EMITOR: Jurnal Teknik Elektro

LoRaWAN-Based Automated Waste Bin Monitoring System Using the Antares Platform

Muhamad Cahyo A. P.*, Sri Kusumastuti, Supriyati, Atikah A J, Erie Rosita C., Muhammad A. Santoso
Teknik Elektro – Politeknik Negeri Semarang
Semarang, Indonesia
*m.cahyoardi.p@polines.ac.id

Abstract – *The system aims at enhancing urban waste management by monitoring garbage bin status in real time using cloud-based visualization. The prototype uses ultrasonic sensors (JSN-SR04T) to measure waste levels, limit switches to check whether the bin's lid is open or closed, and the LoRa RFM95W module for low-power long-range wireless communication. Antares is the cloud interface for dashboard integration and logging of data. Performance testing under varying conditions of environment shows a success rate of 68% in data transmission, with a failure rate of 32%, mainly due to electromagnetic interference. The ultrasonic sensor gave an average error rate of 5–9% in the determination of bin fullness, while the INA219 sensor gave stable power monitoring during standby as well as operational condition. LoRaWAN connectivity proved to be effective to a distance of 7.3 km with stable SNR and RSSI values near the gateway. This system provides an energy-efficient and scalable solution, making it well-suited for smart cities particularly in areas with limited network coverage. The integration of Antares with LoRaWAN not only facilitates real-time data visualization but also enhances decision-making capabilities in decentralized environments. The modular and low-cost design of this prototype further enables easy replication and customization for different urban infrastructure scenarios. Future improvements could focus on enhancing transmission reliability and sensor accuracy to facilitate broader adoption.*

Keywords – *IoT; smart waste management; LoRaWAN; Antares platform; real-time monitoring.*

I. Introduction

WASTE management issues in urban areas of Indonesia are becoming increasingly complex due to high rates of urbanization and population growth. Waste collection systems that still rely on fixed schedules without considering the actual capacity of waste bins often result in waste accumulation, environmental pollution, and increased risk of disease transmission [1, 2]. This inefficiency is further exacerbated by the lack of adaptive systems based on real-time conditions that can accurately respond to the dynamics of waste volume [3].

Internet of Things (IoT) technology offers potential solutions for data-driven environmental management. By utilizing sensors, microcontrollers, and wireless communication, IoT enables automatic, efficient, and real-time monitoring of waste bin conditions [4, 5]. However, various studies that have developed IoT-based monitoring systems generally still use GSM or Wi-Fi networks, which have limitations in terms of range and power consumption [6, 7]. This poses a challenge when the system needs to be implemented widely in complex and dense urban environments [8]. Studies have developed IoT-based systems using sensors, microcontrollers, and wireless communication for real-time monitoring of waste bin levels [9, 10]. These systems offer advantages over traditional fixed-route collection methods, enabling more efficient and adaptive waste management [11]. While some solutions utilize GSM or Wi-Fi networks, newer approaches leverage LoRaWAN technology for long-range, low-power communication [12, 13]. IoT-enabled waste management systems have shown significant improvements in route efficiency, fuel consumption, and overall sustainability [11]. However, challenges remain, including sensing accuracy in various weather conditions and potential security vulnerabilities [14]. Ongoing research focuses on developing hybrid architectures integrating edge and cloud computing for enhanced real-time capabilities and decision support [15, 16].

As a solution to these challenges, LoRaWAN (Long Range Wide Area Network) has emerged as a

The manuscript was received on June 17, 2025, revised on August 26, 2025, and published online on November 28, 2025. Emitor is a Journal of Electrical Engineering at Universitas Muhammadiyah Surakarta with ISSN (Print) 1411 – 8890 and ISSN (Online) 2541 – 4518, holding Sinta 3 accreditation. It is accessible at https://journals2.ums.ac.id/index.php/emitor/index.

superior wireless communication alternative in terms of wide coverage and energy efficiency [17, 18]. Empirical studies show that the implementation of LoRa in waste monitoring systems can extend sensor lifespan, reduce maintenance requirements, and improve data collection efficiency [19]. However, the use of LoRaWAN in Indonesia remains limited and has not yet been widely adopted in integrated waste management systems [20].

