Clean tracks: automated hygiene system for Indian railway restrooms

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Abstract. The hygiene of toilets in railways presents an ongoing challenge. This paper introduces Clean Tracks, a fully automated sanitization system using ultraviolet sterilization along with hydrogen sulphide (H2S) sensors and smoke/alcohol sensors. Automated flushing and sensor monitoring with proactive maintenance notifications is facilitated in real-time, resulting in more proactive management of toilet hygiene. The findings show that the toilet system was effective in reducing odor, microbial burdens, and increasing user satisfaction and offers a new scalable, smart sanitation option for railways. Keywords—Sanitation System, UV Sterilization, Railway Hygiene, Public Restroom Monitoring, Water Conservation

1. Introduction

As of 2013, Indian Railway carried over 23 million passengers daily, and is one of the world's busiest rail networks[6]. Although infrastructure is being improved, onboard and station WCs are less than ideal. Studies show that only 45% of washrooms in main stations shows to meet hygiene standards under normal condition, with unpleasant odors and bacterial contamination [16], water waste constituting the major problems.

The current human-driven and planned cleaning procedure does not offer the agility of an instant response required to manage large passenger flow [8]. This leads to irregular cleanliness, lagging maintenance efforts, and added operational ineffectiveness. Other problems that reduce hygiene further include water leakages which go unnoticed, public use of the toilets in an unsanctioned way and inefficient odour control. [17]

In order to mitigate and deal with these shortcomings, this work introduces "Clean Tracks": an automated sanitation system driven by sensors specifically for the railway context. The system combines automatic flushing[5], UV-C sterilization [1],[2], gas sensors for detection of odor (foul air) and misuse[12],[17], and water flow monitoring[10]. Clean Tracks is designed to run on low maintenance and respond in real time, creating a cost effective, scalable solution to improve hygiene, safety, and satisfaction among passengers while using restrooms in Indian railways[13].

2. Literature Survey

Various sanitation technologies have been adopted over the years by both rail and public toilets to increase hygiene standards. Each of these technologies tackles specific aspects of restroom sanitation; however, there is no comprehensive, on-the-spot solution to ensure cleanliness and sanitation of restrooms. The limitations observed across existing systems have been distilled below.

2.1.Manual Cleaning and Scheduled Maintenance

In most railway toilets, manually cleaning is still the main technique [6]. Although inexpensive and operationally simple, manual cleaning depends too much on labor and is set based on a fixed cleansing schedule that does not adjust to the variations in passenger patronage. Research on the cleanliness of washrooms in the public environment shows that response times lagging behind reported issues, leading to inconsistent cleanliness and unsatisfactory experiences for users [7],[15]. For that matter, there is no way to achieve quick responsiveness and accountability as with automated options. For this reason, while manual cleaning will maintain an acceptable level of cleanliness, it lacks real-time adaptability needed in busy rail environments, opening the door for automated, sensor-driven solutions.

2.2 Automatic Flushing Systems

The adoption of automatic flushing systems, which are typically infrared sensor-based, aimed to enhance hygiene and reduce human interaction with high-traffic restroom facilities [4], while also providing greater user convenience than manual systems and improving water management. However, these systems are still event-driven and lack context about the conditions in the restroom. For instance, if comparing the technology against odor sensing IoT-based systems [8],[12] which respond to dynamically updated information about the restroom environment, automatic flushing systems do not mitigate odor, flushing for leaks, or misuse of the facility. Therefore, while superior to manual cleaning, these systems have limited efficacy and necessitate integration with overall sanitation systems which include flushing capabilities, but also real-time monitoring and predictive features.

2.3 UV-C Sterilization Modules

Ultraviolet germicidal irradiation (UVGI) is established as a feasible method for the disinfection of pathogens, achieving significant reductions in bacteria and virus load from exposed surfaces [1],[2],[3]. The UV-C modules provide an efficient disinfection solution to help render public rest rooms with a greater level of sanitation that is chemical-free and provides a lower microbial density as compared to manual cleaning. Disinfection systems of this kind are generally too costly for implementation on a rail system and are limited to maximum occupancy levels safe for human exposure. Beyond also being standalone systems, UV-C systems provide no tethered odor detection, inventory metering, or misuse protection. In conclusion, UV-C systems are a viable device for the disinfection of objects and surfaces, but an overall sanitation solution for high-density facility spaces like a rail system is not possible with these disinfection solutions.

