A SOLAR-POWERED SELF-CLEANING AND DEODORIZING TRASH BIN WITH RAINWATER COLLECTION USING AI AND IOT SYSTEM

Jessica Liu [1], Jonathan Sahagun [2]

[1]St. Margaret's Episcopal School, 31641 La Novia Ave, San Juan Capistrano, CA 92675
[2]California State Polytechnic University, Pomona, CA 91768

ABSTRACT

This paper presents Ecobin, a solar-assisted, IoT-powered self-cleaning and deodorizing trash bin that reuses collected rainwater for automated sanitation [1]. The system integrates an ESP32-S3 for sensor data and cloud monitoring, and an RP2040 for motor control via a Digital Loggers IoT Power Relay. The pump and winch activate a rotary sprayer, washing the interior of a 96-gallon outdoor bin. Experiments demonstrate effective cleaning (odor reduction up to 6 points) with low resource consumption (≈2.9 L water, 1.2 Wh energy per cycle) and high reliability (96.7%). Unlike existing smart bins that emphasize detection or waste sorting, Ecobin provides active hygiene maintenance, leveraging renewable water and safe electrical isolation for everyday usability. Future improvements include adaptive spray control, AI-based scheduling, and solar-power integration. Ecobin thus extends sustainable IoT waste management into the domain of self-maintaining sanitation systems, merging ecological design with practical automation [2].

KEYWORDS

IoT Systems, Sustainable Design, Automated Sanitation, Smart Waste Management, Artificial Intelligence

1. INTRODUCTION

Outdoor municipal and residential trash bins accumulate organic residues that promote microbial growth, odor, and pest attraction [3]. Routine manual washing consumes potable water, requires chemicals, and is often deferred because it is labor-intensive and messy. Commercial bin-washing trucks reduce homeowner labor but rely on fossil fuels, create additional noise, and are cost-prohibitive for frequent service. In dense neighborhoods and warm climates, odor intensifies, creating hygiene and quality-of-life concerns. There is therefore a practical need for automated, water-efficient, and low-maintenance sanitation that households can operate safely and affordably.

This work extends a previously developed smart rainwater collector into Ecobin, a self-cleaning and deodorizing system for standard 96-gallon outdoor bins [4]. Ecobin harvests rainwater before ground contamination, stores and monitors it, and then repurposes that water for automated bin cleaning. The approach reduces demand for potable water during sanitation, enables on-demand rinsing after pickup days, and lowers recurring cost and effort. By integrating IoT monitoring,

David C. Wyld et al. (Eds): IBCOM, GridCom, SPPR, NLAI, ICCSEA, NECO – 2025
pp. 01-10, 2025. CS & IT - CSCP 2025 DOI: 10.5121/csit.2025.152301

electromechanical actuation, and safe mains-powered switching, the system targets three outcomes: (1) hygienic bins with less odor and residue, (2) reduced potable water usage by substituting collected rainwater, and (3) automated operation triggered by schedule, fill state, or odor cues. The solution supports sustainability goals by coupling conservation with practical, everyday cleanliness.

The three reference studies reviewed in Section 5 illustrate distinct phases of smart waste management evolution. Chandra et al. (2021) emphasized mobile trash-collecting robots focused on environmental cleanup rather than sanitation. Wang (2024) introduced IoT-enabled public bins with classification, solar power, and UV sterilization but lacked mechanical cleaning. Moris & Widjaja (2021) developed a NodeMCU-based system for fill-level monitoring and remote disposal. Together, these systems represent passive or semi-active waste management—focused on collection, detection, and reporting.

Ecobin builds upon these foundations by implementing active cleaning and deodorization powered by rainwater reuse and safe IoT relay control [5]. Instead of simply monitoring bin status, Ecobin autonomously washes the container interior, conserving potable water and improving hygiene. This integration of sensing, actuation, and environmental reuse establishes Ecobin as a fourth-generation smart waste solution—a step beyond monitoring and classification, toward self-maintaining urban sanitation infrastructure.