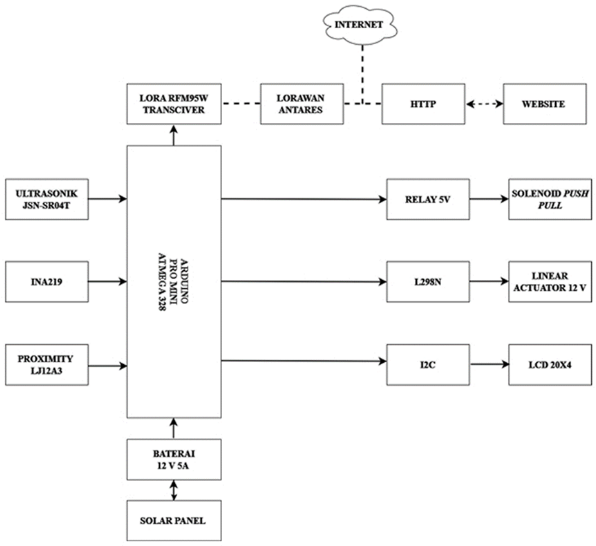


Figure 1: Block diagram of the system

Meanwhile, the Antares platform—a local product from Telkom Indonesia—provides cloud services for IoT device connectivity and an interactive visual dashboard interface [4, 21]. Several studies have tested Antares' performance in various applications, such as energy and environmental monitoring, with results showing its effectiveness in supporting real-time decision making [18, 22]. However, the integration of Antares with the LoRaWAN protocol specifically in waste monitoring systems is still rarely found in the literature [19, 23].

Based on this introduction, this research aims to design and develop an automatic waste bin monitoring system based on LoRaWAN and the Antares platform. This system will monitor waste levels and detect the status of waste bin lids in real time to improve waste management efficiency in urban areas [21, 24]. The main innovation of this research lies in the integration of both technologies into a single system that is energy efficient, has a wide range, and is easy to replicate to support the development of a smart city concept that is in line with local characteristics in Indonesia [5, 22].

These systems employ sensors to monitor bin fill levels and waste types in real-time [25–27]. LoRaWAN enables long-range, low-power data transmission from bins to gateways and cloud platforms for analysis [10, 16]. Advanced features include route optimiza-

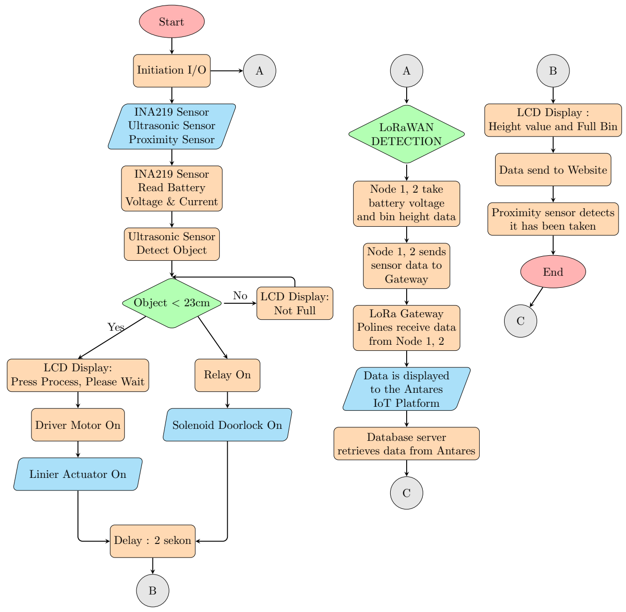


Figure 2: Flowchart of the system

tion algorithms, GPS tracking, and waste classification using deep learning models [11, 28]. Implementation of such systems has shown significant improvements in operational efficiency, cost reduction, and environmental impact [11]. The integration of IoT and ICT in waste management is crucial for developing smart, sustainable cities, with potential applications in Indonesia's new capital, Nusantara [29]. These innovations aim to revolutionize waste management practices and contribute to long-term urban sustainability goals.

II. Research Methods

i. System Block Diagram

The proposed system (Figure 1) is an autonomous control system based on the Arduino Pro Mini (ATmega328) microcontroller. The system integrates sensors, actuators, communication modules, as detailed below:

1. **Power Supply**
   The system utilizes solar panels coupled with a 12V 5A battery for off-grid operation, with the INA219 sensor monitoring voltage and current to ensure efficient energy utilization.
2. **Sensors**
   The system integrates three specialized sensors, a JSN-SR04T ultrasonic sensor for proximity measurement, an LJ12A3 inductive sensor for metal detection, and an INA219 module for real-time battery/load monitoring.
3. **Actuators**
   The actuation system combines a 5V relay-controlled push-pull solenoid for mechanical ac-

tions with a 12V linear actuator driven by an L298N motor driver for precise displacement control.

4. **User Interface & Communication**
   A dual-interface approach combines local visualization (20×4 I2C LCD) with remote monitoring through LoRa RFM95W transmission to Antares LoRaWAN, enabling web-based real-time data access via HTTP protocol.

