these tiers relies on the utilization of the HTTP protocol[18], specifically through the implementation of the GET and POST methods.

4. System components

The main components used to develope the system include

- Microcontrollers
  - Samd21Xplained Pro
  - Raspberry Pi 4
  - Arduino UNO
- Sensors
  - Ultrasonic Sensor (HC-rs04)
  - Temperature sensor (LM35)
  - Flow sensor
- Actuator
  - Électrovanne (ZE-4P 180)

5. Implementation Details

This section consists of a detailed description of the interfacing done in different parts of the prototype :

Figure 2 demonstrates the interfacing of "HC-SR04" and "LM35" with the SAMD21 Xplained Pro microcontroller, using pins 5, 9, and 15.

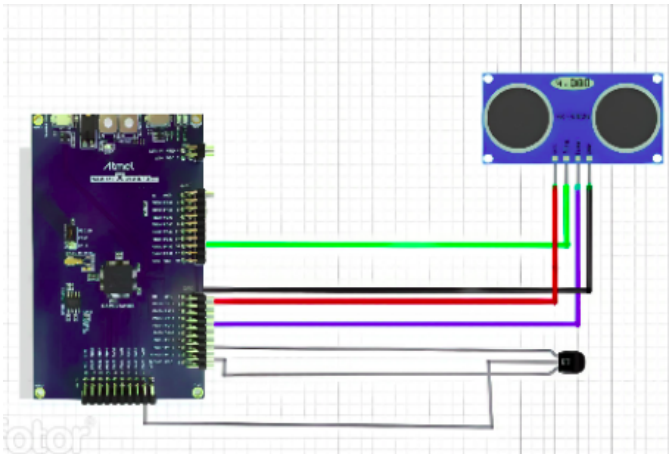


Figure 2. Connection diagram between samd21 and "LM35", "HC-RS04" sensors.

Figure 3 displays the interfacing of two "YFS 201" flow sensors with the initial Arduino UNO, using pins 2 and 3.

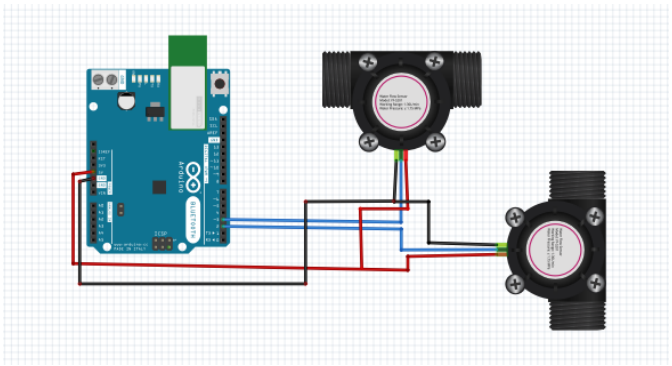


Figure 3. Connection diagram between arduino uno and "YFS 201" flow sensors.

Figure 4 showcases the interfacing of a "YFS 201" flow sensor, "HC-SR04" ultrasonic sensor, and "ZE-4P 180" valve with the second Arduino UNO, employing pins 2, 4, 6, and 7.

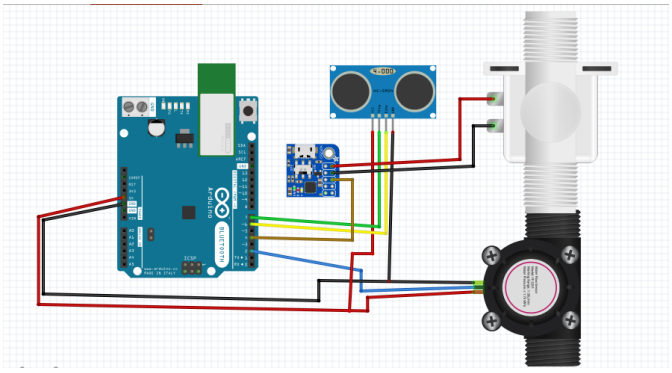


Figure 4. Connection diagram between arduino uno and YFS 201 flow ,ZE-4P 180 valve,HC-SR04 sensors.



Figure 6. Water parametres graphics

6. EXPERIMENTS AND RESULT DISCUSSION

The performance evaluation of the real-time water monitoring system has confirmed its superiority over current manual methods. The findings have showcased a significant enhancement in terms of efficiency, accuracy, and responsiveness. The system enables continuous and remote data collection, thereby reducing time and resource requirements. Moreover, the use of calibrated sensors ensures precise and reliable measurements, mitigating human errors. Swift detection of issues and prompt alerts allows for an immediate response, thereby minimizing risks associated with water quality. Moreover, the system effectively curtails operational costs and errors linked to water management. These evaluation results underscore the paramount importance and potential benefits of the deployed water monitoring system.

The results of monitoring the various water parameters are shown in figure 5 , 6 and 7. The ThingsBoard IoT platform was used to develop the graphical interface of our monitoring system.

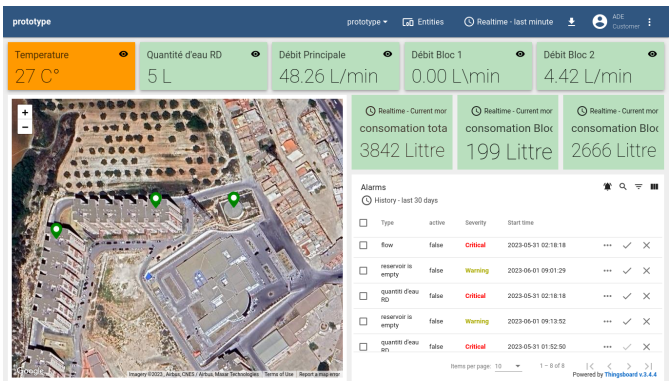


Figure 5. User interface monitoring dashboard home page.

7. CONCLUSION AND FUTURE WORKS

In this work presented a three-tier architecture prototype for an IoT-driven water management system. The prototype enables real-time monitoring of water level, temperature, and flow rate in a distribution tank and two consumption tanks. The system used a SAMD21 microcontroller, two Arduino UNO, and a Raspberry Pi to collect and transmit data, store it in a MongoDB database, and visualize it on ThingBoard. This system has the potential to enhance water management efficiency, reduce wastage, and contribute to sustainable development.

The significance and impact of the three-tier architecture in IoT-driven water monitoring systems cannot be overstated. It offers scalability and flexibility in monitoring water systems, making it suitable for both small-scale and large-scale applications. By leveraging cloud-based platforms like ThingBoard, the collected data can be visualized and analyzed for further insights and decision-making. The system's real-time data transmission capability enables prompt action to be taken in critical situations, ensuring the continuous supply of clean water.

However, it is essential to acknowledge that the proposed system serves as an exemplar of a smart water management system and may not have universal applicability. Different contexts may require diverse components and configurations based on local infrastructure, water resources, and regulations. Therefore, considering the specific needs and requirements of each context is crucial when designing a smart water management system. Future research should prioritize scalability, reliability, and system optimization. Optimizing the system's energy efficiency to prolong the battery life of the microcontrollers and enhance the overall sustainability of the system, integrating advanced analytics techniques such as machine learning algorithms can enable predictive analysis and early detection of water quality issues. Exploring the use of additional sensors, can expand the scope of water quality monitoring and provide more comprehensive insights.

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