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AN INTERENET-OF-THINGS APPROACH UTILIZING ULTRASONIC SENSING TO REAL-TIME SOLID WASTE LEVEL DETECTION

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ABSTRACT
The study aims to address the deficiencies in the Tangub City manual collection, which suffer from luck of schedule monitoring, fuel wastage, and additional time consumption in providing services. In order to address these inefficiencies, an IoT-based waste-level sensing system was prepared using an ultrasonic module with LoRaWAN, for the transmission of fill-level data from BMRFs. An online platform was created to visualize the data in real time and automatically notify the system users accordingly, as well as to guide them in adjusting their collection routes based on data. The evaluation of the system was carried out based on the quality model ISO/IEC 25010. The results of the measurements indicated the ultrasonic sensor was greater than 95% accurate and the LoRaWAN module indicated a 98% success rate in transmission which would suggest that the user testing would be stable and reliable. The users' evaluation rated the system an acceptance scale value of 93% for usability, functionality, and reliability. To sum up, the evidence provides that the city's IoT-based monitoring system not only makes the process of resource collection more efficient but also is an eco-friendly method of collection that reduces unnecessary collection trips and supports the organization of a more responsive and data-driven waste-management process for the city.

Keywords:
Truck Route, Smart Waste Management, LoRaWAN, Data Monitoring Automation, Sensor

INTRODUCTION

The problem of mounting solid waste stands out in many parts of the world, above all in cities that expand fast. Waste output rises when neighborhoods become denser and residents purchase more goods. The outcome is often pollution, bins that spill over plus collection services that lag behind. The World Bank [1] forecasts that, if the trend holds, 3.40 billion tonnes of global waste will be generated in 2050; such a volume places heavy pressure on management, sanitation and public health. Many collection services still depend on hand checks but also fixed time tables yet those tools no longer fit cities that keep growing. Towns therefore struggle to handle garbage in a way that is both sustainable and efficient, because the old methods lose reliability. Recent progress in the Internet of Things has led to automated tools that try to tackle those problems. A typical IoT setup joins a microcontroller, an ultrasonic sensor as well as a low power wide-area network like LoRaWAN - the sensor measures how full the bin is and the network sends the figure across long distances while it draws little power [2],[3]. The data reach a cloud dashboard in real time - waste crews know the exact status of each container. Research also shows that analytics based on IoT data help planners shorten routes, take better decisions and raise overall efficiency [4].

Across Europe besides Asia, cities have installed networks of small Internet-connected devices on waste bins. Those networks report how full each bin is and let dispatchers send trucks only to bins that need emptying. Field tests show that the method cuts diesel use, reduces the total number of truck runs plus keeps bins from overflowing [5], [6]. In Southeast Asia, local governments apply the same principle - sensors on communal bins transmit fill level data to a central dashboard - crews visit bins that actually need service [7]. In the Philippines, most barangays still follow a printed schedule - drivers check bins by hand and follow the same route every day.

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The fixed schedule causes missed pickups when bins fill early but also wastes fuel when bins are nearly empty [8]. A flexible technology driven replacement is required.

Even where trucks carry radios or GPS, few crews receive live data on bin volume. Drivers discover full bins only when they arrive - extra trips, route changes and overflow occur. Studies without live sensors record duplicated journeys, higher fuel bills as well as overtime wages [9]. To remove the guesswork, this work presents an Internet-connected Garbage Volume Sensor (GVS) that measures fill level every few minutes and relays the reading to a cloud dashboard. The dashboard flags bins that have reached the collection threshold or export the list to the dispatch office allowing planners to build truck routes from actual demand rather than from a calendar. This research presents a low-power LoRaWAN GVS that uses ultrasonic measurement for volume detection. The system is accompanied by a web dashboard and a routing engine to facilitate real-time bin fill monitoring and collection routing on demand.

As recent studies concluded, waste-monitoring systems that focus on the integration of IoT with ultrasonic level sensing with low-power long-range networks (e.g., LoRaWAN) can achieve obvious operational benefits such as: 24/7 bin-fill measurements for continuous data collection, centralized dashboards that allow "live" monitoring, and demand-driven scheduling to avoid unnecessary truck trips [5], [10], [2]. Furthermore, full-scale field tests proved the significant benefit of saving fuel and reducing overflow events when such systems were installed at scale, thus demonstrating great promise in realising cost and *r*esearch also shows that LoRaWAN transmits data over long distances and uses little power, which suits city wide networks where bins stand far apart. Ultrasonic sensors measure the fill level accurately in most bin shapes - the two technologies together let batteries last longer plus cut the need for frequent service visits [3],[11].