The system executes a continuous real-time workflow: sensor data acquisition (distance, metal detection, power monitoring) → Arduino-based decision processing → simultaneous physical actuation (solenoid/linear actuator) and multi-channel data presentation (local LCD display and cloud-based remote monitoring via LoRa transmission).

ii. Flowchart of the System

Figure 2 illustrates the sequence of system processes that include steps starting from system initialization, reading data from sensors, to sending information to the Antares platform and displaying data on the website. The system begins with variable initialization, libraries, input-output settings, and LoRa communication. After that, the Arduino Pro Mini processes the data received from the INA219 sensor, LJ12A3 proximity sensor, and JSN-SR04 ultrasonic sensor.

The INA219 sensor functions to monitor battery voltage and send the data to the website. When the ultrasonic sensor detects that the height of the trash can reaches 23 cm, the system will activate the motor driver to move the linear actuator and relay to control the solenoid door lock, accompanied by the display of the message *"Press Process, Please Wait"* on the LCD screen. The pressing process will be carried out three times, and if the trash can is still detected as full, the LCD will display the message *"Trash Full"*. After the trash is emptied, the proximity sensor will reset the system. All data obtained from this sensor is then sent via the LoRa network to the Antares platform and displayed on the website using the HTTP protocol.

iii. Mechanical System Design

The mechanical construction of this tool can be seen in Figure 3. The frame of the trash can is made of iron, while the frame cover uses PVC. The overall dimensions of this tool are 63 cm long, 45 cm wide, and 145 cm high, with the dimensions of the inside of the trash can being 40 cm long, 36 cm wide, and 80 cm high.

According to previous studies, the mechanical design of the proposed system presents a distinct approach compared to existing models. Whereas prior

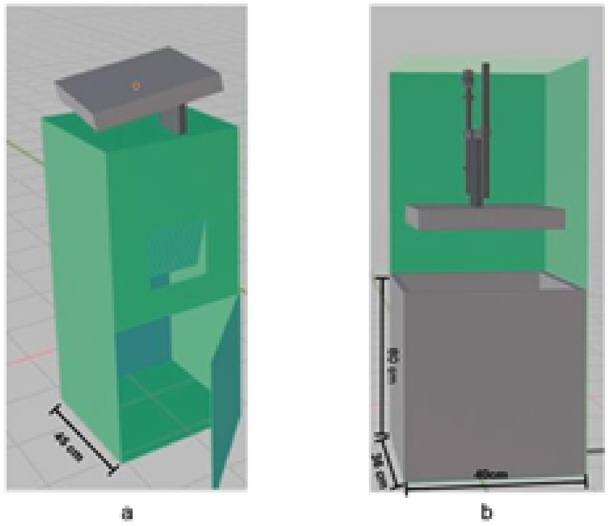
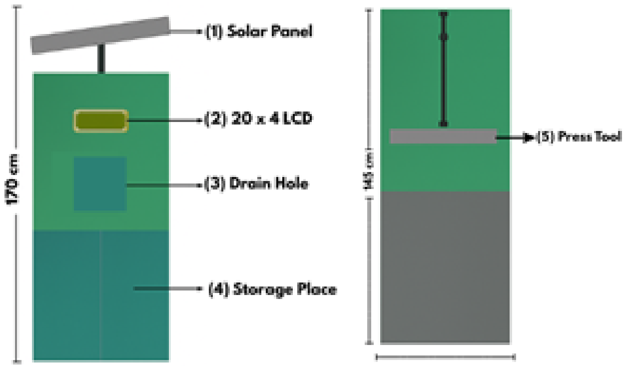


Figure 3: System Mechanical Design



(a) Component Layout A **(b)** Component Layout B

Figure 4: Component Layout of the Smart Bin System

developments primarily focus on lid actuation mechanisms or waste categorization, the system introduced in this research is specifically designed to respond to conditions when the trash bin reaches its full capacity [30, 31]. Recent research in mechanical design has explored innovative approaches across various domains. In rehabilitation, exoskeletons for lower extremities have been developed with multiple degrees of freedom and lightweight materials to enhance mobility [32]. Novel robotic designs, such as a three-legged omnidirectional robot, have been proposed to achieve compact and lightweight structures [33]. Artificial intelligence has been applied to mechanical part design, generating optimized solutions that meet multiple criteria [34]. Model consistency between lumped and distributed parameter models has been addressed using model order reduction techniques [35]. Mechatronic design models have been analyzed to improve product quality and performance [36]. Optimization algorithms have been employed to enhance the design of mechanical components [37]. Additionally, graph neural networks have been utilized for reverse design of mechanical systems, bridging trajectory and mechanical design [38].

