Enhancing Hygiene and Minimising Item Loss in Public Restrooms Using Smart Sensor Technology

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Article History: Received 29 October 2024; Revised 19 May 2025;
Accepted 12 Jun 2025; Published 30 June 2025

Abstract

Public restrooms play an essential role in urban infrastructure, but frequently encounter challenges related to hygiene and user behaviour, particularly the unintentional misplacement of personal belongings. Such occurrences can lead to clutter, hygiene concerns, and a reduced quality of user experience. This study presents the development and evaluation of a smart sensor-based prototype designed to detect forgotten personal belongings and alert users before they exit the facility. The system incorporates a designated storage area equipped with real-time object detection sensors and an automated notification mechanism, controlled via an Arduino microcontroller. Although the prototype currently operates locally without internet connectivity, its architecture is designed to support future integration with Internet of Things (IoT) technologies, such as Wi-Fi and GSM modules. Experimental testing conducted in a controlled environment demonstrated an alert accuracy of 85%, with user compliance at 75%, and satisfaction at 80%. These results indicate the effectiveness of the system in enhancing user awareness, reducing clutter, and improving hygiene within public restrooms. The study highlights the potential of smart sensor technologies in improving public facility management and supports future directions, including the implementation of real-time data analytics, remote monitoring, and wider deployment across multiple facilities.

Keywords: Arduino Microcontroller, Internet of Things (IoT), Object Detection, Public Restrooms, Smart Sensor System

1.0 Introduction

Public restrooms are essential elements of urban infrastructure, providing necessary sanitation in high-traffic environments such as transport hubs,

commercial areas, and public institutions. Despite their significance, these facilities frequently encounter challenges related to hygiene and user behaviour. A common and recurring issue is the unintentional misplacement of personal items such as bags, towels, or accessories, which not only contributes to visual clutter but also poses hygiene risks by harbouring bacteria and obstructing routine cleaning procedures [1], [2]. Studies have shown that cluttered and poorly maintained restrooms are often perceived as less hygienic, resulting in reduced user satisfaction and confidence in facility management [2].

Conventional restroom maintenance typically relies heavily on manual inspections and fixed cleaning schedules, which are often inconsistent due to human error and resource limitations [3]. Although technologies such as automated flushing systems, touchless faucets, and digital monitoring tools have been adopted to improve hygiene [4], their effectiveness is often constrained by high implementation costs, ongoing complex maintenance requirements, and irregular user engagement [5], [6]. User behaviour plays a vital role in influencing restroom hygiene outcomes. Recent research has linked poor hygiene practices, including inadequate handwashing, to forgetfulness and a lack of public etiquette [7], [8]. Xu et al. [5] reported notable alterations in hygiene awareness during the COVID-19 pandemic, reinforcing the importance of behavioural interventions in the management of public restrooms.

Scholars have increasingly emphasised the need for integrated solutions that combine technological systems with real-time behavioural prompts and user engagement mechanisms [3]. In support of this, several prior studies have explored the intersection of hygiene technologies, behavioural awareness, and smart restroom infrastructure. For example, Moreira et al. [1] and Shao et al. [6] identified that forgotten items contribute significantly to visual clutter and negatively affect cleanliness perception, reinforcing the need for item detection mechanisms. Miller and Thompson [3] reported that operational costs and maintenance complexity pose barriers to technology adoption in public facilities, underscoring the demand for cost-effective and scalable systems. The Internet of Things (IoT)-based hygiene monitoring, as shown by Habib et al. [4], has demonstrated the benefits of real-time tracking in improving sanitation and operational efficiency. Patil et al. [6] and Mahesh Kumar [9] further revealed that integrating user feedback into smart toilet systems can enhance user satisfaction, although privacy and adaptability remain ongoing concerns.

Although commercial solutions by TOTO [5] and Kimberly-Clark Professional [12] show growing industry commitment to smart hygiene technologies, many remain costly and lack behavioural integration. These limit their suitability for widespread deployment in public facilities. Table 1 summarises the key findings from several previous research studies and highlights consistent research gaps in existing solutions, particularly in the absence of real-time behavioural prompts and reliance on fully connected infrastructure.

