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# IoT-Enabled Intelligent Restroom with Real-Time Monitoring, UV Disinfection, and Self-Cleaning Mechanism

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*KEYWORDS*

*Internet of Things (IoT), Smart Washroom System, Hygiene Monitoring, RFID Access Control, Gas Sensor, ThingSpeak Cloud, Environmental Monitoring, Smart Sanitation Infrastructure.*

**ABSTRACT**

*The increasing demand for hygienic, efficient, and user-friendly public sanitation facilities necessitates the adoption of intelligent automation and real-time monitoring technologies. This paper presents an Internet of Things (IoT)-enabled Smart Washroom Management System designed to enhance hygiene, safety, and operational efficiency in high-traffic environments such as universities and public institutions. The proposed system integrates an RFID-based authentication mechanism to ensure controlled access, allowing only authorized users to operate the washroom door. An ultrasonic sensor is utilized for real-time occupancy detection, enabling automatic door control and activation of cleaning operations after user exit. To maintain a safe and healthy environment, the system incorporates a gas sensor for detecting odor and harmful gases, while an ultraviolet (UV) light-based disinfection unit performs automated sanitization. A water level sensor continuously monitors the avail- ability of water in the storage tank and triggers a buzzer alert when the level drops below a predefined threshold. The system also uploads real-time data to the ThingSpeak cloud platform, allowing remote monitoring and data analysis. In emergency or abnormal conditions, instant notifications are sent to maintenance personnel through Telegram messaging services to ensure rapid intervention. Furthermore, the system includes automatic fan control for air purification, which activates when poor air quality is detected and deactivates once normal conditions are restored. By integrating IoT connectivity, sensor networks, and cloud- based monitoring, the proposed solution provides a scalable, touchless, and sustainable approach for improving sanitation management. The system enhances hygiene standards, reduces manual monitoring efforts, and supports the*

## 1. INTRODUCTION

Public sanitation facilities play a critical role in maintaining hygiene, health, and overall well-being in urban environ- ments. However, traditional washroom management systems rely heavily on manual inspection and scheduled cleaning routines, which often fail to adapt to dynamic usage patterns and sudden hygiene issues. With increasing urban population and higher usage frequency of public washrooms, there is a growing need for intelligent monitoring and automated management solutions that ensure cleanliness, safety, and operational efficiency. The emergence of the Internet of Things (IoT) has enabled the development of smart infrastructure capable of real-time monitoring, data-driven decision-making, and automated facility control [1].

IoT-based facility management systems integrate multiple sensors, communication modules, and cloud platforms to con- tinuously monitor environmental parameters and infrastructure conditions. These systems can detect abnormal conditions and trigger automated responses or maintenance alerts, thereby improving operational efficiency and reducing manual in- tervention [3]. In the context of sanitation facilities, IoT technologies allow continuous monitoring of occupancy, air quality, water availability, and overall facility status, ensuring timely maintenance and improved user experience [11]. Air quality monitoring using gas sensors such as MQ-135 enables detection of harmful gases and unpleasant odors, which are common challenges in high-traffic washrooms [2].

Recent advancements in IoT architectures have also enabled scalable smart-city applications where multiple facilities can be monitored remotely through cloud-based dashboards and data analytics platforms [8]. Cloud services such as Firebase and IoT analytics platforms allow real-time data storage, visualization, and remote access to facility conditions [4]. These technologies enable facility managers to monitor wash- room conditions continuously and take proactive maintenance actions when necessary. In addition, real-time communication technologies allow instant alerts to be sent to maintenance per- sonnel through notification systems, ensuring rapid response during critical situations [14].

Sensor reliability and energy efficiency are important con- siderations in large-scale IoT deployments. Reliable sensor networks ensure accurate monitoring of environmental param- eters such as air quality, occupancy, and water levels [6]. Meanwhile, energy-efficient IoT systems help reduce power consumption and improve sustainability in smart infrastruc- ture applications [12]. The integration of machine learning techniques further enhances system capabilities by enabling predictive maintenance and environmental forecasting, which can optimize cleaning schedules and resource usage [15].