The main components of this tool are designed to support optimal system functionality. Some of the main components in this tool include: Figure 4.a (1) Solar Panel, which functions to capture solar energy and convert it into electrical energy to operate the system; (2) 20x4 LCD, which is used to display information on the operational status of the trash can, such as the pressing process or the detected trash capacity; (3) Drain Hole, which functions as a channel to dispose of trash that has been filled; (4) Storage Place, which is a place to store trash before further processing; and Figure 4.b (5) Press Tool, which is used to press trash if the trash can is full, in order to optimize the storage capacity. With these components, the system can function automatically in monitoring and managing waste efficiently.

III. Results and Discussion

i. Implementation of Design and Construction

This automatic trash bin monitoring system is designed using LoRaWAN technology and the Antares platform. The JSN-SR04T ultrasonic sensor is used to measure the height of the trash, while the INA219 sensor monitors the battery voltage and current. An LJ12A3 proximity sensor is also installed to detect the trash emptying process as a reset signal. All data from the sensors is processed by the Arduino Pro Mini which then controls the linear actuator to press the trash, as well as the push-pull solenoid which functions as an automatic lock when the trash bin is full. The collected data is sent via the LoRa RFM95 module to Antares, so that the status can be monitored via the website.

ii. Testing of JSN-SR04T Ultrasonic Sensor

Sensor testing was carried out on a trash can with a height of 80 cm using an ultrasonic sensor. This sensor has limited accuracy to detect distances below 20 cm. During the testing process, the sensor gets power from an external battery. In the designed tool, the sensor provides output at a measurement range of less than 23 cm. The data displayed on the LCD is in the form of a percentage, with a value of 20 cm representing 100% and 87 cm representing 0%.

Based on the tests listed in Table 1, if the sensor reads a distance of more than 23 cm, the press tool will not be active. Conversely, when the sensor detects a distance of 20 cm or less, the press tool will operate. However, for distances detected below 20 cm, the display on the LCD still shows a value of 19 cm. Literature on comparable implementations of ultrasonic sensors

Table 1: JSN-SR04T Ultrasonic Sensor Testing

No	Actual Height (cm)	Sensor Height (cm)	Sensor Percentage (%)	Error (%)
1	90	85	3	5.55
2	80	75	18	6.25
3	70	66	32	5.71
4	60	57	45	5.00
5	50	47	60	6.00
6	40	37	75	7.50
7	30	28	89	6.66
8	20	19	0	5.00
9	10	19	0	9.00
10	5	19	0	28.00

indicates that sensors of this type typically exhibit a measurement error ranging from 5% to 10% [39].

iii. INA219 Sensor Testing

Table 2: INA219 Sensor Testing

No	Date	Time	V Battery Standby (V)	Battery Consumption (V)
1	14–15 Aug 2023	14:32–14:34	12.60–11.85	0.75
2	16 Aug 2023	17:01–21:00	12.67–12.47	0.20
3	17 Aug 2023	07:32–15:14	11.85–13.28	1.43
		16:02	–	–
		17:00–21:02	13.17–12.88	0.29

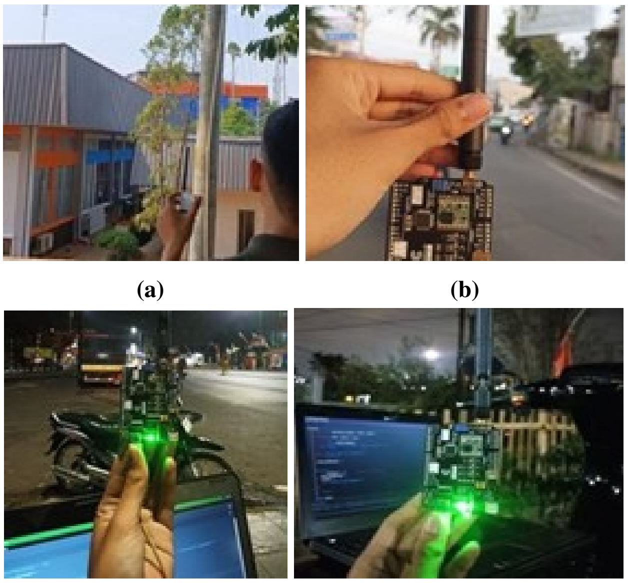
The INA219 sensor measurement aims to monitor the battery voltage before and after being loaded. The measurement process begins by preparing the INA219 sensor and connecting it to a 12V battery voltage source. Furthermore, observations are made by monitoring the voltage through the Solar Cell Controller. After that, the measurement results are recorded and summarized in Table 2 for further analysis.

