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AIoT-Based Smart Public Toilet Management System: An ESP32 Prototype with Cloud Logging, a Multi-Location Dashboard and a Staged Hygiene-Analytics Plan

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Abstract

Most public toilets are cleaned on a timetable. Nobody counts how many people actually used them, nobody notices the water tank running low until it is empty, and the air inside can turn hot and damp for hours without anyone knowing. We built a small prototype to see how much of this can be handled with cheap hardware. An ESP32 reads two infrared sensors across the doorway, an ultrasonic ranger above the tank, a flow sensor on the supply line and a DHT11. A relay board runs a pump when the tank is low and a fan when the climate drifts out of range. Readings go over Wi-Fi to a Supabase table, and a browser dashboard shows several locations along with a rough hygiene score. The hardware sits in a cardboard cubicle; the same logic was also run in the Wokwi simulator, and timestamped rows were seen arriving in the cloud table. The hygiene score comes from fixed rules. A Random Forest classifier is described as a

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later step, but none has been trained, and we report no accuracy figure for it. Throughout, we try to be clear about what each of these inexpensive sensors can and cannot tell us.

Keyword: AIoT, ESP32, smart toilet, sanitation monitoring, water management, Supabase, smart city, Random Forest

I. INTRODUCTION

Think of a public toilet near a bus stand on a festival day. It may be used several hundred times, and the cleaner still turns up at the hour written on the roster. On a quiet Tuesday the same visit is wasted effort. A fixed schedule has no way of telling the two days apart. Water causes a similar headache: once the tank runs dry the toilet is useless, and a tank that nobody checks can also overflow or leak without anyone noticing. Studies of toilet monitoring keep coming back to this picture of paper registers, no overall view, and complaints that reach the authority late [2], [4], [6], [7].

Cheap microcontrollers with Wi-Fi have made it realistic to put sensors in a single cubicle and read them from somewhere else. Our interest was in combining things that earlier work tends to handle one at a time: counting visits, watching water level and flow, tracking the indoor climate, and switching a pump and fan automatically. We also wanted the cloud and dashboard part to actually run, since a lot of student prototypes end at the breadboard.

The problem we set ourselves was to build an AIoT-based management system for a public toilet that monitors and controls things automatically, keeps the place cleaner, depends less on manual rounds and keeps track of water use. Concretely, the objectives were:

1) detect entry and exit with IR sensors and estimate how many people used the toilet;
2) measure tank level with an ultrasonic sensor, measure flow with a YF-S201, and raise an alert when water is low;
3) record temperature and humidity with a DHT11;
4) switch the pump and the exhaust fan through a relay board;
5) push the readings to a cloud database over Wi-Fi;
6) show live status, alerts and history on a dashboard; and
7) leave room for AI-based analysis, to be added in stages once there is data.

This paper offers five things. First, one ESP32 handles occupancy, water, climate and actuation together. Second, we document the wiring, including the level shifting and the power budget, so others can repeat it. Third, we describe a logging path through Supabase and a dashboard in which live and simulated sites are clearly marked. Fourth, we give a simple hygiene indicator along with an honest account of what it misses.

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Fifth, we lay out how a Random Forest could be introduced later, with the data and labelling requirements settled before any training begins.

The paper is arranged as follows. Related work and the research gap come first (Section II), then the architecture (III), hardware (IV), firmware and control rules (V), data handling (VI), dashboard (VII), simulation results (VIII), analytics plan (IX), relevance to current trends (X), limitations (XI) and conclusions (XII).

II. RELATED WORK

Shah and Upadhyay built an e-toilet that flushes by itself, sanitises with UV light, adjusts the water per use and reports through an IoT platform [1]. It works, but the equipment is costly. Horadi et al. take a lighter route with a web server and a cleaner's mobile application that cover water monitoring, ventilation and flushing [2]. Prem Kumar et al. pair a Wi-Fi LaunchPad with a gas sensor to open water and chemical valves and to update an Android app used by the sanitary inspector [3]. Mahalsekar et al. mix air-quality, IR, ultrasonic and RFID sensing, upload to ThingSpeak, and leave machine learning for later [4]. Sirisha et al. concentrate on touch-free use and on monitoring a sewage tank [5]. Two similar designs, by Dhamale et al. and by Devika Rani et al., mark a toilet for cleaning once an ammonia reading crosses a threshold and count visitors with IR or ultrasonic sensors [6], [7]. Rajani and Sravani use an ESP32 with MQTT, gas and climate sensors and threshold alerts, and they too name AI prediction as future scope [8]. A newer automated washroom system aims at hygiene management in university buildings [17].

