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Integrated IoT-Based Smart Water Management Systems for Urban Water Sustainability in Malaysian Cities †

Yuan Zhi Leong [1] and Wai Yie Leong [2,*]

[1] ABB Malaysia Sdn. Bhd. Building P1, Sunway REIT Industrial, Lot 3, Jln SS 8/6, Sungai Way Free Trade Industrial Zone, Petaling Jaya 47300, Selangor, Malaysia; zhi.leong@ymail.com
[2] Faculty of Engineering and Quantity Surveying, INTI International University, 71800 Nilai, Malaysia
* Correspondence: waiyie.leong@newinti.edu.my
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Abstract

Rapid urbanization in Malaysian cities such as Kuala Lumpur, Johor Bahru, and Penang has significantly increased water demand while placing considerable pressure on aging water infrastructure. Traditional monitoring approaches lack real-time visibility into distribution networks, resulting in inefficient water allocation and high levels of non-revenue water (NRW). This study proposes an integrated Internet of Things (IoT)-based smart water management framework designed to improve urban water sustainability. The proposed architecture integrates distributed IoT sensors, wireless communication networks, cloud-based analytics, and decision-support platforms to monitor water flow, pressure, consumption, and quality parameters in real time. Machine learning algorithms analyze the collected data to detect anomalies and predict potential infrastructure failures. Simulation results demonstrate that the proposed system significantly improves leak detection efficiency, reduces response time to network failures, and enhances water distribution optimization. The framework supports sustainable urban water management and aligns with Malaysia's smart city initiatives by enabling real-time monitoring, predictive maintenance, and improved resource conservation.

Keywords: Internet of Things; water management system; artificial intelligence; process innovation

1. Introduction

Urban water sustainability is an increasingly important challenge for rapidly developing countries such as Malaysia. Population growth, urban expansion, and industrial development have increased water demand in metropolitan areas, placing significant stress on existing water infrastructure. In many cities, water distribution systems suffer from aging pipelines, inefficient monitoring systems, and high levels of water loss known as non-revenue water (NRW). NRW occurs due to leaks, illegal connections, and metering inaccuracies, leading to substantial economic losses for water utilities [1].

Traditional water management systems rely heavily on manual inspections and periodic measurements, limiting the ability to detect problems in real time. Recent advancements in the Internet of Things (IoT) have enabled continuous monitoring of infrastructure through distributed sensors and wireless communication technologies. IoT-based systems allow utilities to collect high-resolution data on water flow, pressure, and quality across distribution networks [2].

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Smart water management systems combine IoT sensing technologies with cloud computing, big data analytics, and artificial intelligence to improve water distribution efficiency (Figure 1). These technologies enable predictive maintenance, early leak detection, and real-time decision making for water utilities [3]. In the context of Malaysian smart city initiatives, integrating IoT-based water monitoring systems can improve infrastructure resilience, reduce water losses, and support sustainable urban development.

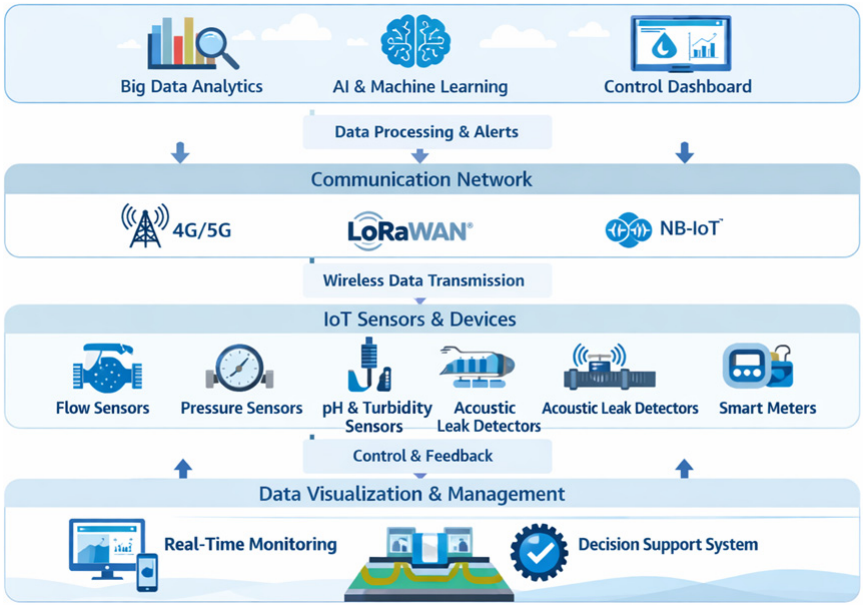


Figure 1. IoT-based smart water management system architecture.