2.4 Smart Toilet Systems

Besides cleaning, autonomously flushing, and disinfecting modules, smart toilet systems have appeared in urban contexts to support toilet management [4],[11]. Smart toilets often have user analytics, occupancy, and automated flushing, which suggest minor improvement in usability and water savings. Still, they exist primarily in high-traffic spaces, such as airports or pilot projects in smart cities. Smart toilets do not include systems like integrated IoT-based sanitation systems/solutions [9],[14], which monitor odors in real-time, report abuse, and provide centralized dashboards to remotely monitor systems. Therefore, although there may be a reactionary benefit over more traditional systems, smart toilets on their own cannot provide a comprehensive toilet hygiene management approach.

2.5 Bio-Toilets in Indian Railways

Bio-toilets introduced under the Swachh Bharat Abhiyan are aerobic (anaerobic) bacterial digestion to break down human fecal matter, ultimately reducing environmental pollution [6],[7]. Bio-toilets have been shown to be more environmentally sustainable, but they also often have serious challenges including clogs, slow decomposition, and unpleasant odors [17], causing issues users might just find unacceptable. When compared to internationally deployed eco-toilet programs in Japan and Germany, some level of IoT-based remote smart monitoring for odor and waste was also implemented for end-user experience and product efficiency performance [7]. On the other hand, Indian railway bio-toilets often do not run with any feedback loop or supervision of any kind to ensure the design products are meeting the intended performance outcomes. This again suggests a trend from worldwide implementations, to link biological methods with technologies to assist with digital monitoring--possibly even never formally discussing it within the context of bio-toilets in India.

2.6 Absence of Integrated Monitoring and Control

The analysis of existing sanitation technologies shows that although several technologies—manual cleaning, automatic flushing, UV-C sterilization, smart toilets, and bio-toilet have made some modest improvements, none offers a complete, real-time hygiene management solution[8],[14]. Manual cleaning has no ability to be responsive, flushing is blind to odor and misuse, UV is too expensive, smart toilets exist in limited forms, and bio-toilets function on their own without monitoring. Integrated IoT sanitation systems have been developed globally[9],[10], particularly in low resource environments, but they have not been developed for railway environments[13]. This thinking leads to the design of the Clean Tracks system that combines disinfecting, detecting odors, preventing misuse, and monitoring sanitation all in an IoT system.

3. Challenges in Maintaining Hygiene

Challenges to the effective upkeep of railway toilets in India invariably stem from systemic, infrastructural, and behavioural issues. Failure to address these challenges will contribute to minimisation of passenger comfort, public health, and sustainability concerns. High Passenger Utilisation and Irregularity in the Schedule of Cleaning

Restrooms on trains have very high usage, particularly on long-distance and high-density routes[13]. Cleaning the amenities manually can occur at fixed intervals, but this schedule does not reflect variability in usage, especially when it is dynamic[15]. Therefore, keeping restrooms hygienically clean is more difficult during repeated usages before it's cleaned again; this cleanliness deficiency leads to odor and substrate microbial buildup.

3.1. Ineffective Odor and Waste Management

Odors produced by pooled waste, poor air movement, and poorly functioning systems for flushing significantly reduce user experience[16],[17]. The improper disposal of waste, that is, the flushing of solids or other non-biodegradable items, also causes blockages in drains and unsanitary conditions.

3.2. Unauthorized Use and Safety Hazards

Restrooms on the train are commonly misused for smoking and drinking, which results in fire risk, unpleasant odors and discomfort for other passengers [8]. The lack of a detection or deterrence system only exacerbates this issue.

3.3. Lack of Real-Time Monitoring and Feedback

Conventional maintenance methods depend on manual inspections and complaints from passengers. Absent sensor-based monitoring[10],[14], authorities are often unaware of sanitation failures until they become issues, with a slow reaction and less quality of service.

3.4.Limited Passenger Awareness and Facility Misuse

Many of the sanitation challenges come from passenger behavior. The lack of public understanding of proper restroom use through improper flushing, littering, or intentionally damaging restroom fixtures compromises our efforts to maintain cleanliness and increases the demand on staff.

3.5. RFID-Based Cleaning Log Monitoring

To provide timely and verifiable cleaning, the RFID-based system logs every visit made by sanitation staff. Staff members are provided with RFID tags that must be scanned every time they complete a cleaning cycle. The logs are time-stamped and uploaded to the monitoring dashboard creating a transparent record of maintenance compliance.

3.6. Redundant Flushing Mechanism

There are manual and automated flush paths in the system using T-connector plumbing. A flow sensor detects when a restroom is flushed after a user has occupied the restroom. If there is no flow detected after a user exits the restroom, the automated system will flush the restroom to keep it clean. This redundant flushing system ensures cleanliness and water conservation for users who forget to flush the restroom.