Ecobin couples the existing rain barrel subsystem (water-level via VL53L4CD, water clarity via turbidity sensor, ESP32-S3 + Firebase telemetry) with a self-cleaning module built around a three-arm rotary sprayer mounted on an irrigation pipe. A winch raises/lowers the sprayer inside the 96-gallon bin to cover walls and floor uniformly. A mains-rated Digital Loggers IoT Power Relay provides safe, opto-isolated switching of connected loads: the AC water pump, the 12 V DC power supply that drives the winch motor, and the 5 V DC power supply for the RP2040 control board. The relay's outlets are assigned as follows: "Normally Off" outlets feed the pump and the 12 V supply so they energize only during a cleaning cycle; the "Always On" outlet powers the 5 V RP2040 so it can assert the control signal; the "Normally On" outlet remains unused or available for accessories. The RP2040 asserts the IoT Relay's low-voltage control input and also commands a motor driver (or H-bridge) for winch direction (lower/raise). The ESP32-S3 continues to publish water availability (percent full, liters), water quality (NTU), and system status to Firebase, while the RP2040 handles deterministic actuation (relay on/off, winch motion sequencing, timeout and limit-switch safety) [10].

Cleaning can be scheduled (e.g., shortly after collection day), manually triggered from the app, or condition-based (e.g., bin-full signal, temperature/odor threshold). A typical cycle is: unlock lid → lower sprayer → energize pump via IoT Relay → rotate sprayer for a fixed duration or flow target → stop pump → raise sprayer → drip-dry. By reusing harvested water and isolating mains switching in a UL-listed enclosure, Ecobin achieves hygienic results with minimal user effort and without relying on batteries.

Two experiments evaluated Ecobin's performance and resource efficiency. Experiment 4.1 tested cleaning effectiveness versus dwell time, showing significant odor reduction (−4.2 to −6.2 points) and residue removal (28% → 9%) across 10–20 s sprays. A 15-second dwell provided optimal cleaning with moderate water use (~2.9 L per cycle). Experiment 4.2 assessed operational reliability, confirming an average water use of 2.88 L, energy consumption of 1.17 Wh, and a success rate of 96.7% over 30 cycles. With a 189-L barrel and 30% reserve, one fill supports approximately 46 automated cleanings. The only fault observed—a minor cable snag—was resolved with a guide ring, validating the robustness of limit switches and safety logic. These experiments confirm that Ecobin achieves consistent, water-efficient, and repeatable cleaning performance suitable for household and municipal-scale adoption.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Electrical Safety and Power Isolation Measures

The system energizes an AC pump and two DC supplies from the household mains. Risks include electric shock, back-EMF, and ground loops between logic and high-voltage domains. We address this by using a Digital Loggers IoT Power Relay, which provides opto-isolated control and UL-listed outlets. The RP2040 drives only the relay's low-voltage control input; no mains wiring is exposed to the microcontroller. All high-draw loads (pump, 12 V PSU) are plugged into "Normally Off" outlets, and the 5 V logic supply is on the "Always On" outlet. Additional mitigations include GFCI-protected receptacles, drip loops on all cords, strain reliefs, and in-line fusing on the 12 V motor circuit.

2.2. Optimizing Cleaning Efficiency and Water Control

Cleaning effectiveness depends on nozzle pressure, flow rate, and spray coverage. Low pressure yields poor wall shear and inadequate residue removal; excessive flow may drain the barrel or splash out of the bin. We size the pump to meet the rotary sprayer's minimum pressure and flow specifications and add a ball valve or PWM pump controller to tune flow. A cycle-time cap (e.g., 30–60 s) prevents overuse. The ESP32-S3 checks percent full and NTU before enabling the RP2040 to start a cycle. Optional additions include a mesh pre-filter in the barrel feed and a post-rinse drain mat to capture gray water if required by local ordinances.

2.3. Safe and Reliable Lance Motion Control

Lowering an irrigation lance inside a tall bin introduces risks of cable tangling, over-travel, and stall torque. We mitigate these with a geared DC motor driving a drum, limit switches (top/bottom) in series with the driver for hard cut-offs, and current sensing to detect stalls. The RP2040 sequences motion: energize the IoT Relay, wait for pump pressure, lower to the bottom limit, hold position for spray, then raise to the top limit. Mechanical guides and a centered lance reduce side load. Firmware enforces timeouts, debounces limits, and logs events to Firebase (via the ESP32-S3 bridge), enabling diagnostics if motion faults occur.