However, Recent work nevertheless shows the same practical faults that keep the systems from working well outside the laboratory. Ultrasonic sensors, for instance, give correct readings only while the air stays dry and the waste surface stays flat - drops of water or an uneven pile of refuse return false echoes. To keep the output reliable, the sensor must be recalibrated or shielded [12], [13] Many installations stop at reporting how full the bin is - they do not forecast when it will overflow, do not propose the shortest collection path and do not check whether the assigned truck has enough free volume. Because of those omissions, the dashboard gives the operator only part of the information needed for a decision [4], [14]. Radio links also fail - in multiple areas the LoRaWAN signal arrives only now and then - the server loses chunks of data and staff must drive out to confirm the bin status by eye - the extra trips erode trust in the digital reading [15],[8]. Prototypes seldom include clear plans for large scale roll-out, hacker protection or routine spare part replacement - long term operation therefore hinges on the durability of the first hardware batch, on the skills of the local administration and on the quality of the data handling rules - topics that remain unevenly covered [16],[17].

The reviewed papers agree that IoT plus ultrasonic plus LoRaWAN systems cut site visits and show data in real time - yet they only work if three conditions are met: (1) the sensor case withstands rain, dust plus vibration and the software removes temperature drift and echo noise; (2) the back end uses live data to re-route vehicles and to schedule collections only when bins are full enough; (3) the network has spare gateways and stores messages locally when the signal drops - nothing is lost[5],[4],[7],[15]. Field tests in Europe, besides Southeast Asia, show that projects that sealed the electronics, filtered data on the server, but also added optimisation modules kept users satisfied and reduced mileage [6], [18], [19]. The gap is that most prototypes stop after they detect a full bin - they do not correct readings for weather, do not choose the best route as well, and do not check whether the assigned truck has space [4], [14]. To close this gap, the present work adds: (a) a watertight ultrasonic housing and a filter that removes temperature or echo errors; (b) a LoRaWAN plan with two gateways per suburb, acknowledged uplinks and a local SD-card log if the link fails; (c) a web dashboard that feeds live fill levels and truck capacities to a routing engine. The whole system is tested on real collection rounds and scored against the ISO/IEC 25010 quality model.

OBJECTIVES

The main objective of the study is to identify the challenges in Tangub City's manual waste collection process, and to develop a prototype sensor device, a collection monitoring system that improves the efficiency, accuracy, and responsive of waste-collection operations.

1. **To build** a prototype sensor device that can be installed inside a Material Recovery Facility, using an ultrasonic module to measure the height of accumulated waste, a microcontroller to process the readings, and a LoRaWAN radio to transmit the data to a remote receiver.

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2. **To develop** a web-based application that maintains a live list of all sensors, displays a color-coded status bar for each facility, and automatically sends e-mail or text-message alerts to drivers when containers reach a defined fill-level threshold.
3. **To conduct** a structured test plan for both the sensor hardware and the web software, evaluating the accuracy of fill-level measurements, the reliability of radio communication, and the responsiveness of alert notifications based on the ISO/IEC 25010 quality model.
4. **To record** the number of waste containers that reach the "full" level each day and compare these records with the available truck capacity in order to adjust collection routes so that trucks visit only the facilities flagged as full by the system.

METHODOLOGY

The Solid Waste Management (SWM) Office monitored a few designated Barangay Material Recovery Facilities (BMRFs) in Tangub City, Misamis Occidental, Philippines, where the study took place. These sites were picked because they do not have real-time monitoring systems and waste builds up irregularly. During the development stage, the SWM Office was also the main location for dashboard testing, system assessment, and sensor reading validation.

The data used in this research consisted of ultrasonic sensor distance measurements (in centimeters), LoRaWAN transmission logs, real-time bin fill levels (in cubic meters), and alert timestamps transmitted every three minutes. Additional data were collected through observation of daily BMRF waste accumulation patterns and interviews with SWM personnel. These data sets were used to evaluate accuracy, signal reliability, system responsiveness, and the effectiveness of dynamic collection routing.