Government initiatives such as the Swachh Bharat Mission emphasize the importance of improved sanitation infrastruc- ture and smart monitoring systems to ensure clean and hy- gienic public facilities [10]. By integrating IoT technologies,

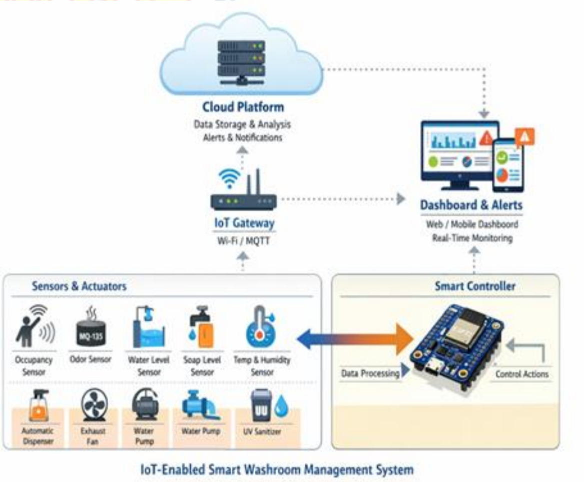


Fig. 1. Conceptual architecture of the proposed IoT-enabled smart washroom management system integrating sensors, cloud connectivity, and automated control mechanisms.

The integration of intelligent sensing, cloud-based moni- toring, and automated control mechanisms provides a scalable and efficient solution for modern sanitation infrastructure. The proposed system aims to improve hygiene standards, enhance operational transparency, and contribute to the development of smart and sustainable public facilities.

## 2. RELATED WORK

The rapid development of the Internet of Things (IoT) has significantly transformed facility management and smart infrastructure monitoring systems. Several researchers have explored IoT-based monitoring platforms to improve oper- ational efficiency, environmental monitoring, and automated maintenance. Kaur et al. [1] proposed an IoT-based facility management framework that integrates sensor networks and cloud computing to monitor building conditions in real time. Their work highlights the importance of automated monitoring systems in improving maintenance efficiency and reducing manual inspection efforts.

Air quality monitoring is one of the critical components in smart sanitation systems. Lee et al. [2] developed a sensor- based environmental monitoring system using MQ-135 gas sensors to detect air pollutants and harmful gases. Their re- search demonstrated that continuous monitoring of air quality parameters can significantly improve environmental safety in indoor spaces. Similarly, Chen et al. [6] investigated the relia- bility of sensor networks in IoT applications and emphasized the need for accurate and dependable sensors for effective environmental monitoring.

Predictive maintenance techniques have also been widely studied in the context of smart buildings and infrastructure management. Sharma et al. [3] presented a predictive main- tenance framework that utilizes IoT data and analytics to identify potential infrastructure failures before they occur. Furthermore, Bhatia et al. [15] demonstrated the effectiveness of machine learning techniques for predictive maintenance in facility management systems, enabling proactive decision-making and optimized resource allocation.

Cloud-based data storage and remote monitoring platforms are essential components of modern IoT architectures. Patel et al. [4] introduced a real-time IoT data storage system using Firebase, which enables continuous data collection and remote monitoring of smart devices. Similarly, scalable IoT architec- tures designed for smart city applications were discussed by Singh et al. [8], highlighting the importance of cloud-based infrastructure for managing large-scale sensor networks and smart services.

Communication technologies also play a crucial role in enabling real-time notifications and interaction between IoT systems and users. Gupta et al. [5] explored automated no- tification systems using communication APIs, while Joshi et al. [14] provided a comprehensive review of real-time communication frameworks used in IoT applications. These systems enable immediate alerts to maintenance personnel in case of abnormal environmental conditions or system failures. In addition to monitoring and communication technologies, user interaction and data visualization are important aspects of smart IoT systems. Kumar et al. [7] proposed user-centric IoT dashboards that provide intuitive visualization and man- agement interfaces for monitoring sensor data. Such interfaces improve usability and enable facility managers to make data-driven decisions more effectively.

Energy efficiency and sustainable IoT deployments have also received considerable research attention. Nguyen et al. [12] discussed energy-efficient IoT deployment strate- gies aimed at reducing power consumption while maintain- ing reliable monitoring performance. Similarly, Reddy et al.[13] presented several ESP8266-based IoT applications for smart environments, demonstrating the feasibility of low-cost wireless microcontrollers in developing scalable monitoring systems.

Machine learning techniques are increasingly being inte- grated with IoT systems for environmental prediction and intelligent decision-making. Zhang et al. [9] developed random forest models for environmental prediction, demonstrating the ability of machine learning algorithms to analyze sensor data and forecast environmental conditions.

## 3. PROPOSED ARCHITECTURE

The proposed IoT-enabled Smart Washroom Management System is designed to automate sanitation monitoring, access control, and environmental management in public washroom facilities. The architecture integrates multiple sensors, com- munication modules, and automated control units to ensure efficient and hygienic washroom operations. The system con- tinuously monitors occupancy, air quality, and water avail- ability while enabling remote monitoring through cloud-based platforms.