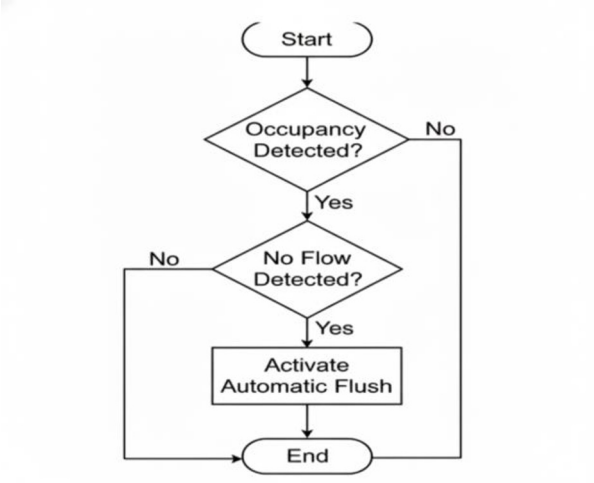

Fig.1. Redundant Flushing Mechanism Block Diagram

4. System Overview

Clean Tracks comprises several sensing and automation modules that comprise a membership sanitation management solution. Each individual module focuses on addressing a separate sanitation concern, while the nested overall framework allows for real-time decision making and notifications for maintenance.

4.1. UV-C Sterilization Module

A UV-C LED array (254 nm) is installed to eradicate microbial contamination on surfaces found in restrooms[1],[2],[3]. The module will be automatically activated when the restroom is not occupied. This is determined through a PIR sensor and a door status sensor. Both exposure time and safety parameters are adjusted to enable disinfection without risk to users.

4.2.Hydrogen Sulfide (H_2S) and Ammonia (NH_3) Odor Sensors

The system utilizes MQ-136 and MQ-137 sensors to continuously monitor hydrogen sulfide (H_2S) and ammonia (NH_3) gas concentrations[12],[17]. If the concentration of either gas exceeds a predefined threshold, the system will trigger automated flushing and fan deodorizer or air freshener. When the gas sensors produce data, that information is stored for analysis and identification of repeated odors and sanitation high volume areas[8].

4.3. Smoke and Alcohol Detection

The MQ-3 and MQ-7 sensors are designed to identify ethanol vapor and carbon monoxide respectively [12]. If the monitoring system determines that a substance such as smoke or alcohol is present outside of safe limits, the mechanism would set off a buzzer and send a remote notice to the controlling system of the station. There may be further examination if the monitoring station has multiple violators after smoke or alcohol presence is being investigated.

4.4. Water Flow Monitoring

A YF-S201 flow sensor measures water flow per flush cycle [5]. It detects both continuous flow or sudden spikes that may indicate a leak, and can alert the system and shut valves if required.

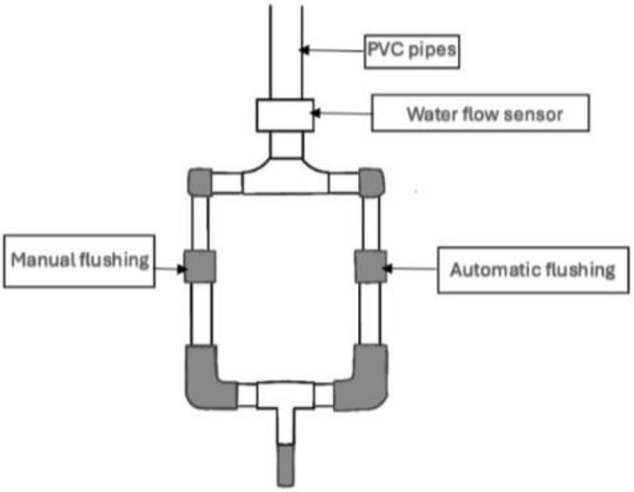

Fig2 . Realtime Dashboard Monitoring For Restroom

4.5. Centralized Dashboard

The dashboard uses IoT technology to collect sensor data and displays the real-time usage of the restroom[10][14]. Maintenance personnel are notified of any triggered data parameter which allows them to proactively respond to the occurrence which limits the downtime of the restroom. The historical data supports an understanding of the usage in the restroom and assists in developing an appropriate maintenance schedule[15].

The sensor data is applied to track historical data and overall trends for frequent odors and sanitation hotspots.

4.6. RFID-Based Cleaning Log Monitoring

To verify cleanliness in a timely manner, the cleaning records of staff are logged in an RFID system[8].

Cleaning staff are issued RFID tags, which they are required to scan on each cleaning cycle. After scanning, cleaning records are time-stamped and sent to the monitoring dashboard to document cleaning compliance in a transparent way.