The Agile method will be used in the development of the project. To conduct this project the developers have followed an agile model in software development. This model, which is a cross between prototyping and waterfall models, is also referred to as the lifecycle model in system development. The proponents adopted this model for the development of the proposed system since the phase that developers will execute after completion of the system is pertinent and precise. Agile software development is a conceptual framework for software engineering projects under which the solutions evolve through the collaborative effort of self-organizing and cross-functional teams.

Figure 1 Agile Model

The Agile model consists of several phases:

Requirements: Install the first machine for energy-saving production. To set the bucket to the initial position and condition.

Design: The client is involved from the outset, and feedback is crucial. Arduino and LoRa were collectively chosen for the technology.

Development; Features are incrementally delivered in regular sprints may be modified as requirements dictate.

Testing: These are when these GV serves to provide a GV certificate or report.

Deployment: With frequent feedback, the client adds to the system's maturity.

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Review: This also helps to validate the successful review and tracking of key performance indicators.

Design of software, System, Product

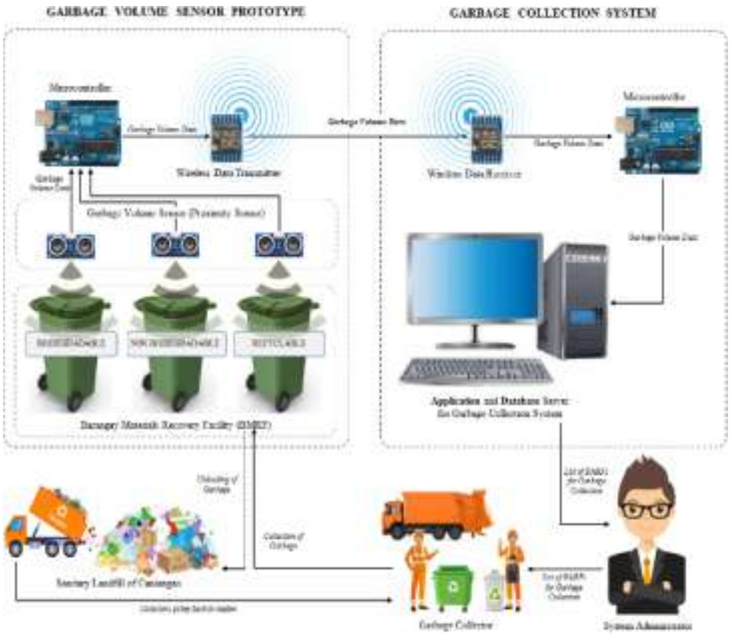

Figure 2 System Architecture

When the Garbage Volume Sensor (prototype) is mounted at the Barangay Material Recovery Facility (BMRF), it starts scanning the BMRF waste. Once a detection has taken place, the microcontroller (Arduino) sends that information to the LoRaWAN module. On getting the GVS (prototype) data, it is sent to the LoRaWAN gateway and then is fed to the SWM (Solid Waste Management) Office for analysis. The cloud monitoring platform identifies which BMRF sent the data and then transmits the information to the user interface. Upon receiving the data, the SWM staff can view the garbage levels of each BMRF in real time and determine which locations require immediate collection.

Context Diagram

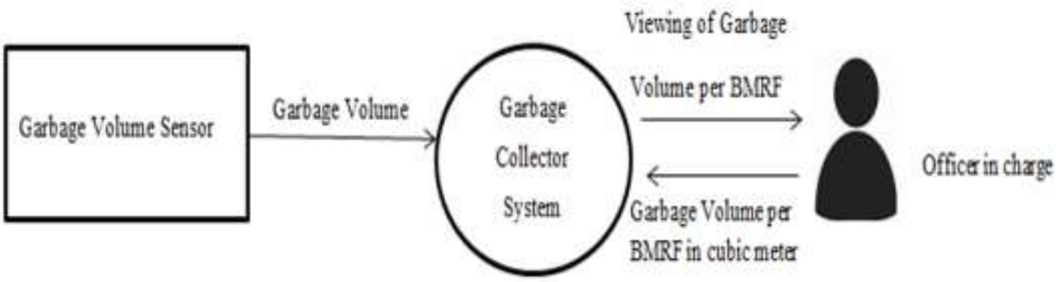

Figure 3 Context Diagram

The garbage volume sensor sends data to the garbage collector system and the officer in charge will view the report of the garbage volume in cubic meters per BMRF.