Table I sets these side by side. Two things stand out. Analytics beyond thresholds are nearly always pushed to future work [4], [8], and measuring flow while also refilling the tank automatically is rarely mentioned. People counting at doorways with infrared parts has been studied separately, and the authors there are frank about the errors when two people walk through together or someone stops in the beam [15], [16]. We keep that in mind and treat our count as a rough indicator.

TABLE I

COMPARISON OF REVIEWED IOT TOILET-MONITORING SYSTEMS

Ref.	Controller / link	Main sensing	Analytics / alerts; stated limitation
[1]	Arduino; IoT platform	Level, user detection, flush	Usage and water tracking; high installation cost
[2]	Web server + cleaner app	Water, smell, ventilation	Real-time alerts; no demonstrated AI prediction
[3]	Wi-Fi LaunchPad; Android app	MQ-series gas	Gas-triggered valves; single parameter

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Ref.	Controller / link	Main sensing	Analytics / alerts; stated limitation
[4]	Arduino + ESP8266; ThingSpeak	Air quality, IR, ultrasonic, RFID	Thresholds; ML only as future work
[5]	Arduino UNO; local display	IR, turbidity, gas, ultrasonic	Thresholds; limited deployment evidence
[6], [7]	Arduino + NodeMCU; GSM / web	Ammonia, IR or ultrasonic count	Ammonia threshold; needs calibration and stable link
[8]	ESP32; MQTT; dashboard	Gas, temperature, humidity, IR	Threshold alerts; AI as future scope; complex setup
This work	ESP32; Wi-Fi to Supabase	IR x2, HC-SR04, YF-S201, DHT11	Pump/fan rules, hygiene score, staged RF (proposed)

A. Research gaps

Six gaps keep showing up. Most systems react after a condition has worsened and do not predict it. Few look at usage patterns such as peak hours. Many are prototypes that have never been tried at scale. Sensing tends to cover one thing, either air or water, instead of the whole picture. Information for the user, like whether a toilet is occupied, is seldom provided. And long-term effects such as water saved are almost never measured. Our prototype speaks mainly to the integration gap. The data it logs could later feed work on prediction and usage behaviour. Scale, user guidance and environmental assessment are left untouched.

III. SYSTEM ARCHITECTURE

Data moves through the system in a fixed order: sense, collect, transmit, store, analyse, act or alert, and finally display (Fig. 1). The sensing layer is the five sensors. The ESP32 forms the edge layer; it filters the signals, applies the pump and fan rules itself and prepares each upload. Keeping those rules on the board means the pump still works if the Wi-Fi goes down. We picked the ESP32 for its built-in Wi-Fi and dual cores, and because its timing behaviour in sensor networks has been examined in the literature [18]; it also turns up in other monitoring projects [19]. Supabase, a PostgreSQL service, is the cloud layer. The analytics layer holds the threshold rules and the hygiene score for now, with a machine-learning block drawn dashed since it does not exist yet. The last layer is the dashboard that managers and cleaning staff look at.