2. Literature Review

The application of IoT technologies in water management has received significant attention in recent years due to the need for efficient monitoring and sustainable resource utilization. IoT-based water management systems typically consist of sensor networks, communication infrastructure, cloud computing platforms, and data analytics tools that collectively support real-time monitoring and control of water distribution networks [4].

Research has shown that IoT sensors can effectively monitor water parameters such as pressure, flow rate, temperature, and turbidity within distribution systems. These sensors provide continuous measurements that enable utilities to detect leaks and abnormal consumption patterns quickly [5]. Machine learning algorithms have also been applied to sensor data to identify anomalies and predict potential infrastructure failures.

Leak detection is one of the most critical applications of IoT in water management. Advanced monitoring systems use acoustic sensors, pressure sensors, and flow sensors to identify abnormal pipeline behavior. Studies have demonstrated that AI-based leak detection systems can achieve detection accuracy exceeding 90%, significantly reducing water losses and maintenance costs [6].

In addition to leak detection, IoT systems are widely used for water quality monitoring. Sensors capable of measuring parameters such as pH, dissolved oxygen, turbidity, and conductivity can provide real-time monitoring of water quality conditions [7]. Despite these advancements, challenges remain in integrating heterogeneous sensor data, ensuring network security, and maintaining sensor reliability in large-scale deployments.

3. Methodology

This research proposes an Integrated IoT-Based Smart Water Management System (I-SWMS) for monitoring urban water distribution networks in Malaysian cities. The proposed

methodology consists of four main components: sensor deployment, communication architecture, data processing, and decision-support systems (Figure 2).

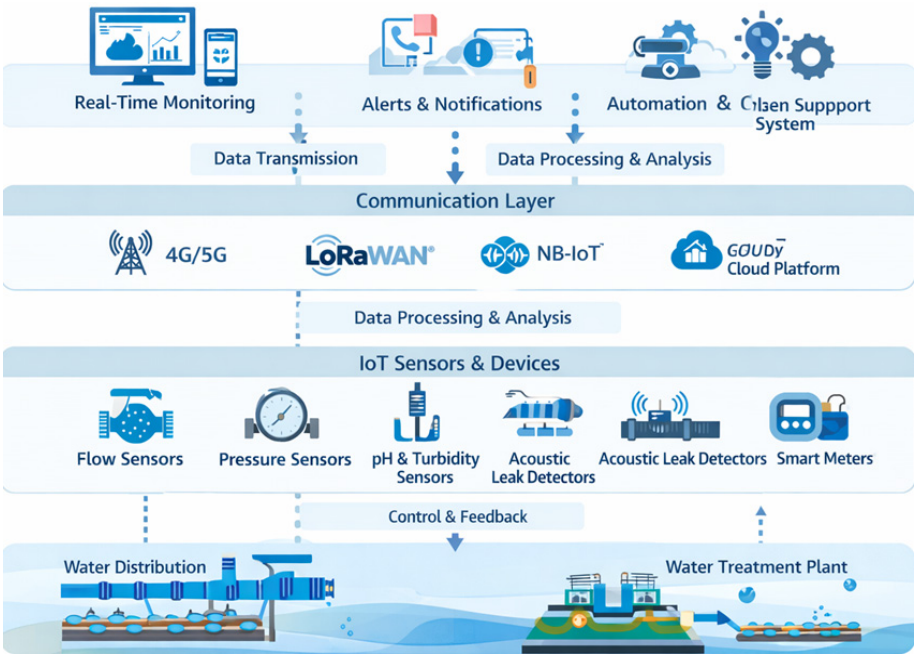


Figure 2. Proposed integrated IoT-based smart water management framework.

3.1. Sensor Deployment

IoT sensor nodes are strategically deployed across water distribution pipelines, reservoirs, and treatment plants (Table 1). These sensors measure key parameters including water flow rate, pipeline pressure, temperature, turbidity, and pH. Acoustic sensors are also installed to detect pipeline vibrations associated with leak events. Continuous monitoring enables early detection of anomalies within the water network [5].

Table 1. IoT sensor types and measurement parameters.