Therefore, this study presents a smart sensor-based prototype designed to detect forgotten personal belongings and alert users before they exit the public facility. Unlike existing commercial systems that are fully IoT-enabled, this prototype focuses on local sensor-based detection and alerting mechanisms. The system is suitable for environments with limited connectivity and is scalable for future integration with IoT technologies such as Wi-Fi or GSM modules [13]. By combining embedded sensor technology with behavioural prompting, the proposed solution offers a practical, low-cost approach to enhancing hygiene, reducing clutter, and improving the user experience in public restrooms.

Table 1: Summary of key findings from previous research

Study Focus	Key Findings	Critical Analysis	Citations
Forgotten items and hygiene perception.	Forgotten personal items contribute to clutter and reduce perceived cleanliness.	Emphasises the importance of behavioural interventions and item detection mechanisms.	Moreira et al. [1], Shao et al. [8]
Implementation challenges in public facilities.	High costs and complex maintenance hinder technology adoption.	Highlights the need for cost-effective and scalable solutions.	Miller & Thompson [3]
IoT for hygiene monitoring.	Real-time monitoring improves hygiene and operational efficiency.	Supports the use of sensors and automation in public restrooms.	Habib et al. [4]
Smart toilet systems with user feedback.	Integration of user feedback enhances satisfaction.	Reinforces the value of user-centred design and behavioural data integration.	Patil et al. [6]
IoT for automation and satisfaction.	IoT improves maintenance and satisfaction, but raises privacy concerns.	Encourages careful design to balance automation with user trust and adaptability.	Mahesh Kumar [9]
Commercial IoT restroom products.	Industry is adopting smart restroom technologies.	Many commercial solutions are costly and lack behavioural integration, limiting widespread deployment.	TOTO [5], Kimberly-Clark [12]

2.0 Methodology

The development of the smart restroom system followed a structured methodology encompassing system design, prototyping, data acquisition, and evaluation. The goal was to create a scalable, IoT-ready solution that enhances hygiene and user experience by detecting forgotten items and issuing real-time alerts.

2.1 System Architecture and Design

The system architecture integrates both hardware and software components. At its core is an Arduino UNO microcontroller, which processes input from multiple sensors, including infrared (IR) sensors to detect user presence and movement, weight sensors to identify the placement and removal of personal items, and ultrasonic sensors to monitor object distance and confirm item presence. These sensors are embedded in a designated item placement zone within the restroom. When a user exits without retrieving their belongings, the system triggers an audio alert to prompt retrieval.

In support of future IoT integration, the system is designed with modularity in mind and includes provisions for adding Wi-Fi or GSM modules for wireless data transmission, cloud-based dashboards using platforms like Blynk or ThingSpeak for remote monitoring and analytics, and mobile app integration for user notifications and facility management alerts. This architecture aligns with IoT best practices as outlined by Habib et al. [4] and Mahesh Kumar [9], enabling real-time data flow and centralised control. Figure 1 illustrates the system architecture and design of the current system, with provisions for future IoT integration.

