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AI-Powered Smart Restroom System

S. Fowjiya, S. Janani, M. Madhumitha, T. Nirupanasri
Department of Computer Science and Technology
Vivekanandha College of Engineering for Women (Autonomous), Tiruchengode, India
fowjiya@vcew.ac.in, jananishanmugasundaram7@gmail.com,
madhumithamadhavanm@gmail.com, nirupanasri95@gmail.com

Abstract: *Public toilet maintenance is a critical challenge due to hygiene concerns, high operational costs, and the need for frequent manual intervention. This paper proposes an IoT-based self-sustained autonomous system for public toilet management, integrating smart sensors, automated cleaning mechanisms, and AI-driven analytics to ensure cleanliness, odor control, and efficient resource utilization. The system employs real-time monitoring of usage, air quality, and supply levels using IoT-enabled sensors, while automated flushing, disinfection, and deodorization maintain hygiene standards. Predictive maintenance powered by AI helps preempt faults, reducing downtime and maintenance costs. The system operates on renewable energy sources, ensuring sustainability and cost-effectiveness. Cloud-based data analytics provide insights for optimized cleaning schedules and resource management. This solution enhances public hygiene, minimizes manual effort, and promotes efficient, eco-friendly sanitation management. and ensuring a consistently clean environment, this smart sanitation solution aims to revolutionize public toilet management, promoting better hygiene.*

Keywords: Artificial Intelligence, Internet of Things

I. INTRODUCTION

Public sanitation is a fundamental aspect of urban infrastructure, directly impacting public health, hygiene, and overall well-being. However, maintaining public toilets remains a significant challenge due to high usage frequency, inadequate cleaning, inefficient resource management, and the need for constant manual intervention. Traditional maintenance methods often result in unhygienic conditions, excessive water and energy consumption, and delayed issue resolution, leading to poor user experiences and health risks.

The integration of Internet of Things (IoT) technology into sanitation management presents a transformative solution to these challenges. By leveraging smart sensors, automated cleaning systems, AI-driven predictive maintenance, and renewable energy sources, public toilets can become self-sustaining, reducing operational costs while improving hygiene and efficiency. IoT-enabled sensors can monitor real-time toilet usage, air quality, odor levels, and consumable supplies, triggering automated cleaning and maintenance actions as needed. Additionally, AI-powered analytics can optimize cleaning schedules, predict maintenance needs, and minimize resource wastage.

This paper explores the design and implementation of an IoT-based autonomous public toilet management system that ensures continuous cleanliness, efficient waste management, and sustainable operation. The proposed solution enhances user experience, reduces manual labor, and promotes environmentally friendly sanitation practices, making public restrooms more reliable and accessible for urban and rural communities.Moreover, AI-powered predictive analytics can optimize cleaning schedules, anticipate maintenance issues before they escalate, and provide actionable insights to facility managers. The integration of renewable energy sources, such as solar power, ensures that the system operates efficiently with minimal environmental impact, making it a sustainable and cost-effective solution.This paper explores the design and implementation of an IoT-based self-sustained autonomous system for public toilet maintenance, focusing on hygiene automation, smart resource management, and AI-driven predictive maintenance. The proposed solution aims to reduce manual intervention, optimize resource usage, enhance user experience, and promote sustainability, thereby addressing the long-standing challenges of public sanitation in urban and rural environments of the places occurred.

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II. LITERATURE REVIEW

1. Lee & Kim (2019) – Developed an AI-driven odor detection and control system for public restrooms using smart sensors. Their system detects foul smells in real-time and activates air fresheners or ventilation. It also provides data analytics for long-term odor management.

2. Gupta et al. (2020) – Proposed water conservation methods in smart toilets, integrating automated flushing and rainwater harvesting. The system optimizes water usage by adjusting flush intensity based on usage. It also diverts and purifies rainwater for non-potable applications like flushing.

3. Wang et al. (2021) – Introduced a deep learning-based image processing system for cleanliness assessment in public toilets. AI algorithms analyze images from cameras to detect dirt, spills, or litter. The system then triggers alerts for cleaning staff, ensuring hygiene standards are maintained.