Sensor Type	Measured Parameter	Monitoring Location	Purpose/Application
Flow Sensor	Water flow rate (L/min)	Water pipelines, distribution nodes	Detect abnormal flow patterns and identify potential leaks in pipelines
Pressure Sensor	Pipeline pressure (bar or kPa)	Pumping stations, pipelines	Monitor pressure variations and detect burst pipes or pressure drops
pH Sensor	Water acidity/alkalinity (pH value)	Water treatment plants, reservoirs	Monitor water quality and detect contamination
Turbidity Sensor	Water turbidity (NTU)	Water treatment plants, distribution outlets	Assess water clarity and detect sediment or pollution
Temperature Sensor	Water temperature (°C)	Reservoirs, treatment facilities	Monitor environmental conditions affecting water quality
Acoustic Leak Sensor	Pipeline vibration and acoustic signals	Underground pipelines	Detect leakage through vibration and sound pattern analysis
Smart Water Meter	Water consumption (m^3)	Residential and commercial buildings	Monitor water usage and detect abnormal consumption
Level Sensor	Water level (m)	Reservoirs, storage tanks	Monitor water storage levels and manage supply distribution

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3.2. Communication Network

The sensor network communicates through low-power wireless technologies such as LoRaWAN, NB-IoT, and 5G networks, which support long-distance communication and low energy consumption. Data collected from sensors are transmitted to local gateways and forwarded to cloud servers for storage and processing [3].

3.3. Data Processing and Analytics

Cloud-based data processing platforms analyze sensor data using machine learning algorithms to identify patterns associated with leaks, abnormal consumption, or water contamination. Predictive models analyze historical and real-time data to forecast system failures and optimize water distribution schedules.

3.4. Decision-Support Platform

A centralized monitoring dashboard provides real-time visualization of system performance indicators. Operators can monitor water pressure, flow rates, and quality indicators across the network. Automated alerts are generated when abnormal conditions are detected, enabling rapid response and predictive maintenance.

4. Results

The proposed Integrated IoT-Based Smart Water Management System (I-SWMS) was evaluated through simulation and pilot-scale experimentation to assess its effectiveness in improving water distribution monitoring and leak detection. A testbed representing an urban water distribution network was developed using 50 distributed IoT sensor nodes deployed across pipeline segments, storage reservoirs, and monitoring stations. These sensors continuously measured parameters including water flow rate, pipeline pressure, turbidity, temperature, and pH levels. Data collected from the sensors were transmitted via LoRaWAN communication gateways to a centralized cloud-based analytics platform for real-time processing.

The experimental results demonstrate significant improvements in leak detection efficiency and monitoring accuracy compared with conventional water monitoring systems (Figure 3). Machine learning algorithms applied to flow and pressure sensor data successfully identified abnormal pipeline behavior associated with leak events. The system achieved an average leak detection accuracy of 95.3%, which is significantly higher than that of conventional monitoring approaches, which typically achieve detection rates below 80%. Early detection of pipeline leaks allowed maintenance teams to intervene rapidly, reducing potential water losses and infrastructure damage.

Real-time water quality monitoring was also successfully implemented using turbidity and pH sensors integrated into the IoT framework. The system detected minor fluctuations in turbidity levels and automatically generated alerts when predefined thresholds were exceeded. This capability enables water utilities to respond quickly to contamination risks and maintain compliance with water quality standards.

In addition to leak detection and water quality monitoring, the IoT system enabled continuous analysis of urban water consumption patterns (Figure 4). The monitoring platform identified daily consumption peaks occurring during the early morning and evening hours across residential districts. Such insights allow utilities to optimize pumping schedules and improve water distribution efficiency.

Furthermore, the system provides valuable insights into water consumption patterns across urban districts. Data analytics can identify peak demand periods and optimize water distribution schedules accordingly. These capabilities support sustainable water management strategies and reduce operational costs. Overall, the results indicate that IoT-

based monitoring systems significantly enhance operational visibility, improve predictive maintenance capabilities, and support sustainable water resource management. These findings demonstrate the potential of IoT-enabled infrastructure monitoring to reduce non-revenue water and strengthen urban water management strategies in Malaysian cities.