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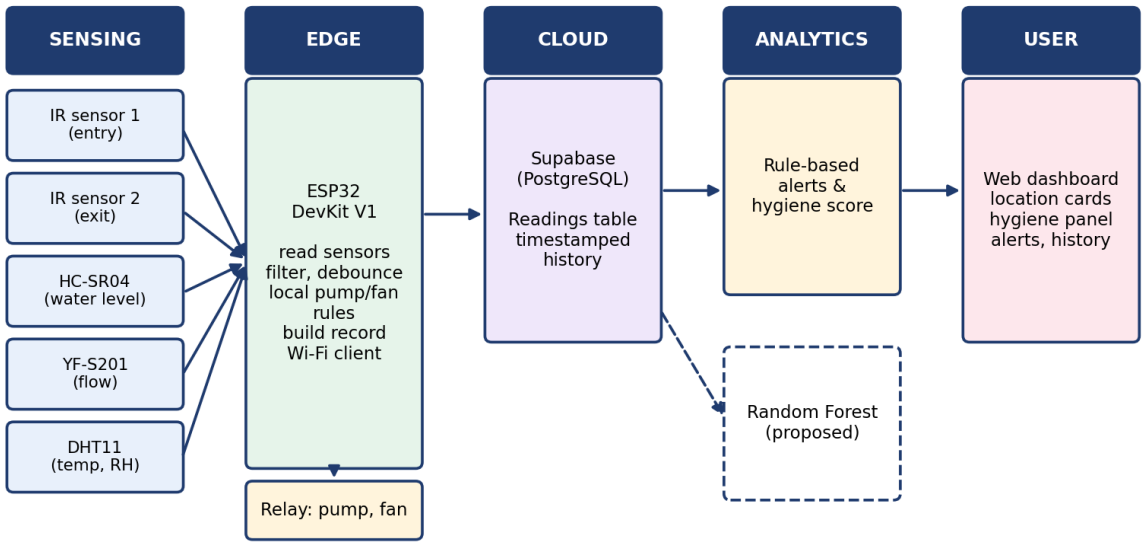


Fig. 1. Layered architecture of the smart public toilet system. The dashed Random Forest block is proposed and has not been trained.

IV. HARDWARE DESIGN

A. Components

The board is an ESP32 DevKit V1. For sensing we used two IR obstacle modules (one at the entrance, one further in), an HC-SR04 ultrasonic ranger rated for 2 to 400 cm, a YF-S201 flow sensor rated for 1 to 30 L/min, and a DHT11 covering 0 to 50 °C and 20 to 90 % RH. A two-channel relay board drives a 5 V submersible pump on channel 1 and a 5 V DC exhaust fan on channel 2. Everything is joined on a breadboard with jumper wires and shares one ground. The model itself (Fig. 2) is a cardboard box lined with tile-pattern paper; a bowl stands in for the commode, a jar holds the water, and a clear tube serves as the flush pipe.

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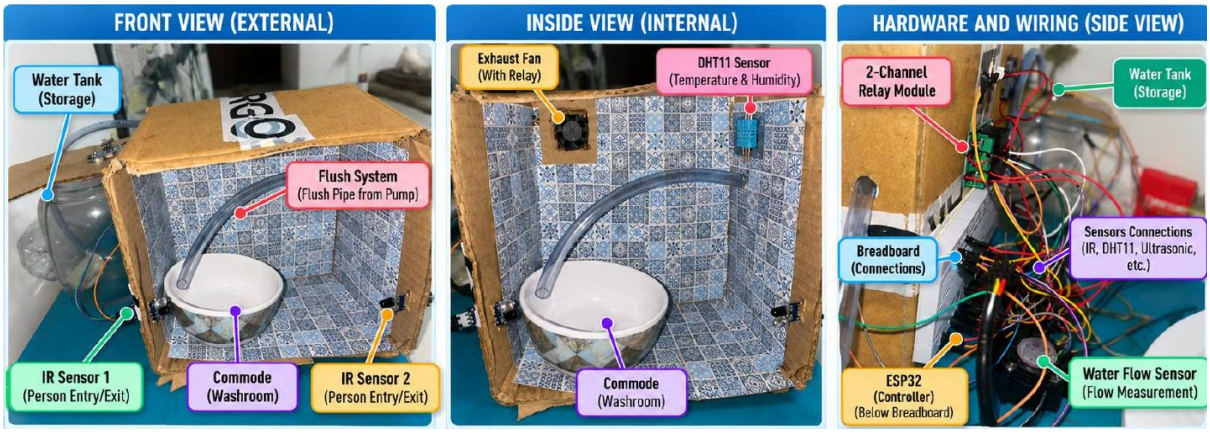


Fig. 2. Hardware model: external view, internal view with the exhaust fan and DHT11, and the wiring side view with the relay module, breadboard, ESP32 and flow sensor.