iv. LORA Testing

Table 3: RFM95 LoRa Measurement

No	SNR (dB)	RSSI (dBm)	Distance (Km)	Gateway Point
1	-3.8	-106	0.13	Gedung Magister Terapan POLINES – Lapangan Hijau Polines
2	-10.8	-114	0.56	Gedung Magister Terapan POLINES – Jl. KH. Sirojudin
3	-8.5	-119	6.7	Gedung Magister Terapan POLINES – Taman Unyil Ungaran
4	-0.5	-107	7.3	Gedung Magister Terapan POLINES – Jl. Untung Suropati Manyaran

Table 3 presents measurements of the performance of the LoRa communication system to ensure smooth data exchange between two devices in the smart trash system. The measurements were carried out using a LoRa module operating at 922 MHz and a Bandwidth of 125 kHz. The parameters that are the focus of data collection are the Signal-to-Noise Ratio (SNR) and the Received Signal Strength Indicator (RSSI). Measurement data was taken through the Antares platform and analyzed to assess the communication performance.



(a) (b) (c) (d)

Figure 5: LORA RFM95 Testing Locations (a) Lapangan Hijau POLINES (b) Jl. KH. Sirojudin (c) Taman Unyil Ungaran (d) Jl. Untung Suropati Manyaran.

(a)
```
{
  "type": "uplink",
  "port": 1,
  "data": {
    "persentase": 96,
    "volume": 32,
    "status": 1
```
(b)
```
{
  "type": "uplink",
  "port": 1,
  "data": {
    "persentase": 85,
    "volume": 47,
    "status": 1
```
(c)
```
  "type": "uplink",
  "port": 1,
  "data": {
    "persentase": 85,
    "volume": 62,
    "status": 1
```
(d)
```
  "type": "uplink",
  "port": 1,
  "data": {
    "persentase": 90,
    "volume": 62,
    "status": 1
```


Figure 6: Data Transmission Results from LoRa to Antares (a - d) Data Sent Successfully

Figure 6 shows the results of successful data transmission from the LoRa device to the Antares platform. At this testing stage, the data transmission process was carried out from several different locations that were still within the range of the LoRa signal. Each test point was selected to test how effective and stable the LoRa connection was in sending data to Antares under various environmental conditions and distances. The test results showed that the data could be received well on Antares, indicating that the transmission system was running smoothly in the tested areas.

After collecting data from the LoRa network test

Figure 7: Network Mapping: Data Transmission from LoRaWAN to LoRa Gateway

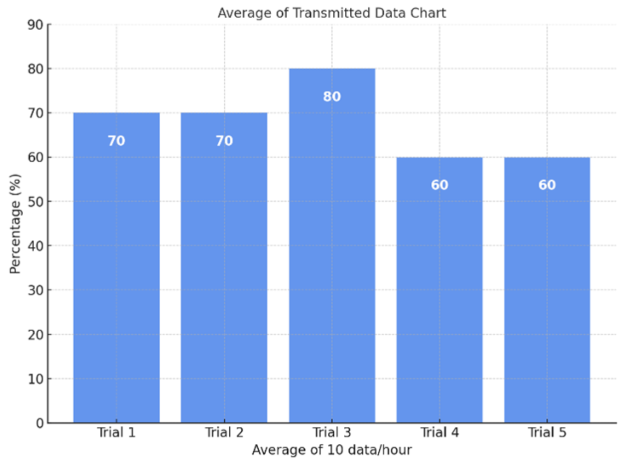


Figure 8: LoRa Transmission Data Graph

results, a network mapping was obtained as shown in Figure 7. Based on these results, it can be concluded that the closer the device is to the LoRa gateway, the higher the Signal to Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI) values. This shows that the signal quality improves as the distance between the device and the gateway decreases. The SNR and RSSI values are influenced by several factors, including the distance the signal travels and the presence of physical interference that can disrupt the stability of data transmission, such as building barriers, vegetation, or interference from other electronic devices. However, it is important to note that the transmission evaluation in this study is limited to SNR and RSSI metrics, without including other key performance indicators such as latency, packet delivery ratio, or time-series data reliability. This limits the comprehensiveness of the system performance assessment and highlights the need for more in-depth communication analysis in future studies.

In the second observation which focused on the data transmission process from the LoRa device to the Antares platform, the results obtained were then visualized in Figure 8. From these observations, it can be concluded that the success rate of data transmission within a time span of one hour was recorded at 68%, while the failure rate of data transmission reached 32%. Data is sent in real time every hour. However, the presence of electromagnetic interference, especially from WiFi devices around the test area, is one of the main causes of failure in data transmission. This interference can cause data packet loss or delay in data reception at the Antares server. Therefore, in implementing a LoRa-based system in a dense wireless device environment, it is necessary to consider these electromagnetic interference factors to minimize the failure rate of data communication.

