Smart AI-Based Public Washroom System for Automated Hygiene Monitoring and Self-Cleaning

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***Abstract*—Public washrooms require continuous monitoring and timely maintenance to maintain hygiene and improve user experience. Conventional systems depend largely on periodic manual inspection, which may result in delayed cleaning, overflowing waste bins, unpleasant odor, unnecessary water consumption, and inconsistent maintenance. This paper presents a Smart AI-Based Public Washroom System that combines Internet of Things (IoT) sensing, embedded control, automation, and privacy-aware design. The proposed prototype uses a microcontroller such as ESP8266/ESP32 together with sensors for user presence, waste-bin level, and environmental or odor-related conditions. Sensor information is processed locally to trigger appropriate actuators, including automatic flushing, cleaning, odor-control, and maintenance alerts. A cloud or mobile monitoring layer can provide remote status information to maintenance personnel. A key design principle is that no camera is required inside the washroom; non-visual sensors are used for automation and monitoring to reduce privacy concerns. The proposed system provides a foundation for intelligent sanitation infrastructure and can be extended with historical data analytics and machine-learning models for predictive cleaning and maintenance.**

***Index Terms*—Smart washroom, Internet of Things, IoT, artificial intelligence, public sanitation, automation, sensors, privacy.**

I. INTRODUCTION

Public sanitation is an important part of healthy and sustainable urban infrastructure. Public washrooms experience variable levels of usage and therefore require timely cleaning, waste removal, odor control, and maintenance. In conventional facilities, these activities are commonly performed through fixed schedules or manual inspection. Such approaches can fail to respond quickly when actual conditions change between inspections.

IoT and sensor technologies provide an opportunity to monitor environmental and operational conditions continuously. Previous smart-toilet and smart-restroom research has investigated sensor-based monitoring, automated operation, usage analysis, and connected maintenance systems [1]– [3]. Building on these approaches, this work proposes a compact smart washroom prototype that combines automated functions with privacy-conscious sensing.

The main contribution of this project is an integrated architecture in which sensor information is processed by a microcontroller to control washroom functions and generate maintenance alerts. The design also emphasizes that visual surveillance is unnecessary for the core automation functions.

II. PROBLEM STATEMENT AND OBJECTIVES

The major problems addressed by the proposed system are delayed cleaning, overflowing waste bins, unpleasant odor, unnecessary water usage, limited real-time monitoring, and privacy concerns associated with camera-based monitoring.

The objectives are to: (1) monitor washroom conditions using sensors; (2) automate selected flushing, cleaning, and odor-control functions; (3) detect waste-bin overflow; (4) provide remote maintenance alerts; (5) reduce dependence on continuous manual inspection; and (6) maintain user privacy by avoiding cameras inside the washroom.

III. PROPOSED SYSTEM

The proposed system is organized into sensing, processing, actuation, communication, and monitoring layers. An ESP8266 or ESP32 can serve as the central controller. An IR or similar presence sensor can detect user activity without capturing images. An ultrasonic sensor can estimate the level of waste in a dustbin. A

gas or environmental sensor can provide an indication of air-quality or odor-related conditions.
The controller compares sensor readings with predefined thresholds. When a threshold is reached, the corresponding actuator is activated. For example, a high dustbin-level reading generates a maintenance alert, while an odor-related reading above a selected threshold can activate an odor-control mechanism. Automatic flushing or cleaning can be triggered according to the programmed operating conditions.

IV. SYSTEM ARCHITECTURE

A. Sensing Layer: Collects user-presence, waste-level, environmental, and optional water-system information.
B. Processing Layer: The microcontroller reads sensor values, applies threshold/rule-based logic, and determines the required action.
C. Actuation Layer: Controls devices such as a water pump, flush mechanism, cleaning mechanism, drying or refreshing unit, and indicator/alert outputs.
D. Communication Layer: Wi-Fi connectivity can transmit selected system information to a cloud or mobile monitoring platform.
E. Monitoring Layer: A dashboard or mobile interface can display washroom status and maintenance alerts.

V. METHODOLOGY

The prototype follows a sensor-to-decision-to-action workflow. After power-up, sensors continuously collect readings. The microcontroller filters or validates the readings and compares them with predefined operating thresholds.
A corresponding actuator is then controlled. System status can also be transmitted through Wi-Fi for remote monitoring.

For waste monitoring, the ultrasonic sensor measures the distance between the sensor and the waste surface. A reduction in measured distance indicates an increase in waste level. For presence detection, an IR sensor provides a non-visual indication of occupancy or activity. Environmental sensing is used to identify conditions that may require odor-control or ventilation action.

The project can additionally include a disposable toilet-seat-paper dispenser and automated drying or refreshing functions. These features are treated as independent actuators controlled according to the system's operating logic.

VI. PRIVACY-AWARE DESIGN

Privacy is particularly important in washroom environments. The proposed design does not require cameras inside the washroom. Instead, non-visual sensors are used to perform presence detection, waste monitoring, and environmental monitoring. This follows a privacy-by-design approach in which the minimum information required for automation is collected.

VII. AI AND DATA ANALYTICS EXTENSION

The initial prototype can use threshold-based automation, while the AI component can be introduced through analysis of historical sensor data. Recorded usage, waste-level, environmental, cleaning, and maintenance data can be used to identify peak usage periods, recurring odor conditions, waste overflow patterns, and maintenance requirements. In a future version, machine-learning models could predict when cleaning or maintenance is likely to be required.

VIII. RESULTS AND DISCUSSION

The prototype is designed to demonstrate the feasibility of automated washroom monitoring and control. Because this paper is prepared from the proposed project design rather than a controlled experimental dataset, numerical accuracy, percentage improvement, energy savings, and prediction accuracy are not claimed. Such values should be reported only after controlled measurements are performed.

The expected functional outcome is that sensor events can be translated into automated actions and maintenance notifications. The architecture is modular, so individual sensors and actuators can be replaced or expanded without redesigning the complete system. The principal practical benefit is the ability to shift washroom maintenance from fixed manual inspection toward condition-based monitoring.

IX. ADVANTAGES

The proposed system can provide automated hygiene-related functions, faster detection of waste-bin overflow, remote monitoring, reduced dependence on manual inspection, improved operational consistency, and privacy-aware sensing. It can also serve as a platform for future predictive maintenance and resource optimization.

X. LIMITATIONS

Sensor readings can be affected by calibration, placement, environmental conditions, and hardware limitations. Wi-Fi-based remote monitoring depends on network availability. Mechanical cleaning and flushing mechanisms require reliable water, power, and actuator control. AI-based prediction additionally requires a sufficiently large and representative historical dataset.

XI. FUTURE SCOPE

Future work can include machine-learning-based predictive cleaning, intelligent water-consumption optimization, improved air-quality monitoring, predictive maintenance, solar-assisted power, cloud analytics, and integration with smart-city maintenance platforms.

Additional non-visual sensing can also be investigated for more accurate occupancy and usage estimation while preserving privacy.

XII. CONCLUSION

This paper presented a Smart AI-Based Public Washroom System that integrates IoT sensing, embedded control, automation, remote monitoring, and privacy-aware design. The proposed architecture addresses practical public-washroom problems such as delayed maintenance, waste-bin overflow, unpleasant odor, and the need for automated operation. By avoiding cameras inside the washroom, the system emphasizes privacy while retaining useful sensing capabilities.

The prototype provides a foundation for future AI-enabled sanitation systems in educational institutions, transportation facilities, hospitals, offices, shopping centers, and smart-city environments.

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