B. Pin assignment and level compatibility

The pin allocation is in Table II and the connections are drawn in Fig. 3. The main electrical rule is that ESP32 pins cannot take 5 V. The HC-SR04 echo line does swing to 5 V, so it goes through a 1 kΩ and 2 kΩ divider that brings it down to roughly 3.3 V. The IR modules and the DHT11 run from the 3.3 V pin, which keeps their outputs inside the safe range automatically. The flow sensor is powered at 5 V. Before connecting its signal wire, measure it with a multimeter; if it idles near 5 V, a divider is needed there as well. The relay board takes 5 V and both loads are small DC devices, so there is no mains wiring anywhere in the model. A 5 V supply rated at 2 A or more feeds the board, relays, pump and fan.

TABLE II

ESP32 GPIO ALLOCATION

Device	**Signal**	**GPIO**	**Note**
IR sensor 1	OUT	27	3.3 V
IR sensor 2	OUT	26	3.3 V
HC-SR04	TRIG	5	out
HC-SR04	ECHO	18	divider
DHT11	DATA	4	3.3 V

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Device	Signal	GPIO	Note
YF-S201	SIG	25	pulse in
Relay	IN1 pump	23	active
Relay	IN2 fan	22	active

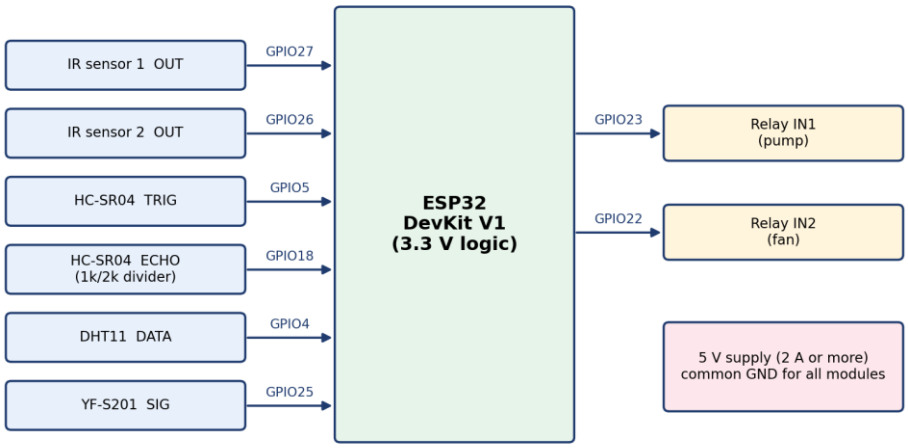


Fig. 3. Connection map between the ESP32 and the sensors and relay module.

C. What each sensor can tell us

Entry and exit. The two IR modules are fixed a few centimetres apart, along the way a person walks. If the entrance sensor fires first and the inner one second, that is an entry; the opposite order is an exit. A debounce time and a limit on the gap between the two triggers filter out noise. Two people walking in together, or someone standing in the doorway, will upset the count. So we read it as a usage indicator rather than a true head count [15], [16].

Water level. The ultrasonic ranger looks down at the water surface. Taking temperature T in °C, the speed of sound is roughly

$$v = 331.3 + 0.606\,T \qquad (1)$$

and the distance to the surface follows from the echo time t:

$$d = v\,t\,/\,2 \qquad (2)$$

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With the empty-tank and full-tank distances measured once, the level in percent is

$$L = (D_{empty} - d) / (D_{empty} - D_{full}) \times 100 \quad (3)$$

Ripples and echoes off the tank wall make single readings jumpy, so we take the median of several. The full-tank distance has to stay above the sensor's minimum range of about 2 cm.

Flow. The YF-S201 emits pulses at a frequency f that is proportional to flow rate Q, f = K Q. The datasheet gives K as about 7.5 Hz per L/min, but the real value moves with the installation and the flow, so it has to be calibrated. After counting N pulses the volume passed is

$$V = N / (60\ K) \quad (4)$$

A small 5 V pump may well deliver less than the sensor's minimum rated 1 L/min, and at such low flow the readings cannot be trusted until the sensor is calibrated.

Climate. The DHT11 is a coarse sensor, good to about ±2 °C and ±5 % RH. It tells us about the room and gives the temperature used in (1). It says nothing about cleanliness or odour.