IV. Conclusion

The LoRaWAN-based automatic waste bin monitoring system developed in this study demonstrates reliable performance and is considered feasible for practical implementation. It successfully monitors waste bin conditions in real time, with a data transmission success rate of 68%. However, a 32% failure rate remains, primarily caused by electromagnetic interference, especially from nearby WiFi devices. The study confirms that the quality of LoRa communication is significantly affected by device-to-gateway distance and environmental interference. The closer the proximity to the gateway, the better the Signal-to-Noise Ratio (SNR) and Received Signal Strength Indicator (RSSI), resulting in more stable communication.

The main contribution of this research is the development of an energy-efficient, long-range automatic waste monitoring prototype using LoRaWAN technology, integrated with the Antares platform for real-time data management. Furthermore, the study offers critical insights into communication challenges, including the effects of distance and electromagnetic interference, which are essential for optimizing smart city IoT infrastructures.

This study has several limitations. Testing was confined to a single operational area, and communication was still affected by high levels of interference. For future work, it is recommended to improve gateway placement strategies, implement interference mitigation techniques such as signal filtering or alternative frequency channels, and integrate the system with artificial intelligence and cloud-based analytics to enhance scalability, reliability, and efficiency. These improvements are expected to support smarter, more sustainable urban waste management within smart city environments.

References

[1] M. Riali, "Pengelolaan sampah kota berdasarkan konsep zero waste," 2020. [Online]. Available: https://doi.org/10.30659/pondasi.v25i1.13037

[2] D. H. O. R. Abdillah and U. Diponegoro, "Analisis strategi pengelolaan sampah di kota semarang," *Article*, vol. 3, p. 10, 2014.

[3] M. N. K. A. Addas 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, p. e0307608, 2024. [Online]. Available: https://doi.org/10.1371/journal.pone.0307608

[4] S. S. H. M. C. A. Prabowo and F. Luthfi, "Low cost wireless sensor network for smart gas metering using antares iot platform," pp. 175–180, 2020. [Online]. Available: https://doi.org/10.1109/iCAST51016.2020.9557692

[5] S. V. et al., "Iot-enabled solid waste management in smart cities," *Smart Cities*, vol. 4, no. 3, pp. 1004–1017, 2021. [Online]. Available: https://doi.org/10.3390/smartcities4030053

[6] L. F. S. N. R. J. D. A. Candia, F. Lo Grasso and D. Vilches, "Lorawan iot solutions for smartcities," pp. 265–269, 2019. [Online]. Available: https://doi.org/10.1109/IOTSMS48152.2019.8939228

[7] R. C. M. S. Shaik, D. Shah and R. R. Marathe, "A lorawan based open source iot solution for monitoring rural electrification policy," pp. 888–890, 2020. [Online]. Available: https://doi.org/10.1109/COMSNETS48256.2020.9027490

[8] M. Lailiyah, "Pengembangan purwarupa tempat sampah otomatis berbasis iot dengan sistem pemantauan kapasitas melalui aplikasi mobile. studi kasus: Kabupaten gresik," *J. Pengemb. Teknol. Inf. dan Ilmu . . .*, vol. 1, no. 1, pp. 1–9, 2024. [Online]. Available: https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/13612

[9] M. Belhiah and M. El Aboudi, "An IoT-Based Sensor Mesh Network Architecture for Waste Management in Smart Cities," *Journal of Communications*, vol. 20, no. 2, pp. 153–165, 4 2025. [Online]. Available: http://dx.doi.org/10.12720/jcm.20.2.153-165

[10] A. S. Bharadwaj, R. Rego, and A. Chowdhury, "Iot based solid waste management system: A conceptual approach with an architectural solution as a smart city application," in *2016 IEEE Annual India Conference (INDICON)*. IEEE, 12 2016. [Online]. Available: http://dx.doi.org/10.1109/INDICON.2016.7839147

[11] 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, p. e0307608, jul 31 2024. [Online]. Available: http://dx.doi.org/10.1371/journal.pone.0307608

[12] S. R. J. Ramson, S. Vishnu, A. Kirubaraj, T. Anagnostopoulos, and A. Abu-Mahfouz, "A LoRaWAN IoT-Enabled Trash Bin Level Monitoring System," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 2, pp. 786–795, 2 2022. [Online]. Available: http://dx.doi.org/10.1109/TII.2021.3078556

[13] M. Cerchecci, F. Luti, A. Mecocci, S. Parrino, G. Peruzzi, and A. Pozzebon, "A Low Power IoT Sensor Node Architecture for Waste Management Within Smart Cities Context," *Sensors*, vol. 18, no. 4, p. 1282, apr 21 2018. [Online]. Available: http://dx.doi.org/10.3390/s18041282