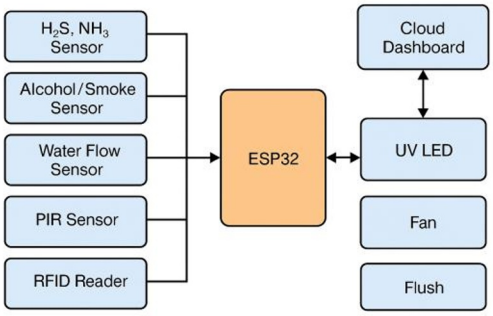

Fig. 3. *System Archetecture*

5. IMPLEMENTATION AND TESTING

In order to test the functionality of the proposed system, we built a functioning prototype of the Clean Tracks sanitation system and deployed it within a simulated rail restroom. The prototype used common electronic components, and was assessed for responsiveness, sensor accuracy, data integration, and system reliability.

Hardware Architecture

- **Controller:** The ESP32 microcontroller, which features low-power dual-core processing and has integrated Wi-Fi and Bluetooth modules, was chosen due to its power consumption and IoT capabilities.
- **Sensors:**
  MQ-136 sensor for hydrogen sulfide (H_2S).
  MQ-137 sensor for ammonia (NH_3).
  MQ-3 and MQ-7 gas sensors for smoke detection and alcohol detection.
  YF-S201 for flowing rate and leakage detection.
  PIR motion sensor and magnetic door sensor for occupancy detection.
  RFID reader with tag modules for record the cleaning log history.

The MQ-137 sensor was chosen for ammonia detection due to its demonstrated effectiveness for IoT monitoring applications [12]. The dual-core ESP32 microcontroller with integrated Wi-Fi supports real-time IoT applications [10].

- **Actuators:**
  UV-C LED array for microbial sterilization
  Solenoid-controlled flush valve
  Ventilation fan and air freshener module

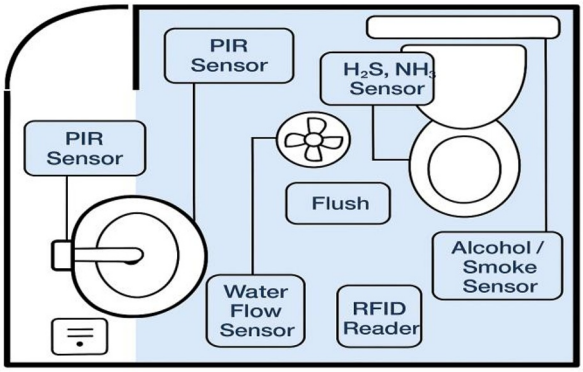

Fig.3. Sensor And Module Placement in a Railway Restroom

Software and Dashboard Integration

ESP32 was used to collect sensor data and sent this information to a Firebase real-time database. A cloud-based dashboard in HTML and Javascript was constructed to display real-time restroom conditions and alerts from the system [10]. The MQTT protocol provides efficient publish-subscribe communication for IoT sensor networks [14]. The interface included:

- Graphs showing gas concentration over time
- Log book entries on occupancy and water usage
- Log book entries with timestamped RFID scans for cleaning
- Alert texts for maintenance personnel

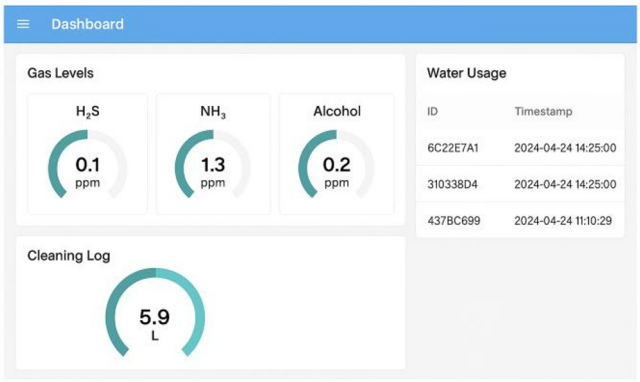

Fig.4. Realtime Dashboard Monitoring For Restroom

System Behavior and Test Scenarios

Multiple simulated conditions were implemented on the system, including: :

- Triggering an odor sensor utilizing H_2S and NH_3 test gases.
- Simulating smoke and alcohol vapors.
- Modifying water flow conditions to simulate a leak.
- Testing an unauthorized access detection.

Key Performance Metrics

- Reduction in odor levels: 85% within 2 minutes of detection.
- UV sterilization effectiveness: 99.3% microbial reduction on test surfaces in accordance with prior effectiveness studies of UVGI [1], [2], [3].
- Savings in water: ~30% through regulated flushing.