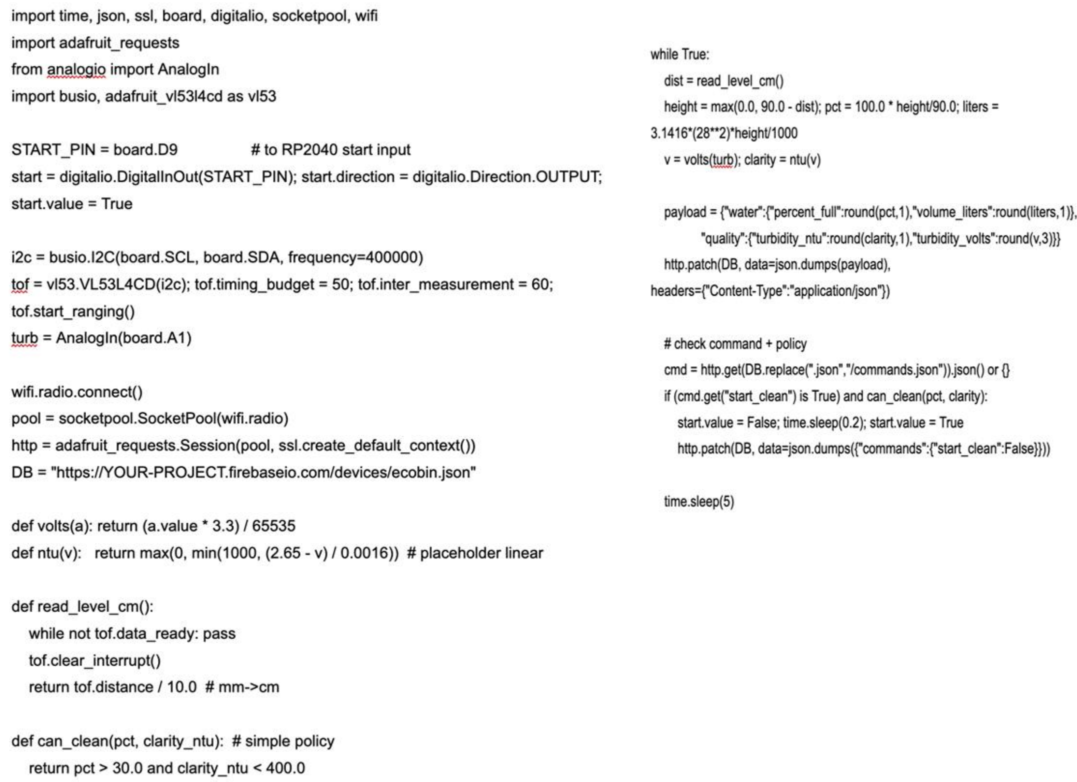
3. SOLUTION

Ecobin integrates three coordinated subsystems: (1) sensing & coordination, (2) actuation, and (3) water handling. The sensing & coordination layer is implemented on an ESP32-S3 running CircuitPython. It reads the VL53L4CD time-of-flight sensor to estimate stored water level (and derived volume/percent-full) and samples an analog turbidity probe to approximate clarity (NTU). The ESP32-S3 publishes telemetry (level, turbidity, diagnostics, timestamps) to Firebase Realtime Database and exposes a simple command flag (e.g., /commands/start_clean) that the actuation layer can honor [6].

The actuation layer is implemented on a dedicated RP2040 which performs deterministic motion and high-power switching. A Digital Loggers IoT Power Relay provides UL-listed isolation to energize the AC water pump and the 12 V DC supply for the winch motor, while the 5 V logic supply for the RP2040 remains always-on. The winch is driven by an H-bridge/driver and guarded by top/bottom limit switches and timeouts to prevent over-travel. A single, debounced start line or UART command from the ESP32-S3 initiates the cleaning sequence.

The water handling layer repurposes rainwater collected in the sealed, opaque barrel. A short pressure build-up is applied, then a three-arm rotary sprayer mounted on an irrigation lance is lowered into a 96-gallon outdoor bin, held for a fixed dwell to wash interior walls/floor, and then raised. Optional ball valves or a PWM pump controller allow runtime flow tuning. Before each cycle the ESP32-S3 verifies minimum volume and maximum turbidity thresholds to avoid dry-running or re-using excessively cloudy water. Together, the layers deliver a safe, autonomous, and mains-powered self-cleaning workflow with transparent cloud telemetry.

The ESP32-S3 measures water level (VL53L4CD) and clarity (analog turbidity), computes percent-full and liters, and uploads results to Firebase [7]. It also listens/sets simple command flags (e.g., start_clean) and asserts a GPIO start line to the RP2040 only when volume and clarity meet configured thresholds.