[14] S. Mdukaza, B. Isong, N. Dladlu, and A. M. Abu-Mahfouz, "Analysis of IoT-Enabled Solutions in Smart Waste Management," in *IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society*. IEEE, 10 2018, pp. 4639–4644. [Online]. Available: http://dx.doi.org/10.1109/IECON.2018.8591236

[15] R. Jadhav and S. Banerjee, "Research for Advancement for Environmental Monitoring using Internet of Things (IoT)," *Publication of the International Journal and Academic Research*, vol. 2, no. 1, pp. 56–64, jun 5 2025. [Online]. Available: http://dx.doi.org/10.63222/pijar.v2i1.25

[16] A. Castro Lundin, A. G. Ozkil, and J. Schuldt-Jensen, "Smart Cities: A Case Study in Waste Monitoring and Management," in *Proceedings of the Annual Hawaii International Conference on System Sciences*. Hawaii International Conference on System Sciences, 2017. [Online]. Available: http://dx.doi.org/10.24251/HICSS.2017.167

[17] A. W. A. Rifai, A. E. Octariano and O. R. D. Srihantaran, "Implementasi modul lora dan gps untuk efisiensi pengumpulan sampah," *Spektral*, vol. 4, no. 2, pp. 207–212, 2023. [Online]. Available: https://doi.org/10.32722/spektral.v4i2.6622

[18] S. P. F. N. Panggabean and A. T. Hidayat, "Sistem pemantauan parameter kelistrikan berbasis komunikasi lorawan dengan platform antares," *J. Electron. Electr. Power Appl.*, vol. 3, no. 1, pp. 145–151, 2023. [Online]. Available: https://journal.peradaban.ac.id/index.php/jeepa/article/view/1427

[19] M. I. Sayekti, "Kata kunci: Arduino uno, hc-sr04, lora sx1276, nodemcu esp32, tempat sampah," Skripsi, p. 84, 2024. [Online]. Available: http://etd.repository.ugm.ac.id/

[20] S. A. D. Setiawan and H. Nurwarsito, "Sistem monitoring tempat sampah berbasis internet of things menggunakan protokol mqtt," *J. Pengemb. Teknol. Inf. dan Ilmu Komput.*, vol. 5, no. 13, 2021. [Online]. Available: https://j-ptiik.ub.ac.id/index.php/j-ptiik/article/view/8629

[21] S. A. S. T. N. M. C. A. Prabowo, I. Sayekti and Supriyati, "Development of an iot-based egg incubator with pid control system and mobile application," *Int. J. Informatics Vis.*, vol. 8, no. 1, pp. 465–472, 2024. [Online]. Available: https://doi.org/10.62527/joiv.8.1.2044

[22] M. R. R. A. A. I. M. La Mema Parandy, Sidiq Syamsul Hidayat and M. C. A. Prabowo, "Design of temperature monitoring and control system in smart hen coop based on internet of things," *J. Inf. Syst. Technol. Eng.*, vol. 2, no. 2, pp. 236–251, 2024. [Online]. Available: https://doi.org/10.61487/jiste.v2i2.68

[23] H. P. Putra and S. N. Wahid, "Pembuatan trainer tempat sampah otomatis guna menyiasati masalah sampah di lingkungan masyarakat," *JEEE-U (Journal Electr. Electron. Eng.*, vol. 3, no. 1, pp. 120–137, 2019. [Online]. Available: https://doi.org/10.21070/jeee-u.v3i1.2087

[24] F. A. B. M. C. A. Prabowo, S. Kusumastuti and E. P. Wardani, "Orbith rancang bangun sistem kontrol dan monitoring budidaya jangkrik menggunakan protokol esp-now berbasis internet of things," *Maj. Ilm. Pengemb. Rekayasa dan Sos.*, vol. 19, no. 1, pp. 52–59, 2024.