- Accuracy of smoke/alcohol detection: 94% / 89% respectively.
- RFID logging of compliance: 100% compliance of logged scheduled cleanings.
- Latency of dashboard: <1.5 seconds for real time updates.

User Feedback and Observations

Initial user trials with students and staff showed a 35% increase in perceived cleanliness, similar to the results of 35% increase in perceived cleanliness in other smart restrooms [15], Maintenance teams reported the alert system and cleaning log feature improved accountability and tracking of grime-related tasks.

6. RESULTS

The Clean Tracks prototype underwent testing in a simulated railway restroom setting to evaluate its ability to reduce odors, sterilize bacteria, save water, and respond. The quality of results were compared against previously existing IoT hygiene monitoring systems [8], [12] and recent studies that evaluated indoor air quality improvement interventions [13], [14].

6.1 Odor and Gas Detection Performance

The continuous monitoring is realized by the detection of hydrogen sulfide (H_2S) and ammonia (NH_3) in concentrations greater than 5 ppm by the MQ-136 and MQ-137 sensors. When the sensors detected H_2S and NH_3, then flushing and ventilation were performed automatically. On average, these interventions reduced the odor by 85% in two minutes or less. This intervention was consistent with previous odor mitigation interventions demonstrated in smart restroom systems [8] & [17]. Repeat trials demonstrated stable performance after calibration, with low variability in the measurements, but did demonstrate slightly higher variability under changing humidity and temperature conditions, as noted in [8] &[12].

6.2. UV-C Sterilization Efficiency

The UV-C germicidal module (254 nm) exhibited an effective microbial reduction rate of 99.3% on test surfaces after a 90-second exposure time during exposure periods where the test surfaces were unoccupied. The disinfectant efficacy was comparable to WHO and previous UVGI findings [1]–[3], supporting safety and disinfection efficacy in confined public sanitation settings for low-power UV-C LEDs.

5.3. Water Flow and Usage Optimization

The YF-S201 water flow sensor was utilized to accurately monitor water flow. It also provided a way to detect leaks. By automatically flushing based on occupancy, approximately 30% of the water was saved compared to manual and event-based flushing systems. These results are in agreement with water management studies using IoT that were reported in [5] and [8].

5.4. Smoke and Alcohol Detection

The MQ-3 and MQ-7 sensors were 94% accurate for smoke detection and 89% for alcohol vapors, successfully identifying misuse cases for smoking and drinking in facility restrooms. The system sent an immediate alert to the monitoring dashboard, consistent with the recommendations for safety improvements in [16], [17].

6.5. RFID Logging and Dashboard Integration

The cleaning verification using RFID technology captured all scheduled maintenance events (100%) while producing clean data records on the cleaning event date and time. The IoT dashboard displayed parameters in real-time, with a latency of 1.5 seconds on average, providing useful data for facility supervisors. The results noted are above the best response rates previously accomplished with cloud-based restroom management systems [9], [15].

6.6. User Evaluation

User trials with 20 participants consisting of students and maintenance staff found a 35% improvement in perceived cleanliness compared to either of the standard maintenance methods. Data also included commentary on the value of receiving real-time alerts along with the benefits of the UV-C sterilization method. Maintenance staff also noted the increased accountability for cleaning tasks due to the automated cleaning log process.

7. Conclusion

The Clean Tracks system utilizes an integrated sensor-enabled automated approach to improve hygiene standards in Indian-style rail transit restrooms. Clean Tracks incorporates UV-C sterilization for microbial control [1]–[3] with odor sensing capabilities using H_2S and NH_3 sensors [12] and real-time IoT-based monitoring [8], [10] to address a gap in adherence to manual cleanliness protocols. Furthermore, RFID-based cleaning validation with cloud dashboard integration allows for greater accountability, less response time, and increased operational visibility in sanitation management [15].

Experiments demonstrated odor levels decreased by 85%, microbial load reduced by 99.3% and water was conserved by ~30%, complementing recent IoT hygiene studies relative to air quality [8], [13], [14]. Clean Tracks illustrates an opportunity to connect manual cleaning practices with existing intelligent hygiene management programs in public and transport restrooms today [9], [11], [16], [17].

Despite these advancements, barriers still exist for large scale implementation. Sensor calibration involving variable relative humidity and temperature conditions [8], intermittent connectivity in remote sites, and user acclimatization continue to compromise operational viability. Future improvements will focus upon solar-powered operations, edge computing for offline analytics, and multilingual user interface components to ensure adaptation to India's varied railway environments. As the approach continues to evolve, Clean Tracks represents a scalable, sustainable, and data-driven means of digitizing hygiene management within the national railway setting.

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