The overall architecture consists of several interconnected modules, including the RFID authentication unit, occupancy detection module, environmental monitoring system, water level monitoring unit, automated ventilation system, and cloud communication interface. An ESP8266 microcontroller acts as the central processing unit that collects data from various sensors, processes the information, and communicates with cloud services such as ThingSpeak for real-time monitoring.

The RFID module is used to provide secure and controlled access to the washroom facility. Only authorized users can access the washroom by scanning their RFID card, ensur- ing safety and controlled usage. Once access is granted, an ultrasonic sensor detects user entry and determines the occupancy status of the washroom. After the user enters, the system automatically closes the door and activates the internal monitoring mechanisms.

To maintain hygienic conditions, an MQ-135 gas sensor is deployed to detect harmful gases and unpleasant odors inside the washroom. When the gas concentration exceeds a predefined threshold, the system automatically activates the ventilation fan to improve air quality. Additionally, a UV- based disinfection unit can be triggered after the user exits the washroom to ensure effective sanitization.

Water availability is monitored using a water level sensor installed in the overhead water tank. If the water level falls below a predefined limit, a buzzer alert is activated to notify

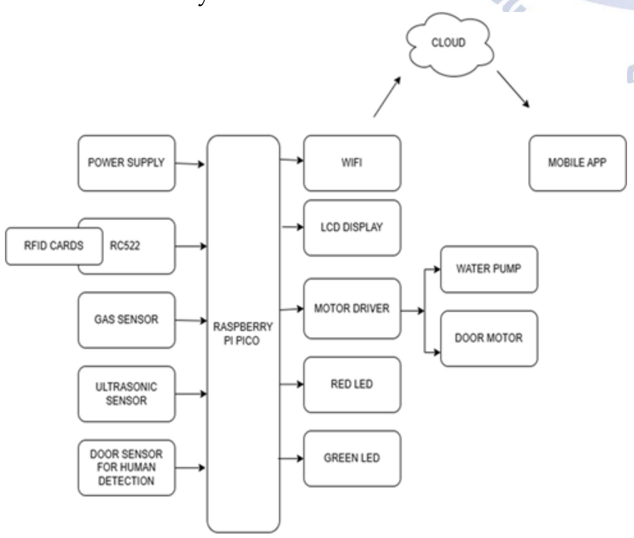


Fig. 2. Block diagram of the proposed IoT-enabled Smart Washroom Management System showing sensor integration, control modules, and cloud connectivity.

The proposed architecture provides a scalable and intelli- gent solution for improving sanitation management in public facilities. By combining sensor-based monitoring, automated control mechanisms, and cloud-based analytics, the system enhances hygiene standards, reduces manual supervision, and ensures efficient resource utilization in modern smart infras- tructure.

## 4. METHODOLOGY

The proposed IoT-enabled Smart Washroom Management System operates through a structured workflow that integrates sensing, data processing, automated control, and cloud-based monitoring. The methodology consists of five major stages: user authentication, occupancy detection, environmental mon- itoring, resource monitoring, and cloud-based notification.

A. RFID-Based User Authentication

The system begins with RFID-based authentication to en- sure that only authorized users can access the washroom facility. When a user scans an RFID card, the system verifies the card ID with the list of authorized IDs stored in the microcontroller memory.

Let the scanned RFID tag be represented as

IDscan (1)

and the set of authorized IDs be

A = {ID1, ID2, ID3, ..., IDn} (2)

If the water level ratio falls below a threshold value Wth, an alert is triggered.

(IDscan ∈ A (3)

If the condition is satisfied, the door mechanism is activated; otherwise, access is denied.

B. Occupancy Detection Using Ultrasonic Sensor

The ultrasonic sensor is used to determine the presence of a user inside the washroom by measuring the distance between the sensor and the object.

The distance measured by the ultrasonic sensor is calculated

as

v × t

E. Cloud Monitoring and Notification

Sensor data including air quality, water level, and occu- pancy status are transmitted to the ThingSpeak cloud platform through the ESP8266 WiFi module. Let the sensor data vector be

S = {O, G, Wr} (10)

where

- O = Occupancy status
- G = Gas concentration
- Wr = Water level ratio

where

D = (4) 2

If abnormal conditions are detected, the system sends real- time notifications to maintenance personnel via Telegram.

- D = Distance between sensor and object

F. System Operation Algorithm

- v = Speed of sound in air (approximately 343 m/s)
- t = Time taken for the echo signal to return

If the measured distance is below a predefined threshold Dth, the system considers the washroom as occupied.