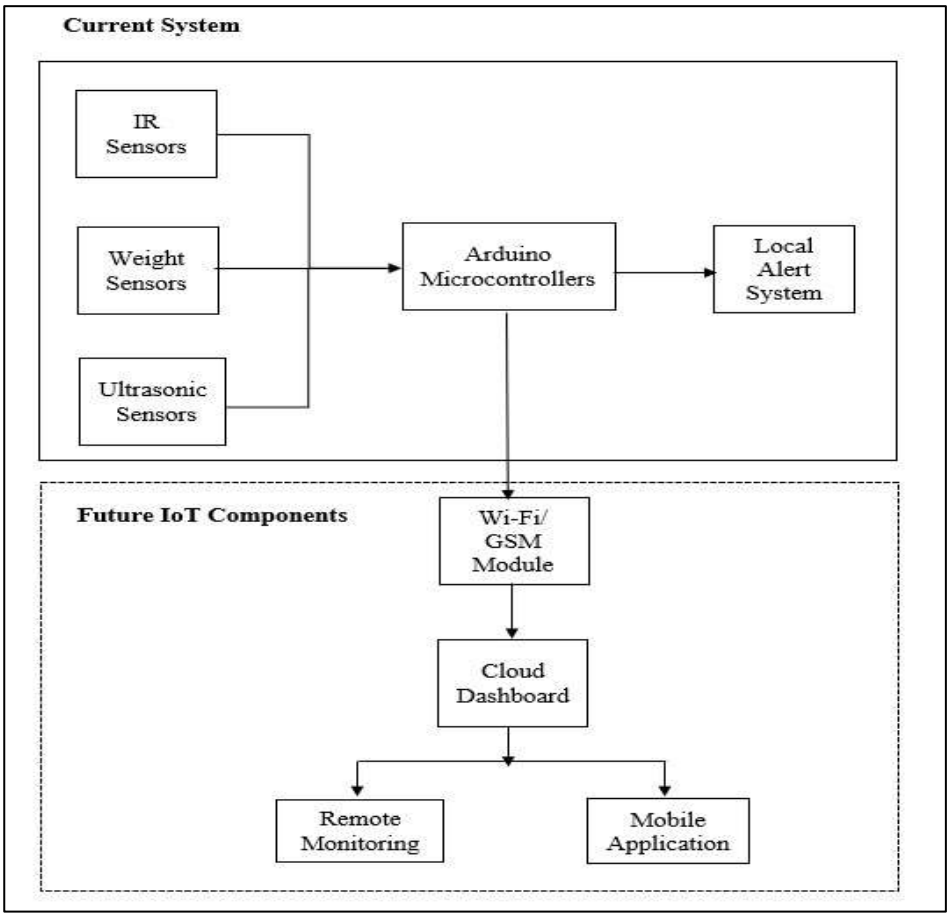

Figure 1: System architecture of the current system with IoT integration components

2.2 Data Collection and Evaluation

System performance was evaluated using both quantitative and qualitative data. Automated logs recorded sensor activity, alert frequency, and system uptime. User surveys captured feedback on alert effectiveness, convenience, and perceived hygiene improvements. Additionally, observational studies were conducted to assess user compliance and behaviour in real-world scenarios. Metrics such as alert accuracy, user compliance rate, and system reliability were analysed using descriptive statistics. This approach is consistent with evaluation frameworks used in prior smart restroom studies [6], [14].

2.3 Implementation and Scalability

The system was deployed in a controlled public restroom environment. The installation involved site assessment and sensor calibration, integration of the alert system with restroom infrastructure, and testing under varying lighting and occupancy conditions. To ensure scalability, the system supports a centralised management dashboard that can monitor multiple restroom units across different locations [15]. This feature is essential for large-scale deployment in malls, airports, or campuses, as emphasised by Horadi et al. [10]. Although the current prototype operates locally, future iterations will include cloud connectivity for real-time monitoring, predictive maintenance, and usage analytics, key features of modern IoT systems [9], [13].

3.0 Results and Discussion

The performance of the smart sensor-based restroom system was evaluated based on four key metrics: alert accuracy, user compliance, system reliability, and user satisfaction. Data were collected through automated logs, user surveys, and observational studies during a pilot deployment in a public restroom setting.

3.1 Alert Accuracy and User Compliance

Table 2 shows the performance results of the smart sensor-based restroom system based on the four key performance metrics. The system achieved an alert accuracy rate of 85%, indicating that the sensors effectively detected forgotten items with minimal false positives. This aligns with findings from Habib et al. [4], who emphasised the importance of sensor precision in IoT hygiene systems. The user compliance rate was 75%, meaning that three out of four users responded to alerts by retrieving their items. However, 25% of users reported occasional annoyance due to repeated alerts, suggesting a need for customizable alert sensitivity.

These results are consistent with prior studies that highlight the importance of balancing automation with user comfort [6], [9]. The system exhibited robust operational stability, featuring a Mean Time Between Failures (MTBF) of 120 hours and a Mean Time to Repair (MTTR) of 30 minutes. The system achieved 95% uptime, seen as exceptional for a prototype deployment. The resilience of public infrastructure is essential, as highlighted by Horadi et al. [10], who observed that downtime in smart systems can profoundly affect user trust and operational efficiency.