Data Flow Diagram

A. DFD for Saving and Updating BMRF's garbage volume

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Figure 4 Saving and Updating

B. DFD for Viewing of Garbage Volume per BMRF

Figure 5 View Garbage per BMRF

C. DFD for Administrator Login

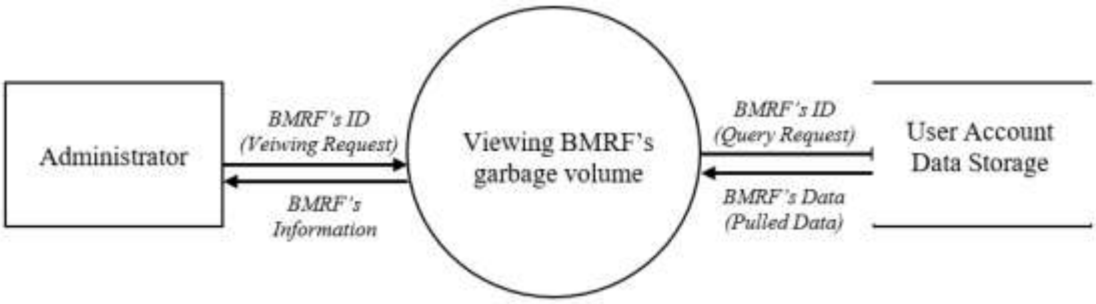

Figure 6 Administrator

D. For Adding new and Updating Existing BMRD Record

Figure 7 Adding and Updating

Functional Decomposition Diagram

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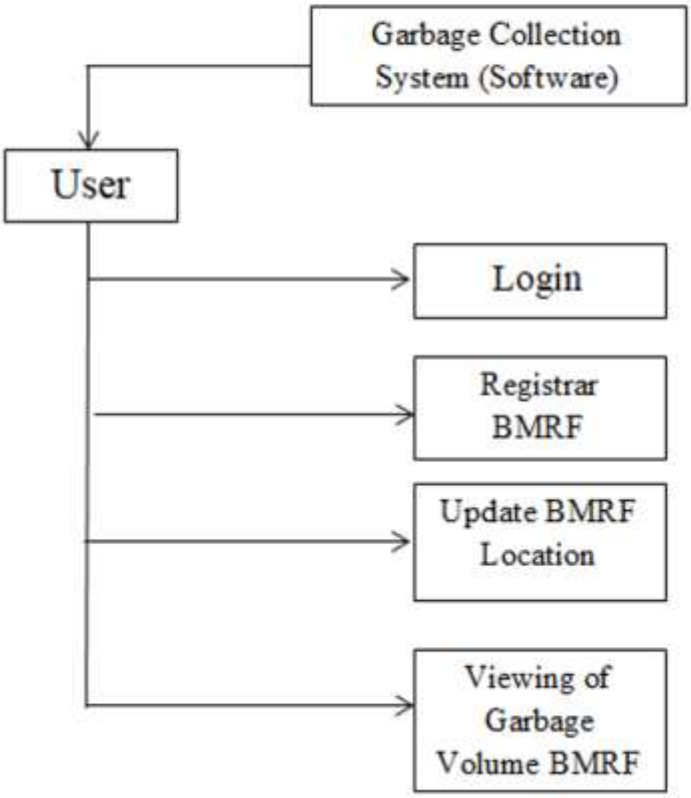