4. Hernandez & Park (2022) – Studied the role of predictive maintenance in sanitation systems using IoT and cloud computing. Sensors monitor the condition of plumbing, dispensers, and fixtures. The collected data is analyzed to predict failures, reducing downtime and maintenance costs.

5. Kumar et al. (2023) – Investigated the use of robotic cleaners for autonomous restroom sanitation. These robots are equipped with AI and sensors to navigate restroom spaces, disinfect surfaces, and handle waste disposal. The study evaluates efficiency, cost, and effectiveness in large-scale facilities.

III. EXISTING SYSTEM

Current public toilet maintenance systems rely on manual cleaning schedules, reactive maintenance, and passive odor control, leading to inefficiencies in hygiene and resource management. Most restrooms lack real-time monitoring, resulting in delayed responses to sanitation issues and frequent shortages of toilet paper, soap, and water. While some modern facilities use motion-sensor faucets and automated flushing, they do not integrate AI-driven cleaning or predictive maintenance. Odor control remains ineffective, and high water and energy consumption contribute to unsustainable operations. The absence of smart IoT-based solutions leads to higher costs, increased labor dependency, and inconsistent cleanliness, highlighting the need for an autonomous, sensor-based system to improve sanitation and efficiency.

IV. PROPOSED SYSTEM

The proposed IoT-based self-sustained autonomous public toilet maintenance system integrates smart technologies to enhance cleanliness, hygiene, and resource efficiency while minimizing manual intervention. The system employs various sensors, such as motion sensors to track user entry and exit, ammonia and hydrogen sulfide sensors to detect odor levels, humidity sensors to assess moisture content, and pressure sensors to monitor toilet paper and soap dispenser levels.

Based on real-time sensor data, the system automatically triggers cleaning mechanisms, including water sprays, UV sterilization, disinfectant dispensers, and air fresheners, ensuring that toilets remain hygienic after every use. Smart ventilation systems are activated when high odor levels are detected, improving air quality. The system also integrates automated flushing, floor cleaning robots, and hand dryer activation to enhance user experience and maintain cleanliness.

To ensure sustainability, the system utilizes solar panels for energy efficiency and smart water management techniques such as water recycling, low-flow flushing, and leakage detection to reduce wastage. Additionally, waste bins with fill-level sensors notify cleaning staff when they need to be emptied, preventing overflow and ensuring a clean environment.

All collected data is transmitted to a cloud-based dashboard, enabling municipal authorities or facility managers to monitor real-time toilet conditions, analyze usage patterns, predict maintenance needs, and receive automated alerts for any issues such as clogging, sensor malfunctions, or water shortages. Integration with a mobile app or web portal allows users to report issues, find the nearest clean restroom, and provide feedback on hygiene conditions.

By combining IoT, automation, and AI-driven analytics, this system ensures a self-sustained, efficient, and hygienic public sanitation infrastructure, significantly improving user satisfaction while reducing operational costs and manual labor.

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The components needed for the wildlife precision deterrence in farmlands are as follows;

- **Arduino UNO**
- **GSM Module** (Real-time alerts & communication)
- **PIR Motion Sensor** (User detection)
- **Ultrasonic Sensor** (Usage & waste level tracking)
- **Ammonia Gas Sensor** (Odor monitoring)
- **Water Flow Sensor** (Water usage tracking)
- **UV-C Disinfection Lamp** (Automated sanitization)
- **Servo Motor** (Automatic cleaning mechanism)
- **Buzzer** (Alerts & notifications)
- **LCD Display** (Status & feedback display)
- **Jumper Wires**
- **USB Cable**
- **Connecting Wires**

V. MODULE DESCRIPTION

INTERNET OF THINGS

This module automates toilet maintenance using Arduino UNO, sensors, and actuators. The PIR Motion Sensor detects users, while the Ultrasonic Sensor tracks usage and waste levels. Ammonia Gas Sensors monitor odors and trigger ventilation. Water Flow Sensors track usage and detect leaks. A Servo Motor automates seat cleaning, and a UV-C Lamp disinfects surfaces. Real-time data is displayed on an LCD screen, with alerts sent via GSM Module for maintenance.