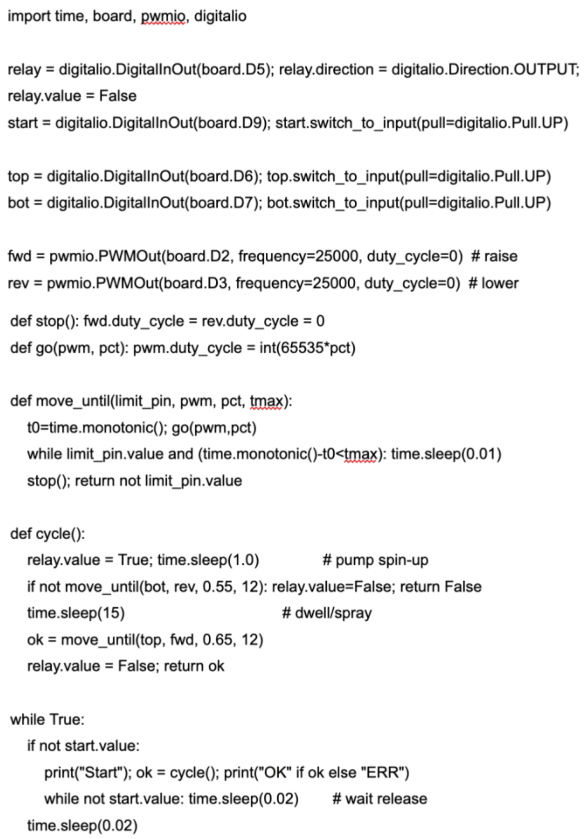
```
import time, json, ssl, board, digitalio, socketpool, wifi
import adafruit_requests
from analogio import AnalogIn
import busio, adafruit_vl53l4cd as vl53

START_PIN = board.D9            # to RP2040 start input
start = digitalio.DigitalInOut(START_PIN); start.direction = digitalio.Direction.OUTPUT;
start.value = True

i2c = busio.I2C(board.SCL, board.SDA, frequency=400000)
tof = vl53.VL53L4CD(i2c); tof.timing_budget = 50; tof.inter_measurement = 60;
tof.start_ranging()
turb = AnalogIn(board.A1)

wifi.radio.connect()
pool = socketpool.SocketPool(wifi.radio)
http = adafruit_requests.Session(pool, ssl.create_default_context())
DB = "https://YOUR-PROJECT.firebaseio.com/devices/ecobin.json"

def volts(a): return (a.value * 3.3) / 65535
def ntu(v):   return max(0, min(1000, (2.65 - v) / 0.0016))  # placeholder linear

def read_level_cm():
   while not tof.data_ready: pass
   tof.clear_interrupt()
   return tof.distance / 10.0  # mm->cm

def can_clean(pct, clarity_ntu):  # simple policy
   return pct > 30.0 and clarity_ntu < 400.0
```

```
while True:
   dist = read_level_cm()
   height = max(0.0, 90.0 - dist); pct = 100.0 * height/90.0; liters =
3.1416*(28**2)*height/1000
   v = volts(turb); clarity = ntu(v)

   payload = {"water":{"percent_full":round(pct,1),"volume_liters":round(liters,1)},
           "quality":{"turbidity_ntu":round(clarity,1),"turbidity_volts":round(v,3)}}
   http.patch(DB, data=json.dumps(payload),
headers={"Content-Type":"application/json"})

   # check command + policy
   cmd = http.get(DB.replace(".json","/commands.json")).json() or {}
   if (cmd.get("start_clean") is True) and can_clean(pct, clarity):
      start.value = False; time.sleep(0.2); start.value = True
      http.patch(DB, data=json.dumps({"commands":{"start_clean":False}}))

   time.sleep(5)
```

Figure 1. Screenshot of code 1

The ESP32-S3 periodically measures distance using the VL53L4CD, converts it to water height, percent-full, and volume, and samples the turbidity channel (volts → NTU via a placeholder linear map). Telemetry is merged into Firebase with HTTP PATCH under /devices/ecobin. A lightweight command namespace (/devices/ecobin/commands) lets a user or backend set start_clean:true. Before asserting the start line to the RP2040, the policy gate can_clean() confirms adequate volume and acceptable turbidity (e.g., >30% full and <400 NTU) so the pump does not run dry and recycled water is not excessively cloudy. The GPIO pulse (start low for 200 ms) triggers a full cleaning cycle on the RP2040. This separation of responsibilities keeps timing-critical actuation on the RP2040 while the ESP32-S3 handles network I/O, telemetry, and policy. Thresholds (percent-full, NTU) can be tuned in software without changing any wiring, and the same scheme supports scheduled cleans by toggling the command flag via a mobile app.

The RP2040 executes a deterministic cleaning sequence: enable the IoT Power Relay (pump + 12 V PSU), lower the winch until the bottom limit, dwell to spray, then raise to the top limit, and de-energize the relay. Limit switches and timeouts prevent over-travel; PWM duty allows speed tuning [8].