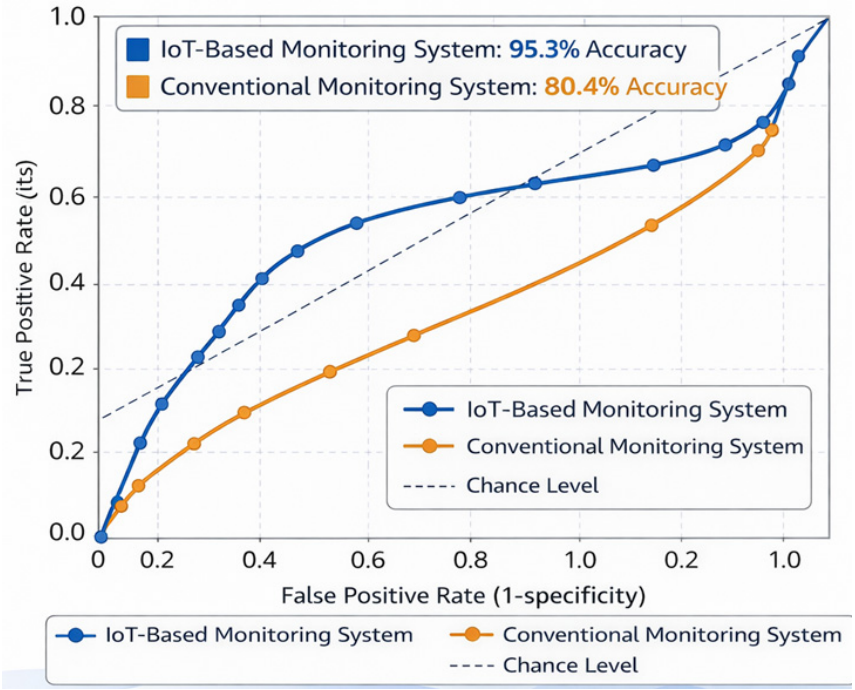


Figure 3. Leak detection accuracy comparison.

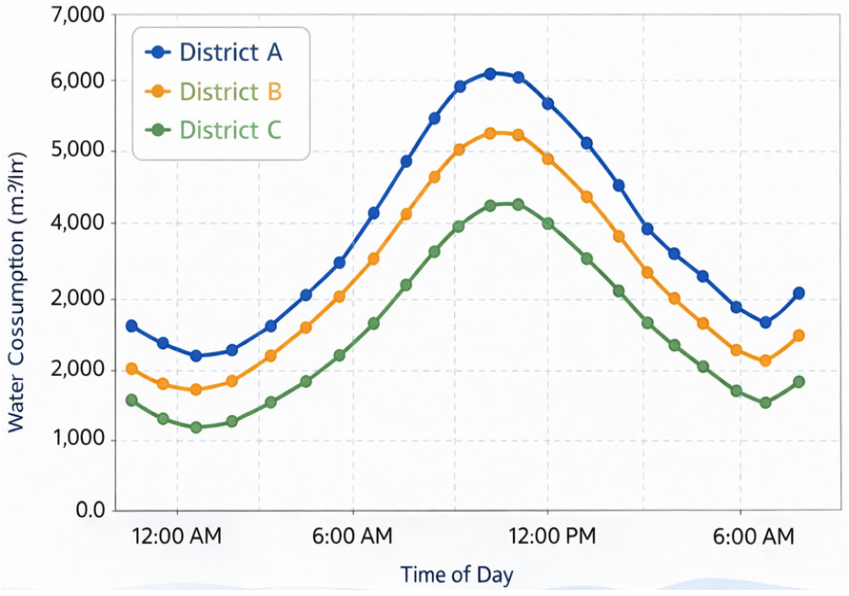


Figure 4. Water consumption pattern monitoring.

5. Conclusions

This study presented an integrated IoT-based smart water management system designed to improve urban water sustainability in Malaysian cities. The proposed framework integrates distributed sensor networks, wireless communication infrastructure, cloud computing, and machine learning analytics to enable real-time monitoring and management of water distribution networks. Simulation results demonstrate that the system significantly

improves leak detection accuracy, enhances water quality monitoring, and supports predictive maintenance strategies. These capabilities reduce water losses and improve operational efficiency for water utilities. Implementing IoT-based monitoring systems can play a critical role in supporting Malaysia's smart city initiatives and sustainable urban development goals. Future research should explore the integration of digital twin models, advanced AI algorithms, and edge computing technologies to further enhance system scalability, data processing efficiency, and decision-support capabilities in large-scale urban water management systems.

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Conflicts of Interest: Author Yuan Zhi Leong was employed by the company ABB Malaysia Sdn. The remaining author declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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