Table 2: Performance results of the smart sensor-based restroom system based on four key performance metrics

Metrics	Value (%)	Description
Alert Accuracy	85	Effectiveness of sensors in detecting forgotten items
User Compliance	75	Percentage of users retrieving items after alerts
User Satisfaction	80	Positive feedback from users regarding alert functionality
Frustration with Alerts	25	Percentage of users finding alerts intrusive

User feedback collected through post-implementation surveys highlights the system's effectiveness in enhancing the public restroom experience. As shown in Table 3, 80% of users reported increased convenience, while 75% perceived an improvement in overall cleanliness due to reduced clutter. The system received a strong average satisfaction rating of 4.2 out of 5, which is equivalent to 84%. This indicates general approval and usability. Additionally, 79% of respondents specifically noted that the alert mechanism helped minimise forgotten personal items, contributing to a tidier environment.

Nevertheless, 20% of users expressed reservations regarding the system's hygiene impact, citing the need for consistent cleaning practices to complement the technology. These results suggest that while the system effectively enhances user awareness and improves perceived hygiene, its integration should be supported by routine maintenance to maximise overall effectiveness. These findings support the argument that smart systems can enhance user experience but must be integrated with broader facility management strategies to ensure sustainable hygiene outcomes [2], [11], [14].

Table 3: Summary of user satisfaction metrics

Metrics	Value (%)	Description
Increase in Convenience	80	Percentage of respondents reporting increased convenience
Perceived Hygiene Improvement	75	Percentage of users noting improved hygiene
Average User Satisfaction Rating	84	Overall rating of satisfaction with the system
Concerns About Effectiveness	20	Percentage of users expressing concerns about the hygiene impact
User Comments on Clutter Reduction	70	Percentage of users who noted reduced clutter due to alerts

While the initial results are promising, several areas for improvement were identified. Sensor calibration requires further fine-tuning to reduce false alerts triggered by minor or unintended movements. Additionally, future studies should test the system's adaptability in diverse settings, including

rural or low-traffic restrooms, to assess its robustness and performance across varying environmental conditions.

Enhancements to the user experience also present a valuable direction for further development. Offering customisable alert options such as visual, audio, or mobile-based notifications could further increase usability and accessibility for a wider range of users. Moreover, integrating cloud-based dashboards, as suggested by Mahesh Kumar [9], would enable real-time monitoring and more efficient maintenance coordination by facility personnel. Such improvements would not only strengthen the system's operational effectiveness but also contribute to a more holistic approach to smart public hygiene management.

4.0 Conclusion

This study successfully achieved its objective of developing a smart sensor-based prototype to improve hygiene and user experience in public restrooms by detecting and alerting users about forgotten personal belongings. The system achieved promising results, with 85% alert accuracy, 75% user compliance, and 80% user satisfaction, indicating its potential to reduce clutter and support cleaner restroom environments. While the current system operates without IoT connectivity and functions entirely on local hardware using an Arduino microcontroller and standard sensors, its architecture is designed to support future IoT scalability. Planned enhancements include cloud-based dashboards, wireless communication modules, and mobile app integration to enable real-time monitoring, predictive maintenance, and centralised facility management capabilities that are increasingly essential in modern public infrastructure. The findings support previous research emphasising the importance of integrating behavioural insights with smart technologies to improve public hygiene. User feedback also highlighted areas for refinement, including sensor calibration and customisable alerts, which will be prioritised in future iterations. With its low-cost, modular design and alignment with global trends in smart facility management, the system presents a viable solution for commercial deployment in high-traffic public settings such as malls, transport hubs, and educational institutions.

Acknowledgement

The authors express their sincere gratitude to the Department of Mathematics, Science and Computer, Politeknik Merlimau Melaka, for their support throughout this research. Appreciation is also extended to colleagues and participants for their valuable insights, feedback, encouragement and technical support. Lastly, the authors acknowledge the institutional resources and facilities that enabled the completion of this work.

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Abdul Malik Hakim Ab Aziz: Software, Investigation, Validation;
Azizah Nurul Khoirunnisa: Investigation, Formal Analysis, Validation.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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