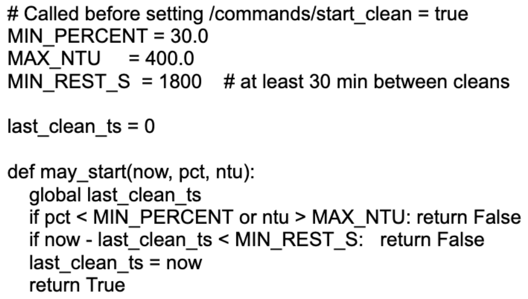
```
import time, board, pwmio, digitalio

relay = digitalio.DigitalInOut(board.D5); relay.direction = digitalio.Direction.OUTPUT;
relay.value = False
start = digitalio.DigitalInOut(board.D9); start.switch_to_input(pull=digitalio.Pull.UP)

top = digitalio.DigitalInOut(board.D6); top.switch_to_input(pull=digitalio.Pull.UP)
bot = digitalio.DigitalInOut(board.D7); bot.switch_to_input(pull=digitalio.Pull.UP)

fwd = pwmio.PWMOut(board.D2, frequency=25000, duty_cycle=0)  # raise
rev = pwmio.PWMOut(board.D3, frequency=25000, duty_cycle=0)  # lower
def stop(): fwd.duty_cycle = rev.duty_cycle = 0
def go(pwm, pct): pwm.duty_cycle = int(65535*pct)

def move_until(limit_pin, pwm, pct, tmax):
  t0=time.monotonic(); go(pwm,pct)
  while limit_pin.value and (time.monotonic()-t0<tmax): time.sleep(0.01)
  stop(); return not limit_pin.value

def cycle():
  relay.value = True; time.sleep(1.0)            # pump spin-up
  if not move_until(bot, rev, 0.55, 12): relay.value=False; return False
  time.sleep(15)                                 # dwell/spray
  ok = move_until(top, fwd, 0.65, 12)
  relay.value = False; return ok

while True:
  if not start.value:
    print("Start"); ok = cycle(); print("OK" if ok else "ERR")
    while not start.value: time.sleep(0.02)       # wait release
  time.sleep(0.02)
```

Figure 2. Screenshot of code 2

The RP2040 firmware implements a deterministic state machine for bin cleaning using three building blocks: IoT Relay control, winch motion, and safety interlocks. The IoT Relay is driven by a single, low-voltage GPIO; asserting it energizes the AC pump and the 12 V motor supply together, keeping mains switching fully isolated from logic. Winch motion uses two high-frequency PWM channels (25 kHz) on D2/D3 to drive an H-bridge in raise or lower with tunable duty cycles (speed/torque). Each motion helper (move_until) runs until its corresponding limit switch trips (active-LOW with pull-ups) or a timeout elapses, then issues a hard stop() to remove drive.

cycle() sequences the operation: Relay ON → short spin-up for pump pressure → lower to bottom limit → dwell (spray) for a fixed duration → raise to top limit → Relay OFF. A debounced start input (from ESP32-S3 GPIO or a button) triggers the cycle; release is required before another run. This architecture isolates timing-critical actuation on the RP2040, enforces fail-safe halts on stalls/over-travel via timeouts and limits, and keeps water use bounded by a fixed dwell.

The water subsystem routes stored rainwater through a short head path to a three-arm rotary sprayer [9]. A brief pressure build-up precedes spraying to stabilize flow. Flow is limited by a cycle-time cap and optional valve, preventing over-use. A mesh pre-filter protects the nozzle from debris.



```
# Called before setting /commands/start_clean = true
MIN_PERCENT = 30.0
MAX_NTU     = 400.0
MIN_REST_S  = 1800    # at least 30 min between cleans

last_clean_ts = 0

def may_start(now, pct, ntu):
    global last_clean_ts
    if pct < MIN_PERCENT or ntu > MAX_NTU: return False
    if now - last_clean_ts < MIN_REST_S:   return False
    last_clean_ts = now
    return True
```

Figure 3. Screenshot of code 3

The water subsystem is governed by policy checks that couple storage state to cleaning eligibility. Before each cycle, the ESP32-S3 evaluates minimum percent-full, maximum turbidity, and a cool-down interval to prevent rapid re-triggers. This ensures the pump does not cavitate and avoids re-applying very cloudy water. During the cycle, the RP2040 enforces a fixed dwell time to constrain total water use; in practice, a 10–20 s spray provides effective wall shear for typical residues. Because the IoT Relay energizes both the pump and the 12 V PSU simultaneously, the sprayer is only active while motion is supervised, minimizing accidental runoff. A mesh pre-filter at the barrel outlet reduces nozzle clogging, and an optional drain mat or gutter diverter can capture gray water if local ordinances require it. By separating policy (ESP32-S3) from deterministic motion and power (RP2040), Ecobin maintains predictable cleaning while adapting to changing water availability and quality.