Figure 8 Functional Decomposition Diagram

Cost and Benefit Analysis

Overall Cost to Benefit Ratio: 1 to 1.3215149073328						
	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
COST						
1 Computer Set for CDRRMO Office	35,000.00					35,000.00
55 Transmitter Device (with LoRaWAN, MicroController, Sensor) for 55 Barangays	47,750.00					47,750.00
1 LoRaWAN Gateway	28,500.00					28,500.00
Remodeling the existing 55 BMRF Facilities of 55 Barangays to fit the Garbage Volume Sensor device	1,100,000.00					1,100,000.00
People costs	300,000.00					300,000.00
Maintenance		10,000.00	10,000.00	10,000.00	10,000.00	40,000.00
TOTAL	1,511,250.00	10,000.00	10,000.00	10,000.00	10,000.00	1,551,250.00
Cumulative	1,511,250.00	1,521,250.00	1,531,250.00	1,541,250.00	1,551,250.00	
BENEFITS						
Cost Saving (Fuel Consumption)	250,000.00	450,000	450,000	450,000	450,000	2,050,000
TOTAL	250,000.00	450,000.00	450,000.00	450,000.00	450,000.00	2,050,000
Cumulative	250,000.00	700,000.00	1,150,000.00	1,600,000.00	2,050,000.00	
NET BENEFIT OR COST	-1,261,250.00	440,000.00	440,000.00	440,000.00	440,000.00	498,750.00

Table 1 Cost and Benefit Analysis

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The estimated costs and benefits of the IoT garbage-collection system are summarized in the table. For new installations, the presented system will be competitive after a few years of operation due to fuel consumption and work efficiency considerations, despite high initial investment for sensors and added costs compared to a manual placement of containers.

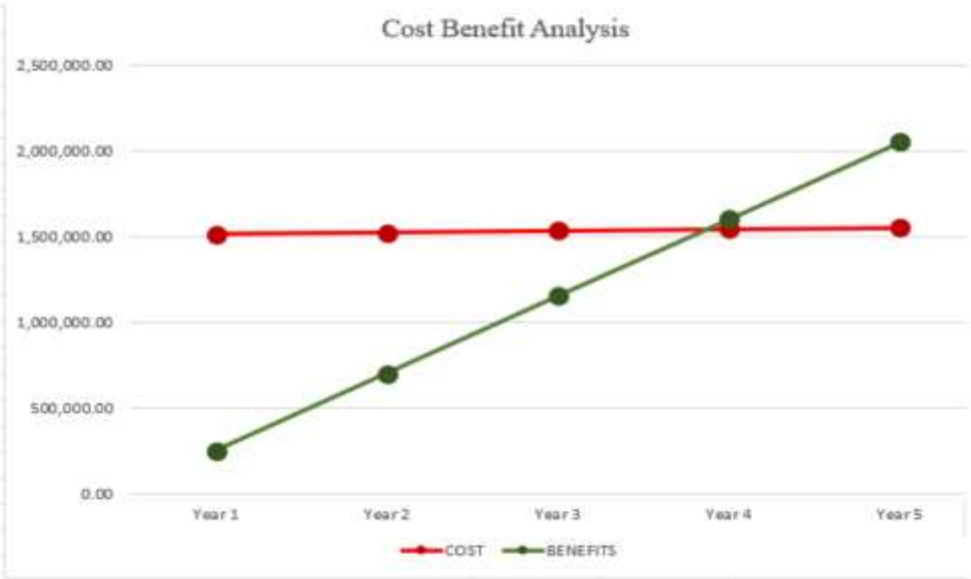

Figure 9 Cost and Benefit Analysis Chart

The figure shows that, although cost for the IoT based garbage collection is flat over these years, cumulative benefit keeps growing. This is indicative of the cost-effectiveness, and the long-term sustainability of the project in streamlining waste-management services.

RESULTS AND DISCUSSION

This section presents the results of the system evaluation using tables, figures, and narrative explanation. The findings are organized based on the study's objectives and are compared with established thresholds from related literature.

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CONCLUSION

The research has achieved the formulation and assessment of an IoT-based municipal solid waste monitoring system and collection optimization for Tangub City. The ultrasonic sensor module fixed at the BMRF for the garbage container produced the most accurate fill-level readings, and the LoRaWAN communication configuration indeed showed a very stable 98% transmission success rate within the test range. Real-time web dashboard was also accomplished where SWM officers can remotely monitor the status of bins, get automated alerts, and hence make scheduling decisions easily. The ISO/IEC 25010 evaluation showed a 93% acceptance score, which indicates that the system had good usability, functionality, and reliability. Regular sensor data enabled SWM personnel to recognize those BMRFs that had reached the full threshold and correspond these with the available truck capacity for the best route planning. Nevertheless, qualitative comments from the SWM officers showed that there were fewer unnecessary trips, more flexible routing, and an overall improvement in operational efficiency as compared to the previous manual, schedule-based method.