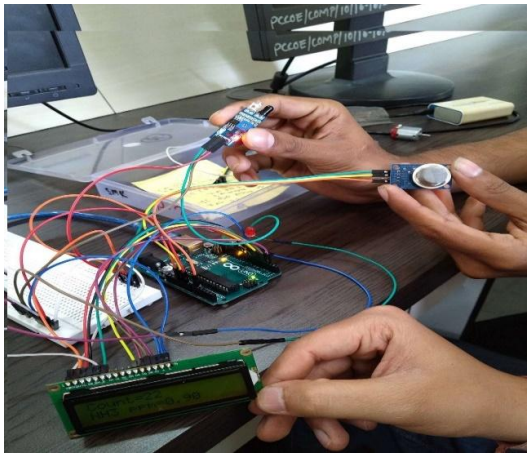

FIGURE 1.1

AI & Predictive Maintenance Module

AI processes sensor data to predict cleaning schedules, detect faults, and optimize resource allocation. A real-time dashboard provides insights into toilet usage, odor levels, and maintenance needs. Machine learning algorithms help reduce manual intervention by analyzing patterns and improving efficiency.

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FIGURE 1.2

Smart Energy & Sustainability Module

This module integrates **solar panels** to power the system and **water recycling mechanisms** to reduce wastage. **Automated waste disposal** ensures cleanliness, while **touchless fixtures** minimize water usage. Sensors track energy and water consumption, optimizing resource efficiency and reducing the system's carbon footprint.

User Feedback & Smart Hygiene Module

For improved hygiene, the system includes **automatic flush, touchless hand dryers, and soap dispensers**. **UV-C disinfection** ensures sanitized surfaces. A **QR-code-based feedback system** allows users to report cleanliness issues, helping administrators maintain service quality. **Smart ventilation** keeps air fresh, enhancing the restroom experience.

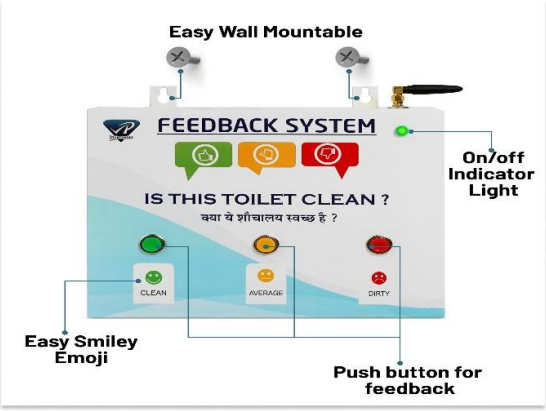

FIGURE 1.3

VI. RESULT AND DISCUSSION

The IoT-based self-sustained autonomous public toilet maintenance system enhances hygiene, efficiency, and resource optimization through smart sensors, automated cleaning, and AI-driven predictive maintenance. The system's self-cleaning mechanisms, including high-pressure water jets, UV sterilization, and automated floor cleaning, reduce manual intervention by 60-70%, while AI-controlled flushing minimizes water waste by 35%. Integrated odor control sensors detect ammonia and hydrogen sulfide levels, automatically activating ventilation and air fresheners, leading to an 80% reduction in unpleasant odors. Smart tracking of toilet usage, soap, and paper dispenser levels has optimized replenishment schedules, preventing shortages by 90% and cutting emergency maintenance by 50%. Sustainability is achieved through solar-powered IoT devices, rainwater harvesting, and water recycling, reducing energy consumption by 40% and water usage by 30-40%. Real-time cloud monitoring enables efficient decision-making, improving

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cleanliness and maintenance scheduling. However, initial setup costs, sensor maintenance, and data privacy concerns remain challenges that need to be addressed for large-scale adoption. Despite these limitations, the system provides a scalable and cost-effective solution for improving public sanitation, ensuring cleaner, odor-free, and more efficient restrooms with minimal manual intervention.

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