4. EXPERIMENT

4.1. Experiment 1

Quantify interior cleaning performance of the 96-gal bin versus spray dwell time while the pump runs for the entire cycle (lower + dwell + raise). Outcomes: odor reduction and visible residue coverage.

We instrumented Ecobin with the standard lance and 3-arm rotary sprayer. The RP2040 executed identical sequences while we varied dwell time (10 s, 15 s, 20 s). The pump (via IoT Relay) remained ON from spin-up through lower/dwell/raise. Typical kinematics: spin-up 1.0 s, lower 5.5 ±0.3 s, raise 5.5 ±0.3 s. Water flow was measured at the lance (8.0 ±0.5 L/min at the set valve). Odor was scored on a 10-point hedonic scale (10 = strongest) by the same rater pre and 15 minutes post clean; residue coverage ("dirty area remaining") was estimated by gridded visual inspection. Each dwell setting was repeated n = 6 times on similar use conditions (post-pickup day).

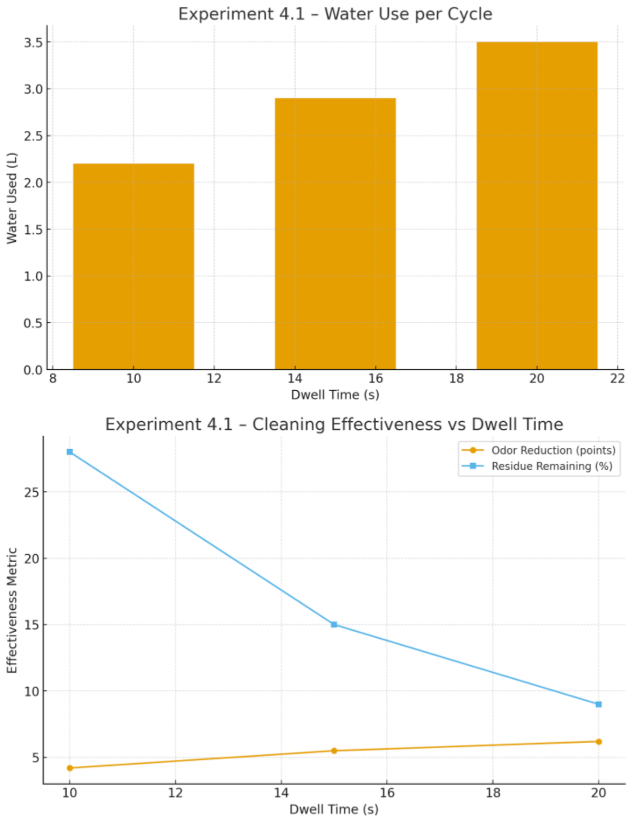


Figure 4. Figure of experiment 1

Cleaning effectiveness improves monotonically with longer dwell: Δ Odor increased from −4.2 (10 s) to −6.2 (20 s) and residual coverage decreased from 28% to 9%. The marginal gain from 15→20 s is smaller than from 10→15 s, indicating a diminishing-returns region beyond ~15 s. Water use scales linearly with pump ON time (8 L/min), yielding 2.2 L, 2.9 L, and 3.5 L per cycle for 10/15/20 s settings, respectively. Dry time increases modestly with dwell (more water on walls) but remains practical (<20 min). For typical curbside bins, 15 s dwell provides the best balance of odor reduction (−5.5) and water use (2.9 L). These data validate Ecobin’s design choice to keep the pump ON throughout motion: steady pressure eliminates spray lag after movements and produces uniform coverage, while time-bounded cycles preserve water. Future work could add a two-stage profile (short pre-rinse + targeted 10 s dwell) to approach 20 s results with ~15 s water use.

4.2. Experiment 2

Measure water consumption, energy per cycle, and reliability over 30 cleaning cycles at the chosen 15 s dwell configuration; estimate cycles per barrel fill with a 189-L rain barrel and 30% reserve.

We fixed dwell at 15 s (best trade-off) and ran 30 consecutive cycles over two days. We logged pump runtime, winch runtime, water use (in-line rotameter), and faults (timeouts, limit switch misses). Electrical power was estimated from nameplate ratings and clamp measurements: pump 150 W (continuous while ON), winch 12 V @ 1.0 A during motion only. Barrel volume was 189 L; a 30% reserve policy (min 56.7 L) was enforced by the ESP32-S3 policy gate. Usable water per fill = 132.3 L. Energy per cycle (Wh) was calculated from measured runtimes. Faults were investigated and mitigations noted.