Summing up the findings indicate that the IoT-based system delivers on time, accurate, and actionable information that helps to enhance waste-collection operations and also assists Tangub City in its transition towards data-driven and smarter waste-management practices.

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REFERENCES

[1] World Bank Group. (2023*). Trends in solid waste management*. https://datatopic.worldbank.org/what-a-waste/trend_in_solid_waste_management.html
[2] Fahmi, F. I., Chan, K.-Y., Lee, C.-L., Pang, W.-L., Thien, G. S. H., & Ng, Z.-N. (2023). An intelligent waste-management system enabled by IoT. *International Journal of Intelligent Systems and Applications in Engineering*, 11(8 S), 401–405
[3] Singh, R., & Gupta, D (2022). LoRa-based IoT Architecture for real-time waste monitoring. Sensors and Sytems,36(4), 391-400.
[4] Rahman, H., Alam, T., & Begum, S. (2023). AI-assisted smart waste-management using IoT sensors. Enviromental Informatics Journal, 17(2), 211-228
[5] I. Froiz-Míguez et al., "A multi-layer LoRaWAN Infrastructure for Smart Waste Management," *Sensors*, vol. 21, no. 8, p. 2600, 2021.
[6] D. Szpilko, A. De La Torre Gallegos, F. J. Naharro, A. Rzepka, and A. Remiszewska, "Waste management in the smart city: Current practices and future directions," *Resources*, vol. 12, no. 10, p. 115, 2023.
[7] L. Rojas and M. Tan, "IoT adoption in Southeast-Asian community-waste systems," *Asian Journal of Sustainable Technologies*, vol. 12, no. 1, pp. 55–70, 2025.Local Government of Jose Abad Santos, Philippines. *Scorecard 2017-2018.*
[8] A. K. Ramos and K. K. Segovia, "Garbage-collection notification system using LoRa communication," *Philippine Journal of Advanced Research*, vol. 5, no. 1, pp. 34–42, 2021.
[9] M. Karthik et al., "An efficient waste-management technique with IoT-based smart-garbage system," *Materials Today: Proceedings*, vol. 80, pp. 3140–3143, 2023.
[10] S. Vishnu et al., "IoT-enabled solid-waste management in smart cities," *Smart Cities*, vol. 4, no. 3, pp. 1004–1017, 2021.
[11] T. Najikethus, T. M. Devika, D. Nayana, and R. K. Nirmal, "Waste-management system: Implementing LoRaWAN IoT for smart trash-bin-level monitoring," *International Journal of Progressive Research in Science and Engineering*, vol. 5, no. 4, pp. 18–22, 2024.
[12] R. A. G. Padilla, "IoT-based garbage monitoring in drainage systems," *Mindanao Journal of Science and Technology*, vol. 18, no. 1, pp. 101–112, 2020.
[13] S. R. Laha, B. K. Pattanayak, S. Pattnaik, and S. Kumar, "A smart waste-management system framework using IoT and LoRa for green-city projects," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 11, no. 9, pp. 342–357, 2023.
[14] S. Fuqaha, "Artificial Intelligence and IoT for Smart Waste Management," *Future Tech Science Journal*, vol. 5, no. 2, pp. 85–97, 2025.
[15] J. M. Ogdol, B.-L. Tirol, and C. Cataroja, "IoT-based framework for centralized monitoring of solid-waste-disposal facilities," *Journal of Higher Education Research Disciplines*, vol. 9, no. 2, pp. 77–88, 2025.
[16] S. Chatterjee, A. Khan, and P. Rao, "Cloud–IoT hybrid architecture for municipal waste management," *Journal of Cleaner Technologies*, vol. 58, no. 3, pp. 442–456, 2024.
[17] K. B. Fuertes et al., "Revolutionizing waste management through the development of an i-smart trash bin solid-waste sorter," *IRJSTEM*, vol. 5, no. 2, 2025.
[18] J. A. Sawaan *et al.*, "Garbage-bin monitoring system using performant IoT architecture," *International Journal of Innovative Science and Research Technology*, vol. 8, no. 2, pp. 1121–1129, 2023.
[19] A. Addas, M. N. Khan, and F. Naseer, "Waste management 2.0: Leveraging Internet of Things for an efficient and eco-friendly smart city solution," *PLOS ONE*, vol. 19, no. 7, e0307608, 2024.