[25] M. F. Imanudin, R. Kinanda, N. Falih, A. A. Arman, E. Sembiring, and S. H. Supangkat, "Enhancing Urban Waste Management: An IoT and LoRa-Integrated Smart Bin System for Volume Monitoring and Analysis," in *2024 International Conference on Intelligent Cybernetics Technology & Applications (ICICyTA)*. IEEE, dec 17 2024, pp. 531–536. [Online]. Available: http://dx.doi.org/10.1109/ICICYTA64807.2024.10913380

[26] E. G. F. Castro and S. G. Yoo, *A Smart Waste Management System Based on LoRaWAN*. Springer Singapore, 2021, pp. 228–240. [Online]. Available: http://dx.doi.org/10.1007/978-981-16-1483-5_21

[27] A. Z. Azmi, N. Mohd Sahar, and M. T. Islam, "Smart Waste Management System Using Lora Technology," *E3S Web of Conferences*, vol. 599, p. 04007, 2024. [Online]. Available: http://dx.doi.org/10.1051/e3sconf/202459904007

[28] T. J. Sheng, M. S. Islam, N. Misran, M. H. Baharuddin, H. Arshad, M. R. Islam, M. E. H. Chowdhury, H. Rmili, and M. T. Islam, "An Internet of Things Based Smart Waste Management System Using LoRa and Tensorflow Deep Learning Model," *IEEE Access*, vol. 8, pp. 148 793–148 811, 2020. [Online]. Available: http://dx.doi.org/10.1109/ACCESS.2020.3016255

[29] S. L. C. Manik, M. A. Berawi, Gunawan, and M. Sari, "Smart Waste Management System for Smart & Sustainable City of Indonesia's New State Capital: A Literature Review," *E3S Web of Conferences*, vol. 517, p. 05021, 2024. [Online]. Available: http://dx.doi.org/10.1051/e3sconf/202451705021

[30] R. K. A. M. Ismail and S. Abdussamad, "Tempat sampah pintar berbasis internet of things (iot) dengan sistem teknologi informasi," *Jambura J. Electr. Electron. Eng.*, vol. 3, no. 1, pp. 7–12, 2021. [Online]. Available: https://doi.org/10.37905/jjeee.v3i1.8099

[31] E. S. K. Fatmawati and Y. Irawan, "Rancang bangun tempat sampah pintar menggunakan sensor jarak berbasis mikrokontroler arduino," *Riau J. Comput. Sci.*, vol. 6, no. 2, pp. 124–134, 2020.

[32] K. Zawalski, M. E. Aktan, P. Falkowski, M. Mazowiec, J. Oleksiuk, B. Leczkowski, Z. Pilat, M. Jarek, E. Akdogan, P. Niedbalski, V. E. Omurlu, and M. Wawrzyniak, "Systematic review of mechanical designs of rehabilitation exoskeletons for lower-extremity," *Archive of Mechanical Engineering*, nov 29 2024. [Online]. Available: http://dx.doi.org/10.24425/ame.2024.152944

[33] D. Feller and C. Siemers, "Mechanical Design and Analysis of a Novel Three-Legged, Compact, Lightweight, Omnidirectional, Serial–Parallel Robot with Compliant Agile Legs," *Robotics*, vol. 11, no. 2, p. 39, mar 24 2022. [Online]. Available: http://dx.doi.org/10.3390/robotics11020039

[34] E. Toptas, "Innovative approach to the design of mechanical parts," *Journal of Mechatronics and Artificial Intelligence in Engineering*, vol. 1, no. 1, pp. 14–20, jun 30 2020. [Online]. Available: http://dx.doi.org/10.21595/jmai.2020.21473

[35] R. Wang, V. Shapiro, and M. Mehandish, "Model Consistency for Mechanical Design: Bridging Lumped and Distributed Parameter Models With a Priori Guarantees," *Journal of Mechanical Design*, vol. 146, no. 5, mar 5 2024. [Online]. Available: http://dx.doi.org/10.1115/1.4064810

[36] U. o. N. N. C. Mechanical Department, National School of Agro Industrial Sciences and U. o. N. N. C. Mechanical Department, National School of Agro Industrial Sciences, "A Review Analysis of Design Models for Mechatronic Product Design Perspectives," 2022. [Online]. Available: https://zenodo.org/records/8094704/files/C97260111322.pdf

[37] R. Rao and R. Pawar, “Constrained design optimization of selected mechanical system components using Rao algorithms,” *Applied Soft Computing*, vol. 89, p. 106141, 4 2020. [Online]. Available: http://dx.doi.org/10.1016/j.asoc.2020.106141

[38] T.-C. Chen, Y.-T. Sheng, S.-T. Liong, S.-Y. Wang, and Y.-S. Gan, “Gnn-based reverse design for mechanical systems: Bridging trajectory and mechanical design,” *Expert Systems with Applications*, vol. 247, p. 123256, 8 2024. [Online]. Available: http://dx.doi.org/10.1016/j.eswa.2024.123256

[39] A. W. A. Rifai, A. E. Octariano and O. R. D. Srihantaran, “Implementasi modul lora dan gps untuk efisiensi pengumpulan sampah,” *Spektral*, vol. 4, no. 2, pp. 207–212, 2023. [Online]. Available: https://doi.org/10.32722/spektral.v4i2.6622