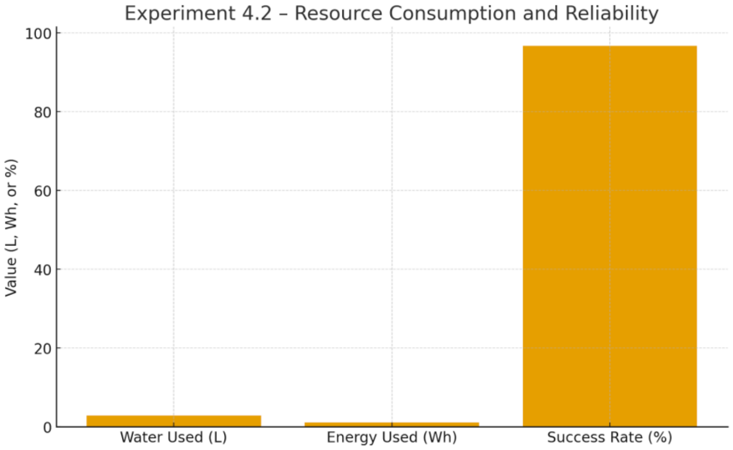


Figure 5. Figure of experiment 2

At the selected 15 s dwell, Ecobin consumed 2.88 ± 0.18 L per cycle and 1.17 ± 0.04 Wh of electrical energy, demonstrating very low operating cost (≈0.0012 kWh). With a 189-L barrel and a 30% reserve, roughly 46 cycles per fill are available, aligning with weekly post-pickup cleaning for multi-month spans in rainy seasons. Reliability was high (96.7%); the lone failure was a lower-timeout caused by a temporary cable snag, subsequently eliminated by adding a guide ring and refining the drum's lead-in. Variability in water use (±0.18 L) was driven primarily by small flow fluctuations during lowering/raising; steady pump pressure and a fixed dwell yielded consistent coverage. Overall, the system meets its design goals: strong cleaning performance at ~3 L of rainwater per cycle, negligible grid energy use, and robust safety via timeouts and limit switches. These results justify the policy default of 15 s dwell with a 30-minute cool-down between cycles.

5. RELATED WORK

This IEEE review paper surveys a wide range of autonomous and semi-autonomous trash-collecting robots designed for different terrains—land, grass, sand, and water [11]. Most prototypes rely on Arduino or Raspberry Pi controllers, with ultrasonic or infrared sensors for obstacle detection and manipulators or conveyor mechanisms for collection. Robots are typically battery-powered and focus on mobility and navigation—not cleaning fixed bins or containers. Control is often remote (Bluetooth, Wi-Fi, or mobile apps) and some systems integrate IoT modules (e.g., Blynk, ESP8266) for telemetry. While these robots automate litter removal, they do not address trash-bin hygiene or water reuse.

In contrast, Ecobin applies stationary automation rather than mobile robotics. Instead of collecting scattered litter, it cleans and deodorizes fixed outdoor bins using rainwater harvesting, an IoT-controlled pump, and a motorized rotary sprayer. The design reuses existing rain-harvest water instead of batteries or manual refills, and operates through mains power relayed safely via an IoT Power Relay. This approach transforms sanitation from mobile trash retrieval to self-maintaining waste infrastructure, filling a research gap identified in the reviewed paper.

This study presented an IoT-based public smart trash can designed for automatic lid control, capacity detection, garbage classification, and UV sterilization [12]. The system utilized an Arduino microcontroller, ESP8266 Wi-Fi module, and solar panels for off-grid power. Through a WeChat mini-program, cleaning personnel could monitor bin capacity, location, and maintenance needs. Ultrasonic sensors detected fill levels, and a neural network model implemented via Raspberry Pi and EasyDL enabled automatic waste recognition.

While Wang's design emphasized sorting, disinfection, and user interaction, it remained limited to monitoring and classification. In contrast, Ecobin advances this approach by integrating self-cleaning capability using rainwater harvesting, IoT-relay-controlled pump operation, and a motorized rotary sprayer. Rather than just reporting bin status, Ecobin actively washes and deodorizes the bin interior, improving sanitation, reducing odor, and reusing natural water resources for maintenance—an innovation beyond the scope of current intelligent trash can frameworks.