Algorithm 1 Smart Washroom Monitoring Algorithm

1: Initialize sensors and WiFi module

2: Load authorized RFID IDs

3: while system is active do

Occupancy = 1 if D < Dth

0 otherwise

C. Air Quality Monitoring

(5)

4: Read RFID tag

5: if RFID tag is authorized then

6: Open washroom door

7: Activate ultrasonic sensor for occupancy detection

The MQ-135 gas sensor is used to monitor the air quality inside the washroom by detecting harmful gases and odor levels. The gas concentration level is measured in parts per million (ppm).

Let the gas concentration be

G = f (Vout) (6)

where Vout represents the analog voltage output of the gas sensor.

If the gas concentration exceeds a threshold value Gth, the ventilation system is automatically activated.

8:end if

9: Measure distance using ultrasonic sensor

10: if distance < threshold then 11: Set occupancy = TRUE 12: end if

13: Read gas sensor value

14: if gas concentration > threshold then

15: Turn ON ventilation fan 16: Send alert notification 17: else

18: Turn OFF fan

19: end if

Read water level sensor

Fan Status =

ON if G > Gth OFF otherwise

(7)

20:

21: if water level < threshold then

22: Activate buzzer

D. Water Level Monitoring

The water level sensor continuously monitors the level of water in the storage tank. The water level ratio can be expressed as

23: Send maintenance alert

24: end if

25: Upload sensor data to ThingSpeak cloud

26: end while

where

Wr =Wcurrent Wmax

(8)

The above methodology ensures efficient monitoring and automation of washroom facilities by integrating IoT sensors, automated control mechanisms, and cloud-based communi- cation. The system enables real-time monitoring, proactive

- Wcurrent = Current water level
- Wmax = Maximum tank capacity

maintenance, and improved hygiene management in public sanitation environments

## 5. RESULTS AND DISCUSSION

The proposed IoT-enabled Smart Washroom Management System was implemented and tested using a hardware proto- type consisting of an ESP8266 microcontroller, RFID module, ultrasonic sensor, MQ-135 gas sensor, water level sensor, ventilation fan, buzzer, and UV disinfection unit. The sys- tem was designed to monitor washroom conditions in real time and automatically respond to environmental changes. The prototype successfully demonstrated automated access control, occupancy detection, air quality monitoring, water level monitoring, and cloud-based notification mechanisms.

Figure 3 shows the complete hardware prototype used for the implementation of the proposed system. The ESP8266 microcontroller acts as the central controller that collects sensor data and communicates with the ThingSpeak cloud platform through WiFi connectivity.

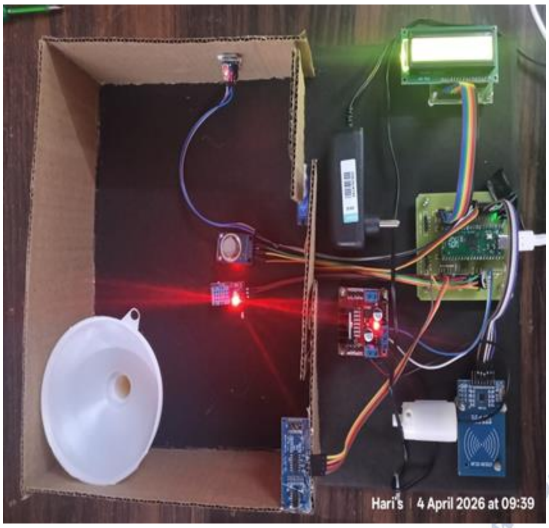


Fig. 3. Hardware prototype of the IoT-enabled smart washroom management system.

The RFID-based authentication module was tested to ensure secure access to the washroom facility. Authorized RFID cards successfully activated the door mechanism, while unauthorized cards were rejected by the system. Figure 4 illustrates the RFID authentication process during system operation

The ultrasonic sensor was used to detect user presence and determine washroom occupancy. When a user entered the washroom, the sensor detected the presence and automatically closed the door to maintain privacy and security. After the user exited, the system triggered the UV disinfection mecha- nism for automated sanitation. Figure 5 shows the occupancy detection mechanism implemented in the prototype.