V. FIRMWARE AND CONTROL LOGIC

The firmware is written with the Arduino framework and follows the loop in Fig. 4. Interrupt routines count IR events and flow pulses, with debounce. Ultrasonic and DHT11 readings are taken at a fixed interval. If a reading times out, comes back as NaN or lies outside sensible limits, it is marked as a sensor fault and left out of the valid data. For the pump we use hysteresis: it starts below a low level and stops only after a higher one is reached, so it does not flicker on and off around a single value. At the end of each cycle the board packs visitor events, temperature, humidity, flow pulses and actuator states into one record and sends it.

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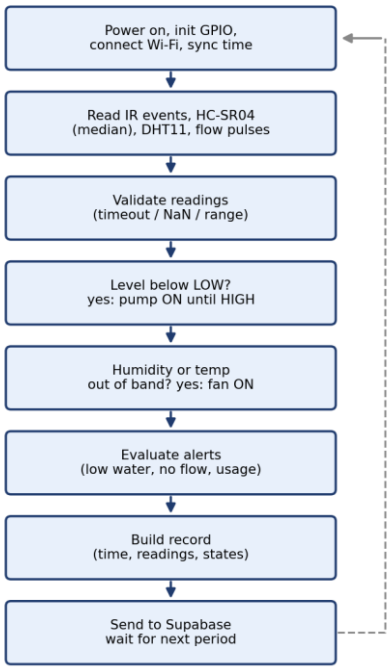


Fig. 4. Flowchart of the ESP32 main loop.

Table III lists the control and alert rules. We have not fixed numeric thresholds here, because they depend on bench calibration. Note that an alert only means something may need attention. It says nothing certain about dirt, and a toilet counts as cleaned only when staff record it.

TABLE III

RULE-BASED CONTROL AND ALERT LOGIC

Rule	Condition	Action
Low water	Level below low limit	Pump ON until high limit
Pump timeout	ON too long, no level rise	Pump OFF; supply alert
No flow	Pump ON, almost no pulses	Dry-run or blockage alert
Climate	T or RH outside band	Fan ON; climate alert
Usage	Visits since cleaning above limit	Cleaning-due cue
Sensor fault	Invalid samples in a row	Fault alert

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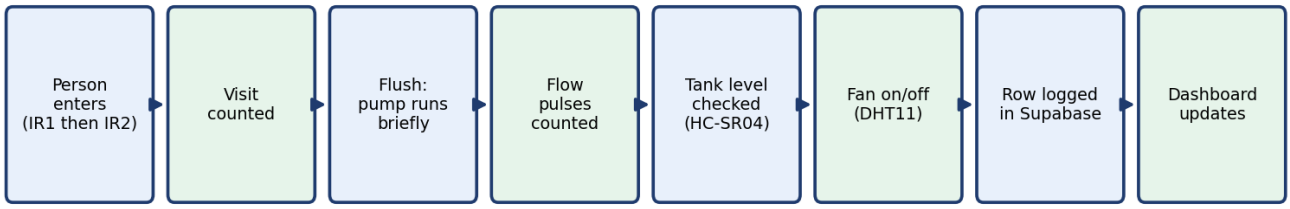


Fig. 5. Operating workflow from a visitor entering to the dashboard update.

VI. DATA PIPELINE AND DATA QUALITY

For storage we went with Supabase. It gives a hosted PostgreSQL table with a REST interface and a table editor, which was convenient for a student project. The Readings table holds an incrementing id, a timestamp, entry and exit flags, temperature, humidity and flow pulses, and every upload from the ESP32 adds one row. This table is also where training data for Section IX would come from.

Raw readings from cheap sensors are noisy, with dropouts and the occasional wild value, and any model trained on them later will only be as good as the cleaning behind it. One survey sorts IoT sensors by the preprocessing each kind needs [13], and another line of work argues for cleaning data streams close to where they are produced [14]. We follow that second idea in a small way: the ESP32 does the first pass, with median filtering of echoes, range checks, fault flags and debounce. Further along, the literature reports learning-based cleaning, for example deep reinforcement learning for IoT sensor data [9], random forest regression for data quality [10], and improved random forests applied to industrial and metering data [11], [12]. None of these is implemented in our prototype. They are options for preparing the dataset offline once real readings pile up.