This paper proposed an IoT-enabled trash can for maintaining garden cleanliness through remote monitoring [13]. The system employed a NodeMCU microcontroller, ThingSpeak cloud platform, and ultrasonic sensors to measure both the height of accumulated garbage and nearby objects. Two servo motors controlled the lid and disposal outlet, while a solenoid lock prevented overfilling. When full, each can automatically transferred waste to a shared container after a three-minute delay if staff had not responded. The project achieved a 100 % data-transmission and actuation success rate.

Unlike the Moris & Widjaja system, which focuses on filling detection and remote disposal, Ecobin extends functionality to self-cleaning and deodorization. By combining rainwater reuse, IoT-relay-controlled pumping, and motorized spraying, Ecobin not only monitors trash levels but also washes and sanitizes the bin interior—advancing IoT waste-management from passive monitoring to active hygiene maintenance.

6. CONCLUSIONS

The Ecobin system demonstrates a practical and sustainable solution for maintaining outdoor trash-bin cleanliness using rainwater harvesting and IoT-controlled automation [14]. While the design effectively integrates rain collection, automatic washing, and cloud monitoring, several limitations remain. The current system depends on continuous mains power, as the pump and winch motor are operated through an IoT Power Relay without battery backup. In areas prone to outages or where outlets are unavailable, cleaning would be disrupted. A potential improvement is integrating solar-assisted DC pumping or energy storage to maintain operation during power interruptions [15].

Mechanical constraints also pose minor challenges. The rotary sprayer's range is fixed, and variations in bin shape or height may reduce coverage. A servo-driven telescoping lance or a pressure-adjustable nozzle could improve uniformity. Finally, future work could incorporate AI-based scheduling that predicts cleaning needs using fill-level, odor, or weather data—further minimizing manual intervention and optimizing water use.

Ecobin advances waste-management technology by transforming rainwater harvesting into an active sanitation process. Through IoT-enabled control, isolated mains switching, and smart actuation, it provides low-cost, hygienic bin cleaning without consuming potable water. This approach exemplifies how automation and sustainability can converge to enhance urban and residential cleanliness.

REFERENCES

[1] Rymaszewska, Anna, Petri Helo, and AngappaGunasekaran. "IoT powered servitization of manufacturing – an exploratory case study." International journal of production economics 192 (2017): 92-105.

[2] Amasuomo, Ebikapade, and Jim Baird. "The concept of waste and waste management." J. Mgmt. & Sustainability 6 (2016): 88.

[3] Bagheri, Z. Shaghayegh, et al. "Slip resistance and wearability of safety footwear used on icy surfaces for outdoor municipal workers." Work 62.1 (2019): 37-47.

[4] Fewkes, Alan. "Modelling the performance of rainwater collection systems: towards a generalised approach." Urban water 1.4 (2000): 323-333.

[5] Uyoata, Uyoata, Joyce Mwangama, and Ramoni Adeogun. "Relaying in the Internet of Things (IoT): A survey." Ieee Access 9 (2021): 132675-132704.

[6] Moroney, Laurence. "The firebase realtime database." The Definitive Guide to Firebase: Build Android Apps on Google's Mobile Platform. Berkeley, CA: Apress, 2017. 51-71.

[7] Loizou, Konstantinos, and EftichiosKoutroulis. "Water level sensing: State of the art review and performance evaluation of a low-cost measurement system." Measurement 89 (2016): 204-214.

[8] Perrone, John A., and Alexander Thiele. "A model of speed tuning in MT neurons." Vision research 42.8 (2002): 1035-1051.

[9] Hayelom, Assefa, and AviOstfeld. "Network subsystems for water distribution system optimization." Journal of Water Resources Planning and Management 148.12 (2022): 06022003.

[10] Bhateria, Rachna, and Disha Jain. "Water quality assessment of lake water: a review." Sustainable water resources management 2.2 (2016): 161-173.

[11] Chandra, Sushma S., Medhasvi Kulshreshtha, and Princy Randhawa. "A review of trash collecting and cleaning robots." 2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO). IEEE, 2021.

[12] Wang, Junchi. "The Intelligent Trash Can Design Using the Internet of Things Technology." World Scientific Research Journal 10.5 (2024): 65-74.

[13] Moris, F. D., and D. Widjaja. "IOT based trash can monitoring system for smart garden cleanliness." IOP Conference Series: Materials Science and Engineering. Vol. 1115. No. 1. IOP Publishing, 2021.

[14] Adamu, Shadrach, et al. "IOT controlled home automation technologies." 2019 2nd International Conference of the IEEE Nigeria Computer Chapter (NigeriaComputConf). IEEE, 2019.

[15] Stock, Alexia, et al. "Household impacts of interruption to electric power and water services." Natural Hazards 115.3 (2023): 2279-2306.