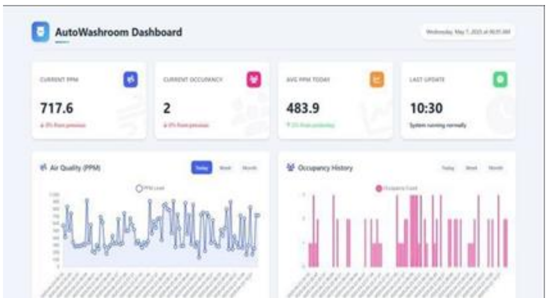


Fig. 5. Occupancy detection using ultrasonic sensor in the smart washroom system.

Air quality monitoring was performed using the MQ-135 gas sensor to detect odor and harmful gases inside the wash- room environment. When the gas concentration exceeded the predefined threshold level, the ventilation fan was automati- cally activated to improve air quality. Once the gas concen- tration returned to normal levels, the fan was automatically turned off. Figure 6 shows the gas sensor integrated into the prototype.

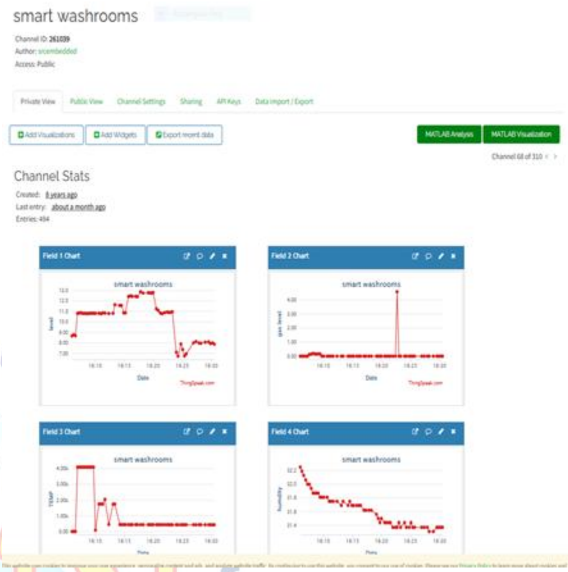


Fig. 7. Real-time monitoring of washroom parameters on the ThingSpeak cloud platform.

In addition to cloud monitoring, the system also provided real-time alert notifications through Telegram messaging ser- vices whenever abnormal conditions such as poor air quality or low water levels were detected. This feature enabled rapid response and proactive maintenance.

Table I summarizes the experimental results obtained during the testing of the proposed system.

TABLE I
PERFORMANCE EVALUATION OF THE PROPOSED SYSTEM

| Parameter | Threshold Value | System Response [3 |
|---|---|---|
| RFID Authentication | Authorized ID | Door Opens |
| Ultrasonic Distance | < 50 cm | Occupancy Detected [4 |
| Gas Sensor Level | > 700 ppm | Fan Activated |
| Water Level | < 30% | Buzzer Alert [5 |
| Cloud Update | Real-time | Data Uploaded to ThingSpeak |
| Alert Notification | Abnormal Condition | Telegram Message Sent |

The experimental results demonstrate that the proposed smart washroom management system operates reliably and effectively in real-time conditions. The integration of sensor- based monitoring, automated control mechanisms, and cloud- based communication significantly improves hygiene manage- ment and operational efficiency. The system also reduces man- ual inspection requirements and ensures timely maintenance through automated alerts and remote monitoring capabilities.

## 6. CONCLUSION

This paper presented the design and implementation of an IoT-enabled Smart Washroom Management System aimed at improving hygiene, safety, and operational efficiency in public sanitation facilities. The proposed system integrates multiple sensors, including RFID for secure access control, an ultrasonic sensor for occupancy detection, an MQ-135 gas sensor for air quality monitoring, and a water level sensor forresource management. These sensors work together with an ESP8266 microcontroller to continuously monitor washroom conditions and automate system responses. The system successfully demonstrated automated door ac- cess, real-time occupancy monitoring, air quality-based venti- lation control, and water level monitoring with buzzer alerts. In addition, sensor data was transmitted to the ThingSpeak cloud platform, enabling remote monitoring and data visualization. The integration of Telegram-based alert notifications further ensured that maintenance personnel could respond quickly to abnormal conditions such as poor air quality or low water levels.

Experimental results obtained from the hardware prototype confirmed the reliability and effectiveness of the proposed system in maintaining hygienic washroom conditions. The automated monitoring and control mechanisms significantly reduce the need for manual supervision while improving sanitation standards and operational transparency.

The proposed solution provides a scalable and cost-effective approach for smart sanitation infrastructure and can be easily deployed in public places such as universities, shopping malls, airports, and railway stations. Future work may focus on integrating machine learning techniques for predictive main- tenance, expanding the system with additional environmental sensors, and developing mobile applications for enhanced user interaction and facility management.

### Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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