VII. DASHBOARD AND HYGIENE INDICATOR

The dashboard is one web page in a dark theme (Fig. 6). At the top is a card for each location showing visitors, temperature, humidity, water level, and whether the fan and pump are on. Lohegaon is the main deployment, connected to the ESP32, and carries a live tag. Alandi and Bhosari are demonstration sites whose numbers are generated, and they are tagged simulated so nobody takes them for field data. If the data source cannot be reached, a backend-offline badge appears.

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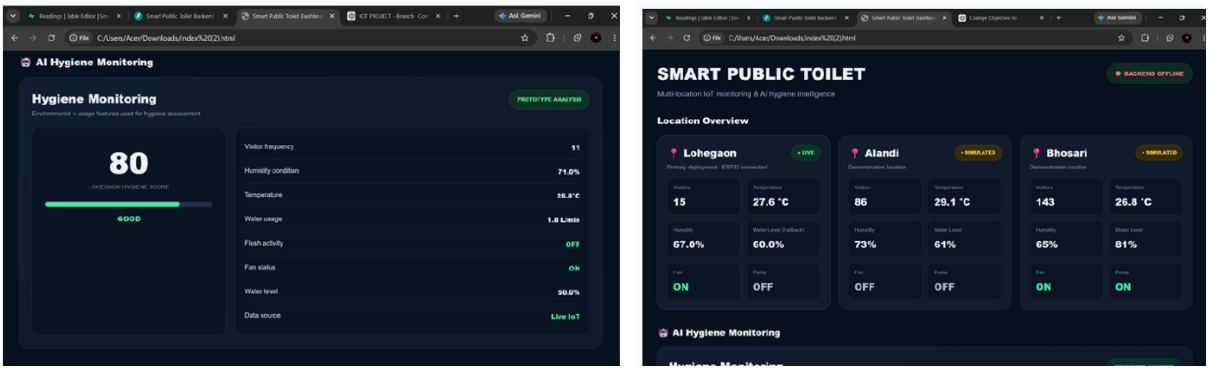


Fig. 6. Dashboard screens: AI hygiene monitoring panel (left) and multi-location overview (right).

Under the cards sits the hygiene panel, with a score out of 100 and a band label. In the screen we captured, Lohegaon scored 80 and was labelled good. The inputs listed beside it were visitor frequency 11, humidity 71.0 %, temperature 25.8 °C, water usage 1.8 L/min, flush activity off, fan on, water level 50 %, and live IoT as the data source. The panel is tagged prototype analysis, and that tag matters. The score blends usage and environmental features. No sensor here detects bacteria or smell, so the number is best read as a way to decide which toilet to inspect first, not as a measure of how clean it is.

VIII. SIMULATION AND LOGGED DATA

Before trusting the physical build, we ran the logic in the Wokwi simulator on an ESP32. Push buttons played the part of the two IR sensors and the flow pulses. An ultrasonic module and a DHT22 model supplied distance and climate, two LEDs stood for the pump and fan relays, and an OLED displayed distance, level, temperature, humidity and pump state. Wokwi offers a DHT22 model rather than a DHT11, so the simulated climate values follow that device; the physical model uses the DHT11. The simulated board wrote to the Supabase Readings table over the network (Fig. 7), and Table IV shows a few of the rows.



Fig. 7. Wokwi simulation setup (left) and the Supabase Readings table receiving timestamped rows (right).

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TABLE IV

SAMPLE ROWS FROM THE READINGS TABLE (SIMULATED DEVICE)

ID	Timestamp	Entry	Exit	Temp °C	RH %
1	2026-09-26 08:55:32	1	0	27.6	63
5	2026-09-26 08:55:51	1	0	27.6	63
8	2026-09-26 08:56:23	0	1	27.6	64
11	2026-09-26 09:02:36	1	0	27.1	64

What this shows is that the sensing logic, the record format and the cloud path hang together. Timestamps are stored to the millisecond, entry and exit appear as event flags, and temperature and humidity move slowly from row to row, as a room's would. What it does not show is how the system performs in the field. These numbers come from a simulator and a model cubicle, and they say nothing about real toilets.

IX. ANALYTICS ROADMAP

A prototype this new produces very little data, so the analytics are planned in stages (Fig. 8). Frameworks that combine IoT sensing with machine learning have been explored for other utilities, water quality being one example [20]. That supports the general approach; it tells us nothing about accuracy for toilets.

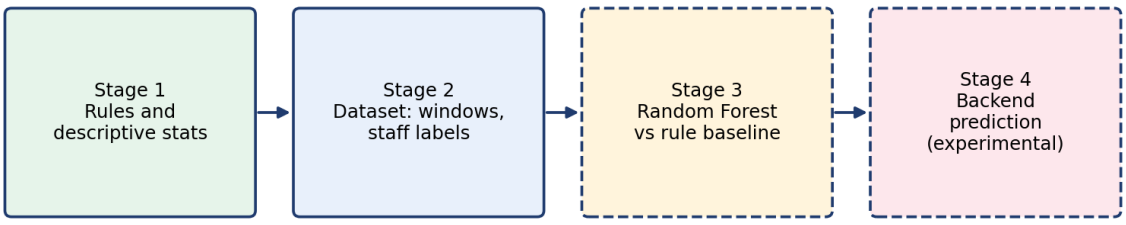


Fig. 8. Staged analytics path. Stages 3 and 4 (dashed) are proposed and not yet carried out.

Stage 1: rules and descriptive statistics. The rules in Table III, plus simple trends like visits per hour and water per visit, give a plain baseline. Any later model has to beat it.

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Stage 2: building a dataset. Readings would be grouped into windows, say fifteen minutes each. Candidate features are the hour of day, weekday or weekend, visitors in the window and since the last cleaning, water used, average temperature and humidity, and minutes since cleaning. A supervised model needs labels, so staff would note an inspection state (OK, attention, needs cleaning) from a fixed checklist at known times. Anything simulated must be tagged as such and kept out of claims about real toilets. The cleaning steps of Section VI apply here.

Stage 3: model and evaluation. We propose a Random Forest first. It copes with tabular data and small samples, needs no feature scaling, and reports feature importances that can be checked against common sense; random forests have also been used for IoT data quality [10]–[12]. Training and test sets should be split by time and not shuffled, otherwise neighbouring windows leak between them. The needs-cleaning class will probably be rare, which makes accuracy a poor yardstick, so precision, recall, F1 and the confusion matrix should be reported next to the rule baseline. If labels cannot be collected, anomaly detection on water use and climate readings is a fallback.

Stage 4: deployment. A trained model would run on a small backend, read the latest window from the database and write back a prediction with a confidence value, shown on the dashboard as experimental. The ESP32 would keep running only the rule-based safety logic. As of now no model has been trained and we report no accuracy.

X. RELEVANCE TO CURRENT TECHNOLOGY TRENDS

The project sits where several current trends meet. IoT makes continuous monitoring cheap. Cloud storage lets one office watch many sites. Analytics and AI point toward maintenance that anticipates problems. Smart-city programmes need data on sanitation, water monitoring supports conservation, and better-kept facilities help public health. Our prototype touches each of these only lightly, and what it demonstrates is the monitoring and cloud side.

XI. LIMITATIONS

A cardboard box and a jar are not plumbing, and a real toilet needs approved fittings and proper electrical safety. Two IR sensors give an approximate count and cannot tell people apart. The DHT11 is coarse. The YF-S201 is unreliable at low flow until calibrated, and ultrasonic ranging can be thrown off by foam, splashes and condensation. Everything depends on Wi-Fi. Only one physical unit exists, and the other dashboard locations are simulated. The hygiene score is a heuristic and has not been validated. The machine-learning stage is still a plan, and the level and flow calibration tables remain to be filled in from bench measurements.

XII. CONCLUSION AND FUTURE WORK

We described a low-cost AIoT prototype that counts doorway events, follows water level and flow, tracks indoor climate, runs a pump and a fan, logs to a cloud table and displays everything on a multi-location dashboard. The cloud path and the dashboard work. The hygiene score comes from rules, and the classifier

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remains a plan rather than a result. Next we want to calibrate the sensors, gather a labelled dataset in a pilot, and test a Random Forest against the rule baseline. Other items on the list are a calibrated gas or odour module, several physical units using MQTT with over-the-air updates, leak detection, a mobile app, and a look